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Potential of Improved Application Techniques for Increasing Fertiliser Use Efficiency

H. L. S. TANDON
Director,
Fertiliser Development and Consultation Organisation,
C-110, Greater Kailash I, New Delhi-110048 (India).

Potential of application techniques for increasing fertiliser use efficiency and issues involved in their adoption have been discussed. Examples concern the efficient use of N, P, K, S, Zn, Fe and Mn, nutrients which are of major practical importance. Improved application techniques can bring about yield advantages of 200-1200 Kg grain|ha and are often enough able to cover the total or a large proportion of the money spent on fertilisers.

A number of improved techniques have yet to find large-scale application. This is a matter of concern. Two possible reasons are that (i) in our system, a mechanism|link is missing which should identify promising techniques and take initatives to see that these are passed on as usable packages to the farm level and (ii) many times our interest in fertiliser efficiency is philosophical rather than one of affirmative action with the result that initial interest losses momentum after their agronomic potential has been shown.

Non-adoption of proven techniques not only robs the farmers of the fruits of using fertiliser efficiently, it also reduce the efficiency of investments in fertiliser research and development. The economic and social cost of improved technologies not finding adoption (in terms of lost production and income) is substantial particularly for a country such as India which is on the doorstep of the 10 million tonne nutrient consumption mark. Some suggestions have been made to take technique evaluation beyond agronomic testing and to accelerate the adoption of proven techniques.

EFFICIENT use of fertilisers is a subject of unconditional importance in practical agriculture. It channelises the resources invested in mining, manufacture and movement of fertilisers to the most productive use. It also ensures that the non-renewable resources used for producing fertilisers, once taken out of the earth are used wisely (efficiently), so as to last longer. Efficient fertiliser use is of equal importance to a farmer, a nation and to humankind as it enables each unit of fertiliser to produce a good crop and higher income.

At moderate levels of application, fertiliser used efficiently enables the farmer to harvest a more than moderate yield. At full application rates, efficient use gives highest possible net profits and helps to protect the environment. At all levels of application, it lowers the per unit cost of producing the crop.

Efficient fertiliser use does not happen automatically in a manner that the sun rises every morning. Practical steps and decisions have to be taken by millions of farmers in order to use fertiliser efficiently.

Towards Efficient Fertiliser Use (EFU)

Fertiliser is said to have been used efficiently if it has produced a higher yield response and a greater proportion of it is recovered in the crop, as compared to a less efficient system. In markets where farmers sell the produce only by weight, EFU must reflect in higher yield per unit nutrient applied. It is obvious that for nutrients which leave a residual effect, EFU has to be measured by combining the direct response with the residual response, which is possible by studying the fertiliser efficiency on cropping system basis.

Efficieent fertiliser use is achieved when *"The most suitable forms of each nutrient are applied in balanced ratios through improved application techniques to a crop variety which can use them to give a higher yield of good quality produce"*. Major components of EFU system are depicted in Figure 1 (62). It is clear that any factor, decision or operation on the farm which affects nutrient availability and yields, will affect fertiliser efficiency. Highest net returns from fertiliser application are the end products from efficient fertiliser application.

Out of the major components stated above, this paper deals with the improved application techniques for increasing fertiliser use efficiency. It must be stated that these techniques are not to be seen merely as mechanical operations but as a part of the efficient farm

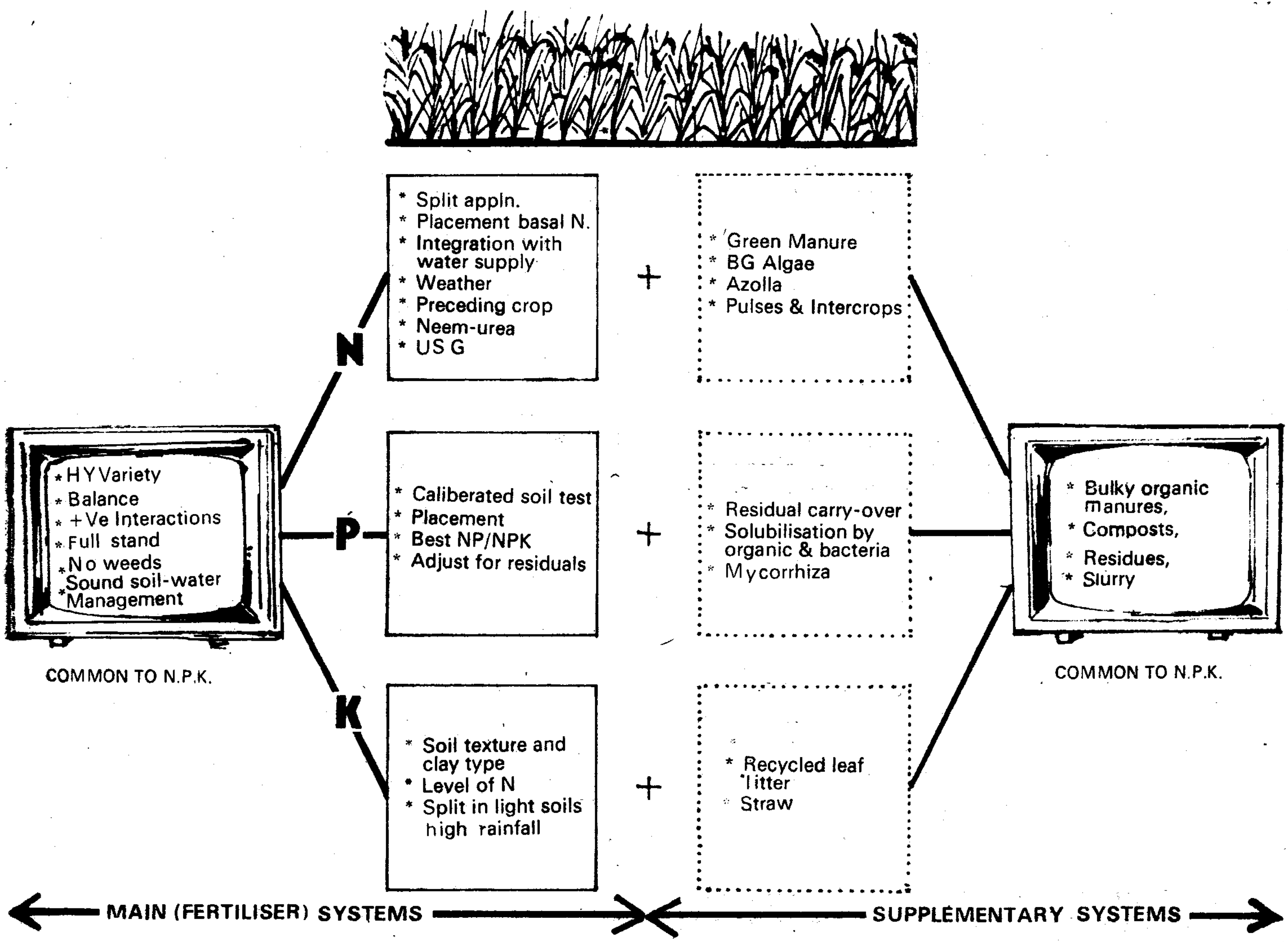

Figure 1—Major components of integrated systems for efficient fertiliser use (62).

management in which the decision-making skill of the farmers and the quality of advisory service available to them are also included.

Improved Application Techniques for Increasing FUE

The versatile nature of fertilisers is truly fascinating. This is reflected in the numerous ways fertilisers can be applied, such as:

- — by bare hands, machines drawn by animals and tractors, by aeroplanes
- — as powders, prills, granules, or marbles
- — as solids, suspensions or clear liquids
- — to the soil, the roots, the leaves, irrigation waters, or to seeds
- — ahead of planting, at planting, or in standing crops.

Improved application techniques have a tremendous bearing on FUE. Such techniques are different for different nutrients, different fertilisers containing the same nutrient, different crops and soil management systems. A large number of techniques have been developed many of which have found varying degrees of practical application. These techniques differ also in the degree of mechanisation associated with them, skills required to use them and their cost factors. While agronomic studies on the potential of various techniques are available, their economic and operational aspects are quite often neglected. To the extent possible, the effort in this paper will be to discuss integrated agro-economic potentials of improved techniques and some steps needed to take them from the labs to the lands.

Improved application techniques for nitrogen

The subject has received considerable attention of research workers (Table 1). Techniques for increasing

N-use efficiency receive high priority because (i) N is used in largest amounts among all fertiliser nutrients—53 per cent share of NPK worldwide, 69 per cent in Asia, 67 per cent in India, (ii) N is often the first and many times the only nutrient used by farmers, (iii) N is quite mobile in the soil and can be lost through one or more routes, and (iv) rice is the single most important crop in Asia and low N-use efficiencies are a matter of universal concern. In India, farmers spent Rs 30 billion on N (Rs 167|ha) during 1985-86. As prilled urea accounts for 85 per cent of the N applied, techniques which can increase the efficiency of urea-N (amide and its successors) are of main interest.

Split application of N

This refers to the application of total dose of N in two or more instalments (splits) during the crop season. The operation can be done with bare hands and is perhaps the most widely used technique for increasing N-use efficiency.

Split application of 100 kg N|ha has the potential of increasing grain yield by 300-1200 kg|ha as a result of more efficient use over the same amount all applied at one time (42, 61, 65). The merits of split application are that it is easy to carry out, needs no machine, provides flexibility to the farmer in planning N applications according to weather conditions or water availability, does not leave large amounts of N exposed to various channels of loss and can even be carried out by members of the farm family. It is attractive where labour is available at acceptable wages and where field conditions permit efficient use of the topdressed N (no stagnant water). We however have no idea of the degree of uniformity of application where N is manually applied.

Table 1—Research strategies for increasing fertiliser use efficiency—example India

Strategy	Relative emphasis				
	N	P	K	S	Zn
Soil testing	x	xx	xx	x	x
Suitable fertiliser form	xx	xx	x	x	x
Drilling/placement	x	xx			
Split application	xx	x	x		
Estimation of residual effect		xx			x
Root dip in nutrient solution		x			x
Tolerant varieties		x			xx
Use of organic materials and microbial solubilisers		x			
Nitrification inhibitors	x				
Slow-release/coated materials	x				
Integrated water-fertiliser management	xx	x			

Source: (47).

Table 2—Advantage of split application of N in rainfed crops

Crop	Extra yield due to split application of N
Finger millet	270 kg/ha
Maize	340 ,,
Sorghum	370 ,,
Pearl Millet	530 ,,
Mean	378 kg/ha
Cost of 40 kg N	205 Rs
Value of extra 378 kg grain	490 Rs

Data source: Spratt, E.D. and Chowdhury, S.L., Field Crops Research 1, 103-126 (1978).

The advantages of split application of N are often sufficient to pay for the money spent on N. Some data on rainfed crops illustrates this (Table 2). The actual number of splits are determined by the total N to be applied, soil texture crop duration and water management practices. Whether to apply N in 1, 2 or 3 splits in irrigated wheat on a sandy soil was dependent on the total N involved (Figure 2). Similarly, results with sorghum show that while a single application of

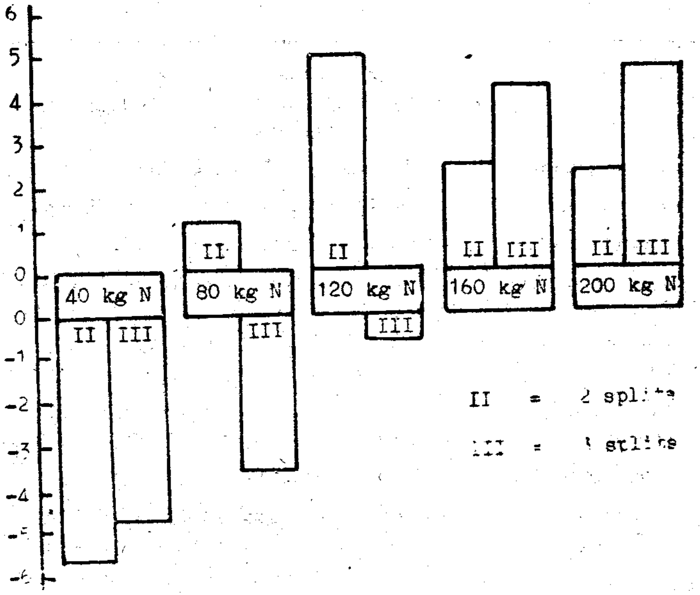

Figure 2—The relation between total N to be applied and the number of splits in a coarse-textured soil under irrigated wheat (Data Source: Sandhu, H. S. and Gill, G. S., *India J. Agric. Sci.* 41 (10), 815-823 (1971).

Table 3—Summary of split application schedules for 100-120 Kg N|ha in seasonal crops in India

Crop	Situation	Suggested application
Wheat (Irr.)	Heavy black soil	All basal
	Light soil	50% at planting, 50% with first irrigation.
	Long duration crop	33% at sowing, 33% after 1 month, 33% after 2 months
Wheat (Unirr.)	Rainfed	All basal, deep placed*
Maize		33% at planting, 33% 30 DAP, 33% 40 DAP
Sorghum		50% at planting, 50% at knee high stage
Potato		50% before planting, 50% before stolon formation.

*40-60 kg N/ha

Source: (55).

60 kg N|ha was satisfactory for a 110-day variety, split application was the efficient practice for a 125-day variety (38). Some overall guidelines for split application of N are summarised in Table 3 with more detailed guidelines for flooded rice in Table 4.

Table 4—Some guidelines for efficient management of N in flooded rice

Situation	Startegy
Water supply assured	Can topdress every 3 weeks upto P.I. stage drain field before topdressing and reflood 2 days later
Soil very poor in N	Relatively more N at planting
Soil moderate in N	Less N as basal, more as topdressings
Permeable soils	More number of splits
Varieties of short duration	Prefer more N as basal and early topdressings
Varieties of long duration	More number of topdressings
Colder growing season	Less N as basal, more as topdressing
Over-age seedlings	More N at planting
Danger of bacterial leaf blight	More number of smaller splits. If BLB is visible, N should be given after consulting a pathologist

Adapted from Guidelines formulated by ten Have. AICRIP publication No. 38 (1971). These strategies are with prilled urea and were developed before materials such as USG or *neem*-coated urea were available.

Technique for placement of N (USG) in flooded rice soils

No other system has thrown more challenges for developing N-application techniques than flooded rice. In recent years, there has been considerable interest in designing products and practices which will enable a farmer to deposit N at a safe place in the rootzone, away from the nitrifying bacteria. Because if the amide and ammonium N are converted to nitrate, it is not only vulnerable to leaching, little can be done to prevent its denitrification and the quantities not taken up by the plant are vulnerable to be lost.

One such development of potential practical importance is the production of urea in the form of 1-g granules, commonly called urea supergranules. These can be mechanically deposited in the chemically-reduced zone, a few cm below the soil surface. A large number of field results with USG are available, both from research stations and from on-farm trials (13,24,29,32, 33,39,40,43,62). Results of 162 trials on farmers fields in the 6 states of eastern India show that in 40 per cent trials, USG and S-coated urea were statistically superior (more efficient) over prilled urea, in 55 per cent trials, all sources were on par and in 5 per cent cases, prilled urea was superior (29). At economically optimum rates of N application, average agronomic efficiency (kg paddy|kg N) was 16 for prilled urea, and 21-22 for the USG and S-coated urea.

Performance of USG is generally superior on fine-textured soils than on coarse textured soils with a high rate of water percolation, though the real challenges of increasing N-efficiency also lie in medium-light soils. In a highly percolating soil (91 per cent sand, percolation rate 109 mm|day), N from USG was lost mainly as unhydrolysed urea during the first three days after application. Once leaching was checked, USG became more efficient (21). It appears that the large granular form, which is an advantage in physical placement becomes a disadvantage in situations where water moves through the soil rapidly and the lower surface area of the USG acts as a constraint in promoting quick hydrolysis and conversion to ammonia. In studies on two contrasting soils, USG was 72 per cent as efficient as prilled urea (3 splits) in the soil with fast percolation but 94 per cent as efficient in a soil with slow percolation (33).

Although a part of the variability in the performance of USG can be due to inadequate site-characterisation, results of INSFFER trials show that some variability still persisted after site characteristics were taken into account (13). Other workers have suggested that the real potential for USG may be under poor water management and not where good water control is possible (73). While N from USG can be leached out in highly percolating soils, in an 15-N study, it has been shown that the total loss of N from prilled urea and deep placed USG was similar (27-29 per cent), the difference being that with prilled urea, volatilisation and leaching contributed equally while with USG 80 per cent of the N loss was from leaching and 20 per cent through volatilisation (56).

It could be that USG coated with S, coaltar or other coverings would be better in very permeable soils while naked USG would be suitable in medium-heavy textured soils from N-efficiency point of view. It is reasonable to consider N to have been efficiently utilised if it can produce about 20 or more kg grain|kg N at the optimum level.

Although field performance of USG is not uniformly consistent (it rarely is for any fertiliser tested under diverse conditions and management levels), USG placed in the soil have the potential of increasing rice yields on an average by 500-600 kg|ha except in very coarse textured soils. This yield advantage is worth Rs 750-900|ha and cannot be overlooked. This advantage is brought about as a result of the more efficient use of N applied.

Adoption of point placement of N through USG is linked to its economics and the availability of suitable applicators. About a dozen applicators are at various stages of testing in India and abroad but their commercialisation is keenly awaited. Some applicators for deep placement of prilled urea have also been developed which can certainly provide the needed flexibility in N-management.

The USG technique brings along five cost components over prilled urea which are:

- about 10 per cent additional cost per unit N over prilled urea
- about 10-15 mandays|ha required for point placement
- cost and maintenance of the applicator
- about 25 per cent more bags may be needed assuming that a bag holding 50 kg prills can hold 40 kg USG
- loss of material due to broken USG during transport and handling (15).

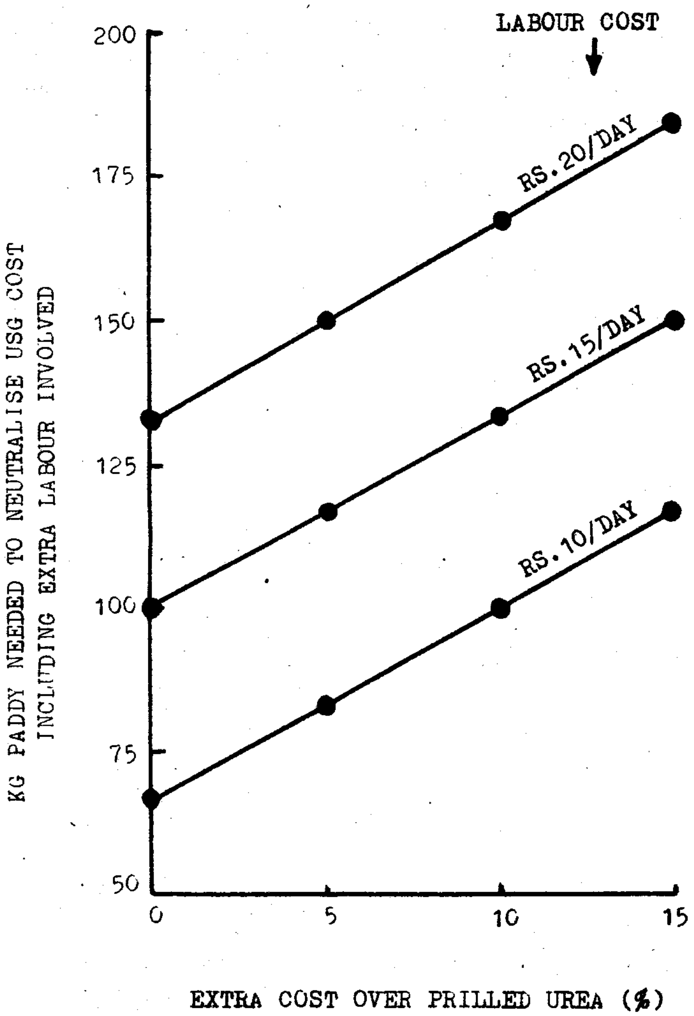

Figure 3—Quantity of paddy required to neutralise extra costs associated with the USG point placement technique at different fertiliser and labour costs over split application (assumptions: 10 mandays|ha; Rice at Rs. 1.50|kg).

All these cost components are usually not built into economic analyses. At this stage, extra costs associated with USG at variable rates of extra nutrient cost and labour needed have been depicted in Figure 3 in terms of extra rice needed to neutralise the extra cost involved in using USG. Such a graph can cater to a range of price situations. It shows for example that if USG cost 10 per cent more than prilled urea and labour wages are Rs 10|day, then a yield increase of 100 Kg rice would be needed to neutralise the cost of adopting USGs. If the potential of USG to produce an extra 600 Kg rice|ha is accepted (Rs 900|ha), it would be an economically attractive proposition under a majority of conditions.

It is thus surprising that the USG has not been commercialised so far in India (41 m ha under rice, 5.8 m t N consumption, 40 per cent of all N going to rice). If the constraint is lack of suitable applicators (in large numbers), efforts to develop and produce these may be stepped up. If the wait is for USG to prform splendidly under all situations|areas, that time will never come nor is it necessary in a country with diverse agro-climatic conditions. In a country with 41 million ha under rice, even if 10 per cent rice area is identified as suitable for using USG efficiently, the gain in terms of extra rice produced can be 2.5 million tonnes each year worth Rs 3.75 billion. At a moderate dose of 50 Kg N|ha, the following picture will emerge:

50 Kg N|ha to 10 per cent rice area=205,000 t N
445,000 t USG

Production capacity needed
(80 per cent capacity utilisation+
10 per cent production in pipeline)=600,000 t USG

Thus to cover every 1 per cent rice area with a assumed dose of 50 Kg N|ha, a production capacity of about 60,000 t USG would be needed. The adoption of this technique will also generate additional opportunities for the applicator industry and several million mandays of employment for farm labour.

Urea treated with neemcake

This is another improved N-application technique with a potential for increasing N-use efficiency. Though results are again variable, a yield advantage of 400-500 Kg rice|ha can be associated with *neem*-treated urea (42,43,62). Part of the variability in performance is because the treatment of urea with *neem* is not standardised and varies from mixing, to blending to coating. Where coalter is used as a sticker in coating, part of the efficiency advantage can be due to the tar barrier (25, 57).

In six years of trials at New Delhi, *neem* coated urea (NCU) increased paddy yield by 430 kg|ha (Rs 650 ha) over prilled urea and gave an apparent N-recovery of 44 per cent as compared to 33 per cent with prills (42, 43). This yield advantage is sufficient to pay for 125 Kg fertiliser N at current prices. In a large number of trials conducted by AICRIP, NCU was only marginally superior to prilled urea applied in splits (40). In a coarse-textured soil, NCU was 1.75 times as efficient as USG but still 75 per cent as efficient as prilled urea given in 3 splits (33). In trials on farmers' fields in Andhra Pradesh, basal application of NCU was 32 per cent more efficient than prilled urea (3 splits) under controlled irrigation but 60 per cent more efficient under uncontrolled irrigation, that is poor water management (49). The loss in rice yield due to poor water management could be stated as:

27 per cent with split application of prilled urea
17 per cent with basal application of *neem*-treated urea

A seminar on FUE concluded that the NCU appears to be a promising material but its spread is heldup mainly because of inadequate availability of *neem*cake (7). Availability here refers to the organised availability or the problems of collection because otherwise the *neem* tree is a household name and grows widely-wildly in India and many other countries.

Potential availability of *neem*cake in India is estimated at 0.33 million tonnes if all the 0.41 million tonnes of seed shed annually are collected and crushed (14). It is still debated whether urea should be treated with *neem* in large factories and the product (36-37 per cent) transported back to the villages or whether farmers should be given bags of *neem*cake which they can treat urea with before application.

For blending, about 200 Kg *neem*cake would be needed to treat one tonne of urea. For coating with a sticker, smaller quantities will be needed. Some estimates show that extra cost per unit N for *neem* coated|blended urea may range between 8 per cent and 33 per cent (Table 5). Lower estimates are based on material produced for research and higher estimate is for a com-

Table 5—Some estimates of additional costs associated with modifications of urea for higher agronomic efficiency

Modified urea	% increase over prilled urea	Remarks
Urea mixed with *neem* cake	8	Mixing (w/o tar etc.)
Urea coated with *neem* cake	11	Actual lab-scale cost
Urea blended with *neem* cake	33	Commercial product (37% N, MAIC)
Urea treated with N-serve	50	Thomas, J., Ph. D. Theses, IARI, (1981)
Urea coated with S	30-50	Thomas, J. and McCune, D.L., Farm Chemicals (1982)
Urea Supergranules (1 g)	20-25	Includes extra labour for placement
Urea coated with gypsum	10-15	36% N, 5% Ca, 4% S*
Urea coated with rock-P	10-15	36% N, 5% P_2O_5*

*Sabapathy, T.R., Madras Fertilisers Ltd., Personal Communication (1986).

For cost factors of coal acids, see text, earlier analysis (62).

mercial product. A 33 per cent extra cost implies that the material must give 33 per cent extra yield response in order to break even. Costs will certainly be lower if the process is carried out near the site of collection|consumption, but frankly rigorous economic analyses are not available. At 33 per cent extra cost, assuming an application rate of 100 Kg|ha, additional response of 130 Kg rice will be required to break-even, beyond which the technique would start becoming profitable.

Curing urea with soil

This is a non-glamorous technique within the reach of any farmer of average holding. Urea is incubated with 4-6 times its weight of slightly moist soil 1-2 days before application. The idea is to enable the urea to hydrolyse and get converted to ammonia under "controlled conditions" so that it is not subject to leaching under poor water control or sudden heavy rains. The technique is simple, practical and cost-effective. The only cost would be the extra labour required to spread a 5-7 times bigger bulk.

Results from Orissa show that 100 Kg N treated with soil (1:6, 72 hrs) produced a yield advantage of 440 Kg rice|ha in the wet season and 610 Kg|ha in the dry season (28). These gains are impressive by any standards and should not be allowed to go waste. Curing of urea with soil was thus 25-27 per cent more efficient than untreated urea. The mean yield gain was 525 Kg|ha which was worth Rs 788. In comparison, the cost of extra labour required at Rs 10|day could be taken as Rs 30-40. This would appear to be a promising technique where conditions are conducive to leaching, heavy showers can be expected, and where the heap itself can be protected from rain.

Foliar application of N

This technique does have the potential of increasing N-use efficiency but due to inconsistent results seems to have received a setback in the list of priorities. The overall position is summed up thus in case of N, in contrast to common belief, the weight of experimental evidence with irrigated as well as unirrigated sorghum and millet show that foliar application does not prove in any way superior to soil application method (16). A foliar spray of N is seen as a possible means of combating certain exigencies of correcting N stress at a critical stage of crop growth. In salt-affected soils, it does represent an efficient technique for supplementing soil—applied N. It appears that part of the setback to this technique in India has been due to lack of studies in canopy characteristics, leaf cover|ha, spray holding capacity of different types|densities of crop canopies, standardisation of spray techniques with the result that what was intended as a foliar spray ended up in part as a liquid topdressing to the soil.

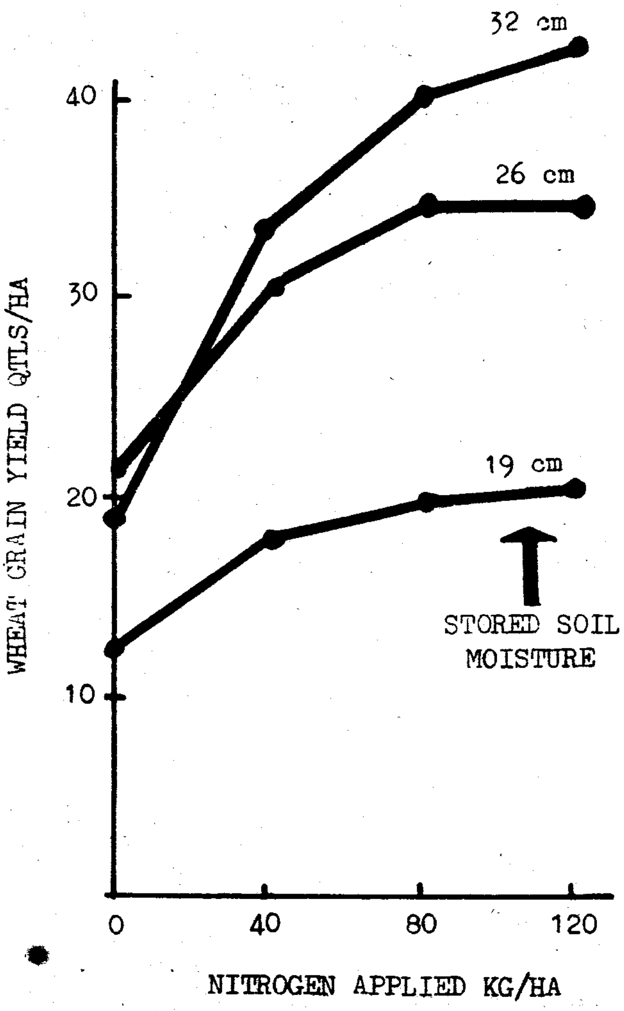

Figure 4—Dependence of N application to dryland wheat on the moisture stored in the soil profile (Data source: Meelu, O. P., *et al., Fert. News,* 21 (9), 34-39 (1976).

Integrated nitrogen-water management

Tailoring N application to available moisture leads to a higher N-use efficiency. An example with rainfed wheat is provided in Figure 4. Depending upon the stored soil moisture, the crop could use any amount of N efficiently in the 40-120 Kg N|ha range. For the technique to be used in practice, farmers need advice on the moisture storage capacity of their field, amount of stored soil water at planting and what does a given amount of rain mean in terms of water available to the crop.

Other improved techniques for N

A number of other techniques have been developed for increasing N-use efficiency. These include nitrification inhibitors, urease inhibitors, urea-coated with materials such as S, lac, rubber, gypsum, phosphate rock, slow-release N-carriers, coal-based fertilisers etc. Many of these have been recently reviewed (43, 26, 50). A number of materials such as N-Serve, Dicyandiamide (DIDIN), conventional S-coated ureas do not hold much promise for the farmers of tropical and sub-tropical areas either because of high cost, inconsistent performance, handling problems or more promising local alternatives (1). Nitrification inhibitor N-Serve is estimated to increase unit N cost by 50 per cent and S-coated urea by 30-50 per cent. Cost estimate for DIDIN is not available, but 7 Kg material is needed to treat 100 Kg urea. Some cost factors have been given in Table 5.

Gypsum-coated urea and rock-phosphate coated urea have shown promise though the site-site variability persists (50). These are estimated to cost 10-15 per cent more than untreated urea but also contain some P, S and Ca.

Coal-derived fertilisers and their potential has been reported from the Central Fuel Research Institute (26). The two coal acids are AMP (ammonium polycarboxylate, total N 14 per cent, available N 9 per cent) and CAMP (Composite ammonium polycarboxylate, total N 16 per cent, available N 14 per cent). Also seems to be holding promise is nitrohumic acid (NHA), an intermediate of coal acid production, for blending with conventional N fertilisers. Field results from CFRI show that the efficiency of N for paddy was improved by 23-29 per cent by using urea with 20 per cent coal acids over urea alone and 75 Kg N|ha produced an extra 2.7 t|ha potatos when it was treated with 20 per cent coal acids. Optimum blending proportion for high efficiency is given as 15-20 per cent by weight of urea and 10 per cent for ammonium sulphate. Production cost estimates (1982 figures) based on bench-scale data were Rs 2000|t for CAMP and Rs 1500|t for NHA. *Benefit cost ratios of* 1:12 *to* 1:25 *have been reported.* At such lucrative B:C ratios it is not clear why these materials have not been adopted or what are the constraints involved for taking them from the labs to the land.

Improved application techniques for phosphorus

The search for improved application techniques for increasing P-use efficiency has received as much attention as for N, though for different reasons (51, 64). Phosphorus is rarely lost from the soil except through erosion. Its being relatively immobile from the site of application and the fact that single crop recoveries of added P are generally within 20 per cent, have led to considerable research to position in the rootzone and to retard its conversion to less active forms in the soil.

Phosphorus accounts for 26 per cent of the fertiliser nutrients used worldwide and 23 per cent in the Asian region. Per unit basis, it is the costliest among the major nutrients which coupled with its low recovery|slow recovery by crops makes it imperative to apply it efficiently.

Drilling or deep placement of P

This can be called as the single most important P application technique for higher efficiency. *Its importance in P management is the same as that of split application in N management* (64). It is a proven technique both for irrigated and rainfed systems, with the exception of flooded rice culture and use of fertilisers having low water-soluble P.

The potential of drilling|deep placement|furrow placement of water-soluble P in increasing P-use efficiency is substantial as illustrated by data summarised in Table 6. These data show that drilling P brought about additional yield advantage of 215-1160 Kg grain|ha (mean 562). This resulted in an enhanced efficiency of 5-16 Kg extra grain|Kg P_2O_5 applied over the same dose

Table 6—The agro-economic advantage of drilling|placement of fertiliser P over surface broadcast in field studies

Crop & area	Studies averaged	Level (kg P_2O_5/ha)	Cost of P (Rs/ha)	Advantage of drilling over P broadcast	
				Extra yield (kg/ha)	Value of extra yield (Rs/ha)
Wheat					
New Delhi	3	50	320	780	1,248
Punjab	2	60	384	300	480
Gujarat	1	60	384	420	672
Maize					
Punjab	1	100	640	1,160	1,508
Sorghum					
New Delhi	1	60	384	344	447
Tamil Nadu	1	90	576	666	866
Finger millet					
Karnataka	1	50	320	435	566
Tamil Nadu	1	35	224	215	280

Source: **Several published sources listed in (64).**

Prices: **P_2O_5 = Rs 6.40/kg, wheat = Rs 1.60/kg, other grains = Rs 1.30/kg.**

given as broadcast. The value of the yield increase as a result of proper P application, is sufficient to pay for all or most of the P applied. Drilling is of particular advantage with (i) wide-row crops in particular, (ii) fertiliser having high water-soluble P, (iii) low rates of application, (iv) restricted moisture. It requires that fertilisers be in granular free-flowing form except when the material is manually dropped in open furrows.

A 2-year field study with wheat on a sandy loam soil showed that P when placed 10 cm deep was 1.4 times more efficient than P broadcast. The efficiency of deep placed P plus restricted irrigation was on par with that of P broadcast plus unrestricted irrigation (72). Deep placement thus has an added advantage when moisture is restricted, a reason why this practice is universally recommended in dryland agriculture also.

Reports from Andhra Pradesh indicate that placement of P in general increased grain production efficiency by 12 per cent in wheat, 16 per cent in castor and 25 per cent in sorghum (44). In Karnataka, P application 7.5-15 cm deep for cereals|tubers and 15-22.5 cm deep for sugarcane was considered an efficient practice (69). For tea in south India, the efficient technique is to apply P 15-25 cm deep at enhanced rates in alternate years (48). In tobacco, spot placement of P led to lower yields which was attributed to faster leaf maturity resulting in lower yields (9). In cassava on acid-laterite soils, P application at surface or 7-15 cm deep were on par (36). For jute, P application 5-10 cm deep and 5 cm to the side of the seed is the technique advocated for higher efficiency (27).

In on-farm trials with dryland sorghum, broadcast application of 80 Kg N+40 Kg P_2O_5|ha gave an average yield of 2570 Kg|ha. When the fertiliser was deep placed, yield was 3700 Kg|ha or 44 per cent more (70). Increase in fertiliser efficiency due to placement was an extra 9 Kg grain for each Kg NP applied. Some other results with dryland crops are given in Table 7. The recent initiatives of the fertiliser industry in developing and popularising fertiliser application machines is in the right direction. Models of bullock-drawn, early-serviceable drills costing less than Rs. 400 are available.

Advancing the time of P application

For fertilisers such as powdered rock phosphate, their application some weeks ahead of planting improves the P-use efficiency and gives higher yield. Illustrative data for the wheat-maize system are given in Figure 5.

Table 7—Comparative efficiency of P application methods for drylands

Methods of P Application	Grain yield relative			
	Finger millet	Chickpea	Soybean	
			A*	B*
Broadcast	100	100	100	100
Drilled	132	137	123	169
Mixed with seed	129	118	123	135

For soybean, A = 40 kg P_2O_5/ha, B = 80 kg P_2O_5/ha

Data sources:

Finger millet: Hegde and Reddy, *Indian Fmg.*, 33(10), 9-11 (1984).

Chickpea: Singh and Venkateswarlu, *Fert. News*, 30(4), 43-55 (1985).

Soybean: Singh and Singh, PAPER in IMPHOS-FAI Seminar January 1986.

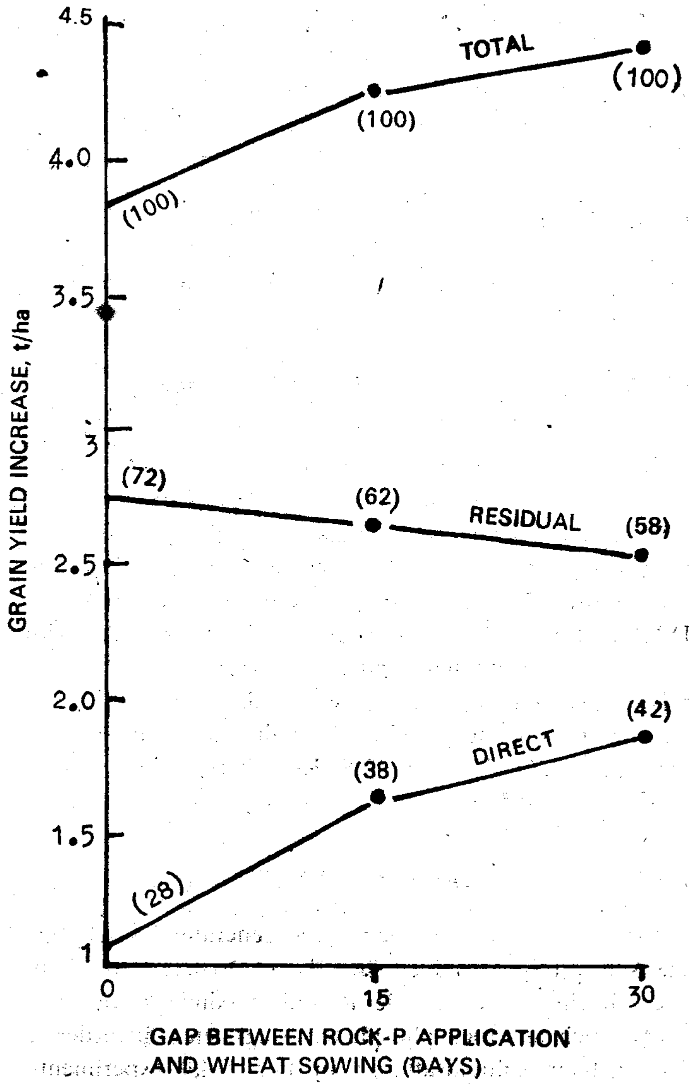

Figure 5—Effect of time of application of rock phosphate on crop yields in a wheat-maize cropping system (30).

Advanced application allows the rock to react with the soil and release some of its P by the time the crop is established. This essentially *is a no-additional cost technique but requires the right decision* at the farm level, and timely availability of fertiliser. The same amount of rock-P applied just before planting wheat produced a total yield increase (wheat + following maize) of 2870 Kg grain|ha but 3400 or 18 per cent more when applied 30 days before planting wheat (30). The monetary gain from the decision to apply P early in this case was Rs 800|ha. The desirability of allowing a reaction period to rock P has also been reported in rice (4).

Dipping rice seedling roots in P slurry

Results are available to show that dipping rice seedling roots in a slurry of P fertiliser before transplanting increases P-use efficiency. Many of the results have been recently summarised (64). Data with rice show that a root dip capable of depositing 20 Kg P_2O_5|ha on the roots can increase rice yields and P-use efficiency compared to higher rates given to the soil (10, 19). Results on the adaptability of this technique under farmers' conditions are not available. Extra costs are around 2 mandays of labour|ha. The possibility of encouraging rural youths or cooperatives in providing a *root dipping service* during the rice planting season can be explored.

Soaking potato seed tubers in nutrient solutions

Some on-station results are available with this technique. In a 4-year investigation, seed tubers soaked in a 1.5 per cent SSP solution for 6 hrs. increased tuber yield comparable to that obained by soil application of 50 Kg P_2O_5|ha (53). The beneficial effect of soaking was more in P-deficient soils. Fertilisers such as MAP, DAP and possibly others can also be used. As with most other techniques, causes for variability and surprises have not been fully researched. For instance, in one report, soaking of tubers in plain water gave a yield increase of 300 Kg and 1300 Kg tubers|ha in two successive years (52).

Decision on the degree of soil-fertiliser contact

Efficient application techniques generally favour that the soil-fertiliser contact should be restricted for fertilisers having water-soluble P and maximised for fertilisers such as rock phosphate, slags, etc. in order to hasten their solubilisation. In two field experiments, fertilisers having more than 30 per cent water-soluble P were more efficient when drilled and rock-P was more efficient when broadcast (13a). In upland rice, best yields were associated with a soil: fertiliser contact of 50 per cent with SSP but 70-90 per cent contact for rock-P or basic slag (Figure 6).

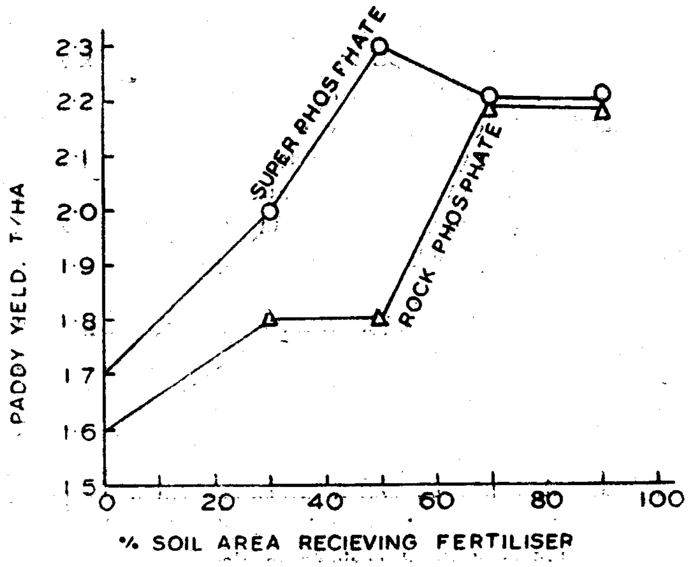

Figure 6—Degree of soil: fertiliser contact and the performance of P-sources of different solubilities for upland rice (Data source: Mahapatra, I. C. and Patnaik, S. in Vertisols and Rice soils of the Tropics. 12th Int. Cong. Soil Science, 212-228 (1982).

Treatment of fertiliser P with organic|inorganic materials

Some interesting research shows how the efficiency of rock P can be increased in neutral-alkaline soils if the rock is pre-incubated with fresh cattle dung (26, 68). Large-scale testing and evaluation of this technique under farmers' conditions is awaited (68). Some other techniques which could have a potential are the development of P-enriched composts (31, 35), integrated use of FYM and P and application of rock P combined with pyrites in high pH soils (34, 67).

Fertiliser SSP coated with biogas slurry, dung or mixed with silicate increased the P utilisation efficiency by 10-70 per cent (10). Quite appropriately, these workers stated that "results indicate the possibility of increasing utilisation of P from applied fertiliser by relatively simple and cheaper agro-techniques. *Though many of the findings to increase the efficiency of P have been striking, the relative merits with respect to their adaptability and economic feasibility remain to be established*".

Table 8—Effect of inoculation with mycorrhiza on the yield and P-uptake under field condition in Karnataka

Crop	P added	Uninoculated		% increase due to VAM	
		Yield kg/plot	P uptake mg/plant	Yield	P uptake
Finger millet	No	1.09	38.0	27	46
	Yes	1.74	72.9	8	28
Chillies	No	1.23	33.0	43	115
	Yes	1.30	38.0	66	167

Data sources: Finger millet: Govindarao *et al.*, Zentbl. Mikrobiol, 138, 415-419 (1983).

Chillies: Bagyaraj and Sreeramulu, *Plant & Soil* 69, 375-381 (1982).

Use of mycorrhizal fungi

Mycorrhizal fungi also known as VAM (Vascicular-Arbuscular Mycorrhiza) colonise plant roots and through this symbiotic association help the plant to gather P in larger quantity or more efficiently. Research on VAM in India is at a modest scale, particularly under field conditions but appears to be gaining attention (8, 10, 23). Lack of crop response to P application under certain situations, is attributed, in part to the possible role of VAM in enabling the crop to make a more efficient use of available soil P (17, 37). The VAM can also increase the efficiency of insoluble P fertilisers (10, 23). Effect of VAM on growth, yield and P uptake have been reported for a number of crops. Some results under field conditions are given in Table 8. The present and future need is for greater research under field conditions, under non-sterile conditions and towards identifying efficient VAM strains for important soil-crop systems.

Use of P solubilising organisms

Current interest in this sector is towards increasing the availability of native soil P as also of fertilisers such as rock-P. *Recent reviews bring out the divergence of views* about the practical importance of using P-solubilising micro-organisms for increasing P efficiency. While the technique is held to be quite useful (8); its impact on crop yields has not been consistent (59) and other workers have concluded that the findings are of little relevance to practical agriculture and the information available so far is inadequate (3). Nevertheless, this is a route which should not be abandoned but studied in all its aspects. All available means of increasing P efficiency should be explored and to the extent possible, techniques should be matched with the environments where they are likely to be effective so that too much hit and trial research can be avoided. Sizable yield increases of rice, wheat, lentil, chickpea, maize and potato have been reported due to inoculation with P-solubilising micro-organisms (8, 54). Well-coordinated research endeavours between microbiologists and agronomists|soil scientists could prove to be worthwhile.

Improved application techniques for potassium

Potassium accounts for 20 per cent of the NPK used worldwide but 8-9 per cent in Asia. Generally potassium is applied to seasonal crops as a part of the basal dose and to perennial crops according to a more spread-out schedule. For higher efficiency in coarse-textured soils and in high rainfall areas, application of K in 2 or more splits is being increasingly advocated for cereals as in Kerala and Uttar Pradesh. Integrated NK top-dressings are thus an emerging practice and some attention may be paid to the development of NK materials (1:1, 2:1). There is an interesting report in which 3 sprays of 2.5 per cent KCl gave a significant increase in sugarcane yield during a drought year compared to a non-drought situation (58). Obviously research on K-use efficiency is much less than for N or P, as is its consumption, though not its requirement by crops.

Improved application techniques for sulphur

Sulphur deficiencies are assuming increasing importance and their correction is a must for obtaining satisfactory fertiliser efficiency (18, 63). Sulphur deficiencies have been reported from 71 countries including India (18, 63, 66). Work on improved S-application techniques in many tropical areas is inadequate as most of the attention is devoted to NPK. Some guidelines based on research in India are provided in Table 9. It brings out that application techniques must essentially match the fertiliser properties with the soil characteristics and take into account crop needs of S and crop duration.

Table 9—Some practices for efficient use of fertiliser sulphur

Material	Efficient technique
Readily soluble materials (AS, APS, SOP)	Basal as well as top-dressing
Less soluble sulphate sources (gypsum)	Prior to planting
Materials which require oxidation (elemental S, pyrites)	4-6 weeks ahead of planting

Source: (63).

Table 10—Practices for efficient use of micronutrients

Element	Situation	Efficient application technique
Zinc	Seasonal crops	Soil application, broadcast/mix
Zinc	Long-duration crops	foliar application
Zinc	Rice seedlings	Root dipping also possible
Zinc	Small doses	Band placement before planting
Iron	Most cases	Foliar spray
Manganese	Most cases	Foliar spray

Source: (12, 20, 46, 60).

Improved application techniques for micronutrients

The deficiencies of Zn are already widespread. Those of iron, manganese and others occur on a lesser scale but can be as important as Zn for the farmers of the area where they are practically important. Much of the research with Zn is in favour of a basal soil application for seasonal crops (20). Improved application techniques vary with the crop and the element (Table 10). Soaking seeds in zinc sulphate solution or coating seed with Zn powder were not found effective but dipping rice roots in 2-4 per cent ZnO suspension was quite effective in correcting Zn deficiency (20). Other reports indicate that root dipping was not very effective but nursery enrichment (5g Zn|sq m) was superior to most methods of Zn application (5). These workers showed that Zn application should not be delayed as its application even two weeks after rice planting was less efficient than application at planting.

Results also indicate that at lower levels of application, band placement of Zn was a superior practice over surface broadcast + mixing (46). Differences between the two methods of application narrowed down as the amount of Zn increased (Figure 7).

For Mn, foliar spray is superior over soil application (60). Four sprays of 0.5 per cent Mn Sulphate produced 5.2 t|ha of wheat while even 20 Kg $MnSO_4$ applied to soil could not yield beyond 2.5 t|ha grain. The other interesting finding in this study was that the spray schedule must start within a month after sowing. Keeping the total amount of Mn the same, more sprays at lower concentration were superior over less sprays of a higher concentration (60).

Improved Application Techniques— Beyond Agronomic Evaluation

For the improved techniques of FUE to find large-scale practical application, their agronomic potential must be translated into economic advantage to the end-user. This is not always done. In addition, where a certain degree of mechanisation accompanies an improved practice, all aspects of machine application and the backup services needed have to be looked into.

In the case of N, the economic aspects of USG, *neem*-treated urea and other techniques have already been discussed in the preceding sections. Available cost estimates associated with various improved fertiliser application techniques are not always available. The author has tried to compile|compute these to stimulate exchange of ideas on agro-economic lines. Cost factors associated with N-use efficiency have been given in Table 5 earlier. *Economic analyses of improved techniques are a must if their practical application is of serious interest.*

The other aspect deserving attention is with respect to fertiliser application machines and their performance. Some estimates of cost factors associated with various fertiliser application techniques are provided in Table 11. These indicate quite clearly that the benefit of using improved practices is many times the cost involved.

Although followup studies are few, indications are that fertiliser application machines are not used with the same skill, accuracy and precision at the farm level as at the research stations. This definitely reduces the potential gains from an improved technique, but to what extent, we do not know. It can not be taken for granted that mechanical application of fertiliser is uniform and free of faults.

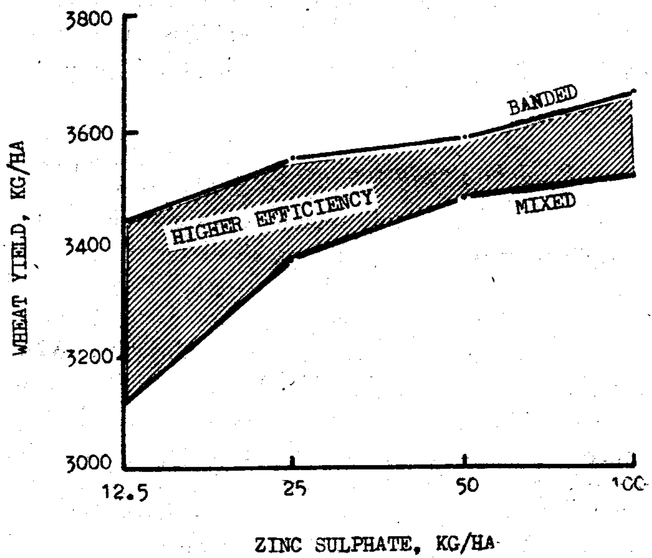

Figure 7—Performance of two methods of Zn application at variable dose for wheat (46).

Table 11—Cost factors associated with improved fertiliser application techniques

Nutrient	No.	Efficient application technique	Cost (Rs/ha) of carrying out the technique	Kg grain @ Rs 1.5/ kg needed to pay for this cost	Remarks
Common N, P, K,	1.	Drilling by bullock-drawn fertiliser drill	45	30	1 ha/day, bullock rental Rs 40 and drill costs
	2.	Drilling by bullock-drawn seed-cum-fertiliser drill	25	16	3-tyne, 1 ha/day cost divided among seed and fertiliser
	3.	Drilling by tractor-drawn seed-cum-fertiliser drill	65	43	4 ha/day. Tractor rental Rs 120/ha plus drill. Costs divided among seed and fertiliser
	4.	Drilling fertiliser behind plough with seeding	50	33	2 days/ha, bullock rental plus labour, cost divided among seed and fertiliser
N	5.	Topdressing	8	5	0.8 mandays/ha/topdressing
	6.	Curing urea with soil (1:4)	40	27	4 mandays/ha/application mainly for spreading the urea-soil mixture
	7.	Foliar spray	20	13	Per spray, 1 manday/ha plus sprayer
	8.	Point placement (USG)	110	73	10 mandays/ha + applicator
P	9.	Drilling/placement	25-65	16-43	See items 1-4 in this table
	10.	Dipping rice roots in P-slurry	22	15	2 mandays to treat seedlings/ha bucket etc.
	11.	P blending with cowdung or biogas slurry	30	20	2 mandays plus Rs 10 for 150 kg manure needed to treat 50 kg P_2O_5/ha
	12.	Advanced application (rock-P)	0	0	Only decision to apply early needed
	13.	P-solubilising microorganisms	15	10	Non-commercial cost
K	14.	Split application	8	5	0.8 mandays/ha/split
S	15.	Advanced application	0	0	Only decision to apply early needed
Zn	16.	Where sprayed	20	13	1 manday/ha/spray plus sprayer cost lower if combined with pesticides application
Fe, Mn	17.	Spray application	20	13	,, ,, ,

Notes: 1. Cost estimates are very approximate and illustrative to stress the importance of economic analyses of fertiliser efficiency techniques.

2. Labour costs are taken at Rs 10/person/day but will obviously vary from place to place and season to season.

3. The cost estimates have been arrived at as a result of discussions with a number of colleagues in research and industry, particularly Dr. Rajendra Prasad, Dr. M.B. Kamath and Dr. A.C. Gaur of IARI, Dr. V. Kumar (IFFCO), Dr. D.S. Yadav (FAI), Dr. S.B. Kute (GSFC) among others.

In the state of Punjab, where farm mechanisation has made relatively more progress, fertiliser drills currently being manufactured were not provided with proper metering plates and calibration charts. In 90 per cent cases, they dropped either too much or too little fertiliser (71). This report stated that "Well defined projects and well directed efforts on the research front for the design, development, testing, evaluation, manufacture and adoption of fertiliser application equipment is unfortunately missing in our country" (71).

Such problems are not confined to developing countries alone. The report by Bull and Crowe (2) shows that 18 per cent operators in UK did not refer to machine instruction book and 51 out of 177 had received no formal training in the use of fertiliser application machinery indicating ample scope for training in correct and uniform fertiliser application. They suggest that for uniformity of application, a C.V. of 20 per cent or less should be acceptable, an ideal would be 10 per cent or below and future goal should be to operate at a C.V. of 5 per cent. In their assessment, an ideal fertiliser application machine should have the following qualities:

— verstalite to apply different fertilisers
— easy to calibrate
— not affected by RPM of the tractor
— not affected by forward speed
— strong, simple design

- easy to clean and dismantle
- ability to have a range of widths
- ability to handle different quantities with same accuracy
- easy to fill
- rate change should not affect spreading pattern.

Proper physical properties of the fertilisers are also important though these are generally not given the due attention. Non-uniform application will result in a non-uniform crop stand|growth which is hardly a favourable condition for high efficiency. Popp (41) drawing attention to the effect of fertiliser quality states that to achieve optimum nutrient distribution and efficiency, fertilisers should have:

- all nutrients in each granule in prescribed ratio
- a uniform particle-size spectrum
- particles of uniform specific gravity and surface properties.

The above discussion is intended to focus on the need for an all-round evaluation of improved application techniques, the major components of which are agronomic, economic, mechanical, technological.

Improved Application Techniques— Some Selected Systems

It is considered necessary to synthesise available information on improved application techniques into some sort of blueprints for efficient fertiliser management. These should essentially be developed for well-characterised environments. Generalised strategies for four systems selected to serve as examples have been outlined in Table 12 for lowland rainfed rice, Table 13 for wheat, Table 14 for potato and Table 15 for sorghum. As the nutrient efficiency aspects have been dealt with above, these are not discussed in detail here.

Table 12—Guidelines for efficient fertiliser application in lowland rainfed rice

Nutrient	Improved application technique
N	Split application under alternate wet-dry regime deep placement under stagnant water conditions
P	Priority application to dry season crop P application to legume preceding rice
K	Split application in coarse textured soil
Zn	Dipping rice seedlings in ZnO suspension

Note: For flooded rice see Table 4 and section on urea supergranules.

Source: (6 other sources).

Table 13—Practices which lead to efficient fertiliser use in wheat—some cases

Aspect	Comparison	Advantage
N application	Split over all basal	40% extra yield
P application	Placement over broadcast	18% extra yield
Weed contuol	Weeded over weedy	52% extra yield
Mulching	Mulching over no mulch	25% extra yield
S deficiency	NPKS application over NPK application	30% extra yield
Zn deficiency	Zn banded over broadcast	3-10% extra yield depending upon the rate of application

Source: (45, 46).

Table 14—Improved techniques for efficient fertiliser use in potato

Nutrient	Efficient practice
Nitrogen	CAN and AS more efficient agronomically. Efficiency of urea-N can be incresed by applying it 5-10 days prior to planting, by split application, mixing with *neem* cake.
Phosphorus (also K)	High water-soluble source more efficient Furrow placement at planting efficient (NPK) Annual applications better than biannual applications (PK) at double the annual dose soaking seed tubers in 1.5% SSP solution an efficient way.
Zinc	Soak seed tubers in 0.05% Zinc Sulphate solution or dip seed tubers in 2% ZnO suspension.

Source: (11).

Table 15—Some improved application techniques for efficient fertiliser use in sorghum

Season	Nutrient	Strategy for efficient fertiliser use
Kharif	N	Apply N in splits starting with basal complete N application by flower primordia stage
Kharif	P	Water-soluble source more efficient drill P below soil surface alongwith other basal nutrients
Rabi	N	Generally drill all N as basal alongwith P in areas expecting little rains but provide for a topdressing if seasonal rains can be expected
Rabi	P	—as in Kharif

Source: (Several Indian data complied in (65)).

While designing blueprints for increasing fertiliser efficiency, it may be useful to conduct some surveys of the fertiliser application techniques already used by farmers in different areas.

Missing Links and Future Needs

When the information on improved application techniques is examined, one finds that a number of techniques have not found wide application. All the reasons for such a state are not known but it is quite clear that if the adoption of an improved technique can increase crop production and fertiliser use efficiency, its neglect can do the opposite. *The social cost in terms of lost production and profits will in any case be substantial.*

The beneficial effect of *neem*cake was reported 15 years ago, of dipping rice roots in P-slurry over 10 years ago and of USG about 5-8 years ago. One must address to the question as to why have they not found large-scale application even in areas where they have been found to be effective. The author believes that in our research-extension-adoption chain, *there is a vital link missing.* This is the link which should identify and pickup promising techniques, reject the ones which fail but select and promote the ones which make the grade. In the absence of such a mechanism, some of the promising practices get neglected or abandoned thus lowering not only possible fertiliser efficiency but also the efficiency of investments made in research. The need for such a mechanism has also been hinted at by Goswami and Kamath (10) and by McCune and Stangel (32) who state that "Mechanisms must be found to transfer technological innovations from researchers to the farmers".

India, standing on the doorstep of a 10 *million tonne nutrient consumption mark is in a unique position to develop and promote improved practices which will increase fertiliser use efficiency.* Some suggestions in this regard are given below:

(1) A systematic survey should be initiated on the fertiliser application techniques employed by farmers in different areas. The efficiency gap can then be estimated. This can easily be made a part of the IFPC.

(2) A network may be setup to regularly monitor fertiliser application techniques on selected sites. Such a network should record and monitor changes in fertiliser application techniques and provide feedback to research and promotion. Soil testing laboratories can be associated in this exercise and should be fully aware of all available techniques.

(3) A mechanism should be created which would identify|pickup promising technologies and get these thoroughly and extensively evaluated. The successful ones should be vigorously promoted and their ready-to-use package developed. Such a mechanism is seen as a *technology bridge.*

(4) Considering the overwhelming evidence in favour of integrated moisture-fertiliser management for raising FUE, suitable *water metering devices* should be developed for the use of farmers, particularly those having controlled sources such as tubewells. The adverse effects of over-irrigation should be highlighted.

(5) Some techniques can be successfully adopted if small-scale custom-service enterprises are setup. These are treatment of urea with *neem*, point placement of USG, dipping rice roots in P slurries, spray operations etc. Models of such enterprises should be developed and these should be offered as economically viable packages which should be eligible for financial|loan assistance. *Let the next five years be devoted to the development of an infrastructure* for seeing an organised network of village|block|taluka|cooperative level custom-service units.

(6) Improved fertiliser application techniques should be integrated into local festivals so that they become a part of rural life and find spontaneous acceptance over time.

(7) Maintenance and minor repairs of fertiliser applicators should be part of all vocational training given to rural youth in the 12-18 age groups. Simultaneously, facilities for renting, maintenance and repair of machines should be encouraged among existing trades in rural area.

(8) There is an urgent need to develop field level literature on fertiliser application techniques which should be simple, well-illustrated and explain a practice in steps. *Existing literature many a time is too abstract, poorly illustrated and not simple enough.* For example, a leaflet entitled Maximising the Efficiency of Applied Fertiliser says that urea should be cured with soil to reduce N loss. It says nothing about what urea curing is and how it can be done.

(9) All field-level training on improved application techniques should be conducted in the form of method demonstrations and *not by lectures or pictures.*

(10) Last but not the least is the need for a greater, *well-planned interaction* between research workers, subject matter specialists operaing at the district level, farm advisors of the fertiliser industry, equipment manufacturers and the end user farmers.

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