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EVALUATING FERTILISER CHARACTERISTICS FOR FARMER USE

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Most fertilisers are evaluated by engineers, agronomists, or marketing specialists, each using different criteria. The purpose of this paper is to evaluate chemical fertilisers in an agronomic sense with the farmer's needs in mind. Illustrations based on USA experience or data are presented with the hope that they will be relevant to the development of fertiliser use in India.

NUTRIENT SOURCE (CHEMICAL CHARACTERISTICS)

Nutrient sources or carriers in fertilisers may vary in agronomic effectiveness due to differences in chemical characteristics. Nitrogen and potassium compounds are usually water-soluble and are little affected by the processing involved in producing mixed fertilisers. In contrast, phosphorus compounds vary widely in citrate and water solubility. The agronomic effectiveness of such compounds in relation to granulation, placement, and soil pH has been studied intensively over the years. In acid soils, water-soluble phosphates are more effective when granulated or with localized placement. By these means the rate of formation of less soluble reaction products is retarded. In calcareous soils, water solubility of phosphates should be fairly high; placement or granulation does not seem to be very important, at least for calcium phosphates. It is generally regarded that phosphates should be applied at or before planting since the crop requires an ample supply of this nutrient quite early in the growth period. Water-soluble phosphates stimulate early growth to a greater extent than do phosphates low in water solubility. This is especially true in areas having low soil temperatures at planting time.

Generally, crops with shorter growing periods require a higher level of water-soluble phosphorus in the fertiliser than do crops

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having a longer growth period. For instance, short-season vegetable crops respond to water-soluble phosphorus to a greater extent than do long-season crops such as maize or cotton.

On soils of high phosphorus levels, water solubility and granulation are not very important factors. Any source that will react with the soil will contribute to maintaining phosphorus levels in the soil.

Since ammonium-nitrogen nitrifies readily in most soils at crop-growing temperatures, the original form of nitrogen added is usually academic. Certain crops respond more favourably to certain chemical forms of nitrogen, however. For example, rice seems to require NH_4-nitrogen early in its growth period, but can use some NO_3-nitrogen later in the growth period. This is fortunate since NH_4-nitrogen is also much more stable in flooded soils; NO_3-nitrogen is subject to substantial atmospheric losses through denitrification upon flooding.

Phosphates and potassium are quite immobile in most soils and accumulate over time as a result of continued fertiliser application. Nitrogen, on the other hand, behaves as a mobile nutrient and generally does not accumulate in cultivated soils of humid regions.

PLACEMENT AND TIME OF APPLICATION

The manner in which fertiliser is applied may also determine desired fertiliser characteristics. In the USA, the former general practice was to apply fertiliser for the crop; that is, in bands at relatively low rates. Yield responses to added phosphorus and potassium were often pronounced. With time, however, fertilisers became cheaper and custom broadcasting of bulk fertilisers became common.

Fertilisers that are broadcast over the soil surface as a preplant operation and subsequently incorporated need not be as high in water-soluble phosphorus as those that are banded beside the seed at planting. The actual level of water solubility needed for each method of application will vary with the crop, soil, and other factors. Generally, band placement results in a greater efficiency per unit of nutrient, particularly for phosphorus and potassium. Therefore, for these nutrients, a lower rate of application is needed for band placement as compared with broadcast. Because of its mobility, placement has less effect on the effectiveness of nitrogen fertiliser when incorporated in the soil. However, band placement of ammonium or ammonia-producing sources near the seed can result in injury; this is particu-

larly true for urea and diammonium phosphate.

Other methods of application affecting the desired form of fertilisers are topdressing and sidedressing; that is, fertilisers applied while the crop is growing. Generally, the nutrient involved is nitrogen where part is applied at planting and part during the later growth period. Atmospheric losses of nitrogen can occur from topdressing (surface placement). This is particularly true for urea during periods of high soil temperature and drying conditions. If sidedressed nitrogen is incorporated into the soil, losses are much lower. Phosphate and potash fertilisers can be applied as topdressing quite successfully to legumes and turf grasses if soil moisture is present near the surface. Any nutrient applied in this way should be in water-soluble form.

With the use of heavier rates of fertilisation in the USA, soil levels of phosphorus and potassium increased and yield responses to these nutrients have become less frequent. With lower soil organic matter levels, greater crop demands, and less legume acreage, nitrogen has become the chief limiting nutrient on many of the cultivated soils in the USA (2). Relative needs among these nutrients may, therefore, shift over time.

If fertiliser supply is critical, as it may be in developing countries and the spring planting season in the USA, farmers may find it advantageous to apply fertiliser during the off-season. Such application of phosphate fertilisers is quite feasible; however, some water-soluble phosphate may be needed near the seed row at planting for early growth stimulation. Application of potash fertilisers in the off-season presents few problems unless soils are coarse-textured; potassium may then leach out of the root zone. Luxury consumption by crops can be reduced by split applications of potash fertilisers during the growing season, but it is not often that economic benefits result from this practice.

Off-season application of nitrogen is much more questionable. On medium to fine-textured soils, ammoniacal nitrogen can be applied providing soil temperatures are too low for rapid nitrification, that is, below 50° F. As a general rule, however, nitrogen should be added as near the time required by the crop as is practical. This is especially important in warmer regions where winters are mild and continuous cropping is not practised.

EASE OF HANDLING AND UNIFORMITY OF APPLICATION

Perhaps the most convincing demonstrations of the effects of

fertilisers on crop yields have resulted from poor handling characteristics of fertilisers. With powdery materials, "bridging" in the fertiliser hopper was common in the USA. The result was a visibly evident skip in the field where less or no fertiliser was applied. Wind also was a problem that resulted in poor distribution of powdered materials. With the advent of granular fertiliser materials, and more recently liquid fertilisers, these handling problems diminished.

However, when granular materials were introduced, other problems were encountered; most of these pertained to segregation of materials during blending, during loading of spreaders, and during application. It is now known that uniform sizing of materials can minimize segregation problems. Since materials manufactured in the USA do not always match in granule size, there still are possibilities that no uniform application can occur. In developing countries where most of the fertiliser is applied by hand, nouniform application through segregation is less likely. Blending of materials varying widely in granule size should be avoided nevertheless. Where rates of application are relatively low, results of nonuniform application can be quite obvious and can lead to farmer disenchantment with the dealer.

"STRAIGHT MATERIALS" VS. "COMPLETE FERTILISERS"

It matters little from an agronomic viewpoint whether nutrients are added separately as straight materials, or as homogeneous complete mixtures. The only exception would be the stimulation of phosphorus uptake that occurs when ammonium nitrogen is positioned in close proximity as in the same granule or band.

For those farmers who are not knowledgeable about plant nutrients, the use of a complete fertiliser (i.e., contains all locally needed nutrients) is more practical than that of separate purchase and application of two or more straight materials. For farmers who are knowledgeable about plant nutrients, straight materials may be a feasible choice, offering possible economic advantages and flexibility in application. The concern here is that the needed nutrients are actually applied.

NUMBER OF GRADES AND RATIOS IN USE

Agronomists consider many factors when preparing fertiliser recommendations for farmers. Soil test results, cropping history, the crop to be planted, farmer's management ability, time and method

of fertiliser application, soil characteristics—all may exert some influence on the rates of individual nutrients in the fertiliser recommendation. If each recommendation were to be translated into a specific ratio of $N:P_2O_5:K_2O$, the result would be a bewildering number of ratios that must be manufactured, transported, and sold. This is largely what has happened in the United States. Over 2,000 grades of mixed fertilisers, representing perhaps 400-500 different ratios, are offered for sale. Fortunately, in any one area not all these 2,000 grades are available. The natural question, however, is "How many of these are really needed?"

The total number of grades produced in the USA is much greater than can be justified on either agronomic or economic grounds. As shown in Table 1, just 3 ratios accounted for 34 per cent of the total mixed fertiliser consumed in 1966-67 and 8 ratios accounted for over half.

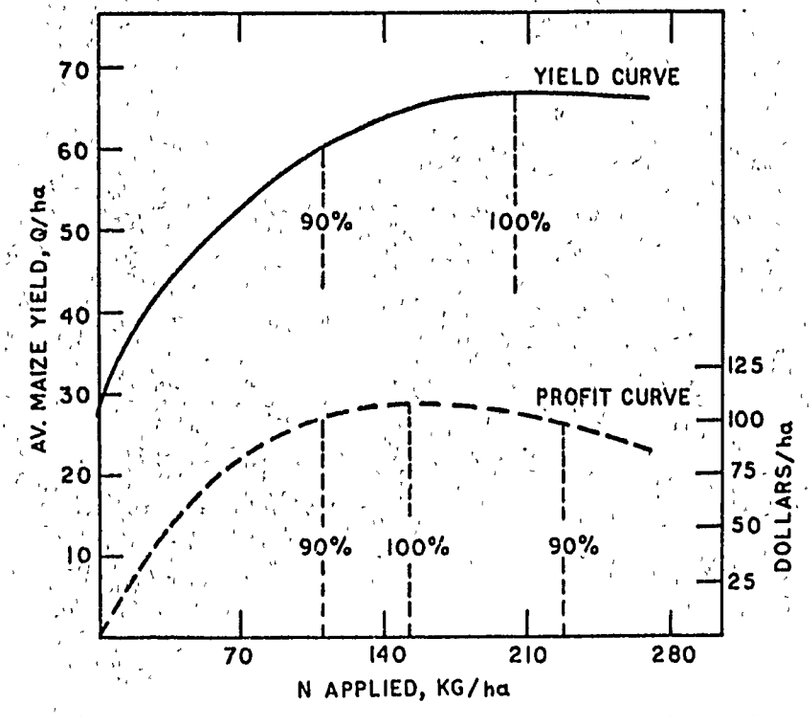
Table 1

Nutrient ratios of mixtures for the 1966-67 year in the USA

	Per cent of total materials consumed
1-1-1	13
1-2-2	11
1-4-4	10
1-2-3	6
1-3-3	6
1-2-1	4
0-1-1	3
1-4-2	3
Total	56

EFFECTS OF VARYING RATE OF A SINGLE NUTRIENT ON YIELD AND PROFIT

Before examining the importance of nutrient ratios, let us first see how variation in nutrient rate affects yields and profits from fertiliser application. Figure I shows the effect of increasing the rate of nitrogen using average yield data from 21 maize experiments con-



The average maize yield response to added nitrogen on 21 experiments and the calculated profit. (Data obtained from annual progress reports by North Carolina State University to TVA)
FIGURE I

ducted in North Carolina[1]. The response to added nitrogen was substantial, with average yield increasing from 26 to 67 quintals per hectare.

A maximum yield of 67 quintals per hectare was attained with 200 kg. of nitrogen per hectare, but 60 quintals (90 per cent of maximum yield) required only 110 kg. of nitrogen. It is pertinent to know how accurately nitrogen fertiliser must be applied to avoid losses in profit. As shown in Figure 1, the rate of nitrogen could have varied in this example from 110 to 220 kg. per hectare with a loss of no more than 10 per cent of the maximum profit[2]. This indi-

[1] From annual cooperative research reports by North Carolina State University to TVA, 1956-57.

[2] Prices used were $4 per quintal for maize grain, and $0. 22 per kg. of nitrogen.

cates that in the general region of the maximum profit point, profit is not a sensitive function of nutrient rate. Needless to say, both yield and profit losses would be more serious at rates associated with the steep portion of these curves. This would be more relevant concern in a country with a tradition of fairly low rates of application.

EFFECTS OF VARYING NUTRIENT RATIO ON YIELDS AND PROFIT

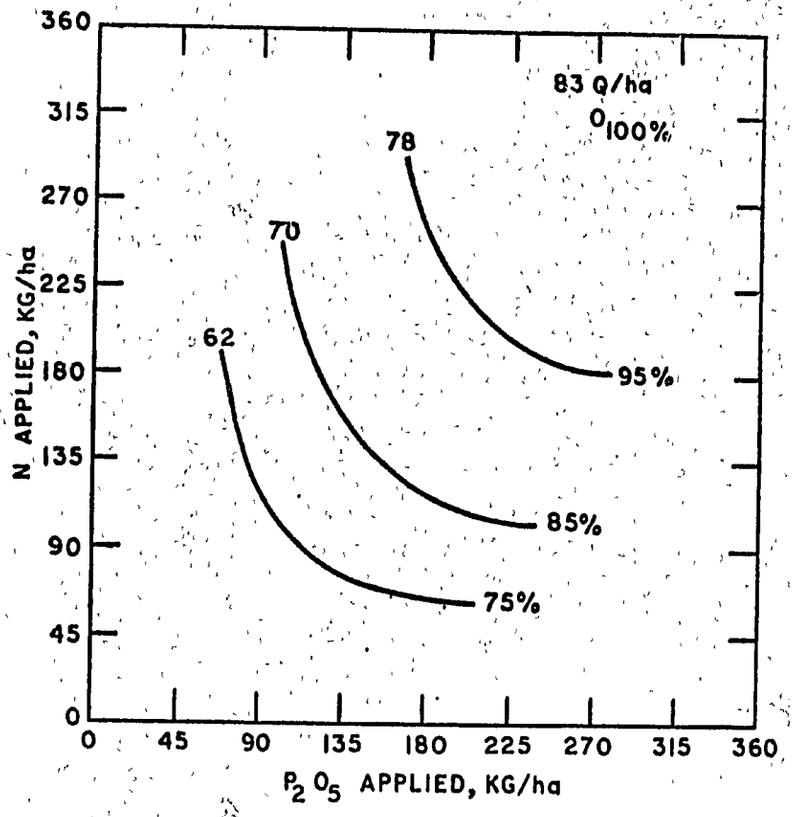
As indicated earlier, many grades and ratios of fertilisers are manufactured but only a few account for most of the mixed fertiliser consumed. Are farmers losing money by using too few ratios or could the number be reduced even more without serious loss?

Agronomic-economic investigations with NPK experiments during the last decade and a half show that plant nutrients "substitute" for each other in a nonphysiological sense. Heady et al. (3) reported responses of maize to added nitrogen and phosphate as obtained via an incomplete factorial. To see the substitution relationships, the results are shown using a yield contour map (Figure 2). That is, the curved lines shown represent different constant yield "levels," tracing out various combinations of nutrients. For example, at a constant yield level of 70 quintals per hectare (85 per cent of the maximum yield), combinations ranging from 200-100-0 to 115-230-0 could have been used. This represents variation in ratio ranging from 2-1-0 to 1-2-0. The other yield contours shown indicate a similar degree of "substitution" between the input factors N and P_2O_5.

The contour map approach can also be applied to profit (1). Using data from the same experiment as above and the then current crop-fertiliser prices[1], the profit map was calculated and plotted in Figure 3. While the cost of fertiliser reduced the maximum to a lower combination of nitrogen and phosphate, a similar "substitutional" relationship was found for the two nutrients. For example, either 130-100-0 or 90-140-0 could have been applied and still 95 per cent of the maximum profit would have been obtained. These combinations represent ratios of 1-0.8-0 and 1-1.6-0.

Nutrient ratios, therefore, may not be as critical as one would suspect. Thus, in answer to our question, farmers should not suffer

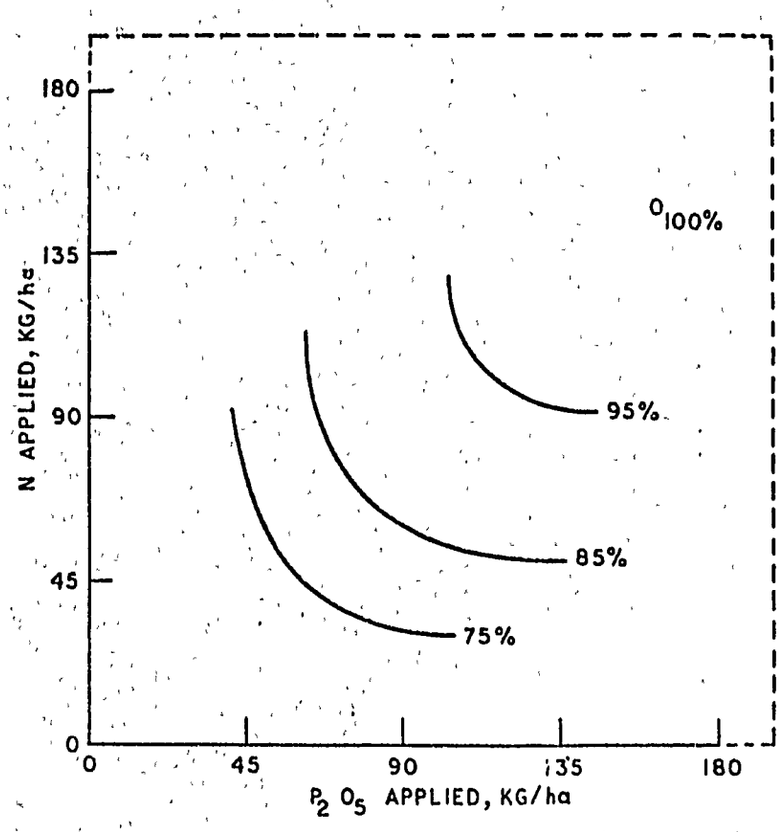
[1] The prices assumed for maize was $4 per quintal and nitrogen was $0.31 per kg. P_2O_5 was assumed to be $0.22 per kg.



Yield contour map of NP experiment on maize. From Heady et al (3). Recalculated by Engelstad (1).
FIGURE 2

losses in yield or profit when they are limited to just a few ratios. The relatively broad yield and profit plateaus between isoquants in both Figures 2 and 3 should not, however, relieve agronomists from recommending fertiliser rates as precisely as possible. Nevertheless, a lot of time should not be wasted in refining recommendations. Such time can better be utilized in other areas of work or research. It should be stressed, however, that all the needed nutrients must still be applied; these data show that rate and ratio are not especially critical.

In view of the costs involved in producing and advertising a wide variety of grades, developing countries should recommend the



Profit contour map for NP experiment on maize. From Engelstad (1).
FIGURE 3

number of ratios according to agronomic needs. Low-analysis grades should also be discouraged. It is much easier to control the list of grades and ratios in earlier stages of development of the fertiliser industry and use than after the proliferation has already taken place. Once grades become established, there is considerable resistance to dropping them. The primary consideration should be to keep the cost of nutrients low for the farmer, rather than to provide a wide choice of ratios and grades for him.

The ratios that are needed in a given locality must be decided according to soil and crop needs on a regional or state basis. Some allowance should be made for shifts in fertility over time; ratio lists

should, therefore, be reevaluated every few years. It should be pointed out, too, that the use of straight materials can reduce the number of grades and ratios needed as complete fertilisers.

Summarizing briefly, the way in which farmers use fertilisers controls the characteristics that affect their efficiency. Granular materials are easier to handle but can segregate when nonuniform sizes are blended. Chemical composition depends, to a limited extent, on crop requirements. Generally, however, fertilisers applied at planting time or during the growth season should have a greater degree of phosphorus water solubility than those applied during off-season. Variation in nutrient ratio, within limits, has a minimal effect on yield and profits derived from fertiliser use. Of more concern is the changing pattern in which farmers use fertilisers. As low rates applied for low-yielding varieties change to high rates applied broadcast and banded for high-yielding varieties, agronomists must be prepared to recommend—and producers to manufacture—fertilisers with new sets of characteristics.

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