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For Efficient Use of Fertilizers, Let's ...

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FOR EFFICIENT USE OF FERTILIZERS, LET'S "KEY ON" NITROGEN

J. W. FITTS

In athletic contests involving teams of several players, the strategy in designing offensive or defensive tactics often involves concentrating on one individual, usually an outstanding player. This player is the key to the team's game plan; thus the frequently used term "keying on a player." In the game plan for soil fertility availability, there are thirteen players involved. These are the elements essential for plant growth which must be obtained from the soil. The front line of this team is the big three of the nutrient elements: nitrogen, phosphorus, and potassium, which are often referred to as the primary elements. Over the past century, most attention in the manufacture and use of fertilizers has been directed to these three elements. Even most fertilizer control laws concentrate on nitrogen, phosphorus, and potassium. The commonly accepted fertilizer formula for mixed fertilizers such as 10-20-10 is aimed at the primary elements. Nevertheless, the other nutrient elements are very important too or they would not be classed as essential for plant growth.

Efficient use of fertilizers translanted into terminology understood by farmers means getting the largest number of kilograms of crop per kilogram of fertilizer applied, which in turn is related to the costs involved. The concept of diminishing return with an increase in fertilizer application is widely accepted. The general growth response curve is illustrated in figure 1. With an increase in fertilizer application the successive increments of yield increase are diminished. Following this concept, the largest return per kilogram of fertilizer applied would be at the lowest rate of application where the curve is steepest. Curves such as this are most often obtained on fields which are very deficient in a given element such as nitrogen. A common practice among research workers is to select fields that are very deficient in an element in order to get a steep slope and highly significant results. This would indicate that for the greatest return per dollar invested farmers should apply low rates of fertilizer and scatter a given quantity of fertilizer over larger areas. In other words, the implication is that less fertilizer might be needed to produce 5,000 kg of maize by growing five hectares at 1,000 kg per hectare than one hectare at 5,000 kg per hectare. Of course this practice assumes there is a large

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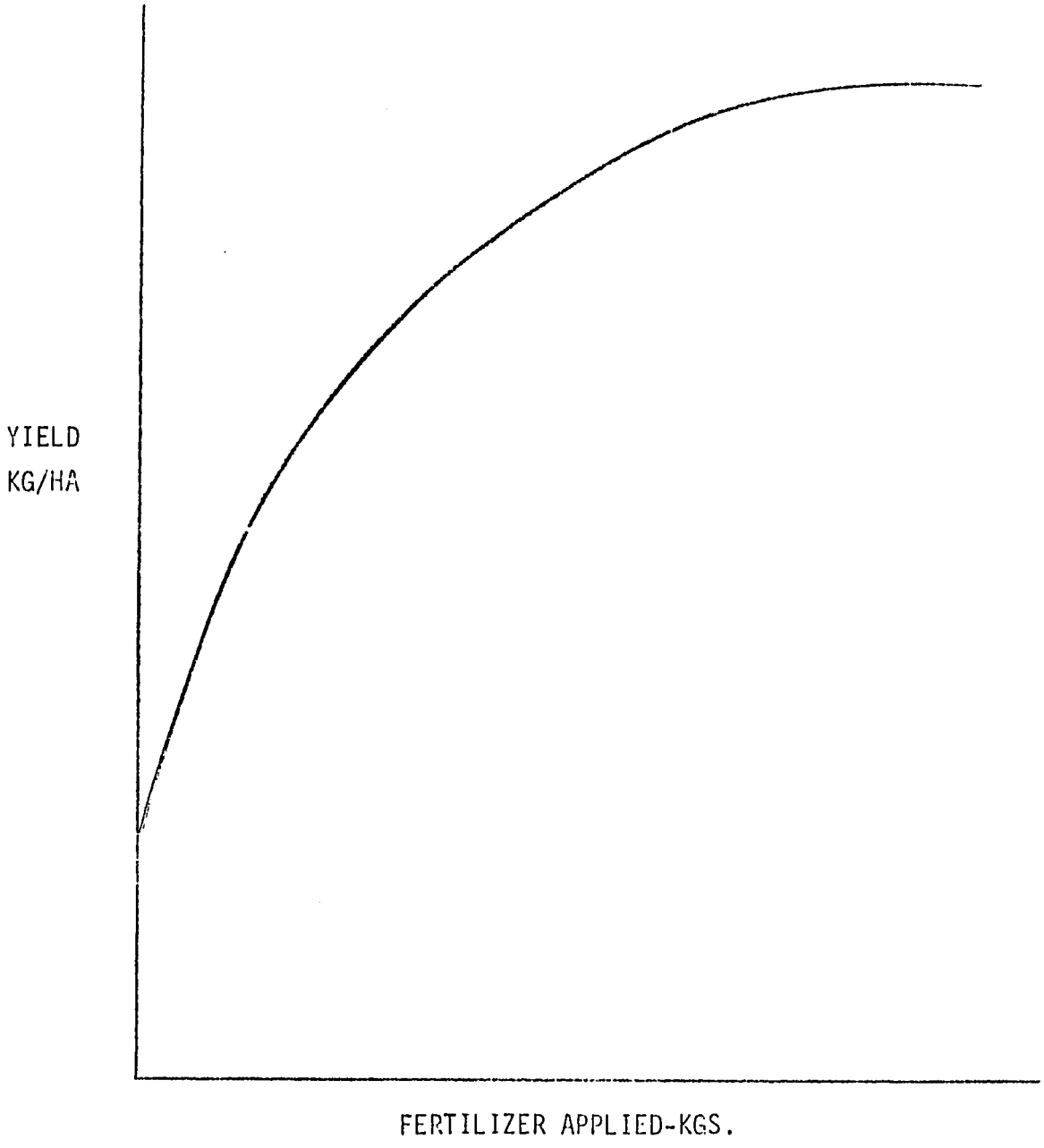

ıre 1 GROWTH RESPONSE CURVE-ILLUSTRATING THE LAW OF DIMINISHING RETURN.

area of tillable land available upon which to scatter the fertilizer. Unfortunately, in most areas of the world today, most of the tillable land is already under cultivation. Thus the question becomes how to attain high crop production efficiently and how to sustain it over a period of years on a given area of land.

In recent years a fresh look is being taken at growth response curves as related to fertilizer application to soils. This approach focuses on Liebig's law of the minimum which simply indicates that the yield of a crop will be governed by the factor or factors in short supply. The yield can be no higher than that permitted by the most limiting factor or factors. This is graphically illustated in figure 2, (5). Let us assume that element A is nitrogen and B is phosphorus. Nitrogen is most limiting in this graph and the initial response will be to nitrogen. The response will be linear until point B is reached where phosphorus also becomes limiting. The response then will be to both nitrogen and phosphorus (AB). The linear response will continue when all other growth factors are optimum until genetic characteristics limit the yield.

Assuming the linear response is correct, an immediate question is what should be the slope of the linear line? Of course, in the linear response model, we are particularly interested in the slope of the response line since this indicates the return from the fertilizer applied. Many factors influence the yield of a crop as indicated in the yield equation (4):

$$\text{Yield} = f\ (\text{soil, crop, climate, management})$$

These same factors will influence the slope of the response line. Crops differ in their nutrient requirements and in their use of the various nutrients. Climatic factors including moisture, temperature, and day length will also affect the slope of the response line. For example; corn growing in the high plateau of Ecuador may require 8 to 10 months to mature compared to 3 to 4 months at a lower elevation and with longer day length. Some of the variables can not be controlled but still need to be appraised. Then management practices should be followed which will give the most efficient results. Other variables can be controlled, and among these are soil fertility and some of the adverse soil conditions such as acidity. For the remainder of our discussion, let us focus our attention on soil fertility and how a deficiency or imbalance may influence the slope of the response curve.

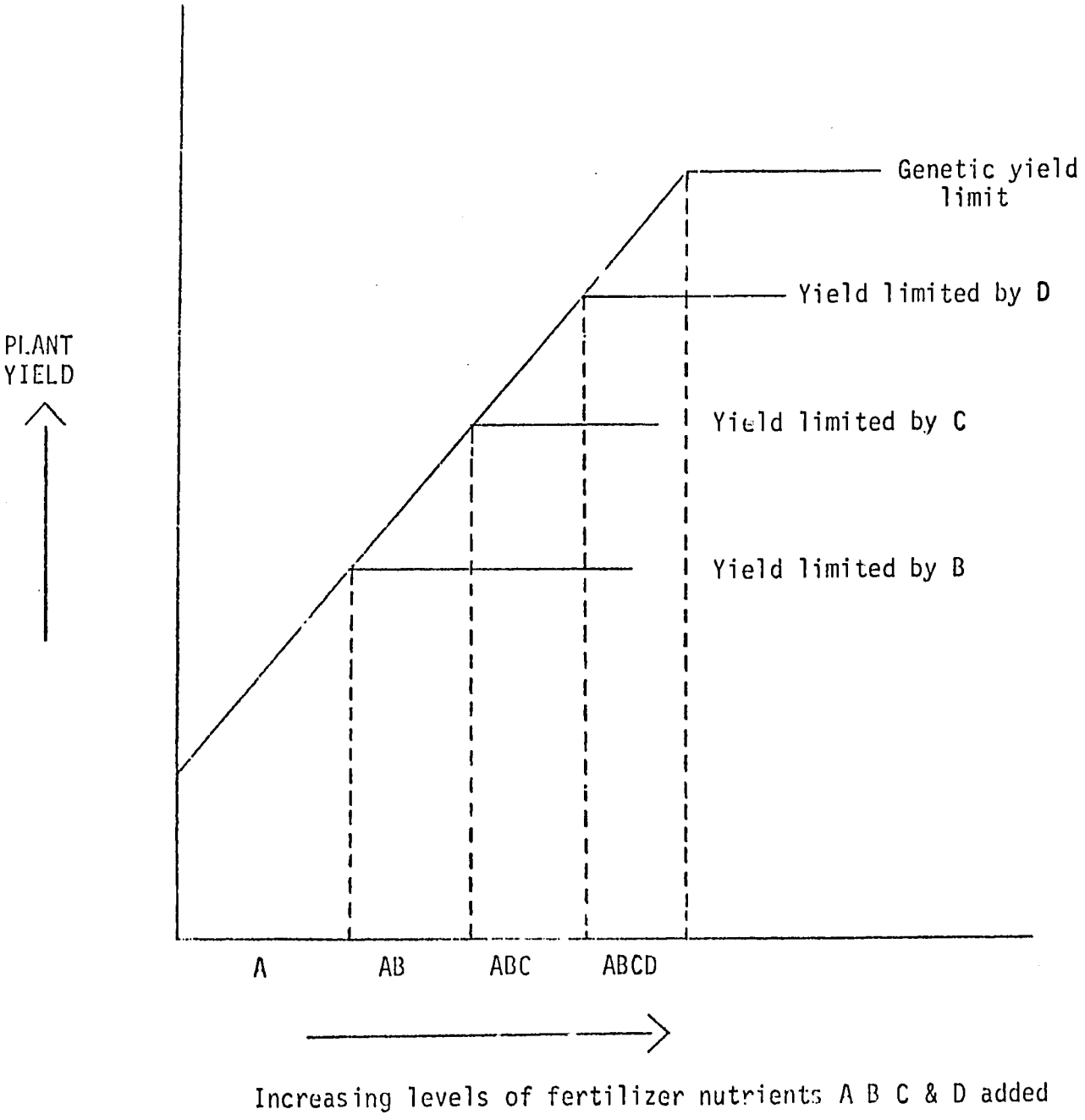

FIGURE 2 THE LINEAR RESPONSE-AND-PLATEAU (LRP) FUNCTION AS BASED ON LIEBIG'S LAW OF THE MINIMUM (5).

Of the elements that are essential for plant growth which are obtained from the soil, nitrogen is most often likely to limit crop growth. Since nitrogen is found primarily in the organic fraction factors affecting the release and availability of nitrogen in soils are somewhat different than that for most of the other essential elements. Bartholomew and Kirkham (2) have pointed out that soil organic matter reaches a state of equilibrium even under cultivation; otherwise, the organic matter content would decrease to zero. Of course where erosion is taking place, this may happen, but for most cultivated areas this is not true. Once the level of organic matter reaches a state of equilibrium, then as much nitrogen must be added as is removed. This means that few soils can sustain high yields of crops without application of additional nitrogen. Biological nitrogen fixation by both symbiotic and non-symbiotic organisms offers a source of nitrogen, but this offers other problems too, such as taking the area out of food crop production when total crop production is considered. What this boils down to is that a certain quantity of nitrogen is needed to produce a certain quantity of crop. If more nitrogen is applied than is utilized by the plant, then efficiency of the fertilizer decreases. The most important question to the farmer is how he can get the greatest amount of grain from each kilogram of nitrogen applied. A low return signifies low efficiency.

In tables 1, 2, and 3 are data reported by Bartholomew (1) but presented in a slightly different manner. Column 2 shows the average amount of nitrogen required to produce the yields shown in column 1. The kilograms of grain per kilogram of nitrogen applied are shown in column 3. Columns 4 and 5 are the same as columns 2 and 3 except the fields from which these average yields were calculated were the better trials and had the highest return of grain per kilogram of nitrogen. Bartholomew reviewed hundreds of field trials from around the world in arriving at the data presented in these tables.

Some interesting observations can be made from these tables. First, the amount of grain returned per kilogram of nitrogen decreases somewhat as the yield increases. This might be expected because more loss of nitrogen from leaching and volatilization is likely to occur at higher rates of application, and also some other elements may begin to become limiting and in turn reduce the efficiency of the nitrogen. Consequently, taking these losses into account, the decrease in

TABLE 1. Nitrogen needed for the production of maize (1).

Yield M. Tons/ha	Average Field Trials		Better Field Trials	
	Nitrogen Needed[1/] Kg	Kg Maize per kg N	Nitrogen Needed Kg	Kg Maize per kg N
1	30	33.3	26	38.5
2	61	32.8	53	37.8
3	94	31.9	82	36.6
4	128	31.3	112	35.7
5	163	30.7	143	35.0
6	200	30.0	175	34.3
7	238	29.4	208	33.7
8	277	28.9	242	33.1
9	317	28.4	277	32.5
10	359	27.9	313	31.9

1/ This does not imply the rates of nitrogen to apply to a field since most soils are able to supply some nitrogen for the crop. To go from one yield of maize to another, subtract the amount of N needed for the lower yield (traditional yield) from that required for the higher yield (goal or plateau yield).

TABLE 2. Nitrogen needed for the production of wheat (1).

Yield M. Tons/ha	Average Field Trials		Better Field Trials	
	Nitrogen Needed[1/] Kg	Kg Wheat per kg N	Nitrogen Needed Kg	Kg Wheat per kg N
1	48	20.8	43	23.3
2	105	19.0	91	22.0
3	174	17.2	147	20.4
4	255	15.7	213	19.5
5	351	14.2	289	17.3
6	463	13.0	373	16.1

1/ This does not imply the rates of nitrogen to apply to a field since most soils are able to supply some nitrogen for the crop. To go from one yield of wheat to another, subtract the amount of N needed for the lower yield (traditional yield) from that required for the higher yield (goal or plateau yield).

TABLE 3. Nitrogen needed for the production of brown rice (1).

Yield M. Tons/ha	Average Field Trials		Better Field Trials	
	Nitrogen Needed[1/] Kg	Kg Brown Rice per kg N	Nitrogen Needed Kg	Kg Brown Rice per kg N
1	40	25.0	30	33.3
2	80	25.0	56	35.7
3	121	24.8	86	34.9
4	163	24.5	117	34.2
5	206	24.3	149	33.6
6	250	24.0	182	33.0
7	294	23.8	215	32.6
8	338	23.7	248	32.3
9	382	23.6	281	32.0
10	426	23.5	314	31.8

1/ This does not imply the rates of nitrogen to apply to a field since most soils are able to supply some nitrogen for the crop. To go from one yield of brown rice to another, subtract the amount of N needed for the lower yield (traditional yield) from that required for the higher yield (goal or plateau yield).

return per unit of nitrogen is not as large as would be expected by the traditionally accepted diminishing return growth response curve. In fact, there is only a decrease of about 3 kgs of grain per kg of nitrogen for a 6 ton per hectare yield spread.

Second, the return in grain in relation to nitrogen applied is approximately a straight line. This is true in both the better field trials and the average field trials.

Third, there is a considerable difference in the amount of grain return per kilogram of nitrogen between the three crops--maize, wheat, and rice. These data indicate that wheat is the least efficient of the three in the use of nitrogen. However, some of this may be due to the fact that wheat is usually grown in drier regions and has less moisture available. Then there is the lodging problem, particularly with some of the older varieties. Nevertheless, there is obviously considerable difference in the efficient use of nitrogen by various crops.

The most important observation of all in reviewing these data is that we can key on nitrogen efficiency as a means of determining how serious the other yield factors may be in limiting the yield in a given field or area.

A generally accepted figure for average farm production is 10 kilograms of grain per kilogram of nitrogen applied. This figure is only about one third of what can be obtained for maize and scarcely more than half for wheat. What does this mean in terms of total production? Let us assume that we have 100 kgs of nitrogen to apply to maize, and our yield production level is five tons per hectare. For the average field trial we would receive 3,070 kilograms of maize from the 100 kgs of nitrogen, and from the better trials we would obtain 3,500 kilograms. The average farm production, however, for the 100 kgs of nitrogen is only 1,000 kilograms of maize. The same situation is true of wheat where, at the 3 ton per hectare yield level, 100 kgs of nitrogen would return 1,720 kgs of wheat on the average trials, or 2,040 kgs from the better fields compared to 1,000 kgs of wheat on most farms. It may be argued that these data are from well conducted field trials which usually are better managed than farmers' fields, but it is also true that the better farmers in all parts of the world are doing as well or better with their farming than is being done on experimental fields.

Thus the goal to increased production from limited supplies of nitrogen should not be to apply low rates over wider areas, but to increase the yield return from each kilogram of N applied. This is the only way we can attain the goals of increased crop production to feed a hungry world.

What about the other essential elements and how might they affect the return from nitrogen? In figure 3 where nitrogen is the only nutrient element applied, the yield increases on a straight line to point B which is reached at rate x. Continuing to apply higher rates of nitrogen as in y or z does not increase the yield; it only decreases the efficiency of the nitrogen that has been applied. The yield reached a plateau at point B because some other growth factor has become limiting. This can be caused by a multitude of factors including a deficiency or imbalance of other nutrient elements. The point is we want to change the slope of lines AB' and AB" to coincide with line AB in order to get the greatest return from each kilogram of nitrogen applied. The steeper the slope the greater will be the return of grain from the nitrogen applied. The slope will be maximized when no nutrient element or other growth factors are limiting.

During the past decade, the International Soil Fertility Evaluation Project has stressed the Cate-Nelson concept (3) of a critical level in the soil for nutrient elements. If a nutrient is below the critical level, it becomes a limiting factor in the yield and a production plateau is reached. A sizeable increase in yield can be anticipated from the application of this element, providing other essential elements are not also limiting because of being below their critical level or because they are out of balance with other nutrients.

Soil analysis generally is used to ascertain if a soil is below the critical level for the various nutrients or if the elements are potentially out of balance. Then a recommendation can be made relative to application of various nutrient elements with emphasis upon those which are likely to give the largest increase in yield. This is really a negative approach since fields that are deficient in an element are most likely to respond. Of course farmers are interested in getting a good response from the fertilizer applied, but generally they are more interested in eliminating nutrient deficiency as a factor in the crop production. This is indicated by the common practice of applying more than enough fertilizer just to be sure an element is not deficient. This practice is most common for high return crops.

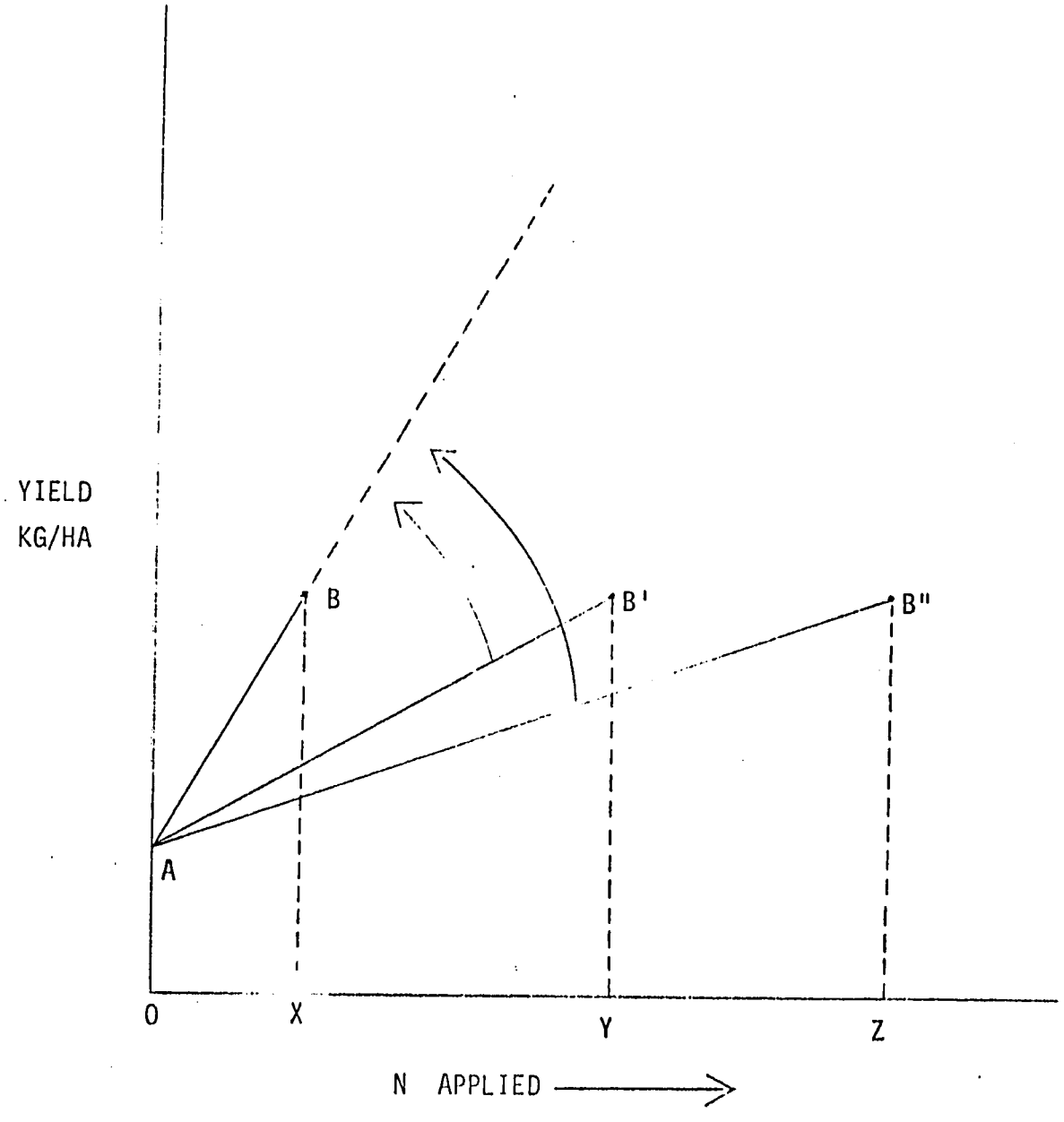

FIGURE 3 TO INCREASE THE KILOGRAMS OF GRAIN PRODUCED PER KILOGRAM OF N APPLIED THE SLOPE OF THE RESPONSE MUST BE INCREASED.

In recent years, our International Soil Fertility Evaluation and Improvement Project has turned its attention also to the elements that are above the critical level in the soil to ascertain the importance of nutrient balance. Soil analysis may indicate that all of the elements other than nitrogen are above the critical level, but yields are not as high as anticipated and the return from the applied nitrogen may not be as high as should be expected. Several factors may be responsible for this, but we are finding that nutrient balance is of real importance. Many studies have been made on the importance of the balance of the three cations calcium, magnesium, and potassium. We also note an important relationship between the microelements iron, manganese, copper, and zinc. Other relationships appear important too such as phosphorus-zinc, phosphorus-sulfur, or nitrogen-sulfur. Any serious imbalance may reduce yield and may reduce the return obtained from the application of nitrogen.

With the introduction of atomic absorption instruments into soil and plant laboratories and with improved analytical techniques, we are now able to do a much better job of scanning all of the essential elements. Of course, correlation studies, both for ascertaining critical levels and to observe optimum balance of elements are a necessity. Techniques developed by Drs. Hunter, Walker, Portch, Miner, and Waugh of the ISFEI staff in conducting potted plant trials have proven very useful in giving additional information relative to nutrient deficiencies or nutrient imbalances.

An interesting observation in these studies is the differences noted in kinds of plants and plant varieties. If a soil is below the critical level for a certain element, most kinds of plants as well as varieties will be affected. Considerable difference may be noted, however, between kinds of plants and varieties in respect to the balance of nutrients above the critical level. For example, Hunter has noted wide differences in optimum balance of nutrients for rice and sorghum in his potted plant studies. The Agricultural Environmental Systems Corporation and the Terranal Corporation observed in their 1974 field trials in the United States that hybrid corns differ considerably in optimum nutrient element balance. The question is how much might this influence nitrogen utilization.

Soil and plant analysis with potted plant trials are very useful tools to ascertain nutrient element deficiencies and imbalances, but trying to test samples from each farmer's field is a huge assignment. To help alleviate this situation, I suggest that it is possible to key on the return from nitrogen as a guide to the severity of existing fertility problems. For this purpose the following suggestions are offered:

The first step should be to establish a plateau or standard yield for the major food crops for each region or community. The plateau yield will be that which can be anticipated when good management practices are followed including the use of good varieties, good seed, etc., and the judicious use of nitrogen.

The purpose of establishing a plateau yield as a standard for the community is to stretch the yields over those presently obtained unless the yields are already quite high. This is necessary in order to meet the demands of the country for increased food production. The only way to increase yields is to recognize the factors limiting the yield and then take steps to correct them. If they can not be corrected efficiently then the yield goal can not be reached and will need to be lowered. For example, if 6,000 kgs per hectare of maize or rice is a good yield for a region and this is selected as the plateau, then if a field reaches this yield level simply by use of good varieties, good cultural practices, etc., but no fertilizer, you know that the soils are relatively fertile. If this yield can not be reached without fertilizer but the use of only nitrogen fertilizers will easily boost the yield to this level, then at present other essential elements are not limiting. However, if the addition of nitrogen fails to increase the yield to the desired level and if the return from the nitrogen is low, then some other elements are likely to be deficient or out of balance. Of course failure to reach the 6,000 kgs plateau may be due to use of a poor variety, shortage of rainfall, etc. and these factors should also be evaluated.

In establishing the plateau yields, I suggest the following steps:

1. Assemble all information that pertains to the yields of the region including yields where fertilized with nitrogen, climatic data, availability of irrigation water, etc.
2. Establish a tentative plateau yield for the various food crops for discussion purposes.

3. Have these reviewed by the Advisory Committee and get suggestions from the various agencies.
4. Meet with local agricultural leaders, including extension personnel and leading farmers, to outline the program and review the tentative plateau yields. Of course suggestions and comments should be welcomed so that a consensus of opinion is obtained relative to what the plateau yields should be.

The plateau yields that are established will be tentative and can be changed as new information is obtained. The main purpose is to establish an obtainable target which can be reached economically but which will stretch the yields above the average being obtained.

The next step will be to refer to table 1, 2, and 3 of this paper or to tables 9, 10, and 11 of Technical Bulletin 6, "Soil Nitrogen - Supply Processes and Crop Requirements", by Dr. W. V. Bartholomew. The amount of nitrogen needed on the average to produce various quantities of maize, wheat, and paddy are presented in these tables. If we know the approximate amount of nitrogen required to produce a given yield, then we can use this figure as a basis for ascertaining the efficiency of nitrogen uptake by the crops being grown. For example; if the traditional or regular yield obtained by the farmer is 2,000 kgs of maize per hectare and a plateau yield for the area has been established as 6,000 kgs, then the table tells us the farmer will have to add another 139 kgs of nitrogen from some source. If he adds this amount of nitrogen and obtains the 4,000 kgs increase, we will know that he obtained the average uptake of nitrogen, but, if he got only 2,000 kgs increase, then the efficiency of nitrogen was reduced by half and some other factor had to be controlling the yield.

What I am proposing is this: since nitrogen is widely used, measure the efficiency of the nitrogen utilization by the maize, wheat, or rice. For normal conditions with good management practices and good varieties, 1 kg of nitrogen should produce 30 to 35 kgs maize, 15 to 20 kgs wheat, and 24 to 28 kgs brown rice. This is not the maximum and many times these ranges will be surpassed but they can serve as a goal that farmers can attain. Farmers usually know what their traditional yields average without fertilizer. Also, usually a sufficient number of field trials and demonstrations have been and are being conducted in the various

farming regions so that this yield can be fairly accurately established. The difference between the traditional yield for an area and the yield obtained by the farmer on his field will indicate the approximate weight of grain he can relate to the nitrogen fertilizer applied (if only N is used). A quick calculation can then be made for the amount of grain produced per kilogram of nitrogen applied. Of course carefully conducted demonstrations within an area should give more reliable information, but both should give an indication of the amount of return being received. If 30 kgs of maize, 25 kgs of rice, or 18 kgs of wheat are obtained per kilogram of nitrogen in reaching the plateau yield, they will know the soil, environmental conditions, and management practices are satisfactory. However, if only about half these amounts of grain are received per kilogram of nitrogen, then other problems exist. Since the general accepted figure is 10 kgs of grain per kg of nitrogen, obviously many problems need to be overcome. I suggest that an outline or guide sheet be prepared to check as a source of problems. The check list should include:

1. Kind of crop
2. Variety
3. Plant population
4. Cultural practices (time of planting, etc.)
5. Climatic conditions
   a. Precipitation, amounts and distribution
   b. Temperatures - high or low, etc.
6. Pest problems (weeds, insects, diseases, nematodes)
7. Soil conditions
   a. Physical limitations
   b. Adverse soil conditions
   c. Soil fertility
      1.1 Deficiency of nutrient elements (below critical level)
      2.1 Imbalance of nutrients

The local farmers or villagers should be able to supply information relative to many of these questions. For soil conditions, further studies will be needed, including soil and plant analysis, possibly fixation studies, and potted plant trials. If the area involved is sufficiently large, then some field trials should

be initiated too for the purpose of testing other information gathered and to more clearly pinpoint the problems. As soon as this information is available, educational steps can be taken to acquaint the farmers with the improved practices they need to follow.

If it is found that the problem is nutrient imbalance, then steps can be taken to correct this condition by (1) altering fertilizer practices, (2) applying certain soil amendments (if economical and they are available), and (3) adapting crops and varieties of crops to the existing soil conditions or to conditions where a minimum of alterations are needed.

This approach to increasing the efficiency of fertilizer use by focusing on one element as a guide to the need for other elements offers a new ball game in soil fertility evaluation. It affords us the best opportunity to quickly appraise fertility conditions, as well as management practices, etc., that influences the amount of grain we will receive from the application of fertilizers. In playing this game let's key on nitrogen!

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