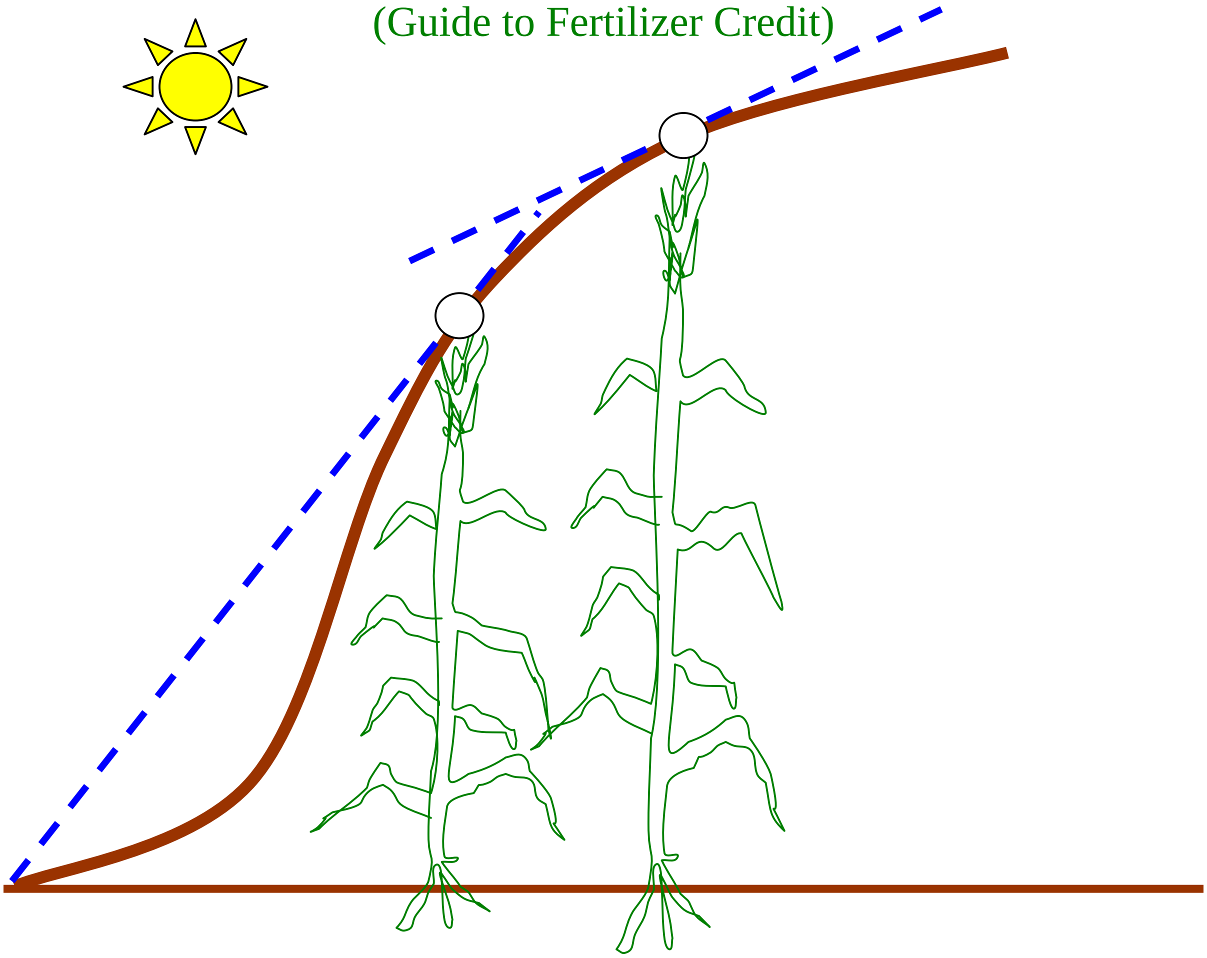
IMPROVING CROP YIELDS IN DEVELOPING COUNTRIES

A PRACTICAL MANUAL

(Guide to Fertilizer Credit)



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Harry Singh Gill

IMPROVING CROP YIELDS IN DC’S SINGH

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"Do your honest day's work,

remember God at all times, and

share your fruits with others."

Guru Nanak (1469-1506, founder of the Sikh Religion).

This book is dedicated to the staff and faculty of Imperial College, London, Wye Campus, Ashford, Kent, England, for the kindness and help they gave me during my years at the college. With special gratitude and appreciation to the following:

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IMPROVING CROP YIELDS IN DEVELOPING COUNTRIES

Table of Contents in Brief

Table of Contents in Detail

INTRODUCTION

This book is the result of an investigation which covers several years and eleven Latin American countries. It is written in the belief that organizations which are designed to aid the poor millions of the developing countries need not continue, through ineptitude, to simply make matters worse.

More than a third of the world's population suffers from malnutrition. In developing countries where most of that population is concentrated, the proportion is far higher. In many of these countries, yearly per capita income ranges from $40 to $200. An entire family in rural Bolivia, to give a random example, must live on $75 a year.

Because of a chronic lack of nourishing food, children in the third world frequently fail to attain full physical and mental development. Many die in infancy; others survive permanently retarded and unable to play a role in the socio-economic life of their country.

Although in the present book it is not my purpose to provide political solutions, it is worth mentioning that much of this suffering is brought about by the fact that in developing countries, notably in Latin America, 4 or 5 percent of the population own anywhere from 80 to 90 of the land, leaving the smallest and least productive areas to the much larger and poorer remainder of the population.

This problem of unequal land distribution is of course aggravated by almost universal population explosion, particularly among the poor in the developing countries.

Since this book takes a purely agronomic view, our point of departure must be the mundane observation that the food produced is simply not enough to meet the needs of the growing populations, and that, as all of the national and international development organizations now agree, one of the most effective ways to increase that production is by the encouragement of fertilizer application and the adoption of improved seed varieties.

Because a large proportion of small farmers in developing countries cannot read, they are uninformed about fertilizers and other helpful agricultural techniques. To meet this problem, non-profit organizations have set up credit programs which provide not only information but money for fertilizer and other inputs.

Unfortunately, the credit provided by these organizations reaches a very small percentage of poor farmers. In Guatemala, in 1974, for example, credit allocations amounted to $ 20.5 million. This figure may sound impressive, but only 0.7% of the farmers with holdings of less than 2 hectares were able to benefit from it.

Still more unfortunate, and more relevant to our purposes is the fact that by far the greater part of all this credit is allocated so haphazardly that, in most cases, it neither helps the farmer to improve his yields nor the agency and the nation as a whole to prosper. On the contrary, the farmer, because of his debt to the agency, is left poorer than before; the credit agency suffers a low loan recuperation rate; and the nation's crop yields continue to be small, at times smaller than they had been before the "aid" had been given.

One who has researched the situation may frequently have heard, in a moment of confidence, words like the following from a farmer: "I did as they told me, but my yields are less than half of what they were last year before they came to "help" me. Now I am in debt, and I don't know how I'll return the money. This year I have to borrow grain to feed my family. My neighbor was wiser: he didn't do anything the credit agent recommended."

In the course of my work, I have heard such statements more than once. After accepting fertilizer credit, the farmers were left poorer than before. The agencies often had loan recuperation rates of 60 percent and needed government grants to keep functioning. Some went out of operation not long after setting up.

For instance, in Bolivia, over the last decade, four credit agencies were established to help farmers with small holdings: i) Yacimiento Petroliferos Fiscals Bolivia (YPFB) , ii) The

Federation National de Ahorros y Prestamos de Cooperativas (FNAP), iii) Bolivian Development Foundation (BDF), and iv) The Centre para Desarollo Social y Economia (CDSE). Of these four, the first two, YPFB and FNAP, are now out of operation due to a very poor rate of loan recuperation; the third, for similar reasons, requires annual grants to operate; and only the last agency (CDSE) is still operating. The success of the last agency is undoubtedly due to the efficient technical assistance that it has provided to its clients.

The fault lies with the agencies themselves. They extend credit with good intentions, but without determining before hand the type and quantity of fertilizer which would give the farmer the best profit. On their behalf, it can be said that their shortcomings are less those of laziness than of ignorance. They have no manual or textbook by which to guide them in allocating funds more efficiently.

The pages that follow represent an attempt to fill that gap, in as specific and systematic a manner as possible. For agronomists, this book outlines the problems which third world farmers face and provides concrete suggestions on how to overcome those problems. In most cases, the suggestions are accompanied by illustrations and / or experimental data found by agricultural institutes.

Although a few of the chapters herein -- notably those dealing with fertilizer field-trials -- require a limited background in agriculture and mathematics, most of the book can be easily read by the layman. Where required, the use of certain mathematical functions is shown.

Mathematical techniques such as analysis of variance, ***"t"*** tests, chi-square and production functions are commonly used by agronomists to determine soil needs and crop yields. In developed countries most of this work is done by computers, but an agronomist in a developing country may not find a computer available. For this reason, these techniques are presented here in step-by-step form. To the best of our knowledge, no other such presentation exists to date.

There are, probably, some other firsts herein. Hunger-signs, plant tests, soil tests and fertilizer field-trials have not previously been treated in conjunction with credit allocation. The field trials are of particular importance: Chapter 4 shows how these trials are conducted and the procedure by which the yield data are analyzed and converted into production functions, which in turn determine the minimum and maximum recommended fertilizer rates. Chapter 7 shows how, by the use of the production function, these recommended rates determine the credit which should be allocated.

In Chapter 8, all the agricultural activities essential to improving crop yield and response to fertilizer are illustrated graphically and accompanied by timetables to leave no doubt as to exactly when each activity, or each stage of each activity, should be carried out to achieve the best results. Such chronologically-arranged illustrations have not been available before and are ideally suited to the illiterate farmer.

There is no attempt made in this book to put forth pet theories. The emphasis throughout is upon the practical application of statistically proven techniques. The overall objective, to improve agricultural credit allocations in developing countries, really encompasses several objectives: to help the farmer increase his crop yields and his profits, to create employment in rural areas, to improve the credit agency's rate of loan recuperation, to maximize the use of the credit agency's rural extension personnel, and to help the countries themselves to their feet by creating greater yields, wealthier and better-nourished citizens, and hope.

FLOW-CHART
To Follow Before Making Fertilizer Recommendations To Farmers

As a quick reference each step tells the reader from which page (e.g. page 85), table (e.g. Table 5.3) or figure (e.g. Fig. 6.3) the information is from in the book.

↓

Step 1. ASK FARMERS THE CROP(S) THEY WISH TO GROW.

↓

Step 2. (Ch.1)

GO TO THE LOCAL FAO OFFICE OR LOCAL AGRICULTURAL RESEARCH STATION AND FIND OUT THE FOLLOWING:

a) the best varieties of the crop that the farmers should use;
b) the best spacing that will maximize the farmers profits;
c) the best time for sowing;
d) the best times to irrigate the crops;
e) the best times to fertilize the crops;
f) the price of crop, fertilizer and liming material; and
g) the most suitable pH for that crop.

↓

Step 3.1. (Ch.1: Section 17) Page 19
If the soil pH **NOT** suitable?

↓

Step 4.1. Whether funds are limited or not.

↓

Step 5.1. (Ch.1: Section 17) Page 19
Give loans only for liming:
i) 12 month loan if it is for calcium oxide or calcium hydroxide.
ii) 18 month loan if the loan is for limestone.
iii) Set up trials with liming and different levels of fertilizer.

↓

Step 3.2. (Ch.1: Section 17) Page 19
If pH is suitable?

↓

Step 4.2. Whether funds are limited or not.

↓

Step 5.2. (Ch.4)

Set up trials with different levels of fertilizer.

↓

Step 6. INFORMATION PRIOR TO SETTING UP FERTILIZER FIELD TRIALS (Chs. 1 and 4)

A) Are there any pre-existing fertilizer recommendations for this particular crop? If so, what are they?
B) What recommendations exist as to timing of fertilizer application? Should, for example, all of the fertilizer be applied at the sowing time, or all at the flowering time? Or should half be applied at sowing and the other half at flowering?
C)Are the crop varieties which the farmer is presently using susceptible to any diseases?

↓ ↓

Steps to Follow Before Making Fertilizer Recommendatios to Farmers

Step 7.1. (Ch.4 : Section 4) (Table 4.1) Page 65
FERTILIZER TREATMENTS IN THE ABSENCE OF OFFICIAL RECOMMENDATIONS

Treatment No.	N	P	K
1	Farmer's Practice		
2	0	0	0
3	10	0	0
4	20	0	0
5	30	0	0
6	40	0	0
7	20	20	0
8	20	0	20
9	20	20	20

Step 7.2 (Ch 4: Section 4) Page 65

Set up Fertilizer Treatments Based on Official Recommendations.

Step 8. (Ch. 4: Section 7) Page 66
DECIDE ON TRIAL PLOT SIZE :
10 meters by 5 meters a crop with rows spaced 0.8 meters apart would need a plot (0.8 x 7=) 5.6 meters.

Step 9. (Ch. 4:Section 9) Page 66
CALCULATE AMOUNT FERTILIZER TO APPLY PER PLOT
The amount of fertilizer needed can be calculated by using the following formula **(Ch.4: Section 10)**

$$\frac{\text{Nutrient rate per Ha.} \times \text{Area of plot}}{\text{Area of hectare}} \times \frac{1}{\text{Nutrient value of fertilizer}} = \text{Amount to be applied.}$$

Step 10 . (Ch. 4: Section 11) Page 70
CALCULATE AMOUNT OF SEED TO APPLY PER PLOT
In this case, the amounts of seed needed for each plot can be calculated in the same way those amounts of fertilizer nutrients were calculated:

$$\text{Kgs. of seed needed per plot} = \frac{\text{Kgs. of seed recommend per Ha.} \times \text{Area of plot}}{10{,}000\ m^2 \text{ (Area of Ha.)}}$$

Step 11. (Ch. 4: Section 12) Page 74
MARK THE WEIGHT OF THE YIELDS FOR EACH PLOT OF THE FIELD TRIAL AS SHOWN IN TABLE BELOW.

Table 5.2: Field Trial (Sample Yields of Thirty Experimental Plots)

Treatment Number (kgs./plot)	1	2	3	4	5	6	7	8	9	10
Block 1										
Block 2										
Block 3										

Step 12. (Ch. 5 : Section 1) Page 73
CONVERT THE ABOVE EXPERIMENTAL PLOT YIELDS INTO YIELDS PER HECTARE.

$$\frac{\text{Yield obtained from the plot}}{\text{Size of the plot}} \times \text{Area of hectare}$$

Step 13. (Ch. 5 Table 5.3) Page 74
PUT THE CONVERTED YIELDS IN A TABLE AS SHOWN BELOW.

Table 5.3 : Crop Yields of the fertilizer Field Trails Converted to per Hectare (kgs./ha.)

	Treatment No.								
	1	2	3	4	5	6	7	8	9
Block No.	**Control**	**10 N**	**20 N**	**30 N**	**40 N**	**50 N**	**20N, 20P**	**20N,20K**	**20N,20P,20K**
1.									
2.									
3.									

Step14. (Ch. 5: Table 5.5) Page 75
DO STATISTICAL TESTING ON THE RESULTS

	Treatment(S)								
Statistical Testing of Following Treatments **DO ANOVA**	1	2	3	4	5	6			
Statistical Testing of Following Treatments **DO "t" Testing**			3			6	7	8	9
Statistical Testing of Following Treatments **DO "t" Testing**						6	7	8	9
Statistical Testing of Following Treatments **DO "t" Testing**							7	8	9
Statistical Testing of Following Treatments **DO "t" Testing**								8	9

Step 15.1.(Ch.5 : Section 2) Page 75
Do ANOVA test of results using different levels of same fertilizers.
Step 15.2. (Ch. 5: Section 3) Page. 78
Do "t" tests on trails using different fertilizers.

Step 16.1. (Ch. 5: Section 2) Page 75
If **NOT** Statistically significant up to 80% level.

Step 16.2.. (Ch. 5: Section 2) Page 75
If Statistically significant at **80%** significant level, do the economic analysis.

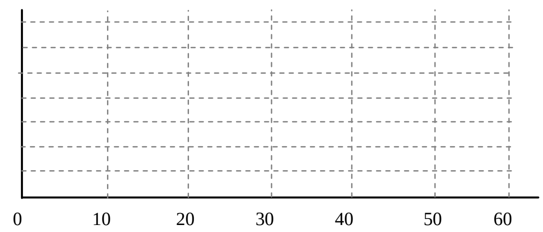
Step 17.1. (Ch. 5)
Set up new trails with higher levels of fertilizers next growing season. Then next season follow from step 5.

Step 17.2. (Ch. 5: Section 2) Page 75
Total the results of each treatment.

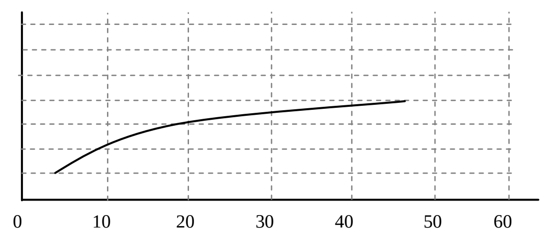
Step 18. (Ch.5 : Section 2) Page 75

	Table 5.6: Yields from treatments 1 to 6 of field trials (kgs. /Ha)						
	Treatment Number						
	Control	10N	20N	30N	40N	50N	Total
Block No.	1	2	3	4	5	6	
1							
2							
3							
Total							
Average							

Step 19. **(Ch.6: Section 2-Fig. 6.1A) Page 96**
PUT THE AVERAGES ON A GRAPH: Fertilizer levels on horizontal axis and outputs on the vertical axis.



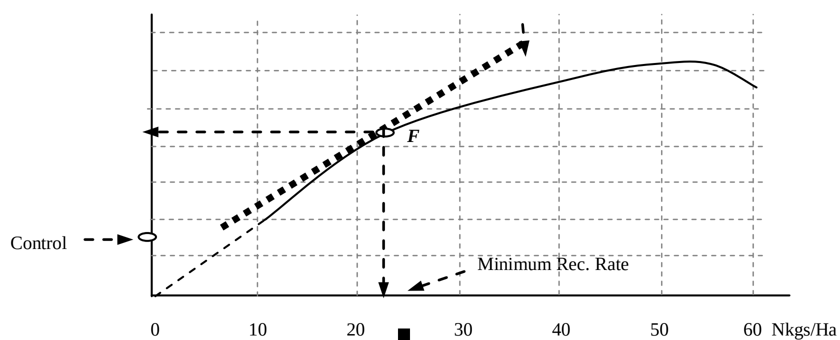
Step 20. **(Ch.6:Section 2-Fig. 6..1B) Page 96**
DRAW A PRODUCTION CURVE USING THE "EYEING" METHOD.



Step 21. **(Ch. 6: Section 2-Fig. 6.1C) Page 96**
READ THE "CHECK" YIELDS FROM THE PRODUCTION CURVE DRAWN.

Step 22. **(Ch. 6: Section 3 –Fig. 6.3) Page 98**
MINIMUM REC. RATE of fertilizer can now be determined by drawing a line tangent to the production curve from the control yield. Where it touches is the minimum R.R. of fertilizer.

Figure 6.3: Determining the Minimum Recommended



Step 23. **(Ch. 6: Section 3-page 101)**
Find out the cost of :

i) output (crop),
ii) Inputs (Nitrogen, Potassium and phosphates)

Step 24. (Ch. 6: Section 3-Page 101)
Standardize the cost of output and inputs to similar units, (e.g. cost the price to dollars per kilo; rupees per ton, etc. for both the output and inputs).

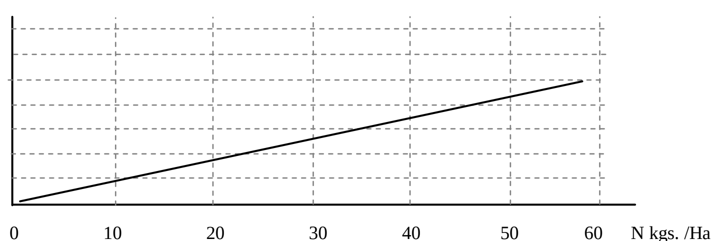
Step 25. 1. (Ch. 6: Section 3-Page 101)
CALCULATE THE "ISO-PROFIT" FRACTION:

Price of Unit Nitrogen (Input)
Price of Unit Crop (Output)

Step 25.2. (Ch.6:Section 3-Page 101)
For the two nutrients in this experiment THE "ISO-PROFIT" fraction is:

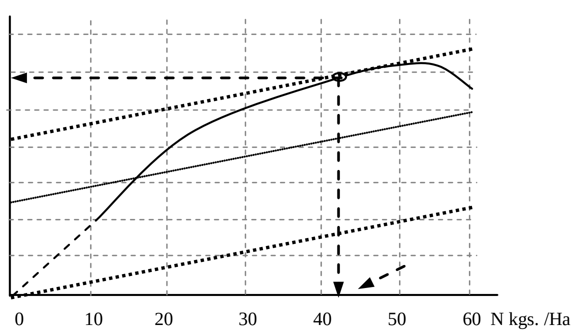
Price of Nitrogen / kg. + Price of Phosphate / kg.
Price of crop / kg.

Step 26. (Ch. 6:Section 3-Fig. 6.4) Page 102
DRAW THE "ISO-PROFIT" LINE on the same graph as the production



Step 27. (Ch.6 : Fig. 6.5) Page 102
Draw a parallel line until it just touches the production curve. Where it touches the production, this gives us the **MAX. R. R. OF FERTILIZER.**

FIGURE 6.5: DETERMINING THE MAXIMUM RECOMMENDED



Step 27.A.
If Funds are LIMITED:
Recommend that each farmer should apply the minimum recommended rate of fertilizer to only part of the farm.

Step 27.B.
If Funds are **UN**LIMITED:
The farmers should be given loans to apply fertilizer to the maximum recommended rate.

Step 28. (Ch.5: Section 3) Page 98
RESULTS OF 1 NUTRIENT AND 2 NUTRIENTS

Step 29.A.
Above 90% level of confidence

Step 29.B.
Above 80% level of confidence

Step 29.C.
Below 75% level of confidence

Step 29.A.
Conduct economic analysis :
If profits are **above** 15%:
i) Give loan for 2 nutrient fertilizer;
ii) Set up fertilizer trials for next year with higher levels of 2 nutrients.

Step 29.B.
Conduct economic analysis
If profits are **above** 25%
i)Give loan for 2 nutrient fertilizer;
ii) Set up fertilizer trials for next year with higher levels of 2 nutrients

Step 29.C
Ignore the results.

Step 30. (Ch.5: Section 3) Page 98
RESULTS OF 1 NUTRIENT AND 3 NUTRIENTS

Step 31.A.
Above 90% level of confidence

Step 31.B.
Above **80%** level of confidence.

Step 31.C.
Below **75**% level of confidence.

Step 31..A.
DO ECONOMIC ANALYSIS:
i) If profits are above 25% make loan for 3 nutrient fertilizer;
ii) Set up fertilizer trails with higher levels of nutrients the next year;
iii) Do statistically analysis between 2 and 3 nutrients treatments.

Step 31.B.
i) Make **NO** fertilizer recommendations this year;
ii) Set fertilizer trails this year with only 1 treatment with 3 treatments.

Step 31.C.
Ignore the results.

Step 32. (Ch. 5: Section 3) Page 98
RESULTS OF 2 NUTRIENTS AND 3 NUTRIENTS

Step 33.A
Above 75% level of confidence

Step 33.B.
Below 75% level of confidence

Step 33.A.
DO ECONOMIC ANALYSIS OF TREATMENT
i) if profits are **above 15%** make loans for 3 nutrient fertilizers;
ii) Next year set up fertilizer trials with higher levels of nutrients.

Step 33.B.
Ignore the results.

Chapter 1

FACTORS AFFECTING CROP YIELD

1. **VARIETY OF CROP**
2. **SEEDING RATE**
3. **DEPTH OF SOWING**
4. **SOIL MAKE-UP**
5. **ORGANIC MATTER**
6. **ADEQUACY OF PLANT NUTRIENTS**
7. **WATER**
8. **SUNSHINE**
9. **TEMPERATURE**
10. **WEEDS**
11. **DISEASE**
12. **INSECTS**
13. **TIMELINESS OF SOWING**
14. **CROP ROTATION, MULTIPLE- AND INTER- CROPPING**
15. **ADEQUATE DRAINAGE**
16. **SEED-BED PREPARATION**
17. **SOIL ACIDITY**

INTRODUCTION

Centuries ago, when there was an abundance of land, and people were fewer, our ancestors cultivated a piece of land for only a season or two. They realized that crop yields from one land area diminished from year to year and that they had to move on to new land to continue to obtain high yields. Their crops removed essential nutrients from the soil, and the farmers did not know, nor, in those days, did they need to know how to replace those nutrients.

Nowadays, of course, land is in increasingly short supply, and there are far more people in the world. At the time of Jesus, the world population was probably about 200 million: in 2000's it is estimated to be 6 billion. It is no longer possible to move from one plot of land to another in order to obtain high crop yields. Rather, we must supply the crop each year with the nutrients it needs. This is done by means of fertilizer application.

Modes of determining the amount and type of fertilizer to be applied to a particular crop on a particular soil, form the subject matter of this book. Waste of money and energy can be avoided by a scientific approach to fertilizer application. Only by such an approach can we be assured that a crop will receive the nutrients required, resulting in high yields and greater profit for the farmer.

A large part of this book will be concerned with certain mathematical functions whereby correct fertilizer application is determined. It would be a mistake, however, for the reader to imagine that the only factor influencing crop yields is the presence or absence of fertilizer. On the contrary, there are many reasons why some farmers get high yields from their land, while others get low yields of the same crop; or why some crops will give higher yields than others on the same soil. In the first place, crops differ in their nutrient needs, and even different varieties of the same crop may require different nutrients.

The principal factors which affect the amount of yield of a particular crop may be listed as follows:

1.	**Variety of Crop**
2.	**Seeding Rate**
3.	**Depth of Sowing**
4.	**Soil Make-up**
5.	**Organic Matter**
6.	**Adequacy of Plant Nutrients**
7.	**Water**
8.	**Sunshine**
9.	**Temperature**

10.	**Weeds**
11.	**Disease**
12.	**Insects**
13.	**Timeliness of Sowing**
14.	**Crop Rotation, Multiple- and Inter-cropping**
15.	**Adequate Drainage**
16.	**Seed Bed Preparation**
17.	**Soil Acidity**

The ability of a crop to produce a given yield as a result of any of the above factors, is referred to as the "response" of the crop. When this response is drawn on graph paper, the resulting line is called a response curve or "production curve" (see chapters 6, 7, and 8). The impact of these factors influence the crops and their response, is shown in Figure 1.1. To visualize the impact of the above factors on a farmer's profit, see Figure 1.2.

FIGURE 1.1: CROP OUTPUT TO LIMITING FACTORS

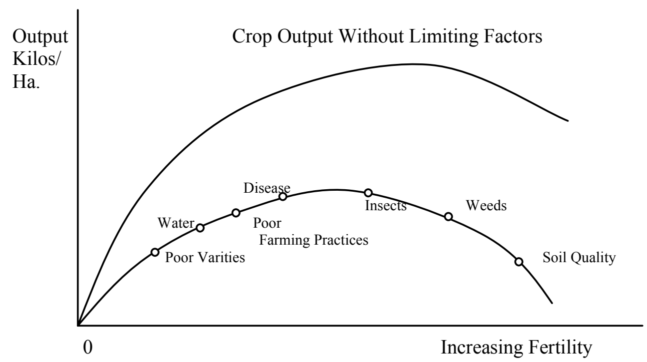
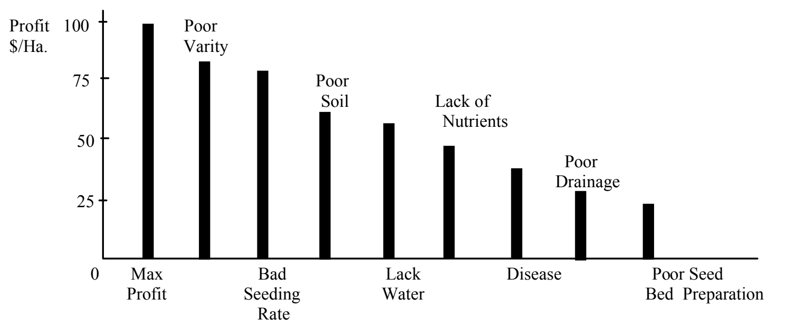


FIGURE 1.2: PROFIT PER HECTARE WITH LIMITING FACTORS

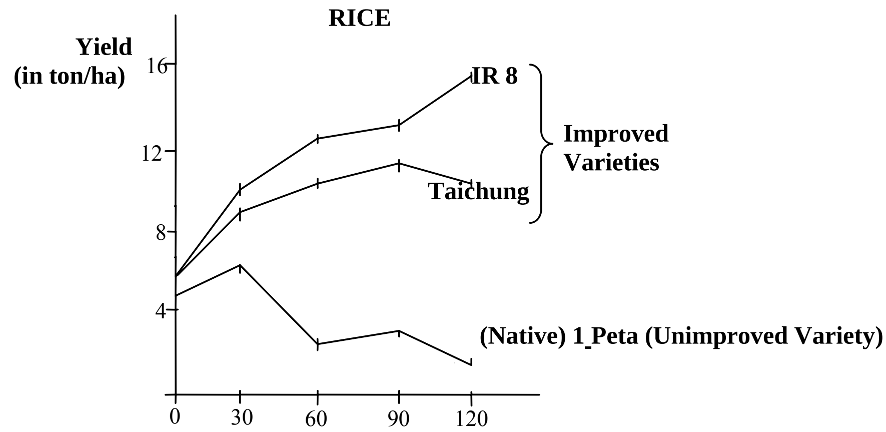


The influence of each of these factors can be appreciated by considering them separately.

1. VARIETY OF CROP

Under exactly the same conditions, two different varieties of the same crop may differ in their yields. One variety may respond better to the fertilizer used or may resist insects better than the other variety. The differences in yields are particularly noticeable between the local and the improved varieties. The latter are bred especially for their ability to respond to fertilizer; the resulting difference in yields can be seen in Figure 1.3 in an experiment with rice varieties conducted by the International Rice Research Institute.

FIGURE 1.3: YIELD DIFFERENCES BETWEEN IMPROVED AND UNIMPROVED VARIETIES



Nitrogen Applied (kg/Ha)

Some improved varieties, referred to as high-yielding, are designed to give higher yields from fertilizer. The crop is bred so that less nutrients are used in developing excess foliage and more are channeled toward developing larger or more grains. An example of such an improved variety, as compared to an unimproved, is given in Table 1.1.

TABLE 1.1: GRAIN-STRAW RATIO OF IMPROVED AND UNIMPROVED VARIETIES OF WHEAT

	Variety	*Yield kilos/Ha.*	*Grain-Straw Ratio*
Improved Varieties	PBW 343	59.10	1: 1.5
Unimproved Varieties (Tall)	C-591	21.00	1:30
Unimproved Variety	Indigenous C-273	21.00	1:30

Other varieties are improved so that their leaves grow larger in order to receive more sunlight and their stalks are strengthened to resist the wind. Still other varieties are improved to resist diseases.

Generally speaking, given the same amount of nutrients in the fertilizer, the improved variety will produce a higher yield than the unimproved variety. A farmer should be careful, however, to sow only that variety of crop which is well-suited to his locality. Needless to say, a crop, no matter how much improved, will only produce high yields in certain soils.

2. SEEDING RATE

The yield that can be obtained from a given unit of land depends upon the number of seeds sown on the land. Up to a certain point, the greater the number of seeds, the greater the yield. If too many seeds are planted, however, the yield decreases. Conversely, if too few seeds are planted, not only is the land not being used to its full advantage, but the extra space encourages excess vegetative growth in the plant and too little growth of the grain. Too much space also encourages the growth of weeds, which compete with the crop for sunlight and nutrients. The significance of the number of plants per unit area (plant population) is shown in Table 1.2.

TABLE 1.2: INFLUENCE OF SOYBEAN PLANT POPULATION ON YIELD

Population (plant/HA)	*Plant Spacing 50 cm. Rows*	*Plants/30 cm.* of Row	*Yield (Kilos per Hectare)*
80,000	5.0	8	20.8
40,000	15.0	4	23.9
20,000	7.5	2	25.4

From the above table we can see that the farmer would obtain higher yields if he sowed only 20,000 plants. The money saved by avoiding excess plant population could be used for fertilizer or some other purpose. In developing countries, the grain saved by not over-sowing could mean a month’s food for a member of the farmer’s family.

Another factor, related to plant population and equally important, is seed-spacing. To use an absurd example, if a farmer were to throw 100,000 soybean seeds in one corner of the field, he would certainly not obtain the same yield as the farmer who sowed his crop systemically. Even minor changes of cropping distances can produce remarkable differences in yields. Table 1.3A shows how differences of row width and plant spacing affected the crop yield of 100,000 soybean plants.

TABLE 1.3A: INFLUENCE OF ROW WIDTH AND PLANT SPACING ON SOYBEAN YIELD (40,000 PLANTS PER Ha.)

Row Width (cms.)	*Plant Spacing (cms.)*	*Plants/30 cms.of Row*	*Yield (kilo. Per Ha.)*
12.5	30.0	1	10.48
25	15.0	2	11.00
50	7.5	4	9.56
75	3.7	8	8.32

It can be observed from the above table that, although each hectare of land had the same number of plants, the highest yield was obtained when the row width was 10" and the spacing between plants 6".

Since, in developing countries, specialized machinery for harvesting is not widely available and, in any case, unprofitable for a small farmer, the farmer is free to adopt that sowing distance which will give him the highest yield. By doing so, he incurs no expense; it is as if he had been given a larger plot of land for sowing.

One should not assume that row spacing in one region of the nation will give the same output per hectare as the other regions. See Table 1.3B. In Northern India, wider row spacing gives higher yields, but in central and eastern regions of India closer row spacing gives higher yields.

TABLE 1.3B: EFFECT OF ROW SPACING ON YIELD OF CHICK PEA (KILOS/HA) IN DIFFERENT REGIONS OF INDIA.

Region	Row Spacing	
	30 (cms.)	45 (cms)
Northern India	984	1,101
North East India	1,690	1,541
Central India	1,524	1,400

3. DEPTH OF SOWING

The depth at which a seed is sown is also a very important factor in crop yield. The sowing depth affects the speed with which the seed can germinate. As shown in Table 1.4, different seeds have different rates of germination at varying depths of sowing.

TABLE 1.4: EFFECTS OF SEED DEPTH (IN CMS.) ON RATE OF GERMINATION (% EMERGENCE).

	Depth in cms.			
Species	*1.25 cms.*	*2.5 cms.*	*3.75 cms.*	*5 cms.*
Maize	25	70	90	90
Alfalfa	64	53	45	19
Red Clover	56	62	22	14
Depth	*5 cms.*	*7.5 cms.*	*10 cms.*	*12.5 cms.*
Wheat	75.2	55.7	17.4	0.0

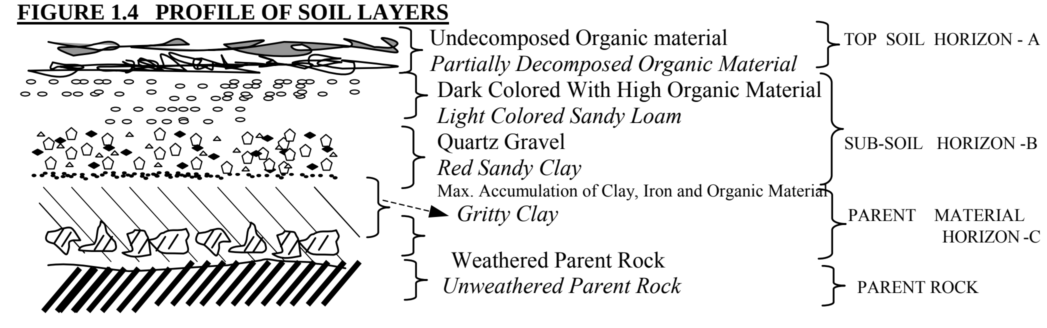
The quicker the germination, the sooner the plant can build resistance against disease and insects, the better it can compete with weeds and the more fully it can utilize the growing season.

4. SOIL MAKE-UP

Soil is the upper layer of the earth and is formed in one of three ways: (1) by slow decomposition of the underlying rock material through the action of the weather and vegetation, referred to as in situ formation; (2) by deposits from rivers or seas, called alluvial soils; or (3) by deposits by the wind of loose or volcanic ash.

Most soils have three layers, or horizons, called A, B and C. In some soils, horizon B may be missing; in others, A or even B may be missing because of erosion. Horizons A and B often have three subdivisions each. A soil containing all three horizons and subdivisions is shown in the figure below.

FIGURE 1.4 PROFILE OF SOIL LAYERS



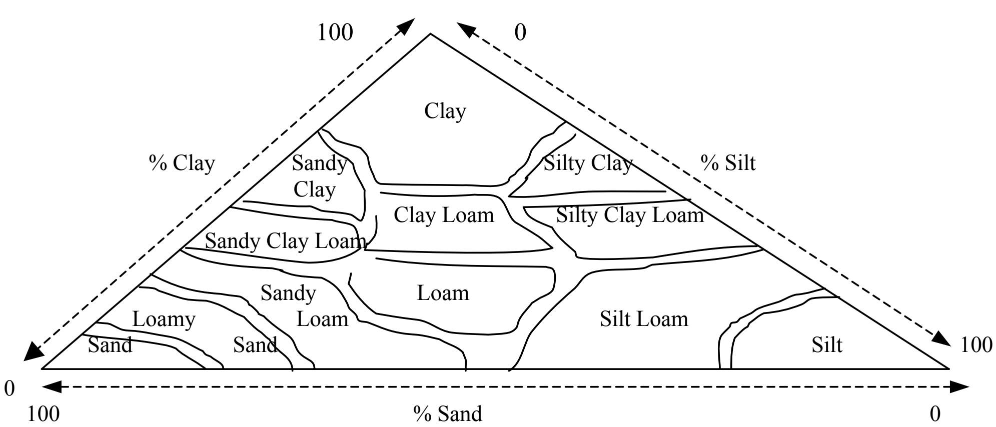
All soils are made up of solid particles derived from rocks, organic matter derived from plant and animal remains, water and air. The amount of water and air in soil varies greatly from season to season. The solid particles occupy about one-half of the total volume of most surface soil. These particles differ in size and may be classified as shown below.

TABLE 1.5: SOIL PARTICLE CLASSIFICATION ACCORDING TO PARTICLE SIZE

Particle Size (mm.)	*Name*
Larger than 2.00	Stones or Gravel
2.0 to .05	Sand
0.05 to .002	Silt
.002 and smaller	Clay

Soils themselves may be classified according to texture, that is, the mixture of sand, silt, and clay which a soil contains. The way in which combinations of particles of varying sizes form different soil textures is shown in Figure 1.5.

FIGURE 1.5: SOIL TEXTURE



The aggregation of soil particles into crumbs or larger units constitutes soil structure. The size of soil units affects the amounts of water and air which the soil is able to contain. A well-structured soil contains about 50% soil material and 25% each of air and water.

Both soil texture and soil structure are important in their effect on crop yield. Soils with large amounts of clay and silt, for example, can store plant nutrients well, but their heaviness and compactness prevents good drainage and air circulation. The effects of this compactness on both the roots and the shoots of maize plants can be seen in Table 1.6.

TABLE 1.6: EFFECT OF SOIL COMPACTION ON THE GROWTH OF MAIZE PLANTS

Treatment	*Weight of Tops (gm.)*	*Weight of Roots (gm.)*	*Total Plant Weight (gm.)*
Compact, dry, fertilized	20.1	11.3	31.4
Loose, dry, fertilized	27.5	9.3	36.8
Compact, wet, fertilized	16.0	6.5	22.5
Loose, wet, fertilized	39.4	14.8	54.2

If, however, the particles of the compacted earth are stable -- that is, if they do not easily break down -- then air and water can circulate more freely, providing the environment necessary to good plant growth.

With sand soils, we are faced with the opposite problem: There is plenty of pore space for air, but the structure is so loose that water and plant nutrients cannot be adequately retained. This loose structure also prevents the plants from getting a good hold on the soil. Thus, when there are strong winds, the plants tend to fall to the ground, spoiling the crop and making harvesting difficult.

As regards to soil texture, there is little a farmer can so. Soil structure, however, can be controlled in the following ways:

(1) by use of an efficient minimum tillage system (too much tillage breaks down particles, creating too fine a soil);
(2) by leaving crop residue on the land surface to increase organic matter in the soil; and
(3) by terracing the hilly parts of the farmland.

5. ORGANIC MATTER

Organic matter is produced in living organisms and is composed of a great variety of carbon compounds. While cultivation tends to break down soil structure, organic matter builds it up and stabilizes it.

In subtropical regions, where the climate is not hot and arid, soils are normally low in organic matter, sometimes as low as 0.1 percent. In spite of this lack, soils may still have good structure because of the abundance of calcium which holds the clay particles together in crumbs.

In tropical regions, organic matter disappears from the soil altogether because of the high temperatures. Here the soil structure is maintained by iron and aluminum oxides.

In temperate regions, where the climate is cool and humid, soils are much richer in organic matter (as high as 5 percent), and soil structure is generally better.

Organic matter improves crop yields by affecting both (1) the physical and (2) the chemical proprieties of the soil. In both respects, the farmer himself can take positive action to improve his soil.

(1) __Improving Physical Properties__

Heavy soils are hard to work, difficult to aerate, and slow to absorb water (thus encouraging erosion by the run-off of the unabsorbed water). All of these disadvantages, however, can be overcome by the introduction of organic matter in the soil. In adequate levels, the organic matter makes the soil more crumbly and easier to work; helps the soil to absorb water more easily, reducing soil erosion; and, by producing a more porous structure, permits better aeration in the root zone.

In the case of sandy soils, organic matter improves the supply of nutrient elements and the soil's ability to hold water.

(2) <u>Improving Chemical Properties</u>

Organic matter is a source of plant nutrients, particularly nitrogen, phosphorous and sulfur. Of the total phosphorous in the soil, organic matter can contain as much as 50 percent. The amount of nitrogen contained by organic matter is much more, although the percentage of the total nitrogen is only about 5. Since soil cannot absorb sulfur, organic matter plays an important part in converting sulfur into sulfate, which the plant can readily absorb. In lesser quantities, organic matter also supplies calcium, magnesium, and potassium to the soil.

A farmer can improve or maintain the level of organic matter in his soil through rotation or by applying animal manure.

6. ADEQUACY OF PLANT NUTRIENTS

Plants, like animals, contain millions of living cells which must have food to stay alive. Animals have to rely on plants or on other animals for their food; they need external sources of complex compounds such as proteins, vitamins and carbon compounds. Plants, however, with the aid of sunlight, are capable of synthesizing all the substances necessary for their growth, from elements present in the soil, air, and water.

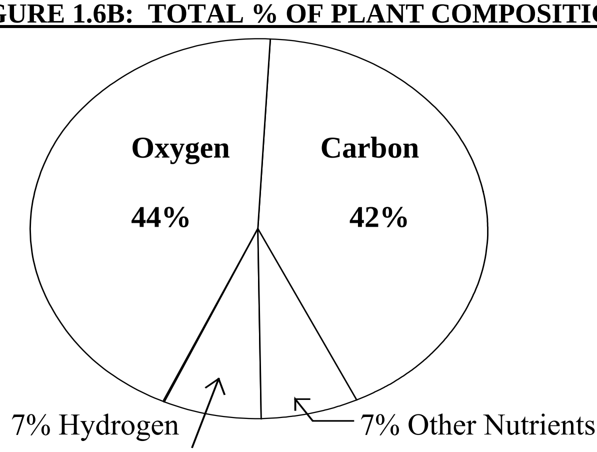
Sixteen nutrient elements are considered essential to plant growth. The first three, carbon (**C**), Hydrogen (**H**), and oxygen (**O**), are obtained from the air and soil water. The other thirteen, available from soil, fertilizer and animal manure, are as follows: nitrogen **(N)**, phosphorous **(P)**, potassium **(K)** , calcium **(Ca)**, magnesium **(Mg)** , sulfur **(S)** , iron **(Fe)** , manganese **(Mn)**, Zinc **(Zn)**, copper **(Cu)** , boron (**B**), molybdenum **(Mo)** and chlorine **(Cl).**

Chemical elements other than these sixteen are also absorbed, but they are not essential.

The essential nutrients, their sources, and the proportions in which they are found in the plant are shown in Figure 1.6A below. Figure 1.6B shows the plant nutrients and their sources and percentage of total plant composition

FIGURE: 1.6-A: SOURCES OF NUTRIENTS		
i) Air:	Carbon (C)	Oxygen (O)
ii) Soil-Water:	Hydrogen (H)	
iii) Soil:	***PRIMARY NUTRIENTS***	***SECONDARY NUTRIENTS***
	Nitrogen (N)	Calcium (Ca)
	Phosphorous (P)	Magnesium (Mg)
	Potassium (K)	Sulfur (S)
	MICRONUTRIENTS:	
	Boron (B); Manganese (Mn), Chlorine (Cl); Iron (Fe) Molybdenum (Mo), Copper (Cu); Zinc (Zn).	

<u>FIGURE 1.6B: TOTAL % OF PLANT COMPOSITION</u>



(A) Nutrients from Air and Soil Water

Most of the nutrients which a plant needs are obtained from the air and the soil water.

The air is a gas consisting of almost 21 percent oxygen (**O**), 79 percent nitrogen (**N**) and 0.03 percent carbon dioxide (**CO2**). Carbon dioxide is especially important for plant growth: taken up by the plant from the air through pores in the leaves, it combines with hydrogen (H) to form carbohydrates and other plant substances. This process, explained in detail on page 15, is called photosynthesis.

Unlike carbon dioxide (**CO2**), the nitrogen in the air cannot be used by most plants. Although air contains about 79 percent nitrogen, only legume crops such as clover, alfalfa, peas and beans can use it. On the roots of legume plants, there are small nodules which contain special microbes. These microbes, supplied with sugar from the plant, provide it with all or at least part of the needed nitrogen in soluble compound form. In some countries, legumes are grown and ploughed under (green manure) as a source of nitrogen. Most plants, however, must get their nitrogen from the soil rather than the air.

B) Nutrients from Soil, Fertilizer and Animal Manure

Thirteen of the essential plant nutrients come from soil, fertilizer, manure or crop residue. These nutrients are divided into three classes, called primary (major or macro-) secondary, and micro- (minor or trace-) nutrients, according to the amounts of each required by the plant:

(1) **Primary nutrients**: nitrogen, potassium and phosphorous. These are the nutrients most likely to be needed in large quantities (as in fertilizer or manures).

(2) **Secondary nutrients**: calcium, magnesium and sulfur. These nutrients, though needed only in small to moderate amounts, are essential to the formation of plant tissue.

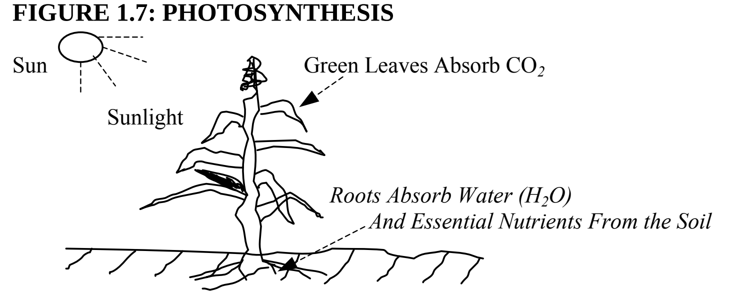
(3) **Micronutrients or trace elements**: needed only in very small amounts, micronutrients are parts of key substances, such as enzymes, in plant growth.

Photosynthesis

A plant evaporates a good deal of water during the course of a day. By means of this evaporation, nutrients from the soil are carried to the plant leaves where, with the help of sunlight, the process called photosynthesis takes place.

Photosynthesis is the transformation of inorganic elements (carbon dioxide, hydrogen, and others) absorbed by the plant from the air and soil, into organic compounds such as sugar and other carbohydrates. These compounds may now be either used by the plant for growth; stored as starches, cellulose and fats; or changed into proteins, by reaction with the absorbed nitrogenous nutrients. The process of photosynthesis is shown in Figure 1.7.

FIGURE 1.7: PHOTOSYNTHESIS



In Green Leaf

$$\text{Carbondioxide} + \text{Water} \xrightarrow[\text{Green Leaves (Chlorophyll)}]{\text{Light in}} \text{Sugars} + \text{Oxygen} + \text{Water}$$

If any one of the thirteen nutrients from the soil is absent, photosynthesis cannot occur, and no sugar, starch, fat or protein can be produced. If the nutrient is present, but in too small an amount, the plant will develop signs of deficiency, will not grow properly, and the yield will be low. In general, the nutrients which most limit growth when in too short a supply are nitrogen, phosphate and/or potassium. Fortunately, the farmer can overcome these deficiencies by applying fertilizer. As we will see in Chapter 2, most fertilizers contain these primary nutrients, and some also contain micronutrients. The latter can be applied individually if necessary.

7. WATER

Plants, like all living things, need water to live and grow. Water helps the plant to dissolve soil nutrients, such as nitrogen and phosphate, so that the roots can absorb them; it helps to transport the absorbed nutrients within the plants; and it acts as a source of hydrogen and oxygen, elements essential to the process of photosynthesis. But water must be available in the proper quantities for the plant to benefit from it. Where there is too little water, the plant is unable to replace the moisture lost through transpiration. As a result, the plant wilts, retarding growth and decreasing yield.

When, on the other hand, the soil has so much water that all the pore space becomes waterlogged, the soil is said to have reached maximum water capacity. This occurs, particularly in fine soils containing clay and silt, when the soil has no drainage or when the water loss through evaporation is too little. Water then replaces air in the soil, preventing the plant roots from breathing and from carrying out their normal function of nutrient uptake. If, however, the waterlogged soil is drained of its excess water, the soil returns to normal “field capacity.” It is important to remember that crops differ considerably in their ability to grow under waterlogged conditions. Paddy rice, for example, is grown under conditions of complete soil submergence, while tobacco is so sensitive to water logging that only a few hours of flooding may ruin an entire crop.

Crops also differ in their water requirements at different times of the growing season. The peak rate of use and the total seasonal requirement vary not only with the kind of crop but with the climate.

Annual crops require little water while they are young and small, but, because of their limited root systems at this age, they may need frequent light irrigation. At this stage even a short drought can retard growth so seriously that the plant will never completely recover.
When plants grow larger, their water requirement becomes greater, but they are also less sensitive to drought. Their root systems are more extensive and can reach further to obtain water.

For cereal crops, maximum yield is likely to be obtained only if an adequate water supply is maintained throughout the life of the crop. Mild or brief drought, however, can usually be compensated by later periods of adequate water. In general, the stage of flowering is the least affected by drought, although this varies from one crop to another. Probably the stage most vulnerable to drought is that of anthesis (period of flowering). Severe stress at almost any stage between floral initiation and maturity is likely to result in decreased yields. How the levels of soil moisture affect crop yields can be seen in Tables 1.7A and 1.7B.

TABLE 1.7A: LEVELS OF SOIL MOISTURE AND THEIR EFFECT ON GRAIN YIELD IN MAIZE

Treatment	Yield (kg/ha)
Irrigated at flowering + 3 more irrigations	9,294
Irrigated at flowering + 2 more irrigations	8,930
Irrigated flowering only	6,384
Wilted at flowering + 2 subsequent irrigations	5,315
Wilted at flowering + 1 subsequent irrigation	4,482

TABLE 1.7B: LEVELS OF SOIL MOISTURE AND THEIR EFFECT ON YIELD IN PEAS

Treatment	Yield (kg/ha)
No Irrigation	850
Irrigation at Branching	1,660
Irrigation at pod formation	1,420
Two irrigations (at branching and Pod Formation	1,770

Although there is little that a farmer can do about the weather, there are certain measures he can apply to control soil moisture: irrigation, where possible; knowing the maturity period of the crop, and planting at the proper time; spreading mulch on the land, thus protecting the soil surface from the beating of the raindrops which may seal the surface, preventing water absorption; use of contour furrowing; and use of agricultural practices which maintain soil structure.

8. SUNSHINE

Plants need the energy of sunlight in order to create their food by the conversion process of photosynthesis, discussed earlier.

There are three elements to consider regarding the influence of light on crop yields: quality, intensity, and duration.

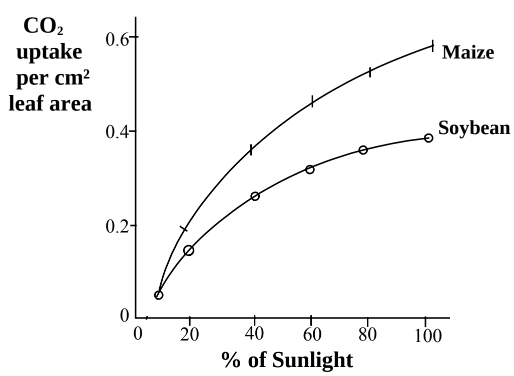
(A) Light Quality (Wavelength)

There is little to be said about light quality, simply because there is virtually nothing a farmer can do to change it. Some research has been done, nevertheless, to see what impact the quality of light has on seed germination. It has been found, for example, in an experiment with the seeds of Grand Rapids lettuce, that 70 percent of the seeds germinated when exposed to a light wavelength of between 660 and 720 (the part of the spectrum known as red), while only 7 percent of the seeds germinated when the wavelength was changed to between 720 and 760 (the far-red part of the spectrum). However, the benefits of such research are not foreseen in the near future, and it is generally believed that the full spectrum of sunlight provides good conditions for plant growth.

(B) Light Intensity

The second aspect of light to consider is light intensity, an element which falls much more within the control of the farmer than does light quality. The impact of light intensity on plant growth, and hence upon crop yield, varies from crop to crop and from variety to variety within the same crop. By using the uptake of carbon dioxide (CO2) as a measure of photosynthesis, we can compare (Figure 1.8) the efficiency of corn and soybean photosynthesis, under varying degrees of light intensity.

FIGURE 1.8: PHOTOSYNTHETIC RATE PER cm^2 OF MAIZE AND SOYBEAN LEAVES



Notice that, at full sunlight, the corn leaf can photosynthesize nearly 50 percent more efficiently than the soybean leaf. Because of this marked difference in the ability of plants to respond to varying light intensity, plants are often referred to as shade species or sun species. Shade species, such as fall tobacco and dogfoot, reach their maximum response to increasing sunlight very quickly; where as sun species, such as corn and sunflowers, continue to respond to increasing sunlight to a much greater extent.

The influence of light intensity on different varieties of the same crop can also be very marked. This is apparent from the yields obtained from different varieties of rice, shown in Table 1.8.

TABLE 1.8: COMPARISON OF GRAIN PRODUCED PER UNIT OF SUNLIGHT FOR THREE VARIETIES OF RICE	
Variety	*Grains Produced per Unit of Sunlight (gms)*
Taichung Native 1	15.5
Milfor	11.5
Peta	8.4

The Taichung (native) rice showed greater efficiency in giving a high yield on cloudy days as well as on sunny days. The other two varieties, especially Peta, needed more sunlight to give a higher yield.

One factor which often reduces light intensity in the field is the shading of one leaf by the other, a phenomenon known as mutual shading. Even on a sunny day, mutual shading prevents some leaves from receiving enough sunlight. When this occurs, the plant uses more carbon in respiration than it can take in through photosynthesis, and thus loses weight. In the case of the Peta variety, when 90 pounds of nitrogen/Ha. were applied, the mutual shading increased to such a degree that the yield was reduced by 50 percent. When no nitrogen was applied, mutual shading was considerably reduced, and only a 10 percent decrease in yield took place.

Mutual shading is most often a direct result of too great a plant population in a given area. The farmer, to make the best use of light intensity, should use proper spacing (see Seeding Rate, page 5) to reduce mutual shading to a minimum. Also, when possible, a farmer would do well to choose that variety of the crop which can give high yields even in cloudy conditions. Nowadays, special plant varieties are bred which do not have excess leaves, and the angle and size of the leaf are such that the plant can better utilize the available sunlight.

(C) Light Duration (Day Length)

The influence of the duration of light on plants is termed photoperiodism. Plants are classified as short-day, long-day or intermediate.

Short-day plants are usually found in the tropics, where the day is about twelve hours long all year round. They will only flower when the day is shorter than some critical period[1]. If the day is longer than this period, the plants will grow leaves and stems but they will not flower and thus will not complete their reproductive cycles. Rice, sugar cane and cosmos are examples of short-day plants.

Long-day plants will flower only if exposed to light for as long as or longer than some critical period. If the days are shorter than the critical period, the plants will -- like the short-day plants but for the opposite reason -- produce only leaves and stems, and not flowers. Long-day plants originate in temperate climates and include barley, wheat, clover and beets.

Intermediate plants flower all year round, completing their reproductive cycle over a wide range of day length. Among these plants are tomato, cotton, sunflower and many wild flowers such as annual meadow grass and red dead nettle.

In general, the behavior of plants can be modified by temperature change, regardless of whether they are long-day, short-day or intermediate. Furthermore, many plants have differing requirements for day length at different stages of the flowering process. This is demonstrated in Table 1.9.

TABLE 1.9: VARYING DAY LENGTH REQUIREMENTS FOR DIFFERENT CROPS AT TWO STAGES OF THE FLOWERING PROCESS		
Crop	**Flower Initiation Emergence**	**Flower**
Winter Cereals	Short-day or low temperature	Long-day
Strawberry	Short-day	Long-day
Spinach	Indeterminate	Long-day
Cosmos	Short-day	Short-day

[1] - Garner and Allard, who discovered photoperiodism in 1920, set this period at 12 hours or less for short-day plants and 12 hour or more for long-day plants. This, however, is an arbitrary scheme. In reality, every plant has its own photoperiod.

Although, nowadays, new varieties of crops are being bred for less sensitivity to day length, a farmer should make sure that the variety he chooses will flower in the day length available in his locality. This is particularly true of new varieties of maize and sorghum which, because they are bred in temperate climates, are not always suitable to the tropics.

Knowing what day length a plant requires can mean the difference between a good and an inferior yield. Hyacinth bean (*Dolichos eblab*), for example, is the only annual legume of any consequence in the Sudan. How soon it flowers depends largely on the amount of daylight it receives. Thus,

with a day-length of 11 hours, it flowers in 56 days;
" " " " 12 hours, " " " 83 days; and
" " " " 13 hours, " " " 127 days.

From these figures, we know that the hyacinth bean is a short-day plant. A farmer in Sudan, by knowing that the day is 12 hours and 1 minute long on October 1st, and 11 hours and 13 minutes long in December, can use these facts to obtain a larger vegetation growth or a quicker seed crop, according to his desire.

9. TEMPERATURE

Temperature changes vary on both a daily and a seasonal basis and are most pronounced in temperate climates. Although different crops have different responses to temperature, no crop is unaffected. Temperature affects the plant functions of photosynthesis, respiration, absorption of water and nutrients, transpiration and enzyme activity. It also affects the rate at which organic matter decomposes in the soil.

Plant growth can be conveniently divided into three stages, each of which is affected by temperature:

(1) germinating stage,
(2) maturing stage, and
(3) flowering stage.

The most favorable temperature for seed germination varies with the plant in question; generally, 65° to 80° F is the best range. Above 100°F and below 40°F, no seed can germinate. In the case of Florida cotton, for example, germination is very slow and stops altogether if the temperature falls below 57°F.

In the case of maturing plants, the influence of temperature also varies from crop to crop. In sugar cane, very little growth takes place with temperatures below 65°F, and the maximum growth and sugar accumulation occurs at temperatures between 85° and 88°F. On the other hand, Irish potatoes yield best at a mean temperature of 60°F, while corn responds best when the temperature is between 77° and 89°F. Corn growth stops if the temperature rises above 113° or drops below 55°F.

Similar differences are to be found in the flowering stage. Brussels sprouts and cabbage require nine weeks of temperatures from 36° to 37°F before they will flower. In contrast, cotton flowers best when the plant is exposed to temperatures above 90°F.

Particularly in tropical climates, high temperatures have a profound influence on organic matter. For every additional degree of temperature above 97°F, 25 pounds of nitrogen per acre may be lost. In unprotected soils, the nitrogen loss may rise to 100 pounds per acre per year.

The rate of decomposition of organic matter is also affected by temperature. The optimum temperature for the microbes which carry out decomposition lies between 75° and 94°F. If the temperature declines, the activity of the microbes is reduced, coming to a complete stop when the soil freezes. The rate of microbe activity increases with the temperature, reaching its maximum at around 85°F.

What little a farmer can do about temperature is important. In temperate climates, he can reduce frost damage to his fruit by eliminating surrounding trees which may prevent necessary circulation of cold air, or, where finances permit, by using burners in the orchards. In tropical climates, except in mountainous localities, frost damage rarely occurs. The farmer can reduce damage by selecting those types of seed best suited to the climate.

10. WEEDS

Weeds can be defined as any plant not desired by the farmer in his field; for example, grass in a wheat field, or oats in a barley field.

Weeds can reduce crop yield in several ways. They compete with the crop for sunlight, nutrients and water. By transpiration, they increase humidity at the soil level, encouraging fungus and bacteria which attack the crop (in the case of cucumbers, for example) or by clogging the harvesting machine.

Weed growth should always be checked as soon as possible, since the longer the weed is allowed to grow, the less the crop yield will be. The competitiveness of weed growth with crop yield is shown in Tables 1.10A and 1.10B.

TABLE 1.10A: THE INFLUENCE OF WEEDS ON MAIZE YIELDS

Weeds Allowed to Grow After Maize Germination (in weeks)	Yield (quintals/ha)	% Less of Yield as Compared with no Weeds
0	147.96	---
2	136.56	7.7
3	127.44	13.9
5	122.92	16.9

TABLE 1. 10B: THE INFLUENCE OF WEEDS ON RICE YIELDS

Starting of Weeding After Rice Germination	*Yield (quintals/ha)*	*% Less of Yield as Compared when weeding started at 3 weeks*
3.0 - weeks after seed germination	24.5	---
6.0 - weeks after seed germination	22.7	7.3
8.5 - weeks after seed germination	14.2	42.0
Starting weeding only at Harvest Time	12.5	49.0

The farmer can control weed growth by several means:

(1) weeding (pulling, or hoeing the land);
(2) use of chemicals;
(3) planting crops that are quick to grow (preventing weeds from growing more than the crop itself); and
(4) fire (burning the residue after harvesting).

In developed countries, where farms are big and spraying is more economic, chemicals are extensively used for weed control. But, in developing countries, recommendations of chemicals for weed control should only be made following a careful study of the agricultural practices of the farmers in question. Farmers in the Sierra region of Ecuador, for example, use weeds in their diet. Recommendation of the purchase of chemicals in such circumstances would not only deprive the farmer of his small savings, but killing the weeds would leave his family more undernourished than before. The outcome could be even worse: if the farmer and his family were to eat the weeds after they had been sprayed, sickness or death could result.

11. DISEASE

The impact of plant diseases on crop yields is immense, and can result in anything from slight damage to total loss of the crop. It has been estimated that the yearly loss of cereal crops in the world is equal to the total cereal production of the United States. With one out of every three human beings undernourished, the world cannot afford such losses.

Disease can be defined as a disturbance in the normal metabolism of the plant, leading to an effect detrimental to the health of the plant. Virus, bacteria, fungi, nematodes and insects are all organisms which produce plant disease.

Plants are considered either (1) susceptible to the disease, in which case considerable reduction, if not total loss of yield occurs; (2) resistant/tolerant, in which case, although the plant shows symptoms of the disease, the loss in yield is limited; (3) immune, in which case the plants show no symptoms, and there is no significant loss in yield.

Diseases may affect plants in any of the following ways:

(1) **Disintegration of plant tissue**. In this case, cell wall material is broken down, usually by the enzyme of a parasite. Example: root disease in hops, caused by Fusarium.

(2) **Alteration of plant growth**. The disease may stimulate growth (Bakauea disease in rice) or retard growth (yellow virus in sugar beet).

(3) **Alteration of reproductive capacity**. This is found particularly in cereals. Example: smut disease, which replaces the ovary with fungal pores.

(4) **Starvation**. Microorganisms may divert plant food substances for their own use; or produce toxins; or mechanically block the vascular (water-conducting) tissues. Any or these actions will result in water deficiency. Example: Verticillium in hops.

(5) **Alternation of respiration and/or photosynthesis**. Mildew and smuts increase respiration at the site of infection; leaf blotch disease, caused by Phynosprium reduces photosynthesis, and thus yield, by as much as 50 percent.

Certain disease controls can only be effective if they are conducted by the government on a national scale; control of diseases brought from foreign countries, or control of one bacterium by introduction of another, are examples. On a local level, however, there are a number of measures which a farmer can take:

(A) Use of Treated Seeds

Disease can sometimes be introduced by the seed itself. It may contain fungus, or fungal spores may be attached to the seed coat. If seeds are treated with dry mercury, copper dust or organo-mercurial seed dressing, the spread of disease can be considerably reduced. Seed dressing is recommended particularly in those localities where fungi or insects are likely to attack the seed before it has germinated. *(**Note**: these chemicals should be handled only when wearing protective clothing because they are very poisonous).*

Seed-dressing was successful, for example, in India where, to control sorghum smuts, the seeds were treated with copper sulphate before sowing.

(B) Crop Rotation

Many diseases are host specific; that is, they require a particular plant to feed upon. If the same crop is grown continuously or too frequently, the disease can gain strength with the passing of time. By crop rotation, the disease can be reduced or eliminated.

(C) Chemical control

Plants can be protected from disease by chemical spraying. The farmer, of course, should be careful to select that chemical which is suitable for control of the particular disease which is attacking his crop.

(D) Planting Date

Sometimes, by changing the planting date, the crop can escape or better tolerate the disease which has afflicted it in the past. The effect of the sowing date on the disease can be seen in Table 1.11.

TABLE 1.11: EFFECT OF PLANTING DATE ON APHID COUNT ON RAYA (*BRASSICA JUNCEA*) IN PUNJAB (INDIA).

	Date of Sowing and Aphid Population per plant		
Time of Aphid Count	*Date of Sowing October 5*	*Date of Sowing October 30*	*Date of Sowing November 25*
Jan -17	0	0.0	0.0
Feb -31	0	7.2	0.0
Feb - 7	0	15.9	6.9
Feb - 14	0	27.7	9.6
Mar -1	0	17.0	60.0
Mar -15	0	17.0	1.6

In some cases, too drastic a change in the sowing date may further reduce crop yields. If the yield loss from too early or late a sowing is greater than it was before the change, the farmer may find it more profitable to grow his crop at normal times.

(E) Resistant Varieties

Some varieties of crops are bred to resist certain diseases. Although a resistant variety may be more expensive, the farmer may save by not having to buy expensive fungicides in the future and by obtaining a greater yield of higher quality.

12. INSECTS

Even in countries where agriculture has been highly developed, crop damage caused by insects is considerable. The damage suffered by some of the major crops in the United States is shown in Table 1.12.

TABLE 1.12: ESTIMATED LOSS IN SOME PRINCIPAL CROPS DUE TO INSECT PESTS IN INDIA , YEAR 2000 (% LOSS)

Crop	*% Loss Through Insect Attack*	*Loss in Million Tons*
Maize	25	3.95
Wheat	5	3.60
Rice	25	28.77
Cotton (Lint)	50	4.70
Sugarcane	20	60.60
Chickpea	10	0.68
Groundnut	15	0.96

The greatest crop damage is caused by the insect in its larval or nymphal stage. The life cycles of the two classes of insects – those which pass through incomplete metamorphosis, and those which pass through complete metamorphosis – are shown below.

(a) Incomplete metamorphosis (cockroaches, caspid bugs)

egg → *nymph* → *adult*

In this type, the nymph has the same mouth parts as the adult and so causes the same type of damage.

(b) Complete metamorphosis (caterpillars, butterflies)

egg → *larva* → *pupa* → *adult*

The larva does not have the same mouth parts as the adult, so the damage done by the larva is of a different type. In this category, the adult in no way resembles the young.

Insects damage plants in the following ways:

(1) Insect larvae eat the sown seed or damage it to such an extent that, even if the seed germinates, the plant soon dies. Such damage is caused by seed worm maggots.
(2) Larvae reduce yields through damage to the plant leaf, either by completely eating it, as in the case of the Colorado beetle; by feeding on a single layer of the leaf, as does the diamond black moth; or by feeding on the tissue within the leaf, as does the larva of the cabbage beetle.
(3) Larvae damage the stem. Cut worms and leatherjackets completely sever the plant from its stem. Cabbage stem weevils feed within the stem. The frit fly feeds on the central shoot of cereal plants like the oat. The wheat stem sawfly causes the stem to swell and become "gouty", thus interfering with the supply of nutrients to the top part of the plant.

(4) Larvae, such as corn leaf aphids and Indian grain moths, may attack the developing or already developed fruit or grain.
(5) Insects such as aphids transmit a virus from one plant to another.
(6) Insects such as thrips and bugs in grain crops, suck out the plant sap.
(7) In Kenya, it has been found recently that the hopping of grasshoppers, which neither eat the plant nor infect it, harms the crop.

13. TIMELINESS OF SOWING

If seeds are sown too early in the season, they may be eaten by birds or worms or attacked by fungi. In maggot-infested soil, if corn, beans or peas are grown too early in the spring, the crop may be destroyed completely before it even has a chance to sprout. On the other hand, if the seeds are sown too late in the growing season, the crop will not have time to reach maturity and, therefore, the yield will not reach its maximum.

In temperate climates, the farmer must utilize as much of the warm season as possible, just as, in tropical climates, he must use the rainy season to his best advantage. In the latter case, the date on which the farmer plants is determined by his estimate of when the rainy season will start. The importance of the sowing date can be seen in the tables 1.13.A, B and C.

TABLE 1.13A: INFLUENCE OF SOWING DATE ON A PHOTOSENSITIVE RICE VARIETY

Sowing Date	*Crop Duration (in days)*	*Yield (kg/ha)*	*Loss in Yield compared to 8 Dec. Yield (%)*
Nov. 10	147	4001.0	20.6
Nov. 23	140	4483.2	11.1
Dec. 22	125	4214.2	16.4
Jan.5	118	3732.2	26.0

TABLE 1.13B: SEED YIELD AS INFLUENCED BY TIME OF SOWING FOR RAYA (QUINTAL /HA.) INDIA

Time of Sowing	*Yield*	*Loss in Yield compared to Oct. 25 Sowing date(%)*
Oct - 10	19.50	13.72
Oct - 25	22.60	0.00
Nov - 10	14.10	37.61
Nov - 25	6.30	72.12

TABLE 1.13C: SEED YIELD AS INFLUENCED BY TIME OF SOWING FOR CABBAGE (QUINTAL /HA.) INDIA

Time of Sowing	*Yield*	*Loss in Yield compared to Oct. 25 Sowing date(%)*
Oct - 10	14.70	0.00
Oct - 25	14.70	0.00
Nov - 10	8.10	44.90
Nov - 25	5.60	61.90

A timely sowing can sometimes provide greater yields than can the application of fertilizer. Since it costs the farmer nothing to change his date of sowing, he should be accurately advised as to what date will give him the highest yield.

14. CROP ROTATION, MULTIPLE- AND INTER- CROPPING

Whether a farmer should plant the same crop year after year (monoculture), … or plant several crops each year (multiple cropping) depends to a large extent on the size of the farmer's holdings and his financial resources. If the farmer cannot afford a partial or total loss of his crop from time to time, multiple cropping is his safest recourse.

Since this book is aimed at helping farmers with small holdings in developing countries, it is recommended that the farmers practice multiple cropping for the following reasons:

(1) The risk of bad weather is minimized. Should bad weather come, and the farmer has grown two or more crops, there is likely to be yield from at least one of the crops, even if another has failed. This point is well-illustrated by the practice of farmers in the drier areas of India. On part of their land they grow rice, and on another part, millet. The farmer may lose his rice in a draught, but he would obtain a yield from millet which is more drought-resistant.
(2) The farmer may employ his time better. Monoculture requires intense labor at certain time of the year, particularly during sowing and harvest, but there is little to do the rest of the year. To a large, specialized farmer who has access to equipment and hired labor,

and who may well want to vacation during the slack season, this is one advantage of growing only one crop. A small farmer, however, would find himself with far too much to do during sowing and harvest, and, with limited job opportunities, would waste time in the off-season. With several crops, the work peaks come at different times, and there is better distribution of the farmer's labor.

Crop Rotation, defined as the changing of the crop from one year to the next, is another technique which, can be beneficial to the farmer with small holdings. By planting, for example, sorghum one year where wheat had been planted the year before, the farmer can break the cycle of certain insects and diseases that thrive on one particular crop.

Rotating crops can also enhance soil fertility; since every crop extracts a different mixture of nutrients from the soil, the change of crop each year reduces the chance of depleting the soil of a particular nutrient. When a legume – such as peas or beans – is planted at frequent intervals, nitrogen is increased in the soil to be used by the crop which is planted the following year. Moreover, peas and/or beans in the diet of a poor farmer and his family would be a valuable addition, since protein is often lacking in diets of rural people in developing countries.

Intercropping, or the planting of one crop between the rows of another (for example, potatoes between corn rows), is another technique available to the small farmer and not practical for the large landowner. By practicing intercropping, the farmer utilizes his farm more intensively, thus preventing perennial and annual weeds from establishing themselves.

The risk of planting only one crop each year is too great for the small farmer, since he could not sustain a loss, should it occur. For the large farmer, however, monoculture has advantages: growing a single crop, the farmer can gradually acquire the know-how to produce the highest yields. He can buy specialized equipment for seedbed preparation, sowing and harvesting and thus become more and more efficient. Finally, he need not be bound to his land all year long, since, during much of the year, he will have little to do.

15. ADEQUATE DRAINAGE

Excess water in the soil makes every phase of farming difficult: seed-bed preparation, sowing, and harvesting the crop on time. More important still, it interferes with crop growth.

In humid climates, more water enters the soil than can be removed by drainage through evaporation. This excess water reduces the amount of oxygen in the soil, but increases the amount of carbon dioxide as the organic matter decomposes. The plant is prevented from growing properly in the following ways:

(1) Germination of the seed is retarded.
(2) High carbon dioxide concentrations decrease root permeability, reduce root development, and thus decrease the root's ability to take up water.
(3) Nutrient uptake is also reduced, since it is dependent upon energy supplied by root respiration.
(4) Susceptibility to disease is increased, because of (a) weakening of the plant cell wall, and (b) growth of anaerobic micro-organisms (those that do not need free oxygen to live).
(5) Availability of nutrients in the soil itself is reduced.

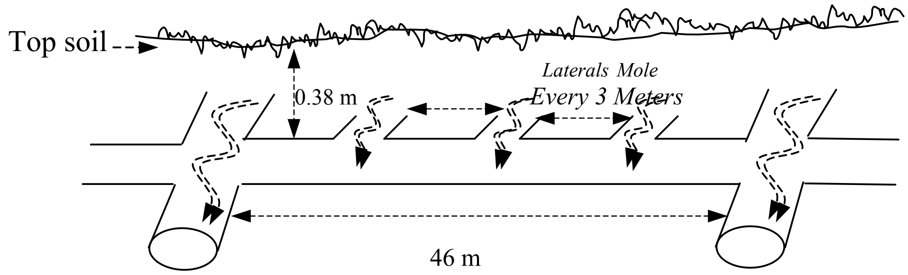
To have good yields in humid climates, drainage is necessary, under the following conditions: When there is a high or fluctuating water table. In such cases, the soil should be drained by a series of pipes or ditches. The effect of a ground water table on winter wheat and potatoes is shown in Table 1.14.

TABLE 1.14: EFFECT OF GROUND WATER TABLE ON WINTER WHEAT AND POTATOES

Depth of Water Table (cms)	*Yield cwt/acre*	
	Wheat	**Potatoes**
40.6	25	104
88.9	34	160
149.8	41	165
177.8	-	132

(1) When the soil lacks permeability. In clays, silty clay loams and clay loams, rain water may not be able to move down through the fine pores fast enough. In such cases, surface drainage – called mole drainage – (small surface ditches) should be employed. Mole drains 3 meters apart are usually most effective, as shown in Figure 1.9.

FIGURE 1.9: MOLE DRAINS WITH LATERALS AND TILE DRAINS



(2) When clay overlies a permeable stratum. In this case, the soil becomes water-logged because the large pores of the gravelly sand beneath cannot exert enough surface tensional pull to empty the fine pores of the clay. Here, too, mole drainage would be necessary.

In arid climates, other problems are caused by excess water. Here drainage is needed to reduce the salts which accumulate on the soil surface because poor irrigation or evaporation of water through the soil capillary tubes (See Figure 1.10).

FIGURE 1.10: LOCATION OF DRAIN PIPE IN RELATION TO LEVEL OF WATER LOGGED SOIL

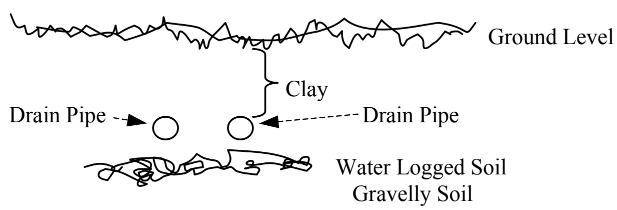
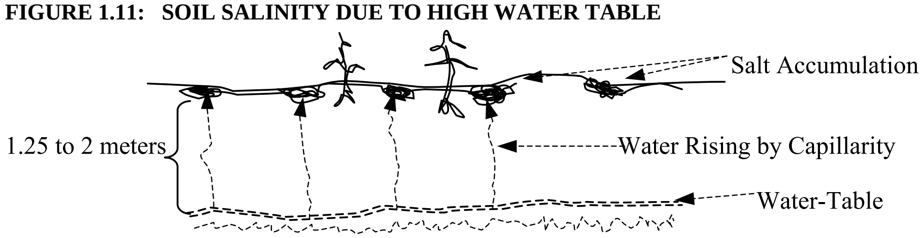


FIGURE 1.11: SOIL SALINITY DUE TO HIGH WATER TABLE



The presence of too much salt (soil salinity) affects crop yields in two principal ways: It retards seed germination, and it reduces the availability of water to the plant. As the salt concentration increases, the osmotic pressure of the soil solution increases, drawing the water out of the seed or the plant. With increasing soil salinity, the plant may become yellowish (chlorotic) and die.

To reduce soil salinity, water must be applied to dissolve the excess salts and carry them through the root zone to the sub-surface drainage. Since, by means of soil capillaries, water may evaporate from a water table of great depth, the drainage should be made at least six feet deep in the ground. In humid climates, where salinity may not be a problem, drainage at depths of 2.5 to 4 feet may be considered.

Credit agencies which wish to extend credit for irrigation should, in many cases, also give credit for drainage. In arid climates, gradual accumulation of salts can make land unproductive for years at a time. In such cases, credit for irrigation without simultaneous credit for drainage could actually hinder rather than help the farmers.

Secondly, where soil salinity is a problem, the farmers should be advised to grow crops which are salt-tolerant. Table 1.15 lists crop tolerance to salt concentration in the soil.

TABLE 1.15 CROPS AND VEGETABLES AND THEIR TOLERANCE TO SOIL SALINITY

Relatively Non-Tolerant	***Moderately Salt Tolerant***	***Relatively Salt Tolerant***	***Highly Salt Tolerant***
CROPS			
Field Bean	Maize	Wheat	Barley
	Sorghum	Oats	
	Soybean	Rice	
	Millet	Rye	
	Castor bean	Alfalfa	

Relatively Non-Tolerant	***Moderately Salt Tolerant***	***Relatively Salt Tolerant***	***Highly Salt Tolerant***
VEGETABLES:			
Celery	Pea	Spinach	Asparagus
	Watermelon		
	Tomato		
	Cabbage		
	Pepper		
	Lettuce		
	Onion		

In general, in cases of soil salinity, the farmer should irrigate more often than in non-saline conditions. He should be advised to water uniformly and to level the land wherever possible.

16. SEED-BED PREPARATION

Seed-bed preparation, depending on how well it is done, directly affects crop yields. Good seed-bed preparation should ensure the following:

(1) that as much water and air as possible are allowed to enter the soil;

(2) that the soil tillage is improved or preserved – thus the top soil should not contain large lumps that inhibit the seed's contact with the soil, nor should it be too finely prepared so that it is likely to seal with rainfall, causing soil erosion: and

(3) that both perennial weeds, such as thistle and annual weeds, such as wild oats, are controlled.

17. SOIL ACIDITY

What is acidity? Water is composed of one atom of oxygen (O) and two atoms of hydrogen (H). The chemical formula is H_2O. Liquid water is very stable, but, if broken down, it separates into one hydrogen ion (H^+), and another hydroxyl ion (OH^-), or

$$H_20 \leftrightarrow H^+ + OH^-$$

Any substance dissolved in water will yield either (i) hydroxyl ion (OH^-), (ii) hydrogen ion (H^+), or (iii) neither, or an equal number of H^+ or OH^- ions.

Acid is defined as a substance which yields hydrogen ions (H^+) when dissolved in water. For example, in the case of hydrochloric acid (HCL):

$$HCL \rightarrow H^+ + CL^-$$

<u>Base or Alkali</u> is defined as a substance which yields hydroxyl ions **(OH^-)** when dissolved in water, e.g. Sodium Hydroxide (**NaOH**):

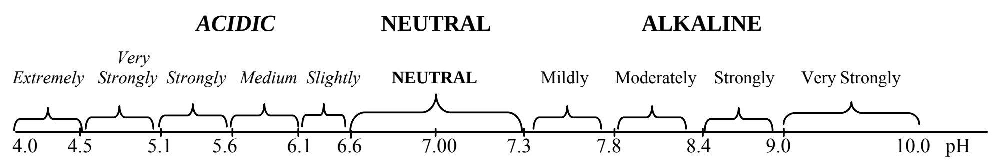
$$NaOH \xrightarrow{H_2O} 2Na^+ + 2OH^-$$

When a substance dissolved in water yields neither **H^+** nor **OH^-** ions, or yields an equal number of each, it is called a <u>neutral</u> substance. Sugar is an example.

<u>pH</u>: The acidity or basicity of a substance is frequently expressed as **pH**. The **pH** ranges from 0 – 14. In a neutral solution, the **pH** equals 7; in an acidic solution the pH is less than 7; in alkaline solutions, it is greater than 7.

Solids vary in **pH** from about 4, for strongly acid soils, to about 10, for alkaline soils. The **pH** range, as related to soils, is shown in Figure 1.12 below.

FIGURE 1.12. SCALE OF SOIL pH



The above **pH** scale is based on the negative logarithm of the concentration of hydrogen (**H^+)** and hydroxyl (**OH^-**) ions. This means that a solution of **pH** 5 has ten times more concentration of hydrogen ions **(H^+)** than a solution of **pH** 6, and a solution of **pH** 4 has ten times more hydrogen ions than one of **pH** 5 or 100 times more than the solution of **pH** 6.

<u>Causes of Soil Acidity</u> There are four different causes which can bring about soil acidity:

(i) Organic matter: Organic matter contains many reactive chemical groups which, behaving like weak acids, are capable of binding H+ ions.

(ii) Carbon dioxide (**CO_2**): In the atmosphere of soil, carbon dioxide reacts with water to form carbonic acid (**H_2CO_3**). The acid then dissociated to give H+ ions:

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

(iii) Aluminosilicate clay materials: In combination with water, aluminum ions (Al^{+++}) of aluminosilicate clay minerals yield H^+, which makes the soil acidic.

(iv) Soluble Salts: The positive charge of soluble salts in the soil interchanges with absorbed aluminum and causes an increase in soil acidity.

<u>Effect of Low pH (acid soils) on the crop</u> Certain crops can tolerate a high H^+ in the soil solution. This can be seen from the table below.

TABLE 1.16: PREFERRED pH OF SOME CROPS

Crop	pH	Crop	pH
Rice	5.5 - 6.5	*Soya bean*	6.0 -7.5
Wheat	5.5 - 7.5	*Groundnut*	6.0 -7.5
Maize	5.5 - 8.5	*Castor*	6.0 -7.5
Sorghum	6.0 - 7.5	*Rapeseed*	6.0 -7.5
Gram	6.5 - 7.5	*Linseed*	6.0 -7.5
Lentil	6.5 - 8.5	*Sunflower*	7.0 - 8.5
Peas	6.5 - 8.5	*Cotton*	7.0 - 8.5

It has been proven that, except in extreme cases, the harmful effects upon the crops are not due directly to high (H^+) but to secondary effects of high (H^+), such as:

(I) **Shortage of Available Phosphate**. When the soil pH is below 6, phosphate reacts with aluminum (Al^{+++}), iron (Ferrous Fe^{+++}) and the organic matter. The phosphate in combination with these chemicals cannot be used by the plant. This non-availability of phosphate due to its reaction with organic matter, Fe^{+++} and Al^{+++}, is termed phosphate fixation.

(II) **Shortage of available Calcium** (Ca^{+++}) to the plant.

(III) **Excess of aluminum** (Al^{+++}), **manganesium** (Mn^{+++}) or **iron** (Fe^{+++}). Excess of aluminum is toxic to most plants; excess of magnesium upsets certain enzyme systems in plants; and excess of Fe^{+++} reduces the plant's ability to transport phosphate from roots to shoots. Generally, plants vary in their susceptibility to Al^{+++} and Mn^{++} toxicity.

Effect of high pH (Alkaline soils) on the crop. The harmful effects of high pH, like those of low pH, are also usually traceable to secondary causes rather than to high concentrations of the (**OH^-**) ions themselves.

Under calcareous soil conditions:

(I) Phosphate becomes less available to the plant because it precipitates out as rock phosphate.

(II) Iron (**Fe^{+++}**), manganese (**Mn^{+++}**) and boron (**B**) often become unavailable to the plant.

Correcting Soil Acidity. To reduce the acidity of a particular solution, (OH^-) is added to it. (OH^-) combines with (H^+) to form water, as shown below:

$$\underset{\text{Acid}}{A\,[H^{+++}]} \quad + \quad \underset{\text{Base}}{B\,[OH^-]} \quad \leftrightarrow \quad \underset{\text{Water}}{H_2O} \quad + \quad \underset{\text{Compound}}{BA}$$

A small addition of (OH^-) ions to an acid solution will gradually reduce acidity. Eventually a stage will be reached where the solution has equal amounts of H^+ and OH^- ions. At this stage the solution is completely neutral: it will have a **pH** of 7. If the treatment were continued, the solution would start to show more OH^- ions than H^{+++} ions. This would increase the pH above 7, making the soil alkaline.

Compounds used for reducing (H^+) ions – often referred to as liming materials – in acid soils are listed in Table 1.17 below.

The ability of the liming materials to neutralize depends upon:

a) **The Neutralizing Value (NV) of the material:** NV is the amount of weight of each type of liming material required to neutralize a given amount of acidity in the soil. NV is represented as a percentage. Pure calcium carbonate ($CaCO_3$) is used as a standard, with a value of 100.

b) **Fineness of Liming Material**: The finer the material, the greater the area it can cover, and the more rapid its action in the soil.

TABLE 1.17: COMMERCIALLY USED LIMING MATERIALS AND THEIR PROPERTIES

Name of Material	Chemical Formula	NV%	Other Information
1)Calcium Hydroxide (builder's lime)	$Ca(OH)_2$	125-145	**Caustic**: must be handled with care.
2) Calcium Oxide (quicklime)	CaO	150-185	**Quick acting**, for situations where quick results are required. Spread well before sowing to prevent seed damage.
3) Limestone: Impure-	$CaCO_3$	100	Requires at least 12-18 months to reduce soil acidity. Big particles require up to 3 years to be effective. Apply near crop row and mix by plowing and disking. **Dolomite**: recommended where magnesium is lacking.
Pure-	$CaCO_3$	75-95	
Dolomite-	$CaMg(CO_3)_2$	109-119	
4) Marl		90-95	
5) Shells		up to 95	Should be thoroughly ground before use.
6) Wood-ash		30-75	Useful side benefit of wood fuel.

Caution in Over-Liming If too much lime is applied to the soil then, because of lack of phosphate and the toxicity of some micro-nutrients, the best crop yields will not be obtained. Therefore, great care should be taken to not over-lime the soil. Once the liming requirements of the soil have been determined, this danger can be avoided as follows:

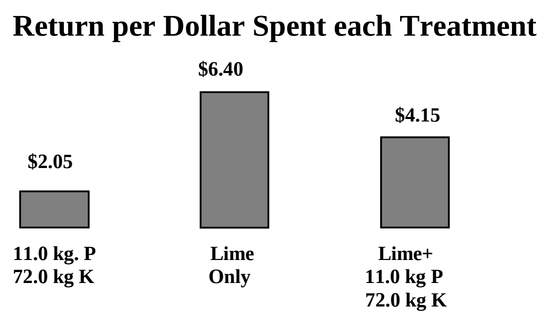
i) Apply dressing in stages at suitable points in the rotation.

ii) In the early stages, grow crops that are more tolerant to acidic soils, and in subsequent years, as the pH rises (becomes less acidic) grow a wider range of crops.

iii) Clay soils, however, present a problem. These soils, when limed up to pH 6.5, start to deflocculate; that is, the clay particles lose their property of adhesiveness. Consequently, clay soils should **never** be limed to pH 6.5, but only to pH 7 or 7.5. The most practical way to correct over-limed soils is to apply heavy amounts of sulfate of ammonia (ammonium sulfate).

Benefits of Liming Liming at proper levels improves the availability of phosphate and calcium and enhances nitrogen fixation by the introduction of a nitrogen-fixing bacteria, rhizobia. It also reduces excess Al^{+++}, Mn^{++}, and iron (Fe^{+++}), which are directly or indirectly determinants to plant growth and, hence, to crop yields. The financial benefits of liming can be seen from the results below.

Figure 1.13:



GENERAL RECOMMENDATIONS:

1) Do not extend credit to a farmer whose soil has pH below the suitable level for the crop that the farmer is going to grow (see Figure 1.13), unless the **farmer has taken corrective** measures (i.e. unless he has applied liming);

2) If funds are limited, it is **better to spend them on liming than on fertilizer**, as the farmer will obtain higher returns for each dollar spent; when there are sufficient funds, the farmer may apply both lime and fertilizer.

3) If credit is provided to farmers for application of limestone, since **limestones require at least 12 to 18 months to reduce soil acidity**, the payment period should be 2 years or more, so that the farmer can obtain the benefits of increased yield resulting from the application of the lime. If the credit is provided for **calcium oxide or calcium hydride, which are very quick-reacting**, then the credit may be provided for a period of 12 months.

4) **It is a waste of money to apply superphosphate**. Either lime or rock phosphate should be applied first.

5) Phosphate fertilizers should have as low a fluoride content as possible. This applies particularly to basic slag.

6) **There is no advantage in applying water-soluble phosphate** (see chapter 2), since it will be rapidly fixed and thus unavailable to the plant. It would be better to apply dicalcium phosphate (CaHPO4).

7) **Whenever possible, mix phosphate fertilizer with farmyard manure**. This reduces phosphate fixation.

8) **Apply granular fertilizer or use fertilizer placement**. (see next chapter for fertilizer terminology).

Chapter 2

UNDERSTANDING FERTILIZERS

1. **WHAT IS THE ROLE OF FERTILIZERS?**
2. **FERTILIZER ANALYSIS OR GRADE**
3. **SECONDARY AND MICRONUTRIENT FERTILIZERS**
4. **NITROGEN**
5. **PHOSPHOROUS**
6. **POTASSIUM**
7. **ANIMAL MANURE**
8. **HOW TO DETERMINE THE AMOUNT AND COMPONENTS OF FERTILIZER TO BE APPLIED**
9. **METHODS OF FERTILIZER APPLICATION**

1. WHAT IS THE ROLE OF FERTILIZERS?

Nutrients needed for plant growth may be leached away by rain or by the previous crop: or they may be present in the soil but, for some reason, inaccessible to the plant. Either of these conditions will prevent the plant from growing to its fullest potential and from providing the optimum yield.

To replace the needed nutrients and thus to obtain a higher profit, the farmer, after analyzing the situation and assuring himself that all the factors discussed in chapter one are as they should be, must apply fertilizer.

What does fertilizer look like?

Depending on what nutrients it contains and how it is made, a fertilizer maybe any one of various colors. Also, materials (conditioners) may be added to prevent the fertilizer from absorbing moisture and caking. Or pigments may be added simply to distinguish one kind of fertilizer from another.

Fertilizer particles are of different sizes and shapes. They come in large and small granules, crystals, pellets, coarse or fine powder. Generally they are solid but may in some cases be dissolved and applied as liquids.

2. FERTILIZER ANALYSIS OR GRADE

Grade (or analysis) refers to the percentage of plant nutrients in a fertilizer. Fertilizers containing only one essential nutrient are referred to as straight or simple fertilizers. Those containing two or three nutrients are variously called compound, complex, mixed, or sometimes binary (2- nutrient) or ternary (3 - nutrient) fertilizers. Besides knowing which or how many nutrients a fertilizer contains, we need to know in what qualities (i.e. the grade or analysis) the nutrients are present. The grade is found by chemically determining the percentage of each nutrient, as follows:

$$\text{Percentage of nutrient in the fertilizer} = \frac{\text{The nutrient content in the fertilizer}}{\text{Total weight of the fertilizer}} \times 100$$

The three nutrients most needed by deficient soil, and therefore most use in fertilizers, are nitrogen, phosphorous and potassium. These three nutrients, which will be examined more closely later in this chapter, are listed on the fertilizer bags or containers as nitrogen ***(N),*** phosphoric oxide, ***(P_2O_5)*** and potash ***(K_2O)***, in that order. In a 10- 20- 15 formula, for example, the first figure represents the percentage of nitrogen, while the second and third figures represent the percentages of phosphate and potash respectively. Thus, in a 100 kilogram bag of fertilizer, the 10- 20 -15 grade means there are 10 kilos of ***N***, 20 of ***P_2O_5*** and 15 of ***K_2O***.

By knowing the fertilizer grade, we can also calculate the fertilizer ratio, i.e. the relative proportion of each nutrient to the other nutrients. For example, a 10-10-10 grade would have a 1: 1:1 ratio of ***N: P_2O_5: K_2O***, while a grade of 10-25-15 would imply a ratio of 1.0: 2.5 : 1.5.

a) Conversion of fertilizer nutrient compounds to their nutrient elements and vice-versa

As mentioned above, fertilizer grades are stated in equivalents of nitrogen, phosphoric oxide and potash-- in other words, as *N: P_2O_5: K_2O*. Recently, however, an attempt has been made to state the fertilizer nutrients in their element: nitrogen, phosphorous, and potassium: thus, *N: P: K*.

In the case of nitrogen, no conversion need be made since it is an element and not a compound like phosphorous oxide or potash.

To convert phosphoric oxide to phosphorous and vice versa, we must follow the procedure given below. Whether the conversion is for the weight of the nutrient or the percentage, the conversion factors are the same.

% or weight of $P_2O_5 = P \times 2.29$
% or weight of $P = P_2O_5 \times 0.43$

Here is an example to illustrate the above: the fertilizer compound of triple phosphate *($Ca(H_2PO_4)_2$)* contains 46 percent of P_2O_5. To determine the amount of *P* in this fertilizer, we multiply the P_2O_5 content of the nutrient by 0.43 (the conversion factor), as follows:

% of ***P*** present = 46 x 0.43 = 19.78 ***P***

Similar formulae exist to convert potash content of fertilizer to potassium and vice versa. Thus,

% or weight of $K_2O = K \times 1.2$
% or weight of $K = K_2O \times 0.83$

If a fertilizer bag indicates that its contents are *N: P_2O_5: K_2O*, and the fertilizer grade is 10-20-10 (i.e. 10% nitrogen, 20 % phosphoric oxide and 10% potash), then we can find out how much *N, P* and *K* are present by the following procedure:

10% ***N*** = 10 % ***N*** (nitrogen needs no conversion)
20% P_2O_5 = 20 x 0.43 = 8.6% of ***P*** (using the formula given on page 3)
10% of K_2O = 10 x 0.83 = 8.3% ***K*** (using the formula given on page 3).

The fertilizer contains, then, 10 % ***N***, 8.6% ***P***, and 8.3% ***K***.

b) Simple (1-nutrient) fertilizer grades

There are many simple or straight fertilizer grades. Table 2.1 gives the common names and grades of the simple fertilizers available in most countries.

TABLE 2.1: THE PRINCIPAL STRAIGHT FERTILIZERS				
COMMON NAME	FORMULA	GRADE OR ANALYSIS PERCENTAGE OF FORMULA		
NITROGEN FERTILIZERS		**N**	**P_2O_5**	**K_2O**
Ammonium chloride	NH_4Cl	24	0	0
Ammonium nitrate	NH_4NO_3	33-34.5	0	0
Ammonium nitrate-limestone	$NH_4NO_3.$ $(NH_4)_2$ SO_4	20.5-26	0	0
Ammonium sulfate	$(NH_4)_2$ SO_4	21	0	0
Ammonium sulfate- nitrate	$NH_4SO_4.$ $(NH_4)_2$ NO_3	26	0	0
Calcium cyanamide	CaN_3	18-22	0	0
Calcium nitrate	$Ca\ (NO_3)_2$	15-15.5	0	0
Sodium nitrate	$NaNO_3$	16	0	0
Urea	$CO(NH_2)_2$	45-46	0	0
PHOSPHATE FERTILIZERS				
Basic slag		0	16-20	0
Di- Calcium phosphate	$Ca\ (H_2\ PO_4)_2$	0	35-42	0
Ground rock phosphate		0	20-40	0
Single or simple Super phosphate	$Ca\ (H_2\ PO_4)_2$ + $CaSO_4$	0	16-20	0
Triple or concentrated Super phosphate	$Ca\ (H_2\ PO_4)_2$	0	46	0
POTASH FERTILIZERS				
Marinate of potash or Potassium chloride	KCl	0	0	60
Sulfate of potash		0	0	50
Sulfate of potash-magnesia	$K_2SO_4.MgSO_4$	0	0	21
Sylinite (double)		0	0	40

c) Compound or mixed fertilizers

There are many compound fertilizers available. They are produced either chemically, as in the case of ammonium phosphates, nitrate of potash and nitro phosphate; or by simple mixing of straight fertilizers.

Generally, we can divide compound fertilizers into three categories, according to nutrient concentration:

i) Low concentrated grades, in which the nutrients represent 15 to 25 percent of the total fertilizer bulk, e.g. 9 - 8 - 4, 6 - 6 - 6.

ii) Medium -concentrated grades, in which the nutrients form 25 - 40 percent of fertilizer bulk, e.g. 15- 9 - 15, 10 - 6 - 10.

iii) Highly concentrated grades, in which nutrients form over 40 percent of fertilizer bulk, e.g., 20 - 20 - 20, 15 - 10 - 25.

Some examples of chemically mixed fertilizers with their properties are listed in Table 2.2.

TABLE 2.2: SOME CHEMICALLY MIXED FERTILIZERS					
Common name	**Formula**	**% Nutrient**	**Method of Application Present ***	**Advantages**	**Disadvantages**
Ammonium phosphates	$NH_4H_2PO_4$	***N***: 11 P_2O_5: 48	Broadcast or row placement	Good in soils which do not need potassium. Phosphorus is completely water solvable.	Causes high Soil acidity. .
Ammonium phosphate Ammonium nitrate	$NH_4H_2PO_4$ NH_4NO_3	***N***:16 P_2O_5: 20	Broadcast or row placement.	Completely water solvable. $N0_3^-$ immediately available.	NO_3^- may be loss through leaching or denitrification. High residual acidity.
Diammonium phosphate	$(NH_4)_2HPO_4$	***N***:18-21 P_2O_5: 46-53	Broadcast	N and P do not separate on bulk blending. Phosphate is completely water solvable.	Danger to seed germination
Potassium nitrate	KNO_3	***N***:13.5 K_2O: 46			
* For methods of fertilizer applications see Section 9 of this chapter.					

The simple mixing (also called mechanical mixing) of straight fertilizer involves no chemical reaction. When solid fertilizers are being mixed, the mixing is referred to as dry bulk blending. This is most common in tropical climates where the use of liquid fertilizer is very rare because of high evaporation.

Bulk blending

Bulk blending is frequently done at the factory where the fertilizers are manufactured. Unfortunately, factories are often unwilling to mix a special fertilizer combination for a particular locality. Because of this and because a locality often requires a special combination of nutrients, it is preferable that the credit agency buy its own bulk blending machine. Thus it need not depend on the factory and can provide the farmer with the combination designed to bring the highest yield and profit.

Having such a machine, the credit agency would of course have to build a storage unit for the fertilizers and would have to hire personnel to do this mixing. But the benefits would outweigh these additional costs. Apart from being able to increase the farmer's profit (thus improving the loan recuperation), the agency would profit by the purchase of fertilizers in large qualities at cheaper rates.

The following guidelines should be applied when bulk blending is to be done:

i) Fertilizers should be mixed only if they are pelleted or granular and of uniform size. If some of the fertilizers were to fine or powdery, it would be best to apply them to the land separately rather than mixed. Also, with some crops, it is better to apply each nutrient at a different time of the growing season.

ii) In mixing straight fertilizers, ammonium should not be mixed with rock phosphate, calcium cynamide, lime or basic slag. Such a mixture would result in the loss of nitrogen through the gaseous ammonium. Urea, however, can be mixed with basic slag.

iii) Water-solvable phosphate fertilizers (such as single superphosphate, concentrated phosphate, and ammonium phosphate) should not be mixed with fertilizers containing lime. In the presence of lime, some of the soluble phosphate changes to an insoluble form which the plant is unable to absorb.

iv) Fertilizer ingredients which are hygroscopic in nature--i.e. which readily absorb moisture-- should be mixed shortly before application. These ingredients, which include urea, calcium nitrate, ammonium nitrate and sodium nitrate tend to form lumps if they are stored after mixing. In tropical climates, urea and nitrates require moisture proof bags for safe storage.

3. SECONDARY AND MICRONUTRIENT FERTILIZERS

The majority of straight fertilizers also contain secondary nutrients (i.e. calcium, sulfur or magnesium), while compound fertilizers frequently contain micro-nutrients (small qualities of iron, boron, or others). Secondary nutrients and micro-nutrients may not always be listed by the manufacturer on the bag or container. In many cases it is unnecessary to list secondary nutrients; for example, single superphosphate-- (Ca $(H_2PO_4)_2$)-- contains calcium in its formula, for which reason calcium is not separately listed. The same is true for magnesium sulfate ($MgSO_4$) and sulfate of potash- magnesia, both of which contain sulfur and magnesium. Various other fertilizers also contain sulfur: single phosphate (12%), ammonium sulfate (23%), potassium sulfate (18%), and natural gypsum (16%).

In the case of micro nutrients, in the absence of a manufacturer's guarantee, there can be no certainty that the micro -nutrients are actually present in the fertilizer in amounts large enough to be of value. Moreover, since fertilizers containing micro- nutrients are more expensive than those without, the farmer should be sure the micro-nutrients are needed before he goes to this expense. He should take soil samples or tissue tests and send them to a fertilizer specialist before recommending the more expensive fertilizer. (How to take soil samples or conduct tissue tests is discussed in the following chapter.) A micro-nutrient such as iron, for example, may be present in the soil but unavailable to the plant. Such a situation should be analyzed before recommending a fertilizer containing more iron. Also, since micro-nutrients are needed only in small amounts, a careless application of a micro-nutrient could replace deficiency with excess, perhaps further harming the crop. Where specific deficiencies are known to exist, specially mixed fertilizers can be prepared containing micro-nutrients along with the ***N- P_20_5 -K_2*** grades. Spray or seed treatments with micro-nutrients may also be used.

Some fertilizers containing micro-nutrients are listed in table 2.3.

TABLE 2.3: MICRONUTRIENT FERTILIZERS

Common name	Formula	Micronutrient Contained
Borax	$Na_2B_4O_7.10H_2o$	Boron ***(B)***
Copper Sulfate	$CuSO_4.5H_2o$	Copper ***(Cu)***
Ferrous Sulfate	$FeSO_4.7H_2O$	Iron ***(Fe)***
Manganese Sulfate	$MnSO_4.7H_2o$	Manganese ***(Mn)***
Muriate Of Potash	KCl	Chlorine ***(Cl)***
Sodium Molybdate	$Na_2MoO_4.10H_2O$	Molybdenum ***(Mo)***
Zinc Sulfate	$Zn_2SO_4.7H_2o$	Zinc ***(Zn)***

As mentioned earlier, although micro-nutrients are needed only in small quantities, if any one of the 16 elements is in short supply, the crop yield will be reduced. (Micro-nutrient deficiency symptoms are dealt with at length in Chapter 3.)

Tables 2.4 and 2.5 illustrate the effects of the lack or absence of a single micro-nutrient or secondary nutrient on crop yields.

TABLE 2.4: COMPARISON OF WHEAT YIELDS WITH ONLY NITROGEN AND WITH NITROGEN PLUS SULFUR

Only Nitrogen	Yield (Cwt/Acre)	Nitrogen + Sulfur	Yield (Cwt/Acre)	% Increase In Yield Due To Sulfur
0	1,820	0	1,848	1.5
40	1,568	40	2,072	32.1
80	1,400	80	2,240	60.0

TABLE 2.5: COMPARISON OF MAIZE YIELDS WITH VARYING LEVELS OF ZINC WHERE THE SOIL IS DEFICIENT IN IT

Zinc Applied (Lbs./ Acre)	Yield (Cwt/Acre)	Increase In Yield %
0.0	1,400	0
0.5	4,088	192.0
2.5	5,432	288.0

Now that we have acquired a basic knowledge of fertilizers, let us turn to a closer examination of the three principal elements which make them useful to us: nitrogen, phosphorous, and potassium.

4. NITROGEN

Nitrogen is essential for all life processes, plant and animal alike. In plants, nitrogen occurs chiefly as protein, but also as amino acids and amino-sugars. Plant cells need nitrogen for respiration, reproduction and a good rate of growth.

If we were forced to choose the most important of the three basic nutrients, it would have to be nitrogen. The measure of success that a farmer enjoys depends largely on how much available nitrogen he is able to give his crop, and how little nitrogen his soil loses. Plants require nitrogen in large amounts and, nowadays, it is expensive to purchase. If proper agricultural practices are not followed, it can easily be lost from the soil.

The main source of soil nitrogen is the air, where it is found as nitrogen gas (N_2). There are approximately 34,500 tons of nitrogen over every acre of land (38, 667.6 kgs. /ha). Despite this seeming abundance, plants cannot utilize gaseous nitrogen directly. It must first be combined with oxygen or hydrogen by the action of lightning, bacteria (free living or symbiotic), or industrial processes.

4.1. Sources Of Nitrogen

a) Lighting

In the presence of lightning, nitrogen combines with oxygen to form oxides of nitrogen. These oxides, in turn, combine with rainwater to form nitrous or nitric acids. The amount of nitrogen that enters the soil in this way is usually not more than 2 lbs. per acre (2.24 kgs/ha) per year.

b) Bacteria

An example of bacterial action upon nitrogen can be found in the case of legumes, which were discussed earlier. Legumes, such as peas or beans, contain a microbe, called Rhizobia, which converts nitrogen in the air into soluble compounds that may be absorbed by the plant through its roots. This process is called nitrogen fixation.

Most legumes require the application of phosphate, calcium or potassium to the soil, if the soil is not strong in these nutrients. Paradoxically, however, the legumes fix more nitrogen when the nitrogen level in the soil is at a minimum. Only at planting time should a small amount of nitrogen be given to the soil, so that the young plant can be adequately nourished until enough

Rhizobia have developed to supply its own nitrogen. Large or continual applications of nitrogen can considerably reduce the activity of the Rhizobia and thus the size and quality of the yield. This point has special importance to the farmer in developing countries, where legumes are frequently inter-cropped with non-legume crops such as corn. (Inter-cropping has been discussed in Chapter one). If, in order to better nourish his corn, the farmer has applied a large quantity of nitrogen, he simultaneously reduces the amount of nitrogen which he would have gotten, free of expense, from his legume crop. He would have been better off had he applied less nitrogen and allowed his legume crop to yield its maximum.

Legumes differ in their capacity to fix nitrogen, as seen in Table 2.6.

TABLE 2.6: AVERAGE FIXATION OF NITROGEN BY LEGUMES

Plant	N Kg/Ha/ Year.	Country
Glyine javanica	110 - 180	Kenya
Wattle (acacia mollissima)	200	South Africa
Centrosema pubecens	30	Nigeria
Clovers and lucern	150 - 200	Temperate regions

Nitrogen fixed in the soil by free living micro-organisms, such as algae and bacteria, amounts to an average of about 6 lbs. per acre (6.72kgs/ha).

c) Industrially- Processed Nitrogen

Industrially processed nitrogen is the greatest single source of nitrogen to the soil. Among the processed nitrogen fertilizers are:

i) Sodium nitrate; ammonium sulfate;
ii) Ammonium nitrate; calcium nitrate; ammonium nitrate- limestone; urea;
iii) Calcium cyanamide; ammonium chloride and ammonium sulfate- nitrate.

The above fertilizers, though all containing nitrogen, differ in important respects: each makes its nitrogen available at a different rate to the plants, and each has a different impact on soil acidity and micro-organisms. Ignorance of these differences could mean a great loss in yield for a farmer. For this reason, some of the important characteristics of the fertilizers are given . in Table 2.7.

TABLE 2.7: PROPERTIES OF NITROGEN FERTILIZERS

Common Name	Physical Conditions	Methods Of Application*	Advantages	Disadvantages
Ammonium Nitrate	Pellets	Broadcast or side dressing	$NO3^-$ immediately available	$NO3^-$- maybe easily lost through denitrification or leaching.
Ammonium Sulfate	Pellets Or Granules	Broadcast or side dressing	Acidic in nature. So maybe useful on alkaline soils.	On acidic soils liming would be required to correct acidity.
Calcium Cyanamide	Prills	Broadcast or side dressing	Because of its high toxicity it can be used for weed control.	May cause damage to seed, if applied too closely to it.
Calcium Nitrate	Granules	Broadcast or side dressing	$NO3^-$- is immediately available. Non-acidic.	Expensive for the amount of *N* in it.
Sodium Nitrate	Granules	Broadcast or side dressing	$NO3^-$ --immediately available. Non- acidic.	
Urea	Granules	Side dressing, broadcast, or spray in solutions.	High water solubility. High N content. Non-leachable when converted to NH_4 form.	Can be lost as NH_4 gas or leached, away if rains soon after application.

(For methods of fertilizer applications see Section 9 of this chapter.)*

Certain other facts, not included in the above table, must be mentioned. Three of the above fertilizers, though excellent sources of nitrogen, represent special risks and problems:

i) **Urea** (Ca $(NH_2)_2$), because of its solubility in water, can be problematic. First of all, if urea is applied to a bare soil surface, it combines with water to form ammonium carbonate $(NH_4)_2CO_3$. This, in turn, breaks into carbon dioxide and ammonia, and the later evaporates, carrying valuable nitrogen with it. Thus a farmer could spend money to apply urea as a nitrogen fertilizer, and the nitrogen could be gone before the plant has had a chance to absorb it. The hydrolysis of urea is demonstrated in the following formulae:

Urea ↑ $CO(NH_2)_2$; NH_3 (Ammonia) ; CO_2 (Carbon dioxide)

$$CO(NH_2)_2 + 2H_2O \longrightarrow (NH_4)_2CO_3 \longrightarrow NH_3 + CO_2$$

The loss of ammonium (and hence of nitrogen) from urea can be reduced if it is applied in quantities of less than 100 lbs. per acre (112 kgs. /ha).

The rapid hydrolysis of urea can also cause ammonia injury to seedlings. This problem can be easily circumvented by placement of the urea at some distance from the seed.

Another problem lies in the fact that urea may sometimes contain biuret, a chemical compound which is toxic to plants. The presence of a high level of biuret could mean a significant loss of crop.

ii) **Calcium cyanamide** is a toxic fertilizer which can easily damage the seed or the young plant. To use it to its best advantage as a nutrient source, apply it two or three weeks before sowing and mix it well with the soil. In alkaline and dry soils, calcium cyanamide often forms a coating around itself, reducing its availability to the plant. This condition also encourages the production of toxic chemicals in the fertilizer.

iii) **Ammonium nitrate** must be stored and handled with extreme care. When mixed with oil and ignited, it will explode.

4.2. NITROGEN FERTILIZERS AND SOIL ACIDITY

With the exception of urea, most nitrogen fertilizers have no immediate effect on soil acidity. In the long run, however, almost all of these fertilizers cause a moderate to strong acidity. Calcium nitrate and sodium nitrate are the only ones which make the soil basic (i.e. increase the pH of the soil).

If small quantities of nitrogen fertilizer are applied yearly, soil acidity due to their application is insignificant. Only if heavy levels are applied will acidity noticeably increase. In the later case, extra liming would be required. To determine the amount of liming necessary, soil tests have to be conducted (see page 53).

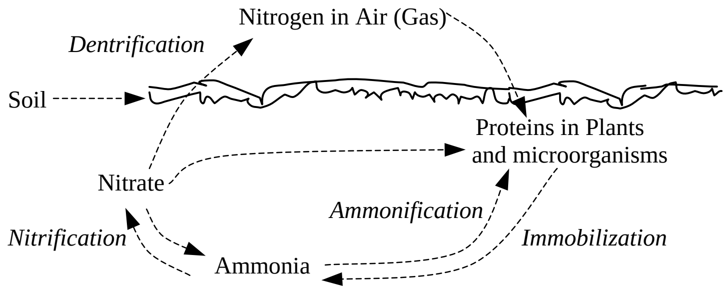
As a general rule, for acid soils, it is better to use nitrogen fertilizers which are alkaline in their effect; and, for alkaline soils, fertilizers which create acidity.

4.3. SOIL CONDITIONS AND NITROGEN UPTAKE BY PLANT

Most of the nitrogen in the soil exists as protein in plant residue and micro-organisms, or as ammonia and nitrate ions. Plant roots, however, can only absorb nitrogen in the later two forms and chiefly in the form of nitrate ions. Ammonia ions, because they adhere firmly to the soil particles, are more difficult for the plant to absorb, and usually must be converted to nitrates by soil micro-organisms. Plants cannot absorb nitrogen as protein, because the protein molecule is too large to enter into the root hair.

The forms in which nitrogen is found in the soil are shown in figure 2.1.

FIGURE 2.1: THE NITROGEN CYCLE



There are three processes, shown in the figure above, by which nitrogen changes from one form to another:

i) __Immobilization__, in which the micro-organisms use the soil nitrogen as food. This nitrogen, because it is inaccessible to the plant, is often called "tied- up" nitrogen. Immobilization is the opposite of ammonification, (also shown above) which is the release of nitrogen, in the form of ammonium, by dead micro-organisms.)

ii) __Nitrification__, the changing of soil ammonia (NH_3) into nitrates which can be absorbed by the plant.

iii) __Dentrification__, the process by which the soil nitrates are lost to the air as gases.

Since the degree to which any of these three processes occurs is dependent upon soil conditions, let us examine each process more closely, in relation to those conditions.

i) Immobilization

All plant material contains nitrogen. But plant material must be decayed and converted to ammonium before a living plant can make use of the nitrogen within it. For this reason, farmers often plough under leftover crop residue, leaving it to decay beneath the soil.

The micro-organisms which decay the crop tissue need both nitrogen and carbon to live. The residue of certain plants, such as alfalfa and other legumes, provide enough nitrogen and carbon to afford a balanced diet to the micro-organisms. The later then multiplying, exhaust all their food and die. With their death, ammonia is released (ammonification), which can be used by the plant.

Certain other plants, such as maize or rice, contain more carbon than nitrogen. When these plants are ploughed into the soil, the micro-organisms die from lack of nitrogen. They release some ammonia, but other micro-organisms quickly use it, and little is left for the plant to absorb. In such a situation, even when nitrogen is applied in the form of fertilizer (nitrates or ammonium compounds), the micro-organisms feed upon it before it can reach the plant. The nitrogen is now inaccessible to the plant or "tied up ". Eventually, of course, these micro-organisms will die and the ammonia will be released; but, in the meantime, the young plant will have gone without nitrogen. The money spent on fertilizer will have been wasted.

There is then, a continuous two- way process. Micro-organisms release ammonia and, at the same time, they use some of it as food (thus tying up nitrogen). If they use it faster than they produce it, then there is none for the plant to absorb; if they release more than they use, there is an adequate supply for the plant.

Here, a simple ratio would be helpful to the farmer. If the soil contains 30 times more carbon than nitrogen (C/N ratio of 30:1), then most of the ammonia will go to the micro-organisms, very little to the plants. When, however, the C/N ratio is less than 15:1, a situation often produced by leguminous crops, then more ammonia is released than the micro-organisms can use. It can thus be absorbed by the plants, or converted into nitrates by the process of nitrification.

The farmer can reduce nitrogen loss by plowing in plant tissue with high carbon content (such as corn stalk or straw) well before the sowing season. Thus, by the time of sowing, the micro-organisms will have already decayed and the young plant will have a good nitrogen supply. The other benefit is that the micro-organisms tie-up the nitrates during the period before the sowing when the nitrates could be washed away by rains.

If, however, this plowing-in were done too close to the time of sowing, the effects would be negative. The rains would not protect the soil from nitrogen loss, and the micro-organisms would be still active by the time the young shoots emerge, leaving them no nitrogen to absorb.

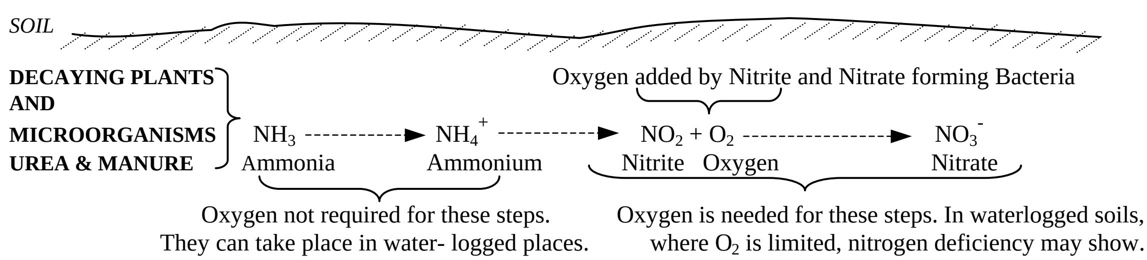
It is a question, then, of timing. Leguminous crops, for example, should be ploughed under just before sowing and not, as in the case of the carbon-rich crops, long before. The legumes, being rich in nitrogen, will reduce the C/N ratio to less than 15:1. In such conditions there is enough nitrogen for both micro-organisms and crop.

ii) Nitrification

Inorganic nitrogen exists mainly in the form of nitrate ions (NO_3^-) and ammonium ions (NH_4^+). The former are supplied by such fertilizers as sodium nitrate, ammonium nitrate and calcium nitrate, and are readily absorbed by the plant root. However, because they are not held firmly by the soil, they are easy leached away by the rain.

Ammonium ions are found in animal manure, decayed animal and plant tissue, and such fertilizers as ammonia and urea. Ammonium ions differ from nitrate ions in that they adhere more closely to the soil, and so must be converted by micro-organisms into nitrates before the plant can use them. The process by which this conversion takes place is called nitrification, shown in Figure 2.2.

FIGURE 2.2: THE NITRIFICATION PROCESS



The process of nitrification occurs best in warm, moist, well-aerated soils with a neutral pH (i.e. a pH of 7). The process is severely impeded by soil water logging, which reduces the oxygen that nitrification bacteria need to live and perform their function.

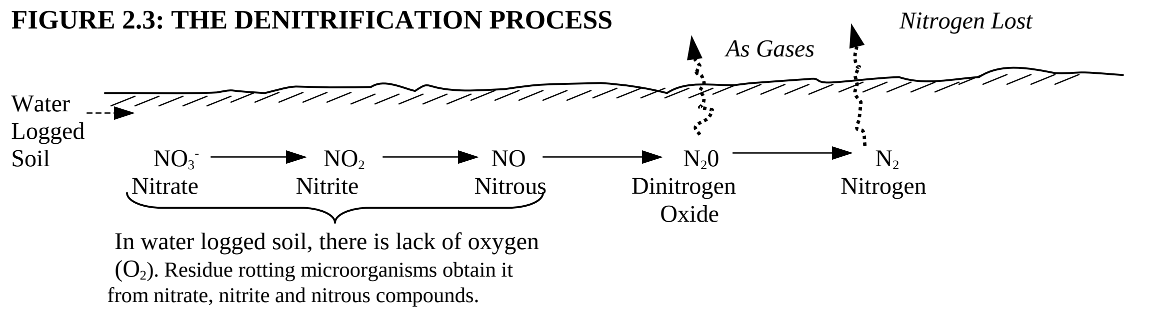
To make available to the plant the ammonia ions in fertilizers containing ammonia compounds, the farmer must create an environment conducive to speedy nitrification. There are two measures he can take:

a) On wet soils, build drainage systems to increase their supply; and
b) On soils with the right moisture content, plough and harrow to increase soil oxygen and the decay of residues.

iii) Denitrification

We have already learned that water logging and poor soil aeration inhibit the conversion of ammonia ions into nitrate ions, thus reducing the availability of nitrogen to the plant. But there is another part of the cycle which water logging affects: it causes the nitrogen ions that are available (from fertilizers or conversion) to turn to gas and evaporate from the soil, thus further depriving the plant of nitrate ions. When soil is water logged, the limited air is not enough for the micro- organisms, which must then obtain their oxygen by the breaking down of soil nitrates. This process, called denitrification is shown in figure 2.3.

FIGURE 2.3: THE DENITRIFICATION PROCESS



In poorly- drained soils, denitrification can be a major problem. There are two principal ways in which it can be eliminated or reduced:

a) By building a drainage system to increase soil air, and
b) By applying fertilizers which contain ammonia ions (NH_4) rather than nitrate ions (NO_3^-). This application, however, should be done well before sowing time. Thus, if by sowing time, the soil has drained-- either by chance in weather or by the construction of drains--, the new nitrified ammonia will be available to the plant; and it will not have been lost by nitrification during the waterlogged period, as the nitrogen in a nitrate fertilizer would have been.

4.4. HOW TO OBTAIN BEST RESULTS FROM APPLIED NITROGEN

The figure 2.1 illustrated the various paths of the nitrogen cycle which we have discussed. We have seen the ways in which nitrogen can be lost from the soil. The following is a review of the measures by which a farmer can reduce that loss and / or enhance his soil's nitrogen content.

i) Return **animal manure** and crop residue to the soil. If crop residue is insect- infested or diseased, then it should be burned. This residue supplies some nitrogen, helps to reduce the leaching away of soluble soil nitrogen, and maintains or increases the level of organic matter.

ii) On **hilly land**, use cover crops or catch crops to reduce soil erosion.

iii) On **sandy soils**, to prevent fertilizer leaching, apply soluble forms of nitrogen fertilizers (such as urea and sodium nitrate) as near the time of cultivation as possible. This will increase the proportion of nitrogen utilized by the crop. (When applying urea, special care regarding placement and timing of application can reduce the loss of nitrogen through volatilization).

iv) **Reduce denitrification** by not applying nitrate fertilizers to soils that are poorly-drained or poorly-aerated.

v) **Grow legumes** where possible.

vi) **Avoid** continuous use of **acid-forming fertilizers**, which lead to decrease in soil **pH** and poor crop yields.

vii) If **calcium cyanamide** is found necessary, it should be applied well **before seeding** and should be mixed thoroughly into the soil to prevent damage to the seed.

viii) **Kill weeds**, which compete with crop for nitrogen and other nutrients.

5. PHOSPHOROUS

Phosphorus, like nitrogen, is to be found in all living things. It forms a large part of the cell nucleus.

In plants, phosphorous is necessary for photosynthesis, for building- up and breaking-down of carbohydrates, and for the transfer of energy within the plant. It is particularly important in the stages of seed germination and the growth of the young plant. It stimulates root growth and, in legumes, helps to form the nodules containing the bacteria Rhizobium (see Chapter 2). Phosphorus also hastens maturity in crops and, in excess can cause the plant to mature too early, reducing the crop yield.

In both soil and plant tissue, phosphorus is present in smaller amounts than are the other two major nutrients-- nitrogen and potassium. If proper agricultural practices are not followed, the small quantity of soil phosphorus may be difficult for the plant to absorb.

Unlike nitrogen, phosphorous cannot move within the soil. Most of it is found in the first foot of the soil, either in organic form, or in inorganic form-- that is, as phosphates (PO_4^-).

Crops differ in their ability to absorb phosphorous. In phosphate form, phosphorous is taken up by plant roots in chemical compounds H_2PO_4 (Orthophosphate) and HPO_4. Somewhat less phosphorous is absorbed in its organic form.

Legumes can extract more phosphorous than can cereal crops.

5.1. Phosphate Fertilizers

Rock phosphate, when combined with certain other chemicals, is the primary source for all phosphate fertilizers.

The phosphate fertilizers most commonly found in the world markets are listed in Table 2.8.

TABLE 2.8: PROPERTIES OF PHOSPHATE FERTILIZERS

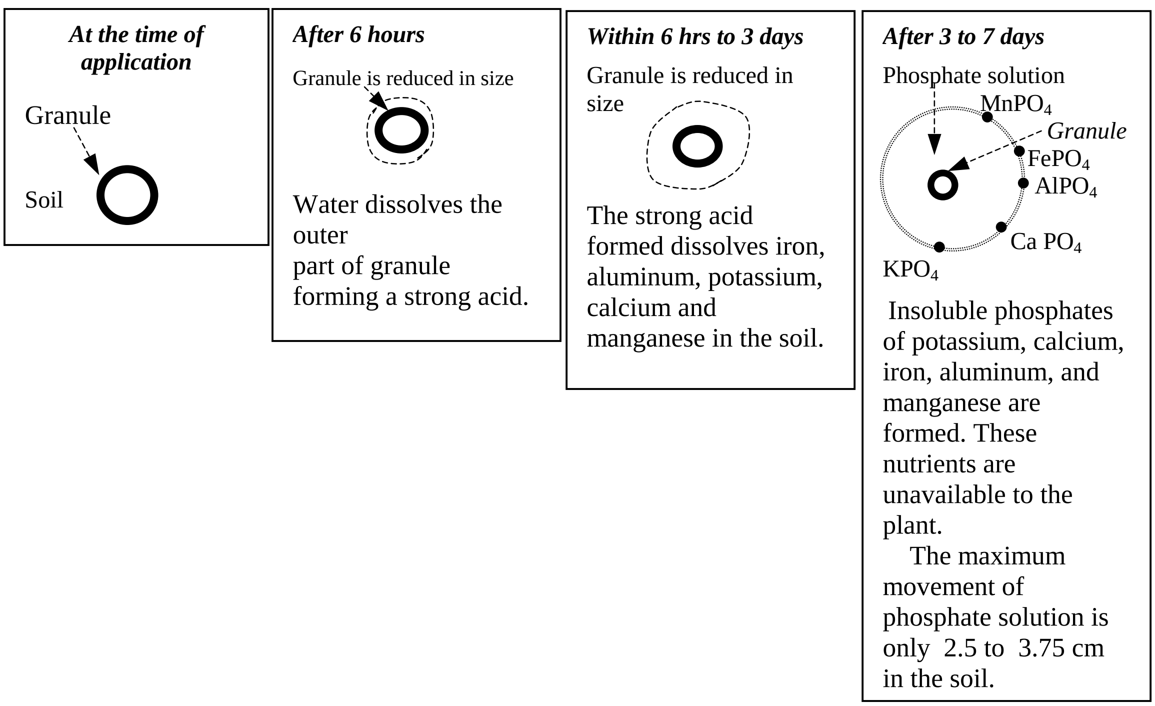
Common Name	% P_20_5	P available (% of total)	Other Information
Single or Simple Super Phosphate	16 - 20	79-100	May be applied by itself or mixed with other fertilizers. Should be recommended where sulfur is deficient in the soil.
Triple or Concentrated Phosphates	46	96 - 99	High source of P. Should be recommended where transportation is a major cost.
Di-calcium Phosphate	35 - 42	98	See table 2.24 chemically mixed fertilizers.
Ammonium Phosphate	48	100	May be mixed or blended with other fertilizers. See table 2.2 for chemically mixed fertilizers.
Di-ammonium Phosphates	46 - 53	100	(As for above, see table 2.2).
Ground Rock Phosphorate	20 - 40	14 - 65	Slow source of P; so should not be applied on short season crops e.g. Tomatoes.
Basic Slag	16 - 20	62 - 94	Alkaline in nature. So a good source of p on acid soils.
Nitro Phosphate	Variable	0 - 70	Good results on acid soils and good for crops with long growing season.

The chief problem represented by phosphorous fertilizers is that only a small fraction of the phosphate contained in them can be made available to the crop. Scientists have defined "available" phosphate as the amount of phosphate which is soluble in water, plus the amount soluble in ammonium citrate.

Even when a fertilizer contains a large proportion of available phosphate, most of that phosphate becomes unavailable within days or even hours after application. This is because the phosphate compound dissolves in the soil water, producing a powerful acid, which in turn dissolves other soil compounds such as iron, aluminum and manganese. The later compounds then combine with phosphorous to form new compounds which, because they are not water-soluble, render the soil phosphate unavailable to the crop.

This process can occur very rapidly, in some cases even before the seeds have had time to germinate. With the passing of time, less and less phosphate is available to the crop. An example of this process can be seen in Figure 2.4. In this case, the superphosphate fertilizer has been applied.

FIGURE 2.4: REACTION OF SOIL AND SUPERPHOSPHATE GRANULES



5.2. FACTORS AFFECTING THE AMOUNT OF PHOSPHOROUS AVAILABLE TO THE CROP

a) Acidity : One of the main factors responsible for making phosphorus unavailable is soil acidity. The impact of the later on phosphorous and other nutrients is dealt with at greater length in Chapter 1. For the present purpose, we may see the influence of soil acidity on the availability of phosphorus in Figure 2.5.

FIGURE 2.5: SOIL ACIDITY AND THE AVAILABILITY OF PHOSPHORUS

	Soil pH	**Availability of Phosphorous**	**Reasons for Availability or Non-availability Of P**
Moderately Alkaline	9.0	High	Sodium ions are dominant over Calcium ions. Sodium phosphate salts are formed which are water solvable, so available to the plant.
Slightly alkaline	8.0	**Low**	Calcium ions become dominant. Tri-calcium phosphate is formed which is less soluble and less available to the plant.
Neutral	7.0	Moderate	
	6.5	**High**	
Slightly acidic	6.0		Phosphorus compounds are highly water soluble, hence more available to the plant.
Strongly acidic	5.0 4.0	**Low**	Phosphorus is precipitated out as insoluble compounds-- such phosphates as iron, aluminum and manganese -- and, therefore, less available to the plant.

b) Uneven distribution of fertilizer: the more uneven the fertilizer distribution, the more difficult it is for the plant roots to reach the phosphate.

c) Soil moisture: too great a soil moisture encourages the chemical process described earlier, leading to less phosphate availability. The drier the soil, the more available the phosphate.

d) Proportion of water- insoluble phosphate in the fertilizer: some phosphates, such as dicalcium phosphate, do not dissolve in water at all. Application of a fertilizer containing too much of these phosphates would surely reduce crop yield.

e) Organic matter: organic matter may provide nearly 50% of all the soil phosphorous. Thus the level of organic matter should be kept high.

f) Soil compaction: where the subsoil is too compact, plant roots find it difficult to grow. They can obtain phosphate only from the upper part of the soil.

5.3. HOW TO OBTAIN THE BEST RESULTS FROM PHOSPHOROUS FERTILIZERS

i) Phosphate fertilizer should not be broadcast, nor should water-soluble phosphate be mixed (i.e. harrowed in) with the soil. These practices increase soil contact with the phosphate and when the soil reacts with the phosphate the later is made unavailable.

ii) Placement of phosphorous in strips beside the seed-rows allows more phosphate to reach the crop.

iii) Still more phosphate can reach the crop if the fertilizer is powdered and not granulated.

iv) If a phosphate which is not very water- soluble is applied-- rock phosphate would be one example-- it should be finely ground and mixed well with the soil to increase the phosphate solution.

v) The soil pH should be neither too highly nor too low. A pH of from 5.50 to 7.0 allows the most available phosphate from both organic and inorganic sources (see Chapter 8 on liming). If the soil has a pH above 7.0, applying fertilizer in which more than 50% of the phosphate is water- soluble.

vi) If a farmer applies phosphate fertilizer or manure to his soil every year, the amount of phosphate removed by the crop is less than the amount added, since less than 20% of the applied phosphate may be absorbed by the crop in the year of application. Thus the phosphate accumulates in the soil, and it would be a needless expense to continue its application. Moreover, high concentrations of phosphate may cause the zinc deficiency in the soil. In corn production this could mean a great decrease in yield.

vii) When transportation of fertilizer to a locality is expensive, if possible, use fertilizer that is high in P_2O_5 -- such as triple phosphate.

In acid soils, however, the amount of phosphate left over from the previous year's application may be quite small. With such soils, it is better to apply small but regular amounts of phosphate.

6. POTASSIUM

Potassium is essential to the plant's formation of sugars and starch and to synthesis of its proteins. It also helps in cell division and growth and, in some plants, enhances the size and color of fruits and vegetables. In cereals, it improves their rigidity of straw and stalks, thus reducing lodging.

Although potassium is fairly abundant in most soils, only 1 to 2% is available to the plant. It does not leach away as much as nitrogen, however, nor does it become unavailable to the degree which phosphate does.

As in the cases of nitrogen and phosphorous, the amount of potassium absorbed differs from one crop to another. An average yield of barley and wheat, for example, may use 11kgs/ha. of potash in the grain and 24 kgs/ha. in the straw. Maize grain, on the other hand, contains about 17 kgs, while alfalfa may contain from 112 to 168 kgs., and other legumes 56 to 84 kgs. Potatoes contain 168 kgs. in tubers and 56 kgs. in vines. With annual crops the uptake of potassium increases as the plant grows in size.

Some plants absorb more potassium than they need, a phenomenon known as "luxury" consumption. Soil potassium may be lost by cropping, leaching (in sandy soils) and erosion.

The most common potassium fertilizers are listed in Table 2.9.

TABLE 2.9: POTASSIUM FERTILIZERS

Common Name	Formula	% of K_2O	Application
Muriate of Potash or Potassium Chloride	KCl	60	Applied directly or may be bulk blended with other fertilizers. Highly solvable and water so may be used as liquid fertilizer. Chlorine in muriate reduces stalk rot in maize; but potatoes are sensitive to chlorine.
Potassium Sulfate	K_2SO_4	48 - 50	It is relatively expensive fertilizer. Sulfur content of the fertilizer maybe useful where it is lacking.
Sulfate of Potash Magnesia	$K_2SO_4.MgSO_4$	22 - 23	It is useful where three nutrients -- potassium, magnesium and sulfur are needed.
Potassium Nitrate	KNO_3	46.6	Its application is desirable crops where chlorine is objectionable, e.g. potato crop. It is well-suited for use as liquid fertilizer.

6.1. Soil Conditions And Plant Uptake Of Potassium

Potassium is found in the soil in three different states, according to its availability to the plant:

a) Ready available;
b) Slowly available; and
c) Unavailable (fixed).

a) <u>Readily-available potassium</u>

In ready-available potassium, there are two parts. One part is water- soluble and free to move with the soil water. The second part, exchangeable potassium, is derived from fertilizers, minerals and crop residues. These two parts, the soluble and the exchangeable exist in equilibrium. The latter immediately compensates a reduction of the former, by crop removal or leaching. Similarly, when the soluble potassium is increased by, say, addition of fertilizer, it is rapidly converted to exchangeable potassium, creating a reservoir for later use. The exchangeable potassium ions are retained by the negative charge on the surface of the soil organic matter and certain clay minerals (illite, monto-millonite, vermiculite and kolinite). These ions are held in this way until their release is needed to balance the equilibrium.

Because of the speed with which this equilibrium is effected, the two types of potassium are classed together as "readily- available".

b) Slowly available potassium

Slowly available potassium is held within clay particles. Its release from these particles is dependent upon several factors, chief of which are: i) the moisture content of the soil, and ii) the concentration of exchangeable potassium, ammonium, calcium, and hydrogen.

When soil is wet, the clay particles expand to allow the potassium ions free movement in and out. When the plant root absorbs the ions, other ions lying between the particles are free to replace the absorbed ions.

If the soil is dry, however, the clay particles move close together, preventing movement of the potassium ions. Thus the availability of these ions varies in a direct ratio with the amount of water in the soil.

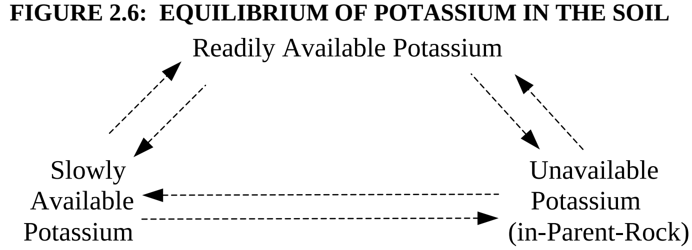
If too much potassium fertilizer is applied, or when the soil has too much hydrogen, ammonium or calcium, the abundance of ions tends to pull the clay particles together. In these conditions, the potassium ions are unable to move to replace the soluble form when necessary, and thus the amount of potassium available to the crop is limited.

c) <u>Unavailable potassium</u>

From 90 to 98% of the total soil potassium consists of unweathered rock fragments and is unavailable to the plant.

Figure 2.6 shows the relation and equilibrium of the three types of potassium.

FIGURE 2.6: EQUILIBRIUM OF POTASSIUM IN THE SOIL



6.2. How To Obtain Best Results From Potassium Fertilizer

Farmers should bear in mind three important facts regarding the potassium in the soil:

a) Excess of potassium can ruin the potassium equilibrium described earlier;
b) Some plants tend to absorb more potassium than they need (luxury consumption); and
c) The larger the amount of potassium in the soil, the more readily it leaches out of the soil.

6.3. Guidelines In Applying Potassium Fertilizers

Keeping these points in mind, the farmer can use the following guidelines in applying potassium fertilizers:

a) Apply the fertilizer in narrow bands.

Particularly in developing countries where the farmers' holdings may be small, money for fertilizer is one of the limiting factors to the increase of crop yield. To make use of the limited fertilizer, application in bands is the most viable method.

But there are physical reasons apart from economic ones. To broadcast potassium fertilizer and mix it with the soil increases its contact with the soil, and, as in the case of phosphate fertilizer (see Figure 2.6), this reduces the potassium's availability to the crop.

Band application is especially useful for crops such as alfalfa that need large amounts of potassium. In these cases an adequate supply of potassium should be applied from the seeding stage.

b) Large amounts of potassium should not be applied all at once.

Some soils are low in potassium and naturally require more potassium fertilizer application. But if too much potassium is applied at a single time, the equilibrium is destroyed and the potassium becomes unavailable. Secondly, the over-application of potassium leads to "luxury" consumption on the part of the plant.

A third danger is to be found in the case of certain crops such as tea and oats, which, if they receive too much potassium, are likely to become deficient in magnesium. In crops such as corn, however, there appears to be little danger of this.

In general, if the amount of potassium required by the crop is large the farmer should divide that amount into several applications spaced throughout the growing season.

c) Do not place potassium fertilizer too close to seeds or to young plants.

When potassium fertilizers dissolve in water, they form potassium salts, which are toxic to germinating seeds and young plants. For this reason, the fertilizer should be placed about 2 inches to the side and 1 in. below the seed or plant. Otherwise, yield may be reduced. (See section on Fertilizer Placement).

At this juncture, as we have concluded our discussions of the three principal nutrients--nitrogen, phosphorous, and potassium-- an important point should be mentioned regarding the effect upon the latter nutrient by the former two, according to their relative mixture in the soil. The usual effects of nitrogen and phosphorus are related to the nutrient balance in the plant. If the supply of these two nutrients is high relative to that of potassium, growth may be rapid in the early stages, but the amount of potassium in the plant may be reduced to a deficiency level later. Even though the high levels of phosphorous may increase the potassium uptake by the plant and nitrogen, extra potassium would have to be added to maintain the balance needed for rapid and continued growth.

On the other hand, a high potassium level combined with low nitrogen or phosphorous supply would result in "luxury" consumption of potassium.

7. ANIMAL MANURE

Thus far in the chapter we have discussed, among other things, the various types of manufactured fertilizers and the essential nutrients used in these fertilizers. Let us turn now to another important and readily available nutrient source: animal manure.

For farmers with small holdings and little cash to spend on modern fertilizers, animal manure provides a good and inexpensive source of the essential nutrients.

The concentration of essential nutrients in animal manure depends not only upon the type of animal, but upon the nature of the animal feed and even the type of bedding used for the animal. (If the animal is bedded on a cement floor, for example, the urine runs off; whereas if straw is provided, the urine adheres to the straw and can mix with the solid excrement). The amount of manure produced per year by different animals, and the proportion of nitrogen, phosphate, potassium oxide and calcium oxide contained by the manure, are shown in Table 2.10.

TABLE 2.10: AVERAGE YEARLY AMOUNT AND COMPOSITION OF SOLID AND LIQUID EXCREMENT OF MATURE ANIMALS (Kgs./Yr.)

	Yearly Production Per Animal/kg/yr.		Nitrogen		Phosphoric Acid		Potash		Lime	
Animal	*Solid*	*Liquid*	*Solid*	*Liquid*	*Solid*	*Liquid*	*Solid*	*Liquid*	*Solid*	*Liquid*
Cattle	860 9.3	3311.3	27.5	31.4	18.1	1.0	13.8	13.5	29.3	0.3
Hogs	993.4	579.5	6.0	1.7	4.6	0.7	4.4	5.8	0.1	--
Horse	5877.5	1324.5	30.6	15.9	17.6	---	14.1	19.9	8.8	6.0
Sheep	413.9	248.3	2.7	4.8	2.0	0.1	1.0	5.2	1.9	0.4
Hens	16.6	--	0.2	--	0.1	--	0.6	--	--	--

The average farm manure in damp condition is usually given the formula 0.5-0.25-0.5, representing, respectively, the percentages of nitrogen, phosphate and potassium oxide (potash).

When manure is spread daily as it is produced, all the phosphate and potassium are returned to the soil, although three-fourths of the nitrogen is lost to the air. The longer the manure is stored, the greater the loss of nutrients. Even when it has been stored only three months, it may lose 50 % of its nitrogen, 25 % of its phosphate and 25% of its potassium.

Generally, and particularly in the case of the small farmer, manure must be stored until there is enough of it to warrant the effort of spreading it. To achieve best results, the stored manure should be ploughed into the soil as soon after spreading as possible. Otherwise, the remaining on the soil surface will lose most of its nutrients.

In addition to providing the essential nutrients, manure is an important source of secondary and micro-nutrients. These vary in their levels from animal to animal and also depend on such factors as feed and bedding. A sample break-down 1,000 kgs. of manure is shown in Table 2.11.

TABLE 2.11: RANGE OF NUTRIENTS (in kgs.) AND 1000 kgs. OF MANURE

SECONDARY NUTRIENTS	Kgs. per 1,000 kgs. of manure
Calcium	1. 088- 33.566
Magnesium	0.726 - 2.631
Sulfur	0.454 - 2.812
MICRO- NUTRIENTS	
Boron	0.009 - 0.054
Copper	0.005 - 0.014
Iron	0.036 - 0.422
Molybdenum	0.001 - 0.005
Manganese	0.005 - 0.082
Zinc	0.014 - 0.082

Apart from its principal function of supplying the crop with needed nutrients, manure fulfills important secondary functions. It improves the physical character of the soil by:

i) Increasing its capacity to hold water;

ii) Stimulating the biological activities of organisms which thrive on animal residue, thus increasing the availability of nutrients; and

iii) Improving the properties of too heavy or too light of a soil by increasing the humus content.

The application of manure can, in some cases, mean a yield to 50% greater than that obtained without manure or fertilizer. In some cases, the yield obtained by manure application compares favorably with that obtained by applying fertilizer. The yields of four crops under the application of a manure or fertilizer, or without the benefit of either, are compared in Table 2.12.

TABLE 2. 12: RESPONSE OF CROP YIELDS TO FERTILIZER AND MANURE IN KENYA
(Yields In Kgs. /Ha)

Crop	No Fertilizer No Manure	*Only* Fertilizer Every Year	*Only* Farm Yard Manure 6,000 kgs /Ha.
Cassava	6,307.8	1,023 0	9,540.2
Maize	583.7	970 3	87 4.9
Sorghum	1,058.2	1,929.4	1,64 9.5
Sweet potato	2,585.9	5,119 .1	5,432. 9

If the farmer compares the price of manure to that of fertilizer-- which is higher than ever, he may find that a greater net income can be obtained from his crop by using manure.

8. HOW TO DETERMINE THE AMOUNT AND COMPONENTS OF FERTILIZER TO BE APPLIED

Earlier in this chapter, compound (or mixed) as well as straight (or simple) fertilizers were discussed. Now, with some practical knowledge of soil needs behind us, we must learn how to be sure that the fertilizer we are applying contains the proportion of nutrients required by the particular soil in question, and also whether the amount of fertilizer is suited to the soil needs.

The amount of fertilizer to be applied depends upon how much of each nutrient is needed by the crop and which fertilizer grades are available in the location.

Let us suppose that the field- trials for a particular crop have been conducted and that it has been found that the farmer must apply 54 kgs of nitrogen, 40 kgs of phosphate, and 20 kgs of potassium per hectare, to ensure a good yield.

Let us also suppose that the fertilizers available in the area are:

i) Sodium nitrate, which contains 16% nitrogen;
ii) Triple phosphate, which contains 46 % phosphate; and
iii) Sulfate of potash, which contains 50 % potash.

By using the formula below we can calculate the amounts of the above nutrients which the farmer must apply:

$$\textbf{Amount of the nutrient to be applied} = \frac{\textbf{Nutrients required in the soil kg. /ha}}{\textbf{Percentage of nutrient present in the material}} \times 100$$

Thus, the amount of each nutrient which the farmer must apply, per hectare, is:

Sodium nitrate = (54/16) x 100 = 337.5 kgs.
Triple phosphate = (40/46) x 100 = 87.0 kgs.
Sulfate of potash = (20/50) x 100 = 40.0 kgs.

The above figures must now be adapted to the size of the particular farm in question. If, for example, the farmer has a holding of 0.85 hectares, then the amount of each nutrient which he must apply becomes:

Sodium sulfate = 33 7.5 x 0.85 = 286.87 kgs.
Triple phosphate = 8 6.0 x 0.85 = 73.1 kgs.
Sulfate of potash = 40.0x 0.85 = 34.0 kgs.

In some cases, the farmer may be able to locate and purchase the exact fertilizer or mixture which he requires or a close approximation of it. But in many cases the farmer will have to create, out of the available primary fertilizers, the particular formula which his crop and soil demand.

If the farmer needs a fertilizer of grade **10 - 5 - 7** i.e. 100 kgs. of fertilizer containing 10 kgs. of nitrogen, 5 kgs of phosphate and 7 kgs. potash; and if the basic materials available are as follows:

Ammonium chloride (24% nitrogen),
Single superphosphate (18% phosphate), and
Sulfate of potash (50% potassium).

(The reader may want to review the use and significance of fertilizer " grades", on the earlier pages of this chapter.). Then the amount of the three primary fertilizers, which a farmer must include in his mixture to obtain the above formula, can be calculated in the following way:

$$\frac{\textbf{Nutrient grade in the fertilizer formula}}{\textbf{\% of nutrient in the primary fertilizer}} \textbf{ x 100} = \textbf{kgs. of fertilizer}$$

The reader can see from the above the equation and that on page 42 are essentially the same; the equations was first used to determine fix to weights of nutrients needed by the soil; now, however, we are using it to obtain the combination required by the grade **10 - 5 - 7**.

The mixture which corresponds to the grade **10 - 5 - 7**, then, contains the following amount of the three nutrients:

Nitrogen = (10/24) x 100 = 41.7 kgs. of ammonium chloride
Phosphate = (5/18) x 100 = 27.8 kgs. of single superphosphate
Potash = (7/50) x 100 = 14.0 kgs. of sulfate of potash.
Total = 83.5 kgs.

The total weight of the three primary fertilizers comes to 83.5 kgs. Theoretically, this amount, applied uniformly, would provide the farmer's soil with the nutrients it requires. It may happen, however, that the amount of land demands 100 kgs. of fertilizer, if it is to be spread uniformly. In such a case, the farmer need only to add the balance (100 - 83.5 =) 16.5 kgs of sand -- a substance of little nutrient value --, to bring the weight up to 100 kgs. so that the fertilizer may extend evenly over the entire land area.

If a particular fertilizer grade (say 10-10-10) is available in the locality, and the farmer needs to apply equal amounts (say, 75 kgs.) of each nutrient, then the matter is simplified. The farmer must apply (75 x 100 =) 750 kgs. of that **10 - 10 – 10** fertilizer grade. Similarly, if the grade is 5- 5 - 5, and the amount needed is still 75 kgs. of each nutrient, the quality applied must be [(75/ 5) x 100 =]1,500 kgs/ha.

Very likely, however, the fertilizers available will not contain nutrients in uniform levels, but will have an uneven representation such as 10 - 6 - 10. In this case, 750 kgs. of the fertilizer mixture will provide the needed 75 kgs. of nitrogen and of potash, but only 45 kgs. of phosphate. In order to supply the missing 30 kgs. (75 - 45 = 30) of phosphate, the farmer must mix the 750 kgs. of fertilizer mixture with another fertilizer containing only phosphate. If, for example, single superphosphate (18% P_20_5) were available, the farmer could add [(30/18) x 100 =] 166.67 kgs / ha. of single superphosphate.

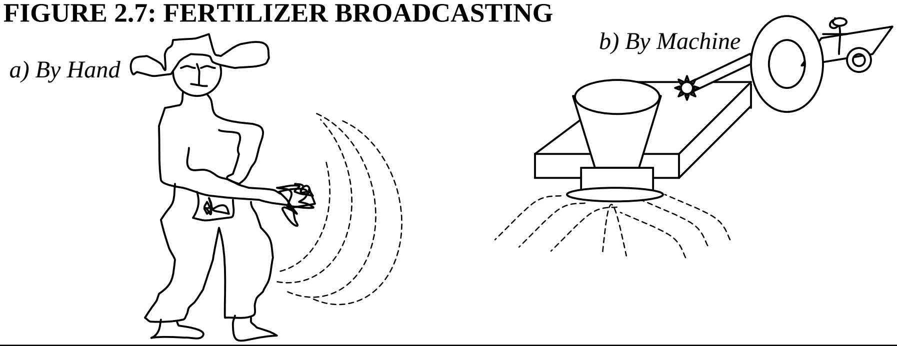
By mixing the fertilizers in this way, the farmer could obtain all the nutrients required. Special instructions and calculations as to mixing have been given earlier in this chapter.

9. METHODS OF FERTILIZER APPLICATION

9.1. Broadcasting

Broadcasting, which has been mentioned throughout this chapter, is a uniform application of the fertilizer over the surface of the land. It is done before the planting of the crop and may be done by hand or by machine. The fertilizer maybe left on the surface, placed just below the soil disking or moved deeper into the soil by plowing.

FIGURE 2.7: FERTILIZER BROADCASTING



a) Under the right circumstances, broadcasting offers several ***advantages***:

i) If the farmer wishes to apply potassium and phosphate only once during the cropping season then broadcasting is the best method. It makes the two nutrients available throughout the season (which for certain crops is better) rather than during just a particular stage of growth.

ii) In some soils, the ploughed-down nutrients are dissolved in the soil moisture, permitting the plant roots to absorb them quickly.

iii) In alkaline soils, the plowing-down of fertilizers with urea or ammonia reduces the loss of gaseous ammonia.

iv) Broadcasting without plowing-down is beneficial on very wet soils. To absorb nutrients, plants need to breathe: the roots on the surface have a good air supply and can better absorb the broadcast nutrients.

b) Equally worthy of mention are the ***disadvantages*** of broadcasting:

i) Cost of fertilizer is an important consideration, particularly to a poor farmer with a small holding. With broadcasting, some of the fertilizer may never come in contact with the plant roots, but be lost by leaching or erosion; or it may encourage the growth of weeds.

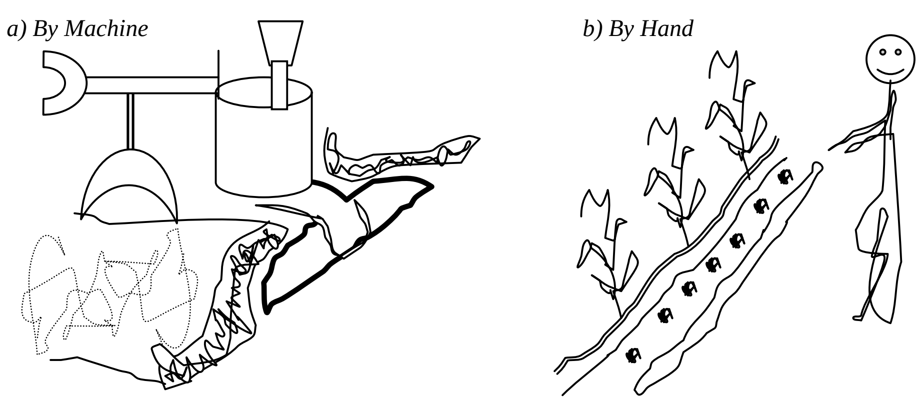
ii) Broadcasting maximizes the contact between the fertilizer and the soil, a situation particularly uneconomical in the case of nutrients such as soluble phosphate. On mixing with the soil, soluble phosphate becomes fixed and thus unavailable to the plant. On very acidic or alkaline soils, many of the micro-nutrients may also become unavailable.

Some of these disadvantages can be overcome by the use of another method of fertilizer application, row or band placement.

9.2. Row or band placement

In row or band placement, the fertilizer is applied at or before the time the seed is planted. The fertilizer is placed in bands under the surface of the soil, to the side and usually below the seed. This method is show in figure 2.8.

FIGURE 2.8: BAND APPLICATION OF FERTILIZER

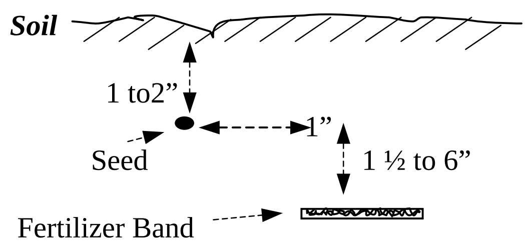


Band application usually requires special equipment, but, if the farmer does not have it, he can simply make a small trench with a hoe beside the plant row and place his fertilizer within it. Where crops are sown by hand and planted in ridges, a pinch of fertilizer may be dropped in a planting hole, under or beside the seed, and covered with soil.

Band application is particularly suitable where a crop needs a plentiful supply of potassium from their earliest stage. One such crop is alfalfa.

Care should be taken to make sure that the fertilizer does not damage the seed, reducing the yield. For beans, cotton, soybean and peanuts, the fertilizer band should be placed from 1 1/2 to 6 inches away from the seed, as in Figure 2.10.

FIGURE 2.10: **PLACEMENT OF FERTILIZER BANDS FOR SOYBEANS AND PEANUTS.**



a) There are several obvious ***advantages*** to the band application method:

i) Sowing and fertilizing can be done simultaneously, saving time and money for the farmer.

ii) No fertilizer is wasted; all of it is within easy reach of the seed. In the case of small grains, for example, only half as much phosphorus as that applied in the broadcast method would need to be applied in bands. (Banding will not give good yields, however, if the overall phosphate level of the soil is very low).

iii) The nearness of the fertilizer to the plant makes the latter grow more quickly. Thus, band placement is often referred to as "starter fertilization".

b) ***Disadvantage*** of band placement:

If care is not taken, improper fertilizer placement may cause damage to the seed. Fertilizers in the soil dissolve in soil water, forming a salt solution. Since the seed has very little salt concentration, and the salt solution outside is higher, the water from the seed is drawn outward to balance the salt solution. Thus the seed wilts and dries, or, depending upon the salt concentration, dies.

Such plant damage or loss, however, can be avoided by proper placement and by proper fertilizer selection. If the high level of a particular nutrient is required, for example, the farmer should use the fertilizer which has the highest grade (most concentration) of that nutrient. By reducing the bulk of the fertilizer near the seed, the chance of salt injury is also reduced. Thus, if 10.0 kgs. /ha of potassium is needed, one could apply either sulfate of potash (21% ***KO***) or muriate of potash (60% ***KO***). With the former (sulfate of potash), 47.61 kgs. would have to be applied, but, with the later (muriate of potash) , only 16.6 kgs. Thus, muriate of potash, by virtue of its concentration, would stand less of a chance of injuring the seed.

Certain nutrients demand special care. Ammonia, for example, is very caustic and must be kept at a distance from the seed.

9.3. Topdressing

The broadcasting of fertilizer after the crop has been planted is called topdressing, and is usually done for grains, cotton, forage and sugarcane. Generally, top dressing is used only for nitrogen fertilizers, since nitrates have the property of moving downward through the soil and must be available in sufficiently large qualities at all the crucial periods of plant growth. Phosphorous and potassium should not be top-dressed, since they are most needed in the plant's early stages and so should be applied at or before sowing time. Also, phosphorus and potassium cannot move down into the soil as nitrogen can.

9.4. Side dressing

Side dressing refers to the placing of fertilizer beside the plant after growth has already begun. This method is used for row crops, such as maize, vines or tree crops. The fertilizer is applied close to or between the rows or around the plants or trees. Except in the cases of trees and other perennial crops, side dressing should not be done with phosphate and potassium fertilizers.

SUMMARY

In this chapter we looked at how do the analysis of fertilizers. We studied the macro-nutrients, such as nitrogen, potassium and phosphate, that plants need in large quantities for proper grow. We also looked at micro-nutrients that plants needs in small amounts to remain healthy and provide maximum yields. We also studied different methods of applying fertilizer – broadcasting, row or band placement, topdressing and side-dressing and we also looked at the advantages and disadvantages of different methods of applying fertilizer.

Chapter 3:

DETERMINING FERTILIZER NEEDS

1. INTRODUCTION

Having now understood the factors affecting crop yield and the important role which fertilizers play, we are faced with the question: How can we accurately select the right type and quantity of fertilizer required by a particular crop and soil?

In a developing country, a credit agency which is responsible for recommending fertilizer to a small farmer or group of farmers, must know two factors:

i) What nutrients are needed in the soil?
ii) How much of each nutrient should be applied to maximize the farmer's profit?

The farmer's yield and profit depend upon the knowledge of these two factors. It is equally important that the credit agency know them, because the higher the farmer's profit the more easily and quickly he can repay his loan and interest. With consistent accuracy in its fertilizer recommendations, the agency's rate of loan recuperation will greatly improve.

It is the credit agency's responsibility to know the farmer's soil well enough that it does not recommend superfluous or unneeded fertilizer nutrients. In Guatemala, for example, the Institute of Agricultural Science and Technology (ICTA) found that in most of the southern part of the country there is no staple crop response to applied potassium. This is probably due to the high percentage of potassium-rich volcanic dust in the soil. Thus for any farmer, and, even more, for any credit agency to recommend a fertilizer containing potassium would be highly irresponsible. Yet this is what was being done by many organizations until better information was available.

The financial factor must always be kept in mind, particularly in developing countries. The cost of fertilizer may constitute up to 25 percent of the farmer's total cost in producing his crop and an even higher portion of his cash cost. If he borrows money to apply fertilizer, he may pay from 10 to 40 percent interest per annum on his credit. (Intermediaries or middlemen have been known to charge up to 100 percent interest on their loans.) If the cost of the fertilizer, its application and the loan interest form 30 percent of the farmer's total production cost, then he must obtain at least 30 percent more gross profit than before, if he is to break even.

If the farmer fails to reap the extra profit required to cover his investment, he may remain perpetually in debt to the agency. The fault lies with the agency itself. Among the possible reasons for failure are the following:

i) The farmer may have applied a more expensive type of fertilizer when a cheaper one would have been equally productive.

ii) The farmer may have applied large amounts of fertilizer when a small amount would have sufficed.
iii) The fertilizer may have been unbalanced, causing lodging, disease susceptibility or late maturing of the crop.
iv) The time of application may not have been right.
v) The seeds may not have had the genetic potential necessary to respond to the fertilizer.

Although it would seem obvious that the fertilizer applied must result in a profit at least great enough to recover fertilizers cost, yet it is surprising how frequently this point is ignored. The Food and Agricultural Organization of the United Nations (FAO) found, through research in the central region of the Dominican Republic, that the cassava plant in that locality does not respond positively to fertilizer until the third harvest. Knowing this, presumably, no credit agency which professes to improve the lot of the poor farmer would recommend that he borrow money to apply fertilizer to his cassava crop during the first two years that he cultivates it. Yet this is precisely what has been done. After the harvest season, the farmer is then expected to repay his loan with interest to the agency. Since such a return cannot come out of nonexistent profits, it must come from the farmer's own savings, if he has any, thus leaving him poorer than before.

A little knowledge is a dangerous thing. To believe that fertilizer is equal to higher profit, and to leave it at that, without examining soil and crop requirements, can, as in the above cases, be disastrous.

A third example is the case of Paraguay. Because Paraguay is a land-locked country, fertilizer, which has to be transported over long distances by land, is prohibitively expensive for staple crops such as corn. This, however, does not keep the credit agencies from recommending fertilizer to poor farmers year after year, pushing them further and further into debt.

Fortunately, fertilizer recommendations need not be so haphazard. There are four ways by which the nutrient needs of a crop can be determined:

i) Look for hunger signs (deficiency symptoms) on the plants.
ii) Perform plant tests (whole plant-tests and tissue-tests).
iii) Obtain soil samples and perform soil tests.
iv) Conduct fertilizer field trails.

The first two measures are not as effective as are the latter two in determining precisely which nutrients are lacking and how much should be applied. The former two, although not without value, are best used to confirm the results of the soil tests and the fertilizer field trials.

The farmer may request credit before or after sowing the crop. If the crop has already been sown, then the credit agent can determine the nutrient needs only by crop hunger signs and plant and tissue-testing. Soil sampling may also be done, but the presence of the crop reduces the chance of obtaining an unbiased sample. If the agency decides to recommend fertilizer solely on the basis of plant-tests and hunger signs, then it must do so immediately so that the crops have time to respond to the nutrients. If, however, the agency feels that too much plant growth has already occurred or that the testing was inadequate, it can recommend fertilizer the following year and still use the results of the plant-tests and hunger sign analysis.

If the farmer has not yet sown his crop and is interested in obtaining credit over a period of several years, the farmer and credit agent should set up fertilizer field trials (discussed in chapter 4). After the first yield, the results of the trials can be analyzed and accurate recommendations can be made for the following year.

Even after the nutrient need has been determined, however, field trials and soil tests should be conducted at periodic intervals. The soil changes; fertilizer nutrients may accumulate, others may become exhausted and still others may be leached. Plant-testing and hunger-sign analysis can be done every year, since they are inexpensive and quickly conducted.

Let us now examine each of the four testing methods individually.

2. ANALYZING PLANT HUNGER-SIGNS

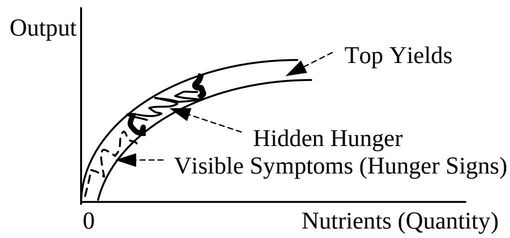
The role of hunger-signs can best be understood if we consider the parallel with human beings. A child who is well-fed on a balanced diet looks healthy and is capable of a lot of exercise. Another child may look just as healthy but tires quickly with exercise; after a doctor's examination, we find that his diet had not been balanced and that, perhaps, a certain vitamin is lacking. This child has "hidden" hunger, not detectable in outward signs.

Another child whose diet is far out of balance, or who simply doesn't eat enough, may not have to be taken to a clinic for analysis. He will be thin or weak or have bad bone structure; it will be obvious that his diet is inadequate or imbalanced. This latter child shows hunger signs.

A similar situation exists with plants. Some look healthy and give good yields; others look healthy and give less yield (these have hidden hunger); still others not only give low yields but look small, pale or discolored. The latter plants show symptoms of nutrient hunger.

These phenomena are graphically represented in Figure 3.1.

FIG. 3.1: HUNGER SIGNS AND HIDDEN HUNGER



Depending upon the degree of nutrient hunger, any of the following may occur to a crop:

i) The young plant dies before it has had a chance to bear fruit: total crop failure.
ii) The plants become stunted, and very little yield is obtained.
iii) The leaves show specific symptoms during the growing season; yields are low.
iv) Plants show no symptoms, but yields are still low.
v) Plants show no symptoms and yields are good. (Only fertilizer field trials, in this case, can tell us what crop needs are.)

In the fourth and fifth cases, there are no hunger symptoms; we must use other methods of testing to discover crop and soil needs. In the first three cases, however, there are hunger signs from which we can judge what nutrients are lacking in the soil. The symptoms may be general or specific. For example, lack of nitrogen and sulphur make the entire plant yellow or pale green (this is often called general chlorosis), while deficiency of iron shows itself only in the younger parts of the plant - the young leaf blades turn white or light yellow, but the veins may be normal.

There are several reasons why hunger signs are not always easy to interpret, however:

i) Some deficiencies are not manifested visibly.
ii) The plant may be deficient in more than one nutrient, the symptoms of one deficiency hiding those of another.
iii) Hunger signs may appear and disappear as the weather changes. In dry weather, soil moisture is reduced, restricting nutrient availability and plant ability to absorb nutrients. In drought conditions, the damage to plants, such as wheat, corn, and sorghum, may be mistaken for nitrogen deficiency.
iv) Hunger signs may be confused with disease or insect damage. Some insects suck juices from plants, reducing plant growth. Toxins of other insects deform plants and produce

symptoms resembling those of mineral deficiency. Some viruses affect leaf patterns in such a way that the results may be confused with symptoms of mineral deficiency.

v) In poorly drained soils, the nutrients may be present but the plants are unable to absorb them. Iron deficiency, in particular, can be caused by poor drainage.

vi) In very acidic or alkaline soils, nutrients may be present but the plants are unable to take them up.

It is obvious, then, in many cases, one should not depend too heavily on hunger-sign analysis. It is always better to include soil testing and fertilizer field trials as means of determining more accurately the nutrient needs of the soil.

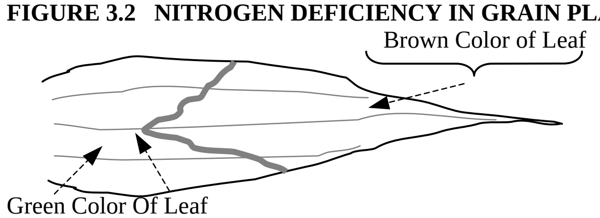
Not only do hunger signs differ from crop to crop, but every nutrient shows a different hunger sign in a single crop. As an example of the latter, let us look at hunger-signs in grains:

a) HUNGER SIGNS IN GRAIN CROPS

i) Nitrogen Deficiency

Nitrogen deficiency results in small unhealthy plants and low yields. Leaves are small, pale or yellowish green. Lower leaves may turn brown and form a V-shaped pattern in the mid-leaf, with the margins remaining green (see Figure 3.2). Or the whole leaf may turn brown and die prematurely. The latter symptom should not be confused with lack of moisture; if the problem were lack of moisture, all of the leaves, and not just the lower ones, would die.

FIGURE 3.2 NITROGEN DEFICIENCY IN GRAIN PLANTS



Treatment: Use side-dressing of fertilizers containing nitrogen.

ii) Phosphorous Deficiency

Symptoms:

(a) Stunted growth, in mild cases
(b) In severe cases, leaves turn pale green and purplish (especially in maize and sorghum not in wheat and rice), or bronzed toward the edges
(c) Plants ripen slowly, remain green, sometimes spindly
(d) Grain is poorly filled; in maize, cob may be misshaped
(e) Low yields

Treatment: Use sidedressing of phosphate fertilizers.

iii) Potassium Deficiency

Symptoms:

(a) In mild deficiency, the plant is stunted and the internodes become small (see Figure 3.3).
(b) In severe deficiency, the outer edges of the leaves (particularly the lower leaves) turn yellow or brown and die. (Figure 3.4)
(c) Stems are weakened and the plants tend to lodge (i.e., fall over).
(d) Yields are small. In corn, the cob may be small and pointed.

Treatment: Sidedress with potassium fertilizer.

FIG. 3.3: MILD POTASSIUM DEFICIENCY

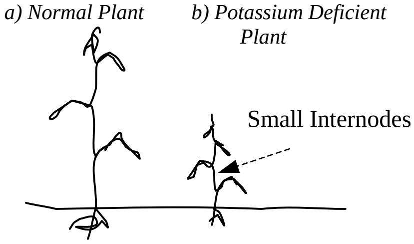
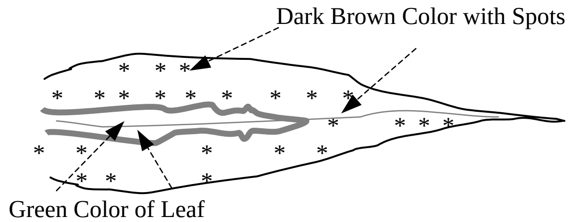


FIG. 3.4: SEVERE POTASSIUM DEFICIENCY



iv) Sulfur Deficiency

Symptoms:

(a) Poor plant growth
(b) Appearance of nitrogen deficiency, with the difference that the entire plant is yellow
(c) All leaves, both old and young, turn yellow
(d) Crop is slow to mature

Treatment: Application of sulfur fertilizer or powdered sulfur or ferrous sulfate.

v) Magnesium Deficiency

Symptoms:

(a) Stunted growth
(b) Leaves turn light green or pale yellow, leaf veins remain green
(c) With continued deficiency, leaves take on yellowish-white stripes

Treatment: On acidic soils, broadcast dolomitic limestone; on basic soils, spray solution containing Epsom salts (magnesium sulfate).

FIGURE 3.5: MAGNESIUM DEFICIENCY

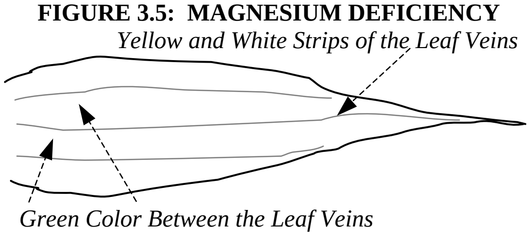
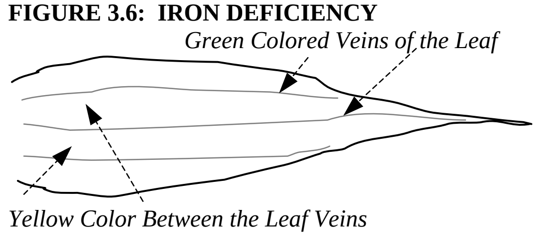


FIGURE 3.6: IRON DEFICIENCY



vi) Iron Deficiency

Symptoms:

(a) Young leaves turn white or pale yellow
(b) Leaves have yellow-green stripes extending full length (see Figure 3.6)

The symptoms of iron and magnesium deficiency are similar, but they can be distinguished by the fact that, with iron deficiency, the entire leaf is paler in color.

Treatment: Spray a solution containing iron. Several sprayings may be needed if deficiency is severe. Soil application is impractical, because iron in the soil converts to an unavailable form.

vii) Manganese Deficiency

Manganese deficiency is prevalent in small grains.

Symptoms:

(a) First and third leaves have gray specks on their margins.
(b) The base of the leaf shows grayish lesions, turning bright yellow or orange at the edge.
(c) The tip of the leaf remains green even while the base is dead.

Treatment: Spray a solution of water-soluble manganese compound (such as manganese sulfate) on the crop leaves. Periodic sprayings are recommended.

viii) Boron Deficiency

Symptoms:

(a) Growing tips may die
(b) Top leaves turn white and may show irregularly-shaped spots between the leaf veins
(c) Plants have a bushy appearance, because the upper internodes do not elongate
(d) Low seed production

Treatment: Little can be done for the same year in which deficiency has been detected. For the following year, mix boron with the fertilizer.

ix) Zinc Deficiency

Zinc deficiency is particularly prevalent in corn and sorghum.

Symptoms:

(a) New leaves are nearly white.
(b) Older leaves show a broad whitish band starting near the leaf-edge and extending to the mid vein. Leaf edges, mid-vein and tip of the leaf remain green.
(c) Internodes are small.

Treatment: Spray crop with zinc solution, or include zinc in nitrogen sidedressing.

b) THE PLACE OF CROP HUNGER-SIGNS IN THE CREDIT PROGRAMM

If a crop shows any of the symptoms described above as evidence of deficiencies, the first thing that should be determined is whether the soil moisture is adequate. If the deficiency signs are merely due to lack of water, they will disappear with rain or irrigation.

If moisture is adequate, however, and the plants continue to show hunger-signs, then the deficient nutrient should be applied as soon as possible, so that the yield will not be lost or diminished in the same growing season. Although the farmer will not perhaps obtain the best possible yield, the credit agency, by a quick loan for the necessary nutrients, can at least prevent a sizeable loss.

If, of course, the plants are already fairly mature, then even the application of a nutrient treatment may not improve yield. In this case, the only benefit of having interpreted the hunger-signs is to use them as confirmation of soil tests or plant tests later in the year.

3. PLANT TESTING

The second method of determining soil and crop needs is that of plant testing. Since the nutrients absorbed by the plant are present in the plant liquid (sap) and plant dry matter, the amount of each nutrient can be found by certain chemical tests on the plant. If plant-testing shows that a particular nutrient or nutrients is below minimum concentration, then it is very likely that the nutrient or nutrients will increase crop yields.

There are two kinds of plant-testing:

a) Tissue-testing, and
b) Whole plant-testing.

a) Tissue Testing

With the tissue-testing method, either a part of the living plant is cut up and shaken in a liquid which abstracts the nutrients from the tissue, or the sap is squeezed out on a test paper and treated with chemicals. Whether the plant has a high or a low concentration of a particular nutrient is determined by comparing the color produced by the plant sap with that produced previously from an already known concentration.

Tissue tests can confirm the existence of deficiencies previously indicated by hunger signs; and in the absence of hunger signs, can detect "hidden" hunger in the crop. If, however, the tissue tests indicate that the nutrients are present as they should be, and yet the plants show poor growth, then there may be problems other than a lack of nutrients in the soil. Perhaps plowing has been inadequate, or roots have been damaged by worms or nematodes.

Tissue testing has the advantage of being inexpensive, and can be done rapidly on the growing crop. To obtain the most information from the tissue tests, the field extension agent should conduct them every time he visits the farmers of a locality. If, perhaps because of poor roads or lack of transport, he has opportunity to conduct only one test, then he should conduct it at the time when the plants use the nutrients most, that is, between the flowering and the early fruiting (grain-forming) stages.

The time of day at which the tests are conducted is important. To obtain the best results, the testing should be done in the mid-afternoon. If the hour is too early or too late, the nitrogen level will be, respectively, too high or too low in the plant and the test may be inaccurate. Ten or fifteen plants should be randomly selected from various parts of the field, and the results can then be averaged.

Which parts of the plant should be tested? The answer to this question differs from crop to crop, but generally it is best not to use leaves that are either too young or too old. The parts which may be used for different crops are shown in Table 3.1.

TABLE 3.1: PARTS OF PLANTS USED IN TISSUE-TESTING

Crop	Nitrogen	Phosphorous	Potassium
Alfalfa	(Leguminous crop- should have enough N)	Leaf Petioles *	Leaf petioles.
Soybean	(Same as Alfalfa)	Petioles in the upper third of plant.	Petioles.
Wheat, Rice, Barley, Oats	Main stem	Leaf tissue near center of plant.	Leaf tissue near center of plant.
Maize	Leaf midrib or main stem.	Leaf midribs near ear.	Leaf blade tissue near ear.
Potatoes	Leaf petioles	Leaf petioles in lower third of plant.	Leaf petioles.

*** Leaf petiole**: *thin stalk by which a leaf is attached to the stem.*

The part of the plant for tissue-testing also depends upon the stage of growth of the plant in question. Tissue-tests for maize, from young plant to flowering stage, are shown in Table 3.2.

TABLE 3.2: PART OF MAIZE TESTED AT DIFFERING GROWTH STAGES

Stage of Growth	Nutrient to be Tested	Part of Plant to Sample	Minimum Test Needed to avoid Hidden Hunger
Less than 40 cms.	***N***	Midrib of basal leaf	High
	P	Midrib of basal leaf	Medium
	K	Midrib of basal leaf	High
40 cms. to ear formation	***N***	Base of stem	High
	P	Midrib of first mature leaf	Medium
	K	Midrib of first mature leaf	High
Ear formation to full growth	***N***	Base of stem	High
	P	Leaf midribs near ear	Medium
	K	Leaf midrib near ear	Medium

The Use of Tissue-Test Results in the Credit Program

After having conducted the tissue-tests, the field extension officer should send the results to the central office where they can be analyzed carefully. The officer's information should include:

i) any disease that was spotted;

ii) the date the crop was sown;
iii) the type of fertilizer, if any, that was applied, and when; and
iv) what the weather had been like in the preceding few days. The tissue test is far from infallible, and all of the foregoing factors have a bearing on the results.

If the field officer has conducted tissue tests four or five times during the growing season (or only once between the flowering and fruiting stages), and if nutrient deficiencies had been found, then the credit agency can use the test results as shown in Table 3.3 (Tissue tests for maize crop).

TABLE 3.3: TISSUE TESTS FOR MAIZE CROP AND ACTIONS TO BE TAKEN

Growth Stage	Nutrient Deficient	Action the Same Growing Season	Decision Making (D.M) Next Year
i) Less than 40 cms.	N	May extend credit for side-dressing.	
	P, K --------►	Only helpful for next years D.M. --------►	Helps to confirm soil tests results.
ii) 40 cms. to ear formation	N	May extend credit for side-dressing..	
	P, K --------►	Only helpful for next years decision making. ----►	Helps to confirm soil tests results.
iii) After ear formation to maturity	N, P, K --------►	Only helpful for next years decision making. ----►	Only of help in determining next years nutrient needs.

It is important to remember that plant tissue testing should not be used as the only guide for fertilizer recommendations. The tissue tests tell nothing more than how much nutrient the plant had at the time the test was conducted. A plant which shows an adequate nitrogen supply, while it is young, may show nitrogen hunger signs later in its growth. Moreover, test results are influenced by external factors such as the time of day; the level of nitrogen, for example, is higher in the morning than in the afternoon.

In short, the best use of tissue-test results is in conjunction with the results of soil analysis and fertilizer field trials.

b) Whole Plant Testing

In whole plant testing, the entire plant is dried and submitted to chemical tests. This method is superior to that of tissue-testing in that the level of several nutrients can be determined accurately. In developing countries, however, the laboratory equipment needed to carry out the chemical analysis is costly and difficult to obtain. Hopefully, in the near future, such equipment will be common and inexpensive.

In conducting whole plant tests, care should be taken that several plants are selected at random and that the tests be conducted at varying stages of growth. The information sent to the laboratory should include: the amount and type of fertilizer applied, and the time of application; the adequacy of drainage on the land; the degree of soil acidity; and the date on which the crop was sown.

4. SOIL TESTING

Soil testing has the distinct advantage over plant testing and hunger-sign analysis, in that the nutrient needs can be determined before the crop is planted. In this way, the credit agency can estimate (1) how much fertilizer a farmer should apply if he is to obtain a given yield, and, assuming that its funds are limited, (2) to how many farmers the agency will be able to extend credit.

The soil is tested to discover what nutrients it contains and in what quantities they are present. The lower the level of the nutrient indicated by the soil test, the greater the amount of this nutrient that must be applied in the fertilizer.

Even when soil tests indicate a high nutrient level in the soil, a small quantity of fertilizer can be applied as a “starter,” to stimulate the early growth of the plant or to maintain soils high fertility.

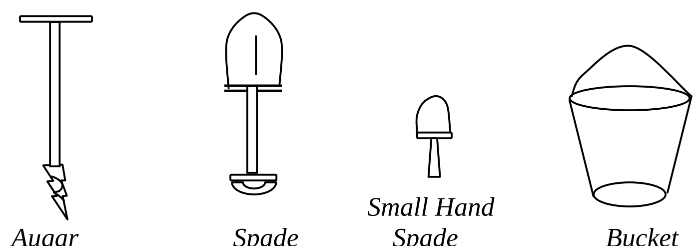
Soil tests are also useful in determining the degree of soil acidity, and in calculating, thereby, the amount of lime which must be applied.

a) How to Take a Soil Sample

The important thing in soil analysis is that soil sample be representative of the field under study. If it is not representative, then the fertilizer recommendation will not be suitable.

The best instrument for taking a soil sample is an augur. In the absence of an augur, a shovel may be used. One should also carry a bucket in which sub-samples may be collected. Sub-samples are the small samples which together make up the final soil sample to be tested in the laboratory. All instruments should be clean before use.

FIGURE 3.7: INSTRUMENTS USED FOR TAKING SOIL SAMPLES

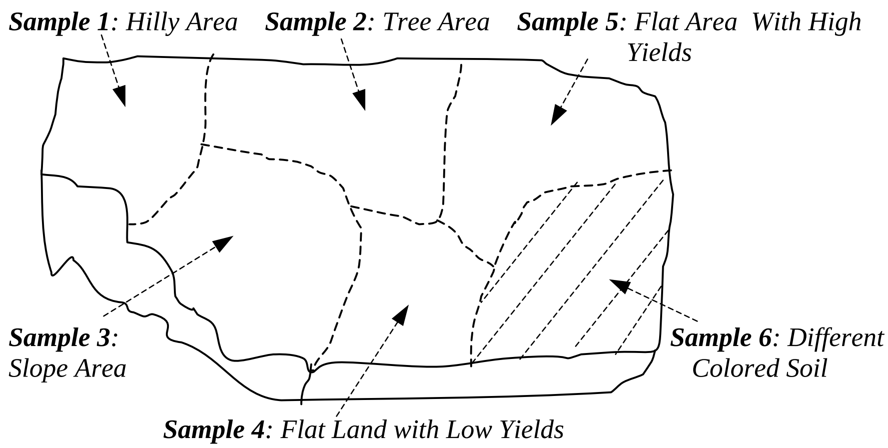


In order to obtain a representative sample, several sub-samples must usually be taken. The land can be divided into several zones on the following bases:

- **i)** Difference in soil color;
- **ii)** Unfertilized and fertilized land;
- **iii)** Land which is flat and land which is hilly;
- **iv)** Irrigated and non-irrigated land;
- **v)** Land with surface drainage and land without;
- **vi)** Differences in crops grown;
- **vii)** Land with high crop yield and land with low crop yield; and
- **viii)** Limed and un-limed land.

The way in which the land can be divided according to the above factors is illustrated in Figure 3.8. Of the eight criteria for division listed above, a farmer may find only two or three, or even none applicable: that is, if his soil is all of the same color, his land is unfertilized and he only grows one crop, then of course he cannot zone according to those criteria. But, even if none of the criteria apply, he should still divide his land in order to obtain a representative sample. An easy rule of the thumb is that a soil sample should never represent a land area greater than hectare. Thus, if the farmer land area is slightly greater than hectare, at least two zones should be made.

FIGURE 3.8: ZONING OF LAND FOR SOIL TESTING

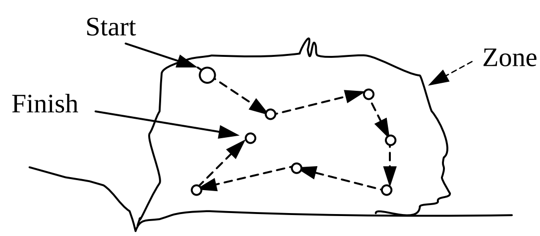


A map, such as the one shown in Figure 3.8, should be made, showing where each soil sample was taken. If different zones of the field show distinct nutrient deficiencies, the farmer can apply his fertilizer accordingly, rather than uniformly over the whole land, thus reducing losses and increasing profits.

Samples should never be taken near homes, canals, trees or roads.

Each sub-sample should be selected from a different area of the zone. The methods of selecting these samples is shown in Figure 3.9.

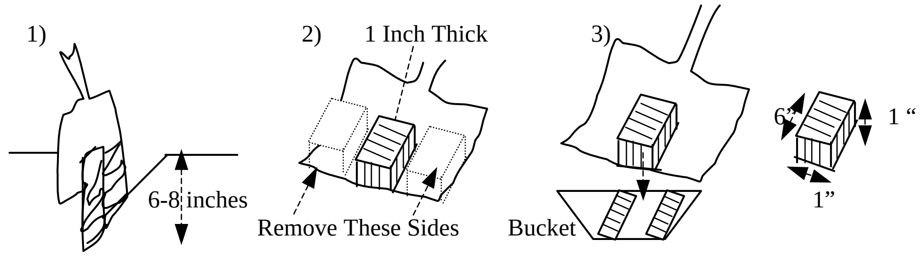
FIG. 3.9: SAMPLING PATTERN IN SEPARATE SOIL ZONES:
Here, one sample represents **8** sub-samples.



Now we are prepared to actually take the sub-sample.

First, remove any vegetation that may lie on the surface of the soil. If an augur is being used, insert it vertically until it penetrates 6 to 8 inches. If a shovel is being used, make a small "v" shaped hole 6 to 8 inches deep. Slide the shovel down the edge of the hole separating a vertical soil layer about 1 inch thick. Out of this layer, cut a strip 1 inch wide strip as the sub-sample. Repeat this operation, in various parts of the zone, at least 8 to 10 times. (See Figure 3.10.)

FIGURE 3.10: HOW TO TAKE A SUB-SAMPLE



If the soil in question is being tested for the first time, it is advisable to take a few samples at a greater depth—12 to 20 inches—to obtain some idea of the nature of the sub-soil. Since the nutrient concentration of the sub-soil is not likely to change for many years, samples from that depth need not be taken every time soil sampling is done. The exception is land where fruit trees or other very deep-rooted crops are grown. In these cases, the sub-soil must be tested every time.

b) Mixing the Sub-Samples

The 8 to 10 sub-samples taken must be mixed together in a clean bucket. The total sample from each zone should weigh at least one pound. Once mixed, put the sample in a clean plastic bag and send it to the laboratory. If the soil sample is wet let it dry before mixing it and placing it in a bag. Each plastic bag should bear the zone number, the name of the farm, village and municipality, to avoid possible confusion.

FIGURE 3.11: MIXING AND LABELING OF SOIL SAMPLES

a) Mixing the Soil Sample *b) Putting the Soil Sample in a Sack* *c) Label the Sample: Mr. Smith's Farm: ZONE 3*

In some countries, there are government-operated laboratories which do soil analysis free of charge or at a nominal cost. Soil samples should be sent to these laboratories at least four weeks before the planting date so that the technicians have sufficient time to complete the analysis, and so that the credit agency can know how much credit it will be able to allocate.

c) <u>Care in Taking the Next Sample</u>

Before moving on to the next soil zone, the bucket and the augur or shovel should be completely cleaned.

d) <u>Related Information to be Sent to the Laboratory</u>

In the interest of obtaining a precise understanding of the nature of the soil, the following information should be gathered and sent to the laboratory:

- **i)** Internal Drainage: good, average, or bad?
- **ii)** Surface drainage: good, average, or bad?
- **iii)** Is the land irrigated or not?
- **iv)** From what canal or river does the farmer obtain water?
- **v)** What crop, and what variety of that crop, does the farmer intend to sow?
- **vi)** What diseases, if any, have affected the crops previously?
- **vii)** Soil tests should be constructed at least once every two years.
- **viii)** What is the history of the field zones over the past three years?

(This information may be set forth as shown in Table 3.4. If different field zones have different crops, then separate histories should be made.)

TABLE 3.4: HISTORY OF A FIELD ZONE OVER THE PAST THREE YEARS.

Year	*Crop Sown*	*Fertilizer Applied*	*Lime Applied*	*Output/Ha*
First	- - - - - - - - -	Date ……..	Date ……..	
		Type …………	Type …………	
		Quantity……..	Quantity……..	
Two Years Ago	- - - - - - - - -	Date ……..	Date ……..	
		Type …………	Type …………	
		Quantity……..	Quantity……..	
Three Years Ago	- - - - - - - - -	Date ……..	Date ……..	
		Type …………	Type …………	
		Quantity……..	Quantity……..	

e) The Place of Soil Test Results in a Credit Program

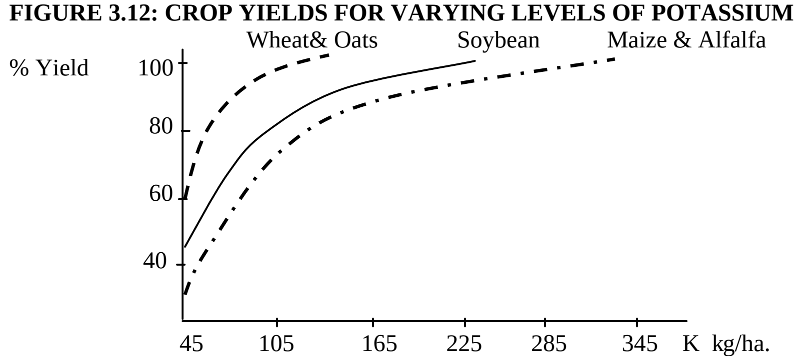
If all soil samples in a given test indicate the same nutrient levels, deficient or otherwise, then the job of the extension officer is easy: he can recommend a fertilizer which will supply the needed nutrients over the entire land area. Complications arise, however, when the samples indicate varying nutrient levels. If only a few samples show a high or low level, they may be ignored; but if low, medium and high levels appear in a regular pattern, then the farmer should be asked to apply fertilizer accordingly, and not to apply it uniformly over his whole land area. This may seem like a lot of work, but in developing countries farmers have only limited funds to spend on fertilizer. If the farmer applies a nutrient only to that zone of the land which demands it, he is not wasting his money on applying it to land which will give him no greater yield. Only if the zone which needs no nutrient is very small, the agency may wish to ignore the difference and suggest that the farmer apply the fertilizer uniformly.

If low, medium, and high test levels are interspersed all over the land, and if the agency, for one reason or another, wishes to use fertilizer of one particular grade, then the decision as to how much credit to extend depends on the amount of funds at the agency's disposal. If funds are limited, the agency should extend credit up to only the low nutrient level; if funds are plentiful, credit can be extended for fertilizer application somewhat above that level.

Where liming is concerned, the soil differences in zones as indicated by the sample must be more carefully regarded. If more lime is applied than necessary to a particular area, the soil may be damaged and crop yields obtained in the future would be lower.

In developed nations, the experimental stations and agricultural colleges have graphs which show how the yield of a crop increases with increasing rates of nutrients. In developing countries, however, such graphs may not be available, particularly in localities where the only agricultural "authorities" operating are credit agencies, usually nonprofit institutions which are not always highly informed. In such situations, the agency must collect yield data for varying levels of nutrients so that it can have a basis on which to judge how much fertilizer a farmer must apply to obtain a given yield. This collected data may be put in the form of graphs such as the following, developed in the United States and showing crop responses to potassium.

FIGURE 3.12: CROP YIELDS FOR VARYING LEVELS OF POTASSIUM



Once the credit agency has developed yield curves like those shown above, the extension agent can explain to the farmer just how much yield he is likely to obtain with and without a particular fertilizer.

Soil testing, although somewhat more effective than hunger-sign analysis and plant testing, has definite limitations. There are only two nutrients, albeit very important ones—phosphorous and potassium---- the availability of which the soil test can determine with high accuracy. Soil tests are also good for evaluating liming requirements. But, as we can see in Figure 3.13, the reliability of soil tests in detecting the other nutrients is not particularly good.

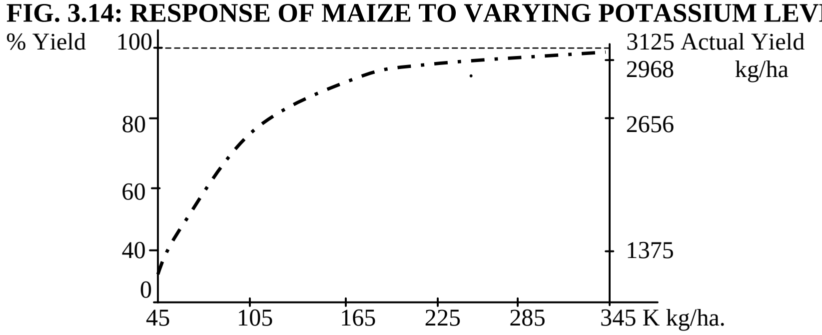
FIG. 3.13: RELIABILITY OF SOIL TESTS IN SHOWING NUTRIENT AVAILABILITY

Test	Good	Fair	Poor	None
Phosphorous	*			
Potassium	*			
Calcium		*		
Zinc		*		
Magnesium			*	
Copper			*	
Nitrogen			*	
Iron				*
Manganese				*
Molybdenum				*
Sulfur				*
Lime Requirement	*			

f) Economic Analysis of Soil Tests

In spite of its shortcomings, the economic importance of soil analysis is plain to see. Suppose that there are three farmers, each with different levels of potassium on his land--- farm A with a low level (say 45 parts per million -ppm), farm B with a medium level (145 ppm) and farm C with a high level (345 ppm). All the three farmers want to grow maize. We will assume the soils of all three are adequately supplied in other nutrients; and if we knew from previous findings that the response of maize to increasing levels of potassium is shown in Figure 3.14.

FIG. 3.14: RESPONSE OF MAIZE TO VARYING POTASSIUM LEVELS



Let us assume that

- **i)** The price of maize is $3.00 per kg
- **ii)** The price of potassium is $20.00 per kg
- **iii)** The interest on loan required by the agency is 10% per year.

Now let us assume three different cases:

- **i)** None of the farmers apply fertilizer.
- **ii)** The extension agent, having heard that potassium increases yields, suggests, without having conducted soil tests, that each farmer apply 100 kg/ha. of potassium. Such recommendations, without regard for soil differences, are very common in the developing countries.
- **iii)** Soil tests are conducted and each farmer applies the level of potassium suggested by the agronomists on the basis of the test results.

The figures on the following page indicate the yields and profit each farmer in each of the three cases will experience.

FIGURE 3.15:

CASE: 1

Net Profits Without Fertilizer Applications

	Farm A	**Farm B**	**Farm C**
Original Level of K	(With K=45 kg/ha)	(With K=145 kg/ha)	(With K=245 kg/ha)
Yields	1,375 kg/ha	2,656 kg/ha	2,968 kg/ha
Profit Price of Crop = $3.0 kg	x $ 3.0	x $ 3.0	x $ 3.0
Net Profit ($)	**$ 4,125/ ha**	**$ 7,968 / ha**	**$ 8,904 / ha**

CASE: 2

Net Profits With Fertilizer Applications But Recommendations made ***without*** Soil Tests

	Farm A	**Farm B**	**Farm C**
Original Level of K	(With K=45 kg/ha)	(With K=145 kg/ha)	(With K=245 kg/ha)
Original Yields	1,375 kg / ha	2,656 kg / ha	2,968 kg / ha
All farmers asked to apply 100/kg/ha of K costing $2,000 in Total			
New ***K*** Level	145 kg/ha	245 kg/ha	345 kg/ha
Yields Obtained	2,656 kg/ha	2,968 kg/ha	3,031 kg/ha
Total Profit Price of Crop =$3.0 kg	$ 7,968/ha	$ 8,904/ha	$ 9,093/ha
Minus cost of Fertilizer $2,000	$ -2, 000	$ -2, 000	$ -2, 000
Minus Interest on Loan = $ 200	$ -200	$ -200	$ -200
Net Profit ($)	**$ 5,768/ha**	**$6,704 /ha**	**$ 6893/ha**

CASE: 3

Net Profits With Fertilizer Recommendations made ***after*** Soil Tests

	Farm A	**Farm B**	**Farm C**
Original Level of K	(With K=45 Kg/ha)	(With K=145 Kg/ha)	(With K=245 Kg/ha)
Original Yields	1,375 kg/ha	2,656 kg/ha	2,968 kg/ha
Soil Tests Conducted			
New K Level	100kg/ha	10 kg/ha	NONE
Yields Obtained	2,656 kg/ha	2,750 kg/ha	2, 968 kg/ha
Total Profit Price of Crop =$3.0 kg	$ 7,968/ha	$ 8,904/ha	$ 9,093/ha
Minus cost of Fertilizer $2,000	$ -2, 000	$ -200	$ 00.00
Minus Interest $ 200 on Loan	$ -200	$ -20	$ 00.00
Net Profit ($)	**$ 5,768/ha**	**$8,030 /ha**	**$ 8,904/ha**

Table 3.5: Comparison of the results of Net Profits ($ /ha)

a) Case 1 with Case 2

	Farm A	**Farm B**	**Farm C**	**Total Net Profit**
Gross Income of Farmers Without Applying Fertilizer	$ 4,125	$7,968	$ 8,904	$20,997
Gross Income of Farmers when Fertilizer Applied *without* soil tests	$ 5,768	$6,704	$6,893	$19,365
% Improvement in Income	+ 39.8	-15.9	-22.6	-7.8

b) Case 1 with Case 3: Comparison of the results of Net Profits ($ /ha)

	Farm A	Farm B	Farm C	**Total Net Profit**
Gross Income of Farmers Without Applying Fertilizer	$ 4,125	$7,968	$ 8,904	$20,997
Gross Income of Farmers when Fertilizer Applied *after* soil tests	$ 5,768	$8,030	$ 8,904	$22,702
% Improvement in Income	**+39.8**	**+0.8**	**- - -**	**+8.1**

What happened when potassium was applied without soil analysis? Hence, when comparing Case 1 with Case 2, Farmer A, out of pure luck, increased his yield by 39.8 percent because his soil was poor in potassium to begin with. Farmer B, however, had his income reduced by 15.9 percent, while farmer C had his income reduced by 22.6 percent. Such results, in a poor country, can mean that a family will go without proper clothing and food. If the total income of the three farmers is considered, there is a reduction of 7.8 percent. The credit agency spent $6,000 only to make poor farmers poorer still.

The case is hypothetical but too often true.

When soil analysis was conducted, (comparing Case 1 with Case 3) farmer A still had 39.8 percent increase in income, farmer B increased his income by 0.8 percent and farmer C had no need to apply fertilizer and so lost nothing through unnecessary spending, $2,000 on fertilizer. The agency in this case increased the net income of the three farmers by more than 8 percent. The other $3,800 (only $200 was lent to farmer B and nothing to farmer C), the money that was not lost through careless spending, could be lent to other farmers to similarly improve their income.

SUMMARY

In this chapter we have examined three of the ways in which a credit agency can determine the nutrient needs of a crop on a particular soil. The three methods--- hunger-sign analysis, plant testing, and soil testing---- have each their merits and demerits. But none of them can compare with actual growing of the crop and observing its response to nutrients. The latter method is called field-trials. The significance and the setting up of fertilizer field-trials forms the subject of the following chapter.

Chapter 4

FERTILIZER FIELD TRIALS

INTRODUCTION

The conducting of a fertilizer field trial consists of 1) the application of varying amounts of fertilizer nutrients to small sections of the field, and 2) the measurement and comparison of the resulting yields.

1. THE BENEFITS OF FERTILIZER FIELD TRIALS

There is no more accurate way of knowing what crop response will be to a given fertilizer on a particular soil, than by actually trying out that fertilizer. The results of such trials give us precise economic data on the rates and combination of nutrients, which will bring the farmer the best returns from his limited funds.

Such accurate knowledge is equally beneficial to the credit agency, which can improve its lending program by calculating the range of fertilizer rates it can give in various financial situations. These calculations will enable the agency to better utilize its extension agents, to improve its loan recuperation, and to increase food production for the country as a whole.

Moreover, the fertilizer field trials enhance the credibility of the agency in the eyes of the farmers, who, once they see their yields increasing, will be much more willing to adopt other agricultural techniques suggested by the extension agents.

2. INFORMATION PRIOR TO SETTING UP FERTILIZER FIELD TRIALS

In the beginning of the farmer-agent relationship, i.e. in the absence of an already-developed confidence between agency and farmer, it is suggested that the farmer's existing techniques (spacing, seed variety, etc.) be respected. Later on, with the success of past fertilizer field trials, it will be necessary to research which crop varieties are best suited to the micro-climate where the trials are being conducted, what is the best sowing rate, at what depth should the seed be sown and other related information. In the first year, however, since nothing is being changed but the fertilizer, the credit agent need gather only the following information:

a) Are there any pre-existing fertilizer recommendations for this particular crop? If so, what are they?

b) What recommendations exist as to timing of fertilizer application? Should, for example, all of the fertilizer be applied at the sowing time, or all at the flowering time? Or should half be applied at sowing and the other half at flowering?

c) Are the crop varieties which the farmer is presently using susceptible to any disease?

3. CHOICE OF FERTILIZER TREATMENTS

In developing countries, the crops grown by farmers with smallholdings can be divided into three categories:

a) Grain crops --- e.g., rice, maize and wheat;
b) Tubers --- e.g., potatoes and cassava; and
c) Leguminous crops --- e.g., beans and alfalfa.

The procedure of setting up fertilizer field trials for these categories is basically the same, except that leguminous crops require higher levels of potassium and phosphorous than do grain crops, and tubers require higher levels of all three primary nutrients.

Since, of the three categories, grains are most generally grown, only field trials for grain crops will be discussed in this book.

When setting up field trials in developing countries, there are limitations to the number of treatments which can be done. Even though the greatest number of treatments possible would give the best results and provide the best base for fertilizer recommendations, yet (1) the farmer's holdings are small and, until he can actually see the benefit of the treatments, he will probably prefer to devote most of his land to cultivation by traditional practices; and (2) if the treatments are too numerous they will be difficult for the extension agent to set up. Finally, of course, (3) since the minimum size of a trial plot is 5 by 10 meters, there is a physical limitation as to how many treatments can be conducted.

4. FERTILIZER TREATMENT IN THE ABSENCE OF OFFICIAL RECOMMENDATIONS

When conducting fertilizer field trials for grain crops, a total of nine field plots should be set apart. The first of these will be fertilized in accordance with the farmer's present practice (if it happens that the farmer is using fertilizer at all).

On the second plot no nutrients at all should be applied. This plot, called the "control treatment," will be important for purposes of comparison later on.

The next four plots should be fertilized only with nitrogen, in varying amounts, as follows:

Plot 1, 10 kgs. N/ha.;
Plot 2, 20 kgs. N/ha.;
Plot 3, 30 kgs. N/ha.; and
Plot 4, 40. kgs. N/ha.

The remaining three plots should be used to test the crop response to phosphate and potassium: the first plot of these three should be treated with 20 kgs./ha. each of nitrogen and phosphate; the second with the same amounts of nitrogen and potassium; and the third with 20 kgs./ha. of each of the three nutrients, nitrogen, phosphate and potassium.

The mixing of the nutrients in uniform quantities of 20 kgs./ha. each will facilitate later analysis. Should there be a difference in yield between one plot and another, it will be obvious to which nutrient's absence or presence the difference is due. The credit agency may, of course, wish to try higher levels of nutrients than those given here, but it should always observe the systematic increment of the nutrients from one treatment to the next.

In all, then, there are nine plots, as shown in Table 4.1. The digit below the nutrient symbol indicates the fertilizer levels that need be applied, in kgs./ha.

TABLE 4.1: FERTILIZER TREATMENTS IN THE ABSENCE OF OFFICIAL RECOMMENDATIONS

Treatment No.	N	P	K
1	Farmer's Practice		
2	0	0	0
3	10	0	0
4	20	0	0
5	30	0	0
6	40	0	0
7	20	20	0
8	20	0	20
9	20	20	20

(This table does not represent an inflexible method. If, for example, the soil sample were to indicate that phosphate is lacking, then 10 kgs. /ha. of phosphate could be added to treatments 2 through 6.)

5. FERTILIZER TREATMENTS WHERE THERE ARE OFFICIAL RECOMMENDATIONS

In some countries, the ministry of agriculture may make recommendations for a particular crop. Although these recommendations are usually of a very general nature, the credit agency can benefit from them by modifying its field trials accordingly. If, for example, the officially recommended fertilizer contained 90 kgs./ha. of nitrogen, 45 kgs./ha. of phosphate and 70 kgs./ha. of potassium, then we could design our trials around the figure 90, just as, on page 5, we previously designed our trials around the figure 20. Thus, following the recommended levels, our treatments could look like Table 4.2.

TABLE 4.2 FERTILIZER TREATMENTS BASED ON OFFICIAL RECOMMENDATIONS

Treatment No	N	P	K
1	Farmers Practice		
2	0	0	0
3	30	0	0
4	60	0	0
5	90	0	0
6	120	0	0
7	90	45	70
8	90	0	70
9	90	45	0
10	0	45	70

By designing the trials in this way, we are taking advantage of guide-lines given us by the government; and, as in Table 4.2. above, should a difference in yields arise, we will be able to attribute that difference easily to the presence or absence of one or another nutrient. Naturally, should the agronomist have other information than that given by the government, provided his information is sound, he may substitute the nutrient levels he thinks best.

6. REPEATING THE FERTILIZER TRIALS

If the field trials are conducted only once, we can never be certain whether the yields obtained were due to the treatment or not. As we learned in Chapter 1, there are many other factors, which influence crop yields. To remove as much doubt as possible, the same treatments should be repeated several times in different areas of the farmland. Since all the treatments will be subjected to, among other things, the same weather, all doubt regarding the effect of the nutrients cannot of course be removed. Also because farms in developing countries are small, the space for field trials is limited. Still, it is recommended that the trials be repeated at least three to four times; from the results, we can better determine statistically if the yields obtained from a particular treatment were due to that treatment or to chance.

Thus, three or four must multiply the number of treatments in any experiment. In the examples given above, the total number of plots required would be 3 x 10 = 30 or 4 x10 = 40.

7. TRIAL PLOT SIZE

Since the holdings of the farmers are small, so the areas of the trial plots must be small also. They must not be so small, however, that their size prevents accurately measurable yields. A larger plot will give yields more representative of the yields we would obtain if we were to use that treatment on the entire farm. More accurate conclusions can be drawn from the results of such a plot. Thus it is recommended that the minimum plot size be 10 meters by 5 meters, wherever possible.

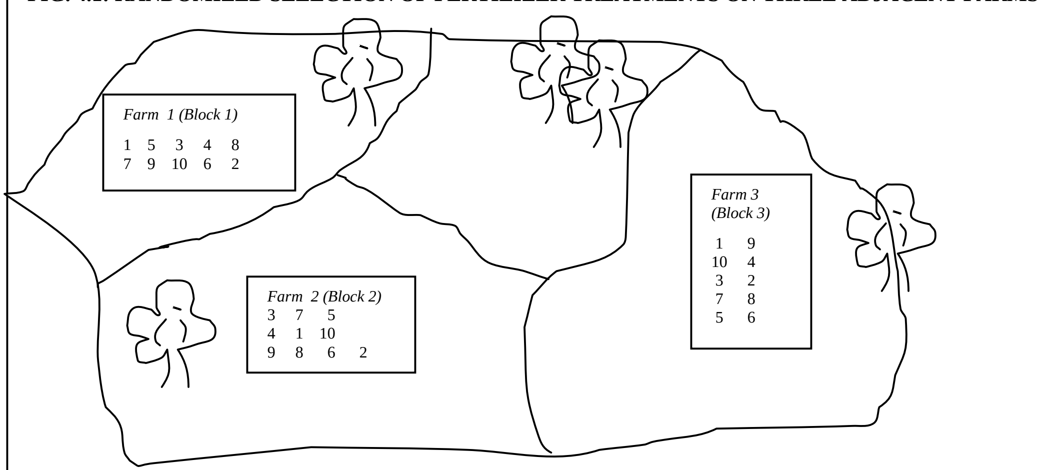
For row crops, the width of the plot should be adjusted to fit the exact number of crop rows. Thus, a crop with rows spaced one meter apart would require a plot of five meters in width; and a crop with rows spaced 0.8 meters apart would need a plot (0.8 x 7) = 5.6 meters or (0.8 x 6 =) 4.8 meters wide. Plot width should be adjusted so that at least four or five rows can be grown.

8. SELECTION OF FARMS FOR FIELD TRIALS

In many cases, farmers who have adjacent holdings with similar soils will grow the same crops. In such a situation, the field trial may be spread over several farms. However if it is necessary a complete set of 10 treatments should be conducted on each farm. If there are farmers with adjacent holdings, then all 30 treatments can be done without using too much of one farmers land.

Once the farmers have been selected, then the plots and treatments should be matched at random, and not systematically. Numbering the treatments on ten pieces of paper can do this. Put the slips of paper in a bag, mix them, and then draw them out one by one. The treatment written on the first paper will be assigned to plot number one, the second to plot number two and so on. The entire set of treatments is referred to as the experimental block. The settings up of fertilizer

FIG. 4.1: RANDOMIZED SELECTION OF FERTILIZER TREATMENTS ON THREE ADJACENT FARMS



trials with ten treatments on adjacent farms are shown in Figure 4.1.

When setting up the field trials, care should be taken to:

- i) Not use fields or parts of the field which have different soils; and
- ii) Make sure that the plots are not near houses or their buildings or pathways or are over shadowed by trees.

9. AMOUNT OF FERTILIZER TO APPLY PER PLOT

The amount of fertilizer to be applied to a plot depends upon:

- **i)** The level of nutrient (kg./ha.) required by the treatment,

ii) The fertilizer grades available in the country, and
iii) The size of the plot.

The amount of fertilizer needed can be calculated by using the following formula:

$$\frac{\textbf{Nutrient rate per Ha. x Area of plot}}{\textbf{Area of hectare}} \times \frac{\textbf{1}}{\textbf{Nutrient value of fertilizer}} = \textbf{Amount to be applied.}$$

a) Using Basic Fertilizer Nutrients

Let us use this formula in an example. Suppose the credit agency has only three basic materials available to them:

i) Sulfate of ammonia, with 21 percent nitrogen (**N**).
ii) Single Superphosphate, with 18 percent phosphate ($\mathbf{P_20_5}$).
iii) Muriate of potash, with 60 percent potassium ($\mathbf{K_20}$).

In order to calculate the amount of each of the above materials needed per experimental plot, we must consult Table 4.1 to find out how much of each nutrient is needed per hectare. Since repeating the entire table would mean needless repetition of calculations, let us select three treatments by which we can determine the requirements for each nutrients:

TABLE 4.3: THREE FIELD TRIAL TREATMENTS (2, 8 AND 10) FROM TABLE 4.1.

Treatment NO.	N	P	K
2	10	0	0
8	20	0	20
9	20	20	20

With these treatments, all three basic nutrients are represented.

i) Fertilizer Calculations for Treatment 2

The amount of nutrient to be applied per Ha. = **10 kgs**.
The area of the plot is, say, **50 m**$^{\mathbf{2}}$.
The area of a hectare is **10,000 m**$^{\mathbf{2}}$.
The nutrient value of ammonium sulfate (21% ***N***) is **0.21**.
Using the formula on Table 2.1 of chapter 2, to find the amount of ammonium sulfate needed to apply per plot (to obtain the nutrient level of 10 kgs./ha.) we find:

$$\text{Amount of fertilizer to be applied to the plot} = \frac{\text{Amount of Nutrient to be applied (kgs. / Ha.) x Plot size}}{\text{Area of Hectare}} \times \frac{1}{\text{Nutrient value of the Fertilizer}}$$

$$\frac{10 \times 50}{10{,}000} \times \frac{1}{0.21} = 0.238 \text{ kgs. of ammonium sulfate}$$

Thus, 0.238 kgs. of ammonium sulfate needs to be applied for treatment 2.

ii) Fertilizer Calculations for Treatment 8

This treatment requires 20 kgs. /ha of nitrogen and 20 kgs. /ha of $\boldsymbol{K_20}$.
The area of the plot is 50m^2.
The area of a hectare is 10,000m^2
The amount of sulphate of ammonia (21% ***N***) needed would be:

$$\frac{20 \times 50}{10{,}000} \times \frac{1}{0.21} = 0.238 \text{ kgs. per plot ammonium sulfate}$$

Now, for potassium. The nutrient value of muriate of potash is 60% or 0.6. Since the amount needed is 20 kgs. /ha., then:

$$\frac{20 \times 50}{10{,}000} \times \frac{1}{0.6} = 0.17 \text{ kgs. per plot of muriate of potash must be applied.}$$

iii) Fertilizer Calculations for Treatment 9

Treatment 9 requires the equivalent of 20 kgs. /ha. of ***N,*** 20 kgs./ha. of ***K*** and 20 kgs. /ha. of $P_2 0_5$.

Again, the area of the plot is 50 m^2 and that of the hectare is 10,000 m^2.

Since calculations for sulphate of ammonia and muriate of potash have already been performed in treatments 2 and 8 above, we need only determine the amount of single superphoshate (18 % $P_2 0_5$) to be applied. Thus,

$$\frac{20 \times 50}{10{,}000} \times \frac{1}{0.18} = 0.55 \text{ kgs. per plot of simple superphospate should be applied.}$$

In all, then, for treatment 10, 0.5 kgs of sulphate of ammonia, 0.6 kgs. of muriate of potash and 0.55 kgs. of simple superphoshate should be mixed and applied to fulfill the requirements of 20-20-20 kgs. per hectare of the three nutrients.

Once the fertilizers for all treatments have been calculated, mixed and weighed, they should be bagged, labeled and placed in a storage unit where they can be found easily and without mistake at the time they are needed.

b) Using Mixed Fertilizers

In some countries the primary nutrients may not be available. The fertilizers available may contain two or more nutrients. If such a situation should prevail, then we cannot apply only one nutrient, as we would like: we would have to apply the other nutrient(s) as well, that is contained in the mixed fertilizer. In such a case, we have to modify the choice of treatments that we can use in the trials. If, say, the mixed fertilizers available are: one containing nitrogen and phosphate (say 20-20-0) and the second one containing nitrogen and potassium (say, 15-0-15) then the choice of the treatments would be as shown in Table 4.4. There same treatments would have to be used in any trial containing two nutrients. For treatments 7, 8 and 9 (those containing 3 nutrients) the fertilizer should be contained so that the nutrient levels approximate to the central treatments of nitrogen.

TABLE 4.4: TREATMENT SELECTIONS WHEN ONLY MIXED FERTILIZERS ARE AVAILABLE OR TESTING OF 2 NUTRIENTS IN THE TRIALS.

Treatment No.	N	P	K
1	Farmers Practice		
2	0	0	0
3	10	10	0
4	20	20	0
5	30	30	0
6	40	40	0
7	20	0	20
8	25	10	15
9	30	20	10

The procedure for calculating the nutrient levels of each treatment of mixed fertilizers is identical to that of calculating the nutrients levels for primary fertilizers. For example, in treatments 2 (containing 10-10-0), the amount of 20-20-0 fertilizer needed to be applied (on 50m ^{2} plot) would be:

$$\frac{10 \times 50}{10{,}000} \times \frac{1}{0.20} = 0.25 \text{ kgs. per plot of fertilizer.}$$

For treatment **7**, (containing 20- 0- 20) the amount of 15-0-15, fertilizer that we would need to apply would be

$$\frac{20 \times 50}{10{,}000} \times \frac{1}{0.15} = 0.66 \text{ kgs. per plot of fertilizer.}$$

When calculating the fertilizer needed for treatment with three nutrients, it is advisable to calculate first for a nutrient that is contained in only one fertilizer. For instance, phosphate is present in only 20-20-0, and potassium is present in only 15-0-15.
Nitrogen however is present in both the fertilizers. In the interest of easier calculations, in this care, one should start with either potassium or phosphate.

For Treatment **8** (containing 20-10-15) the amount of fertilizer, 15-0-15, needed to apply the required 15 kgs/ha. of the nutrient would be:

$$\frac{15 \times 50}{10{,}000} \times \frac{1}{0.15} = 0.50 \text{ kgs. per plot}$$

0.5 kgs/ plot of 15-0-15 fertilizer would also provide the 15 kgs. /ha. of nitrogen.

To apply the remaining 10 kg of nitrogen and 10 kgs of phosphate needed to complete the treatment **8**, we would need

$$\frac{10 \times 50}{10{,}000} \times \frac{1}{0.20} = 0.25 \text{ kgs. per plot of fertilizer containing 20-20-0.}$$

Hence, for treatment **8**, we would need a total of 0.5 kgs. per plot of the fertilizer 15-0-15 and 0.25 kgs. of the fertilizer 20-20-0 per plot.

By following the above procedure, we avoid unnecessary calculations. Had we started our calculations with nitrogen, and not with phosphate or potassium, our progress would have been much more problematic. Our first calculations would have been:

$$\frac{12.5 \times 50}{10{,}000} \times \frac{1}{0.20} = 0.313 \text{ kgs. per plot of fertilizer containing 20-20-0.}$$

We can immediately see that 0.313 kgs./plot of 20-20-0 will also provide 12.5 kgs./ha. of phosphate which is 2.5 kgs./ha. more than we need in the treatment. Similarly, if we try to obtain 12.5 kgs. of the remaining nitrogen from the fertilizer 15-0-15, we would obtain only 12.5 kgs. /ha. of potassium, rather that the 15 kgs./ha. demanded by the treatment.

To avoid such imbroglios, we suggest that the agronomist start the calculations with the fertilizer which contains a nutrient not present in the other fertilizers.

c) Setting of Fertilizer Trials with 3 Nutrients

A credit agency may wish to determine what level of a 3 nutrient fertilizer that will prove most economical. In this case, as in the pervious cases, the trials will be set up with increasing levels of fertilizer. If, for instance, the fertilizer which the credit agency wishes to test is 60-20-40 then the treatments may be as follows:

TABLE 4.5: TRIAL TREATMENTS FOR TESTING FERTILIZER CONTAINING THREE NUTRIENTS.

Treatment No.	N	P	K
1	Farmer's Practice		
2	0	0	0
3	10	3.3	6.6
4	20	6.6	13.2
5	30	9.9	19.8
6	40	13.2	26.4
7	50	16.5	33.0
8	60	20.0	40.0
9	70	23.1	46.2

The formula needed for calculating the fertilizer is the same as used earlier.

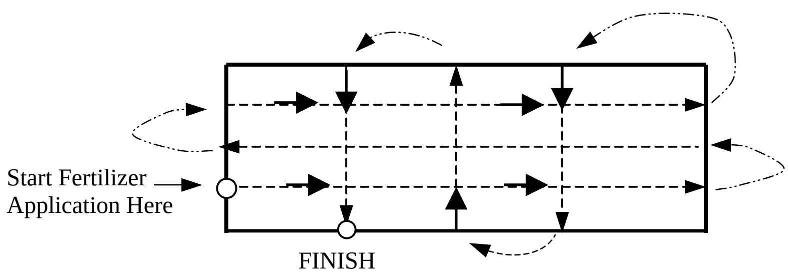
10. APPLYING FERTILIZER TO SMALL PLOTS

Since both the experimental plots and the amounts of fertilizer used are quite small, extra care must be taken to ensure uniform distribution of the fertilizer. By putting some dry soil in a bucket, adding the weighed fertilizer mixture, and mixing the two very thoroughly, the volume of the matter to be spread is increased, making uniform distribution more likely.

a) Broadcasting Method

The broadcasting method of fertilizer application was explained in Chapter 2. Systematic broadcasting for a small plot is best done following the procedure shown in Figure 4.2.

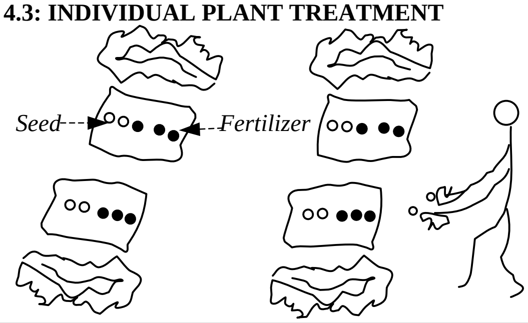
FIGURE 4.2: BROADCASTING FERTILIZERS ON A SMALL PLOT



b) Individual Plant Treatment

For crops which are grown in rows, such as maize and groundnuts, individual plant treatment should be practiced. Small amounts of fertilizer should be dropped in the holes of furrows at a slight distance from, and at the same time as the seed. To ensure uniform distribution, small pinches of fertilizer can be dropped first, so that there will be enough to go around; with the remaining fertilizer, a second round can be made until it is all gone. Then both fertilizer and seed should be covered with soil. See Figure 4.3 .

FIG. 4.3: INDIVIDUAL PLANT TREATMENT



11. AMOUNT OF SEED TO APPLY PER PLOT

Since in the first year, the fertilizer trials would usually be conducted according to the existing agricultural practice of the farmer; the amount of seed need not be calculated. The amount the farmer has sown before should be acceptable. In the following years, however, if a new variety is going to be introduced, then that variety may have a different planting density. In this case, the amounts of seed needed for each plot can be calculated in the same way by which those amounts of fertilizer nutrients were calculated:

$$\text{Kgs. of seed needed per plot} = \frac{\text{Kgs. of seed recommended per Ha.} \times \text{Area of plot}}{10{,}000\ m^2\ \text{(Area of Ha.)}}$$

With seed, as with fertilizer, care should be taken to distribute uniformly.

12. HARVESTING THE FIELD TRIAL CROP

The crop of each plot should be harvested separately, placed in a bag, labeled immediately according to plot and block number, and weighed. If the bags are of a heavy material, they should be weighed both with and without the crop inside so that the weight of the bags can be subtracted and the true yield recorded.

Mark the weight of the yields for each plot of the field trial, as shown in Table 4.6.

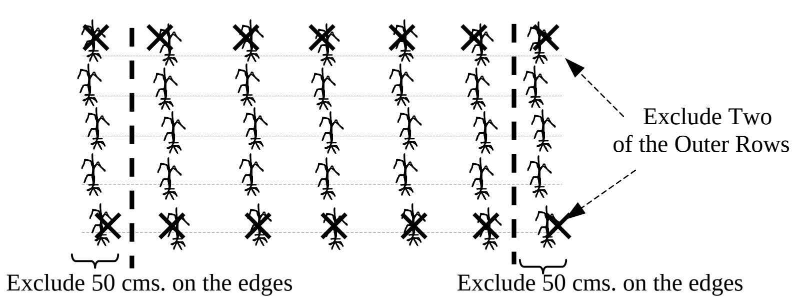
TABLE 4.6: FIELD TRIAL (SAMPLE YIELDS OF THIRTY EXPERIMENTAL PLOTS)

	Treatment Number (kgs./plot)									
	1	2	3	4	5	6	7	8	9	10
Block 1										
Block 2										
Block 3										

To prevent incorrect or biased yield results, **do not include** the yields of the outer margins of the plot. For row crops, **do not include** the yields of the outside rows nor of the last 50 cms at the end of each plot in the weighing. These plants on the perimeter of the plot are exposed to conditions whether favorable or unfavorable, which the plants within the plot do not experience and therefore, are not representative of the plot as a whole. Figure 4.4 shows the crops that should be excluded from weighing.

For broadcast crops do not include 50 cm^2 from each side. If any plot is damaged by cows or other animals note of that plot must be made.

FIGURE 4.4: PLANTS EXCLUDED IN HARVESTING ROW CROP TRIALS



13. ADDITIONAL INFORMATION NEEDED FOR FIELD TRIAL ANALYSIS

Analysis of the fertilizer trials requires the knowledge of other data besides the crop yield per plot, the plot size and, the fertilizer levels. Among these data are:

i) Seeding rate.
ii) Date of sowing.
iii) Dates of weeding, spraying and harvesting.
iv) Incidence of rainfall.

In order to better analyze the above information, it should be arranged in the manner shown in the Appendix. One member of the farming community should be equipped with a small calendar on which to mark dates, and assigned with the task of filling in the information as the field-trial operations are carried out.

Chapter 5

STATISTICAL ANALYSIS OF FERTILIZER FIELD TRIALS

1. INTRODUCTION
2. ANALYSIS OF VARIANCE
3. "t" TESTS
4. MINIMUM AND MAXIMUM YIELDS EXPECTED

1. INTRODUCTION

With our knowledge of fertilizers and how nutrient levels can be determined, let us see how we can use this information to determine more precisely the levels of fertilizer that would give the best profits.

Let us assume that in a remote area, 6 farmers with smallholdings were approached by the extension agent who had been helping the farmers in the neighboring community. They had heard that on the extension agent's advice these farmers had applied some thing called "fertilizer" to their crop and this had helped them obtain higher profits from the same crop than the first farmers did. On talking with the extension agent, these 6 farmers showed great interest in what the agent had to offer and they assured him of their eagerness to work with the agency for several years.

At the time the extension agent met these farmers they had already harvested their crops. There was no possibility of observing any hunger signs on crops or of conducting plant tissue testing. The farmers agreed to have their soils tested and in the coming sowing season agreed to set up the fertilizer field trials. The land of these farmers was fairly uniform in appearance, and they all wished to grow the same crop---- maize. Three of the farmers, having slightly larger holdings than the others, volunteered to use part of their land for setting up the fertilizer trial blocks.

The soil test showed that there was sufficient phosphate and potassium in the soil, but nitrogen seemed to be lacking. The extension agent from experience knew that in that locality, maize was capable of responding well to moderate levels of nitrogen. On this basis, the extension agent selected the choice of treatments mentioned below, in Table 5.1 (Digits below the nutrient symbol represents the nutrient levels at kgs. /Ha.)

Table 5.1

Treatment No.	N	P	K	
1	0	0	0	**(Control and farm's practice)**
2	10	0	0	
3	20	0	0	
4	30	0	0	
5	40	0	0	
6	50	0	0	
7	20	20	0	
8	20	0	20	
9	20	20	20	

Once the fertilizer field trials had been completed, the field extension agent submitted the results with additional information on seeding rates, dates of weeding and harvesting, and incidence of rainfall to the main office for statistical and economic analysis. (Chapter 6 will be devoted to economic analysis; in the present chapter we will examine only the stages involved in performing statistical analysis.)

The purpose of statistical analysis is to determine whether the average yield from a particular fertilizer was a direct effect of that treatment or an accidental occurrence.

The field trials conducted by the extension agent had nine treatments, and the trials were repeated three times, giving a total of (9 x 3 =) 27 plots. The results were as follows:

TABLE 5.2: CROP YIELD FROM THE FERTILIZER TRIALS (gms./PLOT)									
	Treatment No.								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Block No:	Control	10N	20N	30N	40N	50N	20N, 20P	20N, 20K	20N, 20P, 20K
1.	67.00	120.25	213.10	240.50	289.00	314.00	230.00	215.50	222.00
2.	81.35	110.25	208.90	255.74	281.85	320.90	224.15	220.80	228.85
3.	82.65	104.00	224.50	256.75	269.15	308.60	223.85	216.20	232.65

Our first step is to convert the above experimental plot yields into yields per hectare. This procedure is as follows:

$$\frac{\text{Yield obtained from the plot}}{\text{Size of the plot}} \text{ X Area of hectare}$$

For example, in the first plot of the first treatment, the plot yield was 67 gms. This yield converted per hectare would be:

$$\frac{67.00}{50} \text{ x } 1000 = 13{,}400 \text{ gms./ha.}$$

As there are 1,000 gms. to one kilo, we would have

$$\frac{13{,}400}{1{,}000} = 13.40 \text{ kgs./ha.}$$

The results of the conversions give the following yields (Table 5.3)

TABLE 5.3 : CROP YIELDS OF THE FERTILIZER FIELD TRIALS CONVERTED TO PER HECTARE (kgs../ha.)									
	Treatment No.								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Block No.	**Control**	**10N**	**20N**	**30N**	**40N**	**50N**	**20N, 20P**	**20N, 20K**	**20N, 20P, 20K**
1	13.40	24.05	42.62	48.10	57.80	62.80	46.00	43.10	44.00
2	16.27	22.05	41.78	51.15	56.37	64.18	44.83	44.16	45.77
3	16.53	20.80	44.90	51.35	53.83	61.72	44.77	43.24	46.13

It does not really matter whether the above calculation is made before or after the statistical and economic analysis: the outcome is the same. If the yields per experimental plot (i.e. before conversion) were used for analysis, the results would have to be converted to per hectare later, for purposes of recommendation. To avoid later work and possible confusion, therefore, we have chosen to perform the conversion at the present stage.

The questions we must ask in our statistical analysis are: Did increasing levels of nitrogen have any significant impact on the increase of crop yields? And, did increasing levels of nutrient combinations (nitrogen and other nutrients) have any significant impact, as compared to nitrogen alone?

In order to answer these questions we must break the treatments into two groups:

a) Treatments 2 to 6 containing only nitrogen, and treatment 1 (control) which contains no nutrients: and

b) Treatments, which contain mixtures of nutrients: treatment 6 with 2N2P (i.e.2 levels of nitrogen and 2 levels of phosphate), treatment 7 with 2N2K, treatment 8 with 2P2K, and treatment 9 with 2N2PK. In this group we must also place treatment 3 (with 2N), even though it contains only one nutrient; it is necessary here for purpose of comparison, just as the control treatment is in group 1.

To both groups we can apply the same procedure for evaluating statistically significant difference in average yields, but the information we need to know from the second group is much more complex than that which we need from the first. In the first group we need to know only whether there was any significant difference in yield in any treatment in that group. If there is such a difference, it can be explained easily by the fact that one treatment had more or less of the one nutrient than the other treatment. In the second group, however, because of the presence of various nutrients, each individual treatment must be compared with every other. Thus, after comparing treatment (3) say, with treatments (6), (7), (8), and (9), we must compare treatment (6) with treatments (7), (8), and (9), then treatment (7) with treatments (8) and (9) and finally treatment (8) with treatment (9).

Table 5.5	**TREATMENT (S)**								
Statistical Testing of Following Treatments	1	2	3	4	5	6			
Statistical Testing of Following Treatments			3			6	7	8	9
Statistical Testing of Following Treatments						6	7	8	9
Statistical Testing of Following Treatments							7	8	9
Statistical Testing of Following Treatments								8	9

Because of the difference in number of nutrients between the two groups, the results of the groups:

(a) would be more easily analyzed by a technique called **Analysis of Variance**, (This technique is used when different levels of the same fertilizer are applied to different plots.) and;

(b) by a procedure known as **"t" tests** (This technique is used when different fertilizers are applied to different plots.) These two procedures are explained below:

2. ANALYSIS OF VARIANCE (ANOVA)

ANOVA, or Analysis of Variance, is a technique which allows us to investigate the differences in the average yields of several treatments simultaneously. The essence of ANOVA lies in the fact that the total amount of variation in a set data can be broken down into two classes, that amount which can be attributed to specific causes (in this case, increase level of fertilizer), and that which cannot.

The results of treatments 1 to 6 (i.e. group A) are given below for convenience:

	TABLE 5.6: YIELDS FROM TREATMENTS 1 TO 6 OF FIELD TRIALS (kgs./ Ha)					
	Treatment Number					
	Control	10N	20N	30N	40N	50N
Block No.	1	2	3	4	5	6
1	13.4	24.05	40.62	48.10	57.80	62.80
2	16.27	22.05	41.78	51.15	56.37	64.18
3	16.53	20.80	44.90	51.35	53.83	61.72

The reader should bear in mind, in the course of the following steps, that it is not always important to understand the calculations; the important thing is that if the steps are carefully followed, the ANOVA provides the needed answers.

ANALYSIS OF VARIANCE (ANOVA)

Step 1: Number of Treatments = 6

Step 2 : Number of times the treatments replicated (blocks) = 3

Step 3: Put the fertilizer trail results in form a table as shown.	Treatment Number									
		1	**2**	**3**	**4**	**5**	**6**	**Total**	**Step 1**	**Average**
	Block	*Control*	*10N*	*20N*	*30N*	*40N*	*50N*			
	1	13.4	24.1	42.6	48.1	57.8	62.8	248.8	÷6	41.5
	2	16.3	22.1	41.8	51.2	56.4	64.2	252.0	÷6	42.0
	3	16.5	20.8	44.9	51.4	53.8	61.7	249.1	÷6	41.5
Step 4: Total the results		**46.2**	**67.0**	**129.3**	**150.7**	**168.0**	**188.7**			**125.0**
Step 5: Calculate Averages: (Step **4** ÷ Step **2)**		46.2 ÷ 3 =	67.0 ÷3 =	129.3÷3 =	150.7÷3 =	168.0÷3 =	188.7÷3 =			125.0 ÷3 =
		15.4	**22.3**	**43.1**	**50.2**	**56.0**	**62.9**			**41.7**

Step 6

Sum of Squared of Treatments

-1-Yield	-2- Mean	3= 1-2	4=(3)^2	
Treatment-1				
13.4	-15.4=	-2.0	4.0	
16.3	-15.4=	0.9	0.8	
16.5	-15.4=	1.1	1.2	
			6.0	**6.0**
Treatment - 2				
24.1	-22.3=	1.8	3.2	
22.1	-22.3=	-0.3	0.04	
20.8	-22.3=	-1.5	2.3	
			5.5	**5.5**
Treatment -3				
42.6	-43.1=	-0.5	0.3	
41.8	-43.1=	-1.3	1.7	
44.9	-43.1=	1.8	3.2	
			5.2	**5.2**
Treatment -4				
48.1	-50.2=	-2.1	4.4	
51.2	-50.2=	1.0	1.0	
51.4	-50.2=	1.2	1.4	
			6.8	**6.8**
Treatment -5				
57.8	-56.0=	1.8	3.2	
56.4	-56.0=	0.4	0.2	
53.8	-56.0=	-2.2	4.8	
			8.2	**8.2**
Treatment -6				
62.8	-62.9=	-0.1	0.0	
64.2	-62.9=	1.3	1.7	
61.7	-62.9=	-1.2	1.4	
			3.1	**3.1**
			Total	**34.8**

Step 7

Squared deviations (weighted by group size)

-1-Yield	-2- Mean	3= 1-2	4=(3)^2
Treatment-1			
13.4	- 41.7=	-28.3	800.9
16.3	- 41.7=	-25.4	645.1
16.5	- 41.7=	-25.2	635.0
Treatment-2			
24.1	- 41.7=	-17.6	309.8
22.1	- 41.7=	-19.6	384.2
20.8	- 41.7=	-20.9	436.8
Treatment-3			
42.6	- 41.7=	0.9	0.8
41.8	- 41.7=	0.1	0.0
44.9	- 41.7=	3.2	10.2
Treatment-4			
48.1	- 41.7=	6.4	41.96
51.2	- 41.7=	9.5	90.3
51.4	- 41.7=	9.7	94.1
Treatment-5			
57.8	- 41.7=	16.1	259.2
56.4	- 41.7=	14.7	216.1
53.8	- 41.7=	12.1	146.4
Treatment-6			
62.8	- 41.7=	21.1	445.2
64.2	- 41.7=	22.5	506.25
61.7	- 41.7=	20.0	400.0
		Total	**5420.6**

Step 8

Total Sum of Squared Deviations

-1- Yield	-2- Mean	3= 1-2	4=(3)^2
15.4	- 41.7=	-26.3	691.7
22.3	- 41.7=	-19.4	376.4
43.1	- 41.7=	1.4	2.0
50.2	- 41.7=	8.5	72.3
56.0	- 41.7=	14.3	204.5
62.9	- 41.7=	21.2	449.4
		Total	1796.3
		Multiply by Step 3:	x 3.0
		Total	**5388.9**

Step 9: Calculating Degrees of Freedom for treatments : ***(Step 1 minus 1)*** = (6 -1) = **5**

Step 10: Calculating Degrees of Freedom for blocks ***: [(Step 2 minus 1) x Step 1]*** = [(3-1) x 6) = **12**

Step 11: Calculating Degrees of Freedom for Total (all treatments) ***:[(Step 1 x Step 2) minus 1]*** = [(3 x 6) – 1] = 18 –1 = **17**

Step 12: Calculating the ***"F"*** value.

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	***"F"** Value*
Between Treatments	**Step 8**: 5388.9	**Step 9**: 5	**Step 12** = (Step 8/Step 9) 5388.9/ 5 = **1077.8**	**Step 14**= (Step 12/Step 13) 1077.8 ÷ 2.9 = **371.7**
Within Blocks	**Step 6** : 34.8	**Step 10** : 12	**Step 13** = (Step 6 / Step 10) (34.8 /12 = **2.9**	
Total	**Step 7**: 5420.6	**Step 11**: 17		

Step 15: Reading the "F" Value from the "F" table.	**Step 9 :** we go **across** the "F" table. (5 in this case).	2.39 for 90% confidence Level
	Step 10: we go **down** the "F" table . (12 in this case).	

Having found the ***F*** ratio, we have completed the calculations necessary to the Analysis of Variance. Now, to find out whether the yields from the five fertilizer treatments were statistically significant, we must consult the ***F*** tables in Appendix 3 at the end of the book. (For practice questions of reading ***F*** values, turn to the study section at the end of the chapter).

	Between ***Treatments***: Follow the ***Top*** of the F Table (Number from **STEP 9)**	→ 5
Within **Blocks**: Follow the numbers **Below :** (Number from **STEP 10)**		↓
↓		↓
12 ------→	------→	*2.39*

Memory aid:

i)**Treatment:** can stand for ***Top***: this means follow the F numbers on the top of F table.
ii) **Blocks**: can stand for ***below***: this means follow the F numbers that go ***below***).

Find the column in the table that corresponds to the degrees of freedom of the treatments (i.e. 6-1=5). Follow this column downward until the row corresponding to the degrees of freedom of the blocks is reached, 12 in this case. Note the number is 2.39.

If the F ratio ***calculated*** in the analysis of variance is greater than the F ***number in the table***, there is less than one chance in ten (10%) of the difference in treatments having been insignificant.

In our case, the calculated F ratio for 5,12 degrees of freedom was 375.76. Since this figure is ***greater*** than the F table numbers for 5,12 degrees of freedom, we can say that there is ***significant difference*** in yields among the treatments. In other words, increasing levels of nitrogen caused significant increase in crops, and this increase was not due to coincidence.

If **Calculated** F Number is **<** than F value in the Table:	Different levels of fertilizer were ***not proven to be responsible*** for the differences in crop output.
If **Calculated** F Number is **>** than F value in the Table: 371.6 > 2.39	Different levels of fertilizer were ***responsible*** for the differences in crop output.

If difference in yields among treatments do not prove to be statistically significant, than trials should be repeated, using greater levels of nitrogen than before. If the differences do show statistical significance, than we should conduct an economic analysis, which is explained in the next chapter.

If statistically significant above 80 %	Conduct economic analysis and if needed, conduct trials the following year with higher levels of fertilizer.
If statistically significant above 75%	Do not do any economic analysis, but repeat fertilizer field trials using greater levels of nitrogen than before.
If ***not*** statistically significant above 75%	Ignore the fertilizer treatments altogether.

Go to the appendix at the end of this chapter to do one example to see that you really understand how to conduct ANOVA and to see if the results were statistically significant.

3. *"t"* TESTS

Now that we have statistically analyzed the result of the fertilizer field trials with only one nutrient, we may turn to those trials (Groups B) that used more than one nutrient. To use the analysis of variance technique for Group B, where every treatment must be compared individually with every other, would mean too much tiresome calculation. To avoid this, a different procedure known as the "*t*" test will be used. ***(Look at "t" Table at the end of the book).***

To test if the difference in averages in the yields of treatments (***3***) and (***7***), for example, is statistically significant, we perform the following preliminary operation:

i) ***Steps 1 to 17*** helps us to calculate the ***"t"*** value;
ii) ***Step 18*** helps us to see if Treatment ***7*** is statistically significant than treatment ***3***;
iii) ***Steps 19A to 19H*** helps us to calculate the range of yield we would get from Treatment ***7***; and
iv) ***Steps 20A to 20H*** helps us to calculate the range of yield we would get from Treatment ***3***.

"*t*" Tests	**COMPARING TWO TRIALS WITH DIFFERENT FERTILIZER TREATMENTS**			
	TREATMENT 3 (20 N)		**TREATMENT 7(20N20P)**	
Step 1: Put the fertilizer trail results in a table as shown.	Block	Yield Kg./ha	Block	Yield Kg./ha
	1	42.62	1	46.00
	2	41.78	2	44.83
	3	44.90	3	44.77
Step 2: Total the results	**129.30**		**135.60**	
Step 3: Number of blocks.	3		3	
Step 4: *(Step 2÷Step 3)* Calculate Means:	*129.30* / 3 = **43.10**		*135.60* / 3 = **45.20**	
Step 5: Calculate the variances: S^2_3 and for S^2_7	$(42.62 - \mathbf{43.1})^2 = (-0.48)^2 = +0.2304$		$(46.00 - \mathbf{45.2})^2 = (+0.80)^2 = +0.6400$	
	$(41.78 - 43.1)^2 = (-1.32)^2 = +1.7424$		$(44.83 - 45.2)^2 = (-0.37)^2 = +0.1369$	
	$(44.90 - 43.1)^2 = (+1.80)^2 = +3.2400$		$(44.77 - 45.2)^2 = (-0.43)^2 = +0.1849$	
	= 5.2128		**= 0. 9618**	
Step 6: Number of times each treatment was replicated (No. of blocks)	3		3	
Step 7: *(Step 6 minus 1)* Number of times each treatment was replicated minus 1.	$= (n_3 - 1)$ $= (3 - 1) =$ **2**		$= (n_7 - 1)$ $= (3 - 1) =$ **2**	
Step 8: ***(Total of Step 7)*** Total Degrees of Freedom:	2 + 2 = 4			
	TREATMENT 3: S_3^2		**TREATMENT 7:** S_7^2	
Step 9: *(Step 5 ÷ Step 7)*	Step 5 / Step 7 = 5.2128 / 2 **= 2.6064**		Step 5 / Step 7 = 0. 9618 / 2 **= 0.4809**	
Step 10: (Step **9** x Step **7**)	(2 x 2.6064) = **5.2128**		(2 x 0.4809) = **0.9618**	
Step 11: Add results of Step **10**	5.2128 + 0.9618 = **6.1746**			
Step 12: (Step 11÷Step 8) Pooled Variance**:** Finding S^2	Step 11 / Step 8 = ***6.1746*** / ***4*** **=1.5437**			
Step 13: Square Rt. of Step **12**.	√ Step 12 = √ 1.5437 = **1.2424**			
Step 14: Differences of Step **4**	45.20 - 43.10 = **2.1**			
	TREATMENT 3:		**TREATMENT 7:**	
Step 15A: (1÷Step 6)	$1/n_3 = 1/3 =$ 0.3333		$1/n_7 = 1/3 =$ 0.3333	
Step 15 B: Total of Step 15A	(0.3333 + 0.3333) = **0.6666**			
Step 15C: (Square root of Step 15B). Square Root of the Sum of the inverses of the number of treatment.	√ (0.6666) = **0.8165**			
Step 16: (Step **13** x Step **15C**)	(Step 13 x Step 15) = 1.2424 x 0.8165 = **1.0144**			
Step 17: (Step **14**÷ Step **16**) "*t*" value	Step 14 / Step 16 = ***2.1*** / 1.0144 **= 2.0701**			

How to read if yield from Treatment 7 is statistically significant.				
Step 18A: Degrees of Freedom :***Step 8***	4			
Step 18B: Look at "t" Table at the end of the book and look at Deg. Of Freedom in Step ***18A*** and different levels of confidence.	*Levels of Confidence(%)* ***(Look at "t" Table at the end of the book).***			
		90%	**80%**	75%
	D of Fred. 4	2.132	**1.533**	0.74
	Calculated Value ⟶		**2.0701**	
The Value in Step 18B (2.0701) is greater than ***80%*** level but smaller than 90 % level. So we can say with ***80%*** level of confidence that 2P in fertilizer in Treatment 7 will give higher yields.				

HOW TO CALCULATE THE RANGE OF YIELD ONE WOULD GET WHEN *TREATMENT 7* IS APPLIED:				
	TREATMENT 7			
Step 19A: Degrees of Freedom for Treatment 7: from Step 7 (number of blocks for Treatment 7 minus 1)	(3-1=)2			
Step 19.1B : Level of Confidence read from Step 18B:	80%			
Step 19.1B: Read Value Levels of Confidence below.	***80%*** Level of Confidence and ***2*** degrees of freedom. ***(Look at "t" Table at the end of the book).***			
	Levels of Confidence			
		90%	**80%**	75%
	D of Fred. 2	2.92	**1.886**	0.816
Step 19C: Square Root of ***Step 3***: For Treatment 7	√ 3 =1.73205			
Step 19D: Square Root of ***Step 9***:For Treatment 7	√ 0.4809 = 0.6935			
Step 19E: (***Step 19D ÷ Step 19C***)	0.6935 ÷ 1.73205 = 0.4004			
Step 19F: (***Step 191.B x Step 19E)***	1.886 x 0.4004 = 0.7551			
Step 19G: *Minimum* yield from Treatment 7: ***(Step 4 - Step 19F)***	45.2 - 0.7551 = 44.4449			
Step 19H: *Maximum* yield from Treatment 7:***(Step 4 + Step 19F)***	45.2 + 0.7551= 45.9551			

HOW TO CALCULATE THE RANGE OF YIELD WHEN *TREATMENT 3* IS APPLIED:	
	TREATMENT 3
Step 20A:Degrees of Freedom for Treatment 3: from ***Step 7*** (number of blocks for Treatment 3 minus 1)	(3-1=) 2
Step 20B.1 : Level of Confidence read from **Step 18B**:	80%
Levels of Confidence (Look at "t" Table at the end of the book).	
Step 20B.2: Read Value of Levels of Confidence below ***80%*** level of Confidence and ***2*** degrees of freedom. *D of Fred. 2*	**80%** **1.886**
Step 20C: Square Root of ***Step 3*** for Treatment 3.	√ 3 =1.7321
Step 20D: Square Root of ***Step 9*** for Treatment 3.	√ 2.6064 =1.6144
Step 20E: ***(Step 20D ÷ Step 20C)***	1.61444 ÷1.7321 = 0.9321
Step 20F: ***(Step 20B.2 x Step 20E)***	1.886 x 0.9321 = 1.7579
Step 20G: *Minimum* yield from Treatment 3: ***(Step 4 - Step 20E)***	43.1 - 1.7579 = *41.340*
Step 20H: *Maximum* yield from Treatment 3: ***(Step 4 + Step 20E)***	431 + 1.7579 = *44.859*

Level of Confidence (Step 18)

Now that the "*t*" value has been calculated for the field trial treatments, compare this "*t*" value with the value indicated (for the same number of degrees of freedom) in the "*t*" table 2 in the Appendix at the end of this chapter.

Beginning with the "***t***" table figure for the highest level of confidence (90% level) compare this figure with the calculated **"*t*"** value. Then compare the figures representing lesser levels of **"*t*"** value. Then compare the figures representing lesser levels of confidence (but always with the same number of degrees of freedom), until a figure is found which is smaller than the calculated value. At this point we can say that the yields were statistically significant to the degree indicted by that figure.

For example, the calculated **"*t*"** value found by comparing the yields of treatments ***(3)*** and ***(7)*** was 2.0701. The degrees of freedom were 4. To illustrate this, the part of the "t" table for four degrees of freedom is given below: ***(Look at "t" Table at the end of the book).***

TABLE 5.7:			**LEVELS OF CONFIDENCE %**		
Degrees of Freedom			**90**	**80**	**75**
Deg. of Freedom 4			2.132	1.533	0.740
"*t*" value we calculated:				***2.0701***	

The calculated value is smaller than the 90% level of confidence but greater than the 80% levels. Thus we can say with 80% confidence the presence of ***2P*** in treatment (7) was responsible for the increase in yield of the crop and that this was no accident; unless 1 in 4 chance came out. "***t***" tests should now be conducted for the other treatments to see which ones gave significant yields. The Levels of Confidence that result from these tests can be employed in the following ways:

In comparing a one –nutrient treatment with a two-nutrient treatment, if we obtain a level of confidence of, 80 or above, we can:

a) use the yield results for a fertilizer recommendation for the following year, and
b) set up more fertilizer trials containing the same two nutrients.

If the level of confidence proves to be 75% or less, we should simply ignore the results.

Since a fertilizer with three nutrients is bound to be more expensive than one with two, we must have slightly higher Levels of Confidence to use as basis for recommendations. Thus, when comparing a one-nutrient treatment with a three-nutrient, we need a level of confidence of 90% or above to be able to make a fertilizer recommendation for the following year and to set up more three-nutrient trials. If the level of confidence is from 80% to 90%, we should not make a recommendation and we should not set up an entire three-nutrient experiment the following year; rather, we should include only one treatment with three nutrients in our experiment. If the confidence level is 80% or below, we should ignore the results altogether.

In the case of comparing a two nutrient treatment with one of three- nutrient, we can again lower our requirements for the level of confidence, since the difference between the two treatments is that of one nutrient that had to have been responsible for the significant yield increase. Thus, with a level of 75% or above, we can safely recommend the three-nutrient fertilizer the following year and set up new three-nutrient field trials. A level of confidence below 75%, however, warrants neither recommendation nor trials and should be ignored.

Let us apply the above guidelines to the actual calculated levels of confidence in our sample treatments:

CONFIDENCE LEVELS AND FERTILIZER RECOMMENDATIONS		
Comparing :	**Level of Confidence**	**Recommendation**
1 NUTRIENT WITH 2 NUTRIENTS 2 N & 2N2P or 2N & 2N2K	90% level of confidence	i) Conduct economic analysis and recommend fertilizer applications next year if profits are going to be more than **15%.** ii) Set fertilizer trials next year with higher levels of 2N2P nutrients.
	80% level of confidence	i) Conduct economic analysis and recommend fertilizer applications next year if profits are going to be more than **25%.** ii) Set fertilizer trials next year with higher levels of 2N2P nutrients.
	Below 75%	Ignore the results.
1 NUTRIENT WITH 3 NUTRIENTS 2N & 2N2P2K	90% level of confidence	i) Conduct economic analysis and compare the results with any treatment containing 2 nutrients that gave statistically significant yields, in this case 2N2P. ii) Recommend fertilizer applications next year if profits are going to be more than **25%.** iii) Set fertilizer trials with higher levels of nutrients the next year.
	80 % level of confidence	i) Make no recommendations for fertilizer applications. ii) Set fertilizer trials with only 1 treatment with 3 nutrients.
	Below 75 % level of confidence	Ignore the results.
2 NUTRIENT WITH 3 NUTRIENTS 2N2P & 2N2P2K	Above 75% level of confidence	i) Conduct economic analysis and recommend fertilizer applications next year if profits are going to be more than **15%.** ii) Set fertilizer trials with higher levels of nutrients the next year.
	Below 75% level of confidence.	Ignore the results.

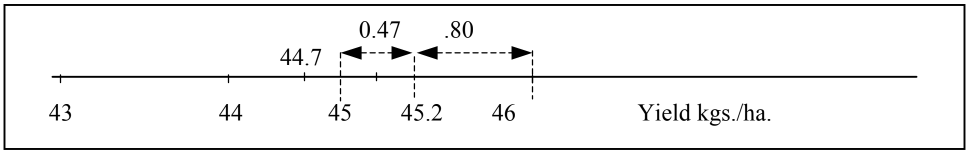
4. MINIMUM AND MAXIMUM YIELDS EXPECTED

Before the credit organization recommends a particular level of fertilizer to a farmer, it should be fairly certain that the farmer stands a good chance of benefiting from that fertilizer level.

For example, the average yield obtained from fertilizer treatment ***7*** was 45.2 kgs/ha. If the experiment was conducted again, and all factors—fertilizer level, weather conditions, etc—were exactly reproduced, it is very unlikely that we would obtain the same yield as for the previous year. Although we cannot predict the following year's yield on the basis of the experimental treatments, we can, at least, know the range of the previous year's yields and from these figures, perform some important calculations. The highest and lowest yields from treatment ***7*** were, respectively, 46.00 and 44.77 kgs/ha. Let us compare these two figures with the average yield for treatment 7:

TREATMENT 7	
46.00	45.20 average
45.20- average	44.77-
0.80	0.43

These differences can be graphically represented (from the experimental trials) as follows:



Thus far, we know the average yields and the lowest and highest yields obtained, but we still do not know what range of yields would be obtained, say, nine out of ten times (90% level of confidence) or four out of five times (80% level of confidence). These ranges, fortunately, can be calculated by use of the statistical "t" tables shown in appendix 3. This is shown in the table above from Step 19.

If, for example, we want to calculate the range of yields, which will occur for treatment ***7***, one out of five times, we must do as follows:

(Step 4): The average yield, Y7 (already calculated above) = 45.2 kgs/Ha.

(√ Step 9): The value of S_7^2 (calculated above, Step 1)= .4809

(Step 22): Thus, the value of $S_7 = \sqrt{0.4809} = .6934$

(Step 19A): The degrees of freedom (n-1) where n is the number of times the trials were repeated (i.e. 3). Degrees of freedom, then, (3-1) = 2.

Now turn to the "***t***" table in the appendix of this book for the '***t***' distribution to obtain the value indicated for the 80% level of confidence. Look to row 2, in this case, corresponding to 2 degrees of freedom. And we see that in the '***t***' table for 80% level of confidence and 2 degrees of freedom gives the value 1.886.

Now knowing the appropriate values of S_7, S, t and n, insert these values into the formula below:

(Step 19A to 19H)

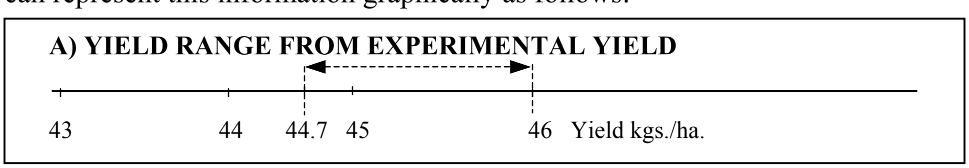
TREATMENT 3 : MINIMUM AND MAXIMUM YIELDS AT 80% LEVEL OF CONFIDENCE					
Minimum Yield				*Maximum Yield*	
$\hat{y}_7 - t_{\infty/2}$ x $(S/\sqrt{N})$	<	$\hat{y}_7$	<	$\hat{y}_7 + t_{\infty/2}$ x $(S/\sqrt{N})$	$\hat{y}_7 = 45.2$
45.2 – 1.886 (0.6934 / √ 3)	<	45.2	<	45.2 + 1.886 (0.6934 / √ 3)	n=3
45.2 – 1.886 (0.6934 /1.732)	<	45.2	<	45.2 + 1.886 (0.6934 /1.732)	S=0.6934
45.2 – 1.886 x 0.400	<	45.2	<	45.2 + 1.886 x 0.400	$t_{\infty/2}$ =1.886
45.2 – 0.7551	<	45.2	<	45.2 + 0.7551	
Minimum Yield = **44.44**	<	45.2	<	**45.96** *Maximum Yield*	

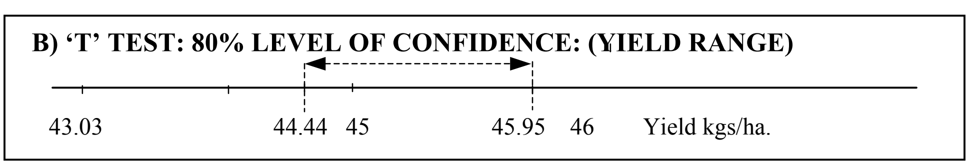
On the basis of these calculations, we can say that, if the trials with treatment ***7*** were repeated five times, the yields would fall between 44.44 and 45.96 four of those times.

But what has been the benefit of finding the confidence limits? Why couldn't we have simply used the experimental results?

From the experimental results (from Treatment ***7***) the range of yields obtained was 46.00 for the highest yield and 44.77 for the lowest yield. But, by calculating confidence limits, we know that, four out of the five times, the yield will fall between 44.44 and 45.96.

We can represent this information graphically as follows:





The procedure by which we determine the limits of confidence has an even greater value when we apply it to a comparison of treatments, particularly when the treatments have a cost to the farmer. Thus, taking only the two statistically significant treatments (i.e. 3 and 7), and leaving aside the rest, we can judge which of the two fertilizer mixtures to recommend. In other words, we do not want to recommend the more expensive treatment (7) if there is a good chance of achieving the same results by use of the cheaper mixture (3).

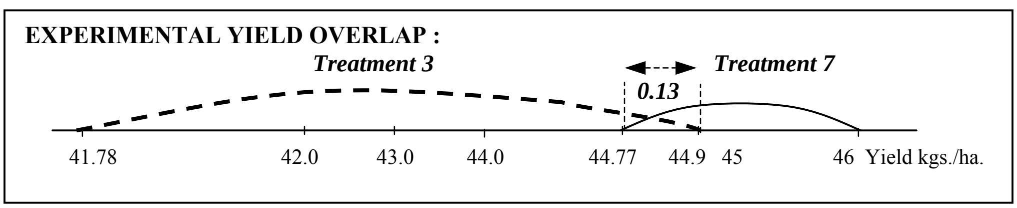
The range of yields from the *experimental* results of treatment ***3*** was:

44.90	Highest plot yield obtained (Block 3)
- 41.78	Lowest plot yield obtained (Block 1)
3.12	

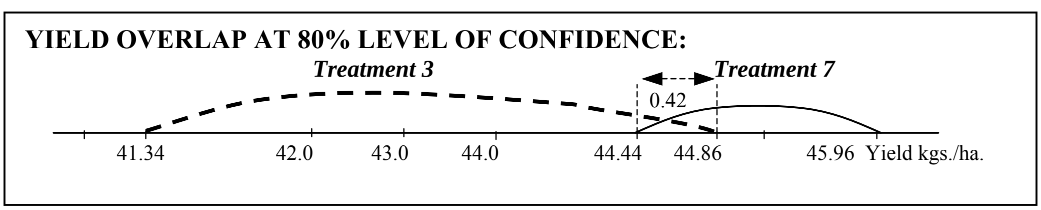
By calculating the expected minimum and maximum yields expected, we get the following results: (Step 20A to 20H).

TREATMENT 7 : MINIMUM AND MAXIMUM YIELDS AT 80% LEVEL OF CONFIDENCE					
Minimum Yield				*Maximum Yield*	
$\hat{y}_7 - t_{\infty/2}$ x $(S/\sqrt{N})$	<	$\hat{y}_7$	<	$\hat{y}_7 + t_{\infty/2}$ x $(S/\sqrt{N})$	$\hat{y}_7$= 43.1
43.1– 1.886 (1.6144 / √ 3)	<	43.1	<	43.1+ 1.886 (1.6144 / √ 3)	n=3
43.1– 1.886 (1.6144 /1.732)	<	43.1	<	43.1+ 1.886 (1.6144 /1.732)	S=1.6144
43.1– 1.886 x 0.9321	<	43.1	<	43.1+ 1.886 x 0.9321	$t_{\infty/2}$ =1.886
43.1– 1.7579	<	43.1	<	43.1+ 1.7579	
Minimum Yield = **41.340**	<	43.1	<	**44.859** *Maximum Yield*	

Now, by taking the ranges of yields from the experimental results of both treatments (3 and 7), we notice an overlap, as shown below:



From the above range of overlap (i.e. from 44.77 to 44.90) we can see that the yields of treatment 3 could equal or even slightly exceed those of treatment 7, which is the more expensive treatment. The range of overlap is 0.13 kg./Ha. or about {[(0.13)/(41.78 - 44.90)] x 100=}4% of the total range of treatment ***3***.



If, however, we consider the 80% level of confidence, then the overlap changes somewhat:

From the above diagram, we can see that the range between the highest yield of treatment ***3*** and the lowest of treatment ***7*** is 44.86- 44.44= 0.42, which is an overlap of 10% of the total range of treatment ***3*** yields {(0.42)/(44.86-41.34)}= 12%.

In the case of the experimental data, the overlap was only 4%. Therefore, we know that treatment ***3***, once out of five times, will give a yield higher than the lowest yield of treatment ***7***. If we had calculated our results from only the experimental data, we could have assumed the above to occur only once out of 25 times (4%).

So, when recommending a treatment to a farmer, the agency must bear in mind the chances that a cheaper treatment (treatment ***3***, in this case) could produce a yield as high as that produced by a more expensive treatment (treatment ***7***). Whether the 80% or the 90% level of confidence is chosen depends upon how expensive the treatment is: the more expensive the treatment, the higher the level of confidence should be, since more is at stake.

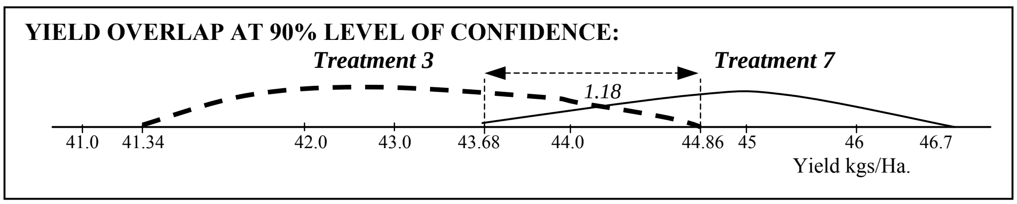
If, however, the cost of phosphate were $45/kg, then the extra cost of treatment 7 would be $ 90, and we should be careful on recommending this treatment. The additional cost warrants the use of a 90% level of confidence.

Using a 90% level of confidence, the yields of treatments 3 and 7 may appear as follows:

Treatment 3 –yield range: 41.34 to 44.86
Treatment 7-yield range: 43.68 to 46.72

The overlap is 44.86 - 43.68 = 1.18. Thus, {[(1.18)/(44.86-4.134)]x100}=0.335%
In other words, the overlap represents 33.5% of the total range of treatment ***3***. We know, then, that treatment 3 will show yields as high as those treatments ***7***, nearly one third of the time.

In the above example, given the high price of phosphate, we should be wary of recommending treatment ***7*** since there is more than a 33% chance that the farmer may obtain a yield equally large by just applying treatment 3, which is much cheaper.



If the treatment had contained two or three fertilizer nutrients, the procedure for conducting the statistical analysis would have been the same.

Comparing 1 Nutrient with 3 Nutrient Treatment

Now let us see if the output from a one-nutrient treatment was statistically significant than a three-nutrient treatment by using “t” tests.

“t” Tests	**COMPARING TWO TRIALS WITH DIFFERENT FERTILIZER TREATMENTS**			
	TREATMENT 3 (20N)		**TREATMENT 9 (20N20P20K)**	
Step 1: Put the fertilizer trail results in form a table as shown.	Block	Yield Kg./ha	Block	Yield Kg./ha
	1	42.62	1	44.00
	2	41.78	2	45.77
	3	44.90	3	46.13
Step 2: Total the results	**129.30**		**135.9**	
Step 3: Number of blocks.	3		3	
Step 4: ***(Step 2/Step 3)*** Calculate Means:	*129.30* / 3 = **43.10**		*135.90* / 3 = **45.3**	
Step 5: Calculate the variances: S^2_3 and for S^2_9	$(42.62 - \mathbf{43.1})^2 = (+0.48)^2 = +0.2304$		$(44.00 - \mathbf{45.3})^2 = -1.3)^2 = +1.6900$	
	$(41.78 - 43.1)^2 = (-1.32)^2 = +1.7424$		$(45.77 - \mathbf{45.3})^2 = (0.47)^2 = +0.2209$	
	$(44.90 - 43.1)^2 = (+1.80)^2 = +3.2400$		$(46.13 - \mathbf{45.3})^2 = (0.83)^2 = +0.6889$	
	= 5.2128		**= 2.5998**	
Step 6: Number of times each treatment was replicated (No. of blocks)	3		3	

Step 7: ***(Step 6 minus 1)*** Number of times each treatment was replicated minus 1.	$= (n_3 - 1)$ $= (3 - 1) =$ **2**	$= (n_7 - 1)$ $= (3 - 1) =$ **2**
Step 8: ***(Total of Step 7)*** Total Degrees of Freedom:	2 + 2 = 4	
	S_3^2	S_9^2
Step 9: ***(Step 5 ÷ Step 7)***	$\frac{\text{Step 5}}{\text{Step 7}} = \frac{5.2128}{2}$ **= 2.6064**	$\frac{\text{Step 5}}{\text{Step 7}} = \frac{2.5998}{2}$ **= 1.2999**
Step 10: (Step **9** x Step **7**)	(2 x 2.6064) = **5.2128**	(2 x **1.2999**) = **2.5998**
Step 11: Add results of Step **10**	5.2128 + 2.5998 = **7.8126**	
Step 12: (Step 11/Step 8) Pooled Variance**:** Finding S^2	$\frac{\text{Step 11}}{\text{Step 8}} = \frac{\mathbf{7.8126}}{\mathbf{4}}$ **= 1.9532**	
Step 13: Square Rt. of Step **12**.	√ Step 12 = √ **1.9532**= **1.3976**	
Step 14: Differences of Step **4**	45.30 - 43.10 **= 2.2**	
Step 15A: (1/Step 6)	$1/n_3$ = 1/3 = 0.3333	$1/n_9$ =1/3 = 0.3333
Step 15 B: Total of Step 15A	(0.3333 + 0.3333) = **0.6666**	
Step 15C: (Square root of Step 15B). Square Root of the Sum of the inverses of the number of treatment.	√ (0.6666) = **0.8165**	
Step 16: (Step **13** x Step **15C**)	(Step 13 x Step 15) = 1.3976 x 0.8165 = **1.1411**	
Step 17: (Step **14**/ Step **16**) "***t***" value	$\frac{\text{Step 14}}{\text{Step 16}} = \frac{\mathbf{2.2}}{\mathbf{1.1411}}$ **= 1.9280**	
HOW TO READ IF YIELD FROM TREATMENT 7 IS STATISTICALLY SIGNIFICANTLY.		
Step 18A: Degrees of Freedom :***Step 8***	4	
Step 18B: Look at Table ..and look at Deg. Of Freedom in Step ***18A*** and different Levels of Confidence.		***Levels of Confidence(%) (Look at "t" Table at the end of the book).***
		90% | 80% | 75%
	D of Fred. 4	**2.132** | 1.533 | 0.740
	Calculated "t" value	**1.9280**
	The Value in Step 18B (**1.9280**) is smaller than ***90%*** level. As we are comparing a one-nutrient with a three-nutrient treatment (the more expensive one) we can say that when looking at ***90%*** level of confidence that there is no evidence that 2P2K in fertilizer in Treatment 9 will not give higher yields when compared to treatment 3.	
RESULT:	As the calculated "t" value (1.9280) is below the 90% level of confidence, no economic analysis should be done for treatment 9 this year. But as the calculated "t" value (1.9280) is greater than the "t" value above the 80% level of confidence, next year set more trials with higher levels of 2N2P2K.	

APPENDIX A

Formula for "*t*" test

On this basis, we are ready to begin our calculations:

$$t = \frac{(\hat{y}_3 - \hat{y}_7)}{\sqrt{\frac{(n_3 - 1) S_3^2 + (n_7 - 1) S_7^2}{(n_3 + n_7 - 2)} \left(\frac{1}{n_3} + \frac{1}{n_7} \right)}}$$

Step 2 Calculating the variances

Find the variance (s^2) of treatment (3) (s^2_3) and of treatment (iii) (s^2_7) For example

$$= \frac{\Sigma (Y_{3i} - \hat{y}_3)^2}{n_3 - 1}$$

n =	the number of times the field trial was repeated (3, in this case) the result of each field –trial for treatment (3).
Σ	Called " sigma", means the total of
Y_{3i} =	The yields of each-trial for treatment (3).
Y_{7i} =	The yields of each-trial for treatment (7).
$\hat{y}_3$ =	The average of the yields of the field trial for treatment (3).
$\hat{y}_7$ =	The average of the yields of the field trial for treatment (7).

Because the sample is small, statistical procedure requires that we pool the results of S_3^2 and S_7^2 to get S^2:

$$S^2 = \frac{(n_3 - 1) S_3^2 + (n_7 - 1) S_7^2}{n_3 + n_7 - 2}$$

($n_3 + n_7 - 2$) gives the degrees of freedom.

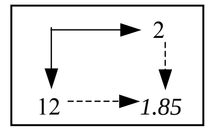
<u>Calculating the "t" value</u>

We can now calculate t as follows:

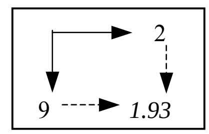
$$t = \frac{\hat{y}_7 - \hat{y}_3}{S \times \sqrt{1/n_3 + 1/n_7}}$$

Chapter 5 – STUDY GUIDE QUESTIONS: Analysis Of Variance (ANOVA)

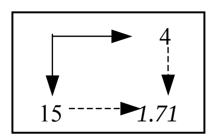
1) Fertilizer trials with 3 different treatments of fertilizer were set. The trials were repeated 5 times. Look up the F value at 80 % level. ***(Look at F Table at the end of the book).***

	Degrees of Freedom		
Number of treatments (t) of fertilizer: t = 3	Step 9 = (t – 1) = 3-1=2	Read on the top side of ***F*** table	
Number of blocks (b) for each treatment: b = 5	Step 10: t (b-1) = = 3 (5-1) **= 3 x 4 =12**	Read below on the left side of the ***F*** table	

2) Fertilizer trials with 3 different treatments of fertilizer were set. The trials were repeated 4 times. Look up the F value at 80 % level. ***(Look at F Table at the end of the book).***

	Degrees of Freedom		
Number of treatments (t) of fertilizer : t = 3	Step 9 = (t – 1) = 3-1=2	Read on the top side of ***F*** table	
Number of blocks (b) for each treatment : b= 4	Step 10 = t (b-1) = = 3 (4-1) **= 3 x 3 =9**	Read below on the left side of the ***F*** table	

3) Fertilizer trials with 5 different treatments of fertilizer were set. The trials were repeated 4 times. Look up the F value at 80 % level. ***(Look at F Table at the end of the book).***

	Degrees of Freedom		
Number of treatments (t) of fertilizer : t = 5	Step 9 = (t – 1) = = 5-1=4	Read on the top side of ***F*** table	
Number of blocks (b) for each treatment : b = 4	Step 10 = t (b-1) = 5 (4-1) **= 5 x 3 =15**	Read below on the left side of the ***F*** table	

4) The results of treatments 1 to 6 are given below. Calculate the F value and determine if different levels of nitrogen are statistically significant at 80% level. Then suggest what should you do (or not do) this year and what you should do the following year. ***(Look at F Table at the end of the book).***

	Table1 : Yields from treatments 1 to 6 of field trials (kgs. Ha.)					
	Treatment Number					
	Control	10N	20N	30N	40N	50N
Block No.	1	2	3	4	5	6
1	13.4	17	18	15	17	15
2	16.27	15	14	19	19	18
3	16.53	16	17	18	20	21

1. ANALYSIS OF VARIANCE (ANOVA)

Step 1: Number of Treatments = 6

Step 2 : Number of times the treatments replicated (blocks) = 3

Step 3: Put the fertilizer trail results in form a table as shown.	Treatment Number								
		1	2	3	4	5	6	**Total**		**Average**
	Block	*Control*	*10N*	*20N*	*30N*	*40N*	*50N*			
	1	13.4	17	18	15	17	15	95.4	÷6	15.90
	2	16.27	15	14	19	19	18	101.27	÷6	16.88
	3	16.53	16	17	18	20	21	108.53	÷6	18.09
Step 4: Total the results		**46.20**	**48**	**49**	**52**	**56**	**54**			**50.87**
Step 5: Calculate Averages: (Step **4** ÷ Step **2)**		46.2 ÷ 3=	48÷3=	49 ÷ 3=	52 ÷ 3=	56.0÷3	54÷3=			50.87 ÷3 =
		15.40	**16.00**	**16.33**	**17.33**	**18.67**	**18.00**			**16.96**

Step 6

Sum of Squared of Treatments

-1-Yield	-2- Mean	3= 1-2	4=(3)^2	
Treatment-1				
13.4	-15.4=	-2.00	4.00	
16.3	-15.4=	0.87	0.76	
16.5	-15.4=	1.13	1.28	
			6.04	**6.04**
Treatment - 2				
17	-16.0=	1.00	1.00	
15	-16.0=	-1.00	1.00	
16	-16.0=	0.00	0.00	
			2.00	**2.00**
Treatment -3				
18	-16.33=	1.67	2.78	
14	-16.33=	-2.33	5.44	
17	-16.33=	0.67	0.44	
				8.67
Treatment -4				
15	-17.33=	-2.33	5.44	
19	-17.33=	1.67	2.78	
18	-17.33=	0.67	0.44	
				8.67
Treatment -5				
17	-18.67=	1.67	2.78	
19	-18.67=	0.33	0.11	
20	-18.67=	1.33	1.78	
				4.67
Treatment -6				
15	-18=	-3.00	9.00	
18	-18=	0.00	0.00	
21	-18=	3.00	9.00	
				18.0
			Total	**48.03**

Step 7

Squared deviations (weighted by group size)

-1-Yield	-2- Mean	3= 1-2	4=(3)^2
Treatment-1			
13.4	- 16.96=	-3.56	12.64
16.3	- 16.96=	-0.69	0.47
16.5	- 16.96=	-0.43	0.18
Treatment-2			
17	- 16.96=	0.04	0.00
15	- 16.96=	-1.96	3.82
16	- 16.96=	-0.96	0.91
Treatment-3			
18	- 16.96=	1.04	1.09
14	- 16.96=	-2.96	8..74
17	- 16.96=	0.04	0.00
Treatment-4			
15	- 16.96=	-1.96	3.82
19	- 16.96=	2.04	4.18
18	- 16.96=	1.04	1.09
Treatment-5			
17	- 16.96=	0.04	0.00
19	- 16.96=	2.04	4.18
20	- 16.96=	3.04	0.27
Treatment-6			
15	- 16.96=	-1.96	3.82
18	- 16.96=	1.04	1.09
21	- 16.96=	4.04	16.36
		Total	**71.68**

Step 8

Total Sum of Squared Deviations

-1- Yield	-2- Mean	3= 1-2	4=(3)^2
15.4	- 16.96=	-1.56	2.42
16.00	- 16.96=	-0.96	0.91
16.33	- 16.96=	-0.62	0.39
17.33	- 16.96=	0.38	0.14
18.67	- 16.96=	1.71	2.93
18.00	- 16.96=	1.04	1.09
			7.88
		Multiply by Step 3:	x 3.0
			23.64

Step 9: Calculating Degrees of Freedom for treatments : ***(Step 1 minus 1)*** = (6 -1) = **5**

Step 10: Calculating Degrees of Freedom for blocks ***: [(Step 2 minus 1) x Step 1]*** = [(3-1) x 6) = **12**

Step 11: Calculating Degrees of Freedom for Total (all treatments) ***:[(Step 1 x Step 2) minus 1]*** = [(3 x 6) – 1] = 18 –1 = **17**

Step 12: Calculating the ***"F"*** value.

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	
Between Treatments	**Step 8**: 23.64	**Step 9**: 5	23.64/ 5 = 4.729	4.729÷ 4.003= **1.181**
Within Blocks	**Step 6** : 48.03	**Step 10** : 12	48.03 /12 = 4.003	
Total	**Step 6**: 71.68	**Step 11**: 17		

Step 13: Reading the "F" Value from the "F" table.	**Step 9 :** we go **across** the "F" table. (5 in this case).	1.74 for 80% confidence Level
	Step 10: we go **down** the "F" table . (12 in this case).	

If **Calculated** F Number is **<** than F value in the Table: 1.181 < 1.74	Different levels of fertilizer ***were <u>not</u> responsible*** for the differences in crop output.
If **Calculated** F Number is **>** than F value in the Table:	Different levels of fertilizer ***were responsible*** for the differences in crop output.

The F ratio ***calculated*** in the analysis of variance is smaller than the F ***number in the table***, hence different levels of fertilizer ***were not responsible*** for the differences in crop output at 80% level of confidence. As the results are below even a 75% level of confidence (F value of 1.54), there is no statistical evidence that would support using these levels of fertilizer hence no fertilizer trials should be set up the following year.

5) Fertilizer trial with two treatments 20N and the other with 20N20P was set up. Block 2 of the first treatment had been eaten or ruined by cows. Rest of the outputs were as shown in the table below: ***(Look at "t" Table at the end of the book).***

Calculate : i) the "***t***" value of this fertilizer trials; (**HINT**: Deg. of Freedom is 3 from Step 8).

ii) Determine if the output from 20P in the second treatment is statistically significant at 80% level of confidence.

iii) Determine what you would do this year and the following year.

	Treatment	
	3	**7**
Block No.	20N	20N20P
1	42.62	46.00
2	0.00	44.83
3	44.90	44.77

(For clarity the answer is on the next page).

***"t"* Tests**	**COMPARING TWO TRIALS WITH DIFFERENT FERTILIZER TREATMENTS**			
	TREATMENT 3 (20 N)		**TREATMENT 7(20N20P)**	
Step 1: Put the fertilizer trail results in form a table as shown.	Block	Yield Kg./ha	Block	Yield Kg./ha
	1	42.62	1	46.00
	2	0.00	2	44.83
	3	44.90	3	44.77
Step 2: Total the results	**87.52**		**135.60**	
Step 3: Number of blocks.	2		3	
Step 4: *(Step 2÷Step 3)* Calculate Means:	$\frac{87.52}{2}$ = **43.76**		$\frac{135.60}{3}$ = **45.20**	
Step 5: Calculate the variances: S^2_3 and for S^2_7	$(42.62 - 43.76)^2 = (-1.14)^2 = +1.2996$		$(46.00 - \mathbf{45.2})^2 = (+0.80)^2 = +0.6400$	
			$(44.83 - 45.2)^2 = (-0.37)^2 = +0.1369$	
	$(44.90 - 43.76)^2 = (+1.14)^2 = +1.2996$		$(44.77 - 45.2)^2 = (-0.43)^2 = +0.1849$	
	= 2.5992		**= 0. 9618**	
Step 6: Number of times each treatment was replicated (No. of blocks)	2		3	
Step 7: *(Step 6 minus 1)* Number of times each treatment was replicated minus 1.	$= (n_3 - 1)$ $= (2 - 1) =$ **1**		$= (n_7 - 1)$ $= (3 - 1) =$ **2**	

Step 8: ***(Total of Step 7)*** Total Degrees of Freedom:	1 + 2 = **3**

	TREATMENT 3: S_3^2	**TREATMENT 7: S_7^2**
Step 9: *(Step 5 ÷ Step 7)*	$\frac{\text{Step 5}}{\text{Step 7}} = \frac{2.5992}{1}$ = **2.5992**	$\frac{\text{Step 5}}{\text{Step 7}} = \frac{0.9618}{2}$ = **0.4809**
Step 10: (Step **9** x Step 7)	(1 x 2.5992) = **2.5992**	(2 x 0.4809) = **0.9618**

Step 11: Add results of Step **10**	2.5992+ 0.9618 = **3.561**
Step 12: (Step 11÷Step 8) Pooled Variance**:** Finding S^2	$\frac{\text{Step 11}}{\text{Step 8}} = \frac{3.561}{3}$ **=1.187**
Step 13: Square Rt. of Step **12**.	√ Step 12 = √ 1.187 = **1.0895**
Step 14: Differences of Step **4**	45.20 - 43.76 = **1.44**

	TREATMENT 3:	**TREATMENT 7:**
Step 15A: (1÷Step 6)	$1/n_3 = 1/2 = 0.5$	$1/n_7 = 1/3 = 0.3333$
Step 15 B: Total of Step 15A	(0.5 + 0.3333) = **0.8333**	

Step 15C: (Square root of Step 15B). Square Root of the Sum of the inverses of the number of treatment.	√ (0.8333) = **0.9129**
Step 16: (Step **13** x Step **15C**)	(Step 13 x Step 15) = 1.0895 x 0.9129 = **0.9946**
Step 17: (Step **14**÷ Step **16**) "*t*" value	$\frac{\text{Step 14}}{\text{Step 16}} = \frac{1.44}{0.9946}$ **= 1.4479**

How to read if yield from Treatment 7 is statistically significantly.

Step 18A: Degrees of Freedom :***Step 8***	3

Step 18B: Look at "t" Table at the end of the book and look at Deg. Of Freedom in Step ***18A*** and different levels of Significance.	*Levels of Confidence (%)* ***(Look at "t" Table at the end of the book).***		
	90%	**80%**	75%
D of Fred. 3	2.353	**1.638**	0.764
Calculated "t" value ➔		**1.4479**	

The Value in Step 18B (**1.4479**) is smaller than ***80%*** level value in the "***t***" table (**1.638**). From the given results this year we cannot say that that 2P in fertilizer was responsible for increasing yields this year.
RESULT: Do not do economic analysis this year but next year set up the trials with same levels of fertilizer.

6) If a fertilizer treatment is carried out, determine the range of the yields for the 80% level of confidence (that is one out of five times) if the results were as follows:

i) Mean = 45.6 (step 4) .
ii) Number of times the trials were replicated (blocks) n=10 (step 6).
iii) *s* = 2.4 (square root of Step 9).

Answer:
Step 1: Calculate the deg. of freedom= (n-1) =10-1 =9
Step 2: Look at ***"t"*** table at the end of the book. and see the value of 80% level of confidence and 9 Deg. of Freedom = 1.383.
Step 3: Put in the formula in the table below.

6: Minimum and Maximum Yields at 80% Level of Confidence											
Minimum Yield						*Maximum Yield*					
$\hat{y}_7$ -	$t_{\infty/2}$ x	(S/ √ N)	<	$\hat{y}_7$	<	$\hat{y}_7$ +	$t_{\infty/2}$ x	(S/ √ N)		$\hat{y}_7$=	45.6
45.6 -	1.383 x	(2.4/ √ 10)	<	45.6	<	45.6 +	1.383 x	(2.4/ √ 10)		n=	10
45.6 -	1.383 x	2.4/3.1623)	<	45.6	<	45.6 +	1.383 x	2.4/3.1623)		S=	2.4
45.6 -	1.383 x	0.7589	<	45.6	<	45.6 +	1.383 x	0.7589		$t_{\infty/2}$ =	1.383
45.6 -	1.0496		<	45.6	<	45.6 +	1.0496				
Minimum Yield = 44.5504			<	45.6	<	46.6496 = *Maximum Yield*					

7) If a fertilizer treatment is carried out, determine the range of the yields for the 90% level of confidence (that is one out of ten times) if the results were as follows:

i) Mean = 35.7 (step 4) .
ii) Number of times the trials were replicated (blocks) n=16 (step 6).
iii) *s* = 6.12 (square root of Step 9).

Answer:

Step 1: Calculate the deg. of freedom= (n-1) =16-1 =15
Step 2: Look at ***"t"*** table at the end of the book. and see the value of 90% level of confidence and 15 deg. of freedom=1.753.
Step 3: Put in the formula in the table below.

7 : Minimum and Maximum Yields at 80% Level of Confidence											
Minimum Yield						*Maximum Yield*					
$\hat{y}_7$ -	$t_{\infty/2}$ x	(S/ √ N)	<	$\hat{y}_7$	<	$\hat{y}_7$ +	$t_{\infty/2}$ x	(S/ √ N)		$\hat{y}_7$=	35.7
35.7 -	1.753 x	(6.12/ √ 16)	<	35.7	<	35.7 +	1.753 x	(6.12/ √ 16)		n=	16
35.7 -	1.753 x	(6.12/4)	<	35.7	<	35.7 +	1.753 x	(6.12/4)		S=	6.12
35.7 -	1.753 x	1.53	<	35.7	<	35.7 +	1.753 x	1.53		$t_{\infty/2}$ =	1.753
35.7 -	2.68209		<	35.7	<	35.7 +	2.68209				
Minimum Yield = 33.01791			<	35.7	<	38.38209 = *Maximum Yield*					

8) If a fertilizer treatment is carried out, determine the range of the yields for the 80% level of confidence (that is one out of five times) if the results were as follows:

i) Mean = 55.4 (step 4).
ii) Number of times the trials were replicated (blocks) n=12 (step 6).
iii) s = 4.21 (square root of Step 9).

Answer:
Step 1: Calculate the deg. of freedom= (n-1) =12-1 =11.
Step 2: Look at ***"t"*** table at the end of the book. and see the value of 80% level of confidence and 11 deg. of freedom=1.363.
Step 3: Put in the formula in the table below.

8: Minimum and Maximum Yields at 80% Level of Confidence										
Minimum Yield						*Maximum Yield*				
$\hat{y}_7$ -	$t_{\infty/2}$ x	(S/ √ N)	<	$\hat{y}_7$	<	$\hat{y}_7$ +	$t_{\infty/2}$ x	(S/ √ N)	$\hat{y}_7$=	55.4
55.4 -	1.363 x	(4.21 / √ 12)	<	55.4	<	55.4 +	1.363 x	(4.21/ √ 12)	n=	12
55.4 -	1.363 x	(4.21 / 3.4641)	<	55.4	<	55.4 +	1.363 x	(4.21 / 3.4641)	S=	4.21
55.4 -	1.363 x	1.2153	<	55.4	<	55.4 +	1.363 x	1.2153	$t_{\infty/2}$ =	1.363
55.4 -	1.6565		<	55.4	<	55.4 +	1.6565			
Minimum Yield = 53.7435			<	55.4	<	57.0565 = *Maximum Yield*				

9) If a fertilizer treatment is carried out, determine the range of the yields for the 90% level of confidence (that is one out of ten times) if the results were as follows:

i) Mean = 71.5 (step 4) .
ii) Number of times the trials were replicated (blocks) n=19 (step 6).
iii) s = 5.78 (square root of Step 9).

Answer:
Step 1: Calculate the deg. of freedom= (n-1) =19-1 =18.
Step 2: Look at ***"t"*** table at the end of the book. and see the value of 90% level of confidence and 18 deg. of freedom=1.734.
Step 3: Put in the formula in the table below.

9 : Minimum and Maximum Yields at 90% Level of Confidence										
Minimum Yield						*Maximum Yield*				
$\hat{y}_7$ -	$t_{\infty/2}$ x	(S/ √ N)	<	$\hat{y}_7$	<	$\hat{y}_7$ +	$t_{\infty/2}$ x	(S/ √ N)	$\hat{y}_7$=	71.5
71.5 -	1.734 x	(5.78/ √ 19)	<	71.5	<	71.5 +	1.734 x	(5.78/ √ 19)	n=	19
71.5 -	1.734 x	(5.78/4.3589)	<	71.5	<	71.5 +	1.734 x	(5.78/4.3589)	S=	5.78
71.5 -	1.734 x	1.3260	<	71.5	<	71.5 +	1.734 x	1.3260	$t_{\infty/2}$ =	1.734
71.5 -	2.2993		<	71.5	<	71.5 +	2.2993			
Minimum Yield = 69.2007			<	71.5	<	73.7993 = *Maximum Yield*				

10) If a fertilizer treatment is carried out, determine the range of the yields for the 90% level of confidence (that is one out of ten times) if the results were as follows:

i) Mean = 15.24 (step 4).
ii) Number of times the trials were replicated (blocks) n=16 (step 6).
iii) *s* = 2.39 (square root of Step 9).

Answer:
Step 1: Calculate the deg. of freedom= (n-1) =16-1 =15.
Step 2: Look at ***"t"*** table at the end of the book. and see the value of 90% level of confidence and 15 deg. of freedom=1.753.
Step 3: Put in the formula in the table below.

10***: Minimum and Maximum Yields at 80% Level of Confidence***											
Minimum Yield						**Maximum Yield**					
$\hat{y}_7$ -	$t_{\infty/2}$ x	(S/ √ N)	<	$\hat{y}_7$	<	$\hat{y}_7$ +	$t_{\infty/2}$ x	(S/ √ N)	$\hat{y}_7$=	15.24
15.24 -	1.753 x	(2.39 / √ 16)	<	15.24	<	15.24 +	1.753 x	(2.39 / √ 16)	n=	16
15.24 -	1.753 x	(2.39/ 4)	<	15.24	<	15.24 +	1.753 x	(2.39/ 4)	S=	2.39
15.24 -	1.753 x	0.5975	<	15.24	<	15.24 +	1.753 x	0.5975	$t_{\infty/2}$ =	1.753
15.24 -	1.0474		<	15.24	<	15.24 +	1.0474			
Minimum Yield = 14.1926			<	15.24	<	16.2874 = *Maximum Yield*				

Chapter 6

ECONOMIC ANALYSIS OF FERTILIZER FIELD TRIALS

1. INTRODUCTION

With the fertilizer field trials completed and statistically analyzed, the economic analysis can now be conducted to determine how much profit a farmer will make with each level of fertilizer applied; from this information, a credit agency can find the fertilizer level which will give the farmer the optimum financial return from his particular crop.

For economic analysis, just as for statistical analysis, the fertilizer treatments can be divided into two categories:

a) Treatments containing only one nutrient (nitrogen in this case), with the control treatment included, and

b) Treatments containing more than one nutrient. In this category only those fertilizer treatments are of economic interest which were found to be statistically significant in the ***'t'*** tests in Chapter 5.

Range Of Fertilizer Recommendation Levels

When only one nutrient is involved, the fertilizer level which a credit agency should recommend lies between the point at which the fertilizer applied gives the highest *average* yield (i.e. where the average product is the highest) and the point at which the farmer would obtain the highest profit.
From these two points we deduce, respectively,

a) The minimum recommended rate (Min. R.R.)

b) The maximum recommended rate (Max. R.R.)

There is a third point which, though not essential to fertilizer recommendation, can be very helpful. This is called the point of biological maximum yield; also called the maximum biological rate of fertilizer.

To illustrate how these points are calculated, the results of treatment that contained only nitrogen will be analyzed. In order to determine the biological maximum, maximum and the minimum recommended levels, we must obtain a production curve (also called a "response" curve) of the crop to varying levels of nitrogen.

2. FITTING THE PRODUCTION CURVE

The production curve can be obtained in one of two ways, either by drawing a curve connecting the various yield points, or by fitting a mathematical equation (called a regression line) to the yield results. The first of these two methods is called graphing or "eyeing". For our purposes, the information that we can obtain from the production curve obtained by "eyeing" is sufficient to make the fertilizer recommendations to the farmers.

Write the results of the first six treatments in the form of a table, add up the treatment columns of the first three trials, and find the averages as shown in Table 6.1.

Table 6.1 : Calculating the Averages of the Treatment Results. (Converted to per kgs./Ha. From Ch. 5)

	Treatment No.								
Block No.	1	2	3	4	5	6	7	8	9
	Control	10N	20N	30N	40N	50N	20N, 20P	20N,20K	20N,20P,20K
1.	13.40	24.05	42.62	48.10	57.80	62.80	46.00	43.10	44.00
2.	16.27	22.05	41.78	51.15	56.37	64.18	44.83	44.16	45.77
3.	16.53	20.80	44.90	51.35	53.83	61.72	44.77	43.24	46.13
Total	46.20	66.90	129.30	150.60	168.00	188.70	135.60	130.50	135.90
Average Yield	46.2÷3= 15.40	66.9÷3= 22.30	129.3÷3= 43.10	150.6÷3= 50.20	168.0÷3= 56.00	188.7÷3= 62.90	135.6÷3= 45.20	130.5÷3= 43.50	135.9÷3 = 45.30

Next, using the averages as yields of the nitrogen levels applied, mark the results on a graph, as shown in Figure 6.1A. Now draw a smooth curve, starting from the lowest level of nitrogen (in this case 10 kg. /Ha) as shown in Figure 6.1B., and not from the average of control. The shape of the curve should indicate the response of the crop to nitrogen.

Figure 6.1A.: Yields Obtained from the Trials

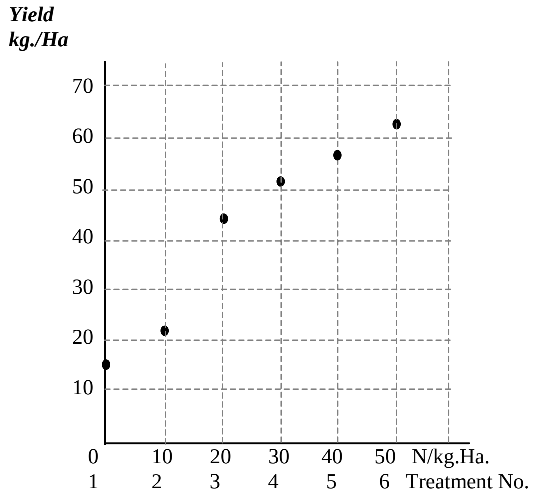
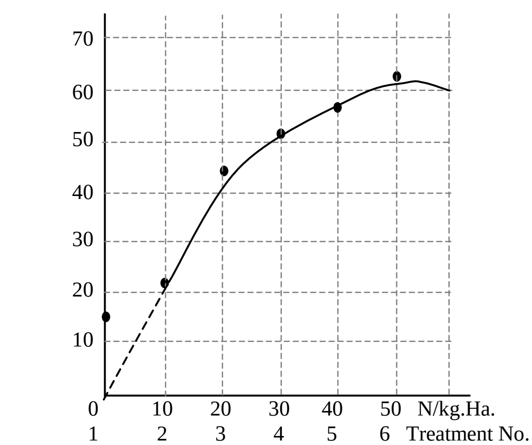


Figure 6.1B. Obtaining of the Production curve by graphing "eyeing"



The yields indicated by the graph line---also called the "check" yields---as derived from Figure 6.1C. are shown below. **NOTE**: Check yields will be different from the calculated averages.

How to get "Check Yields"

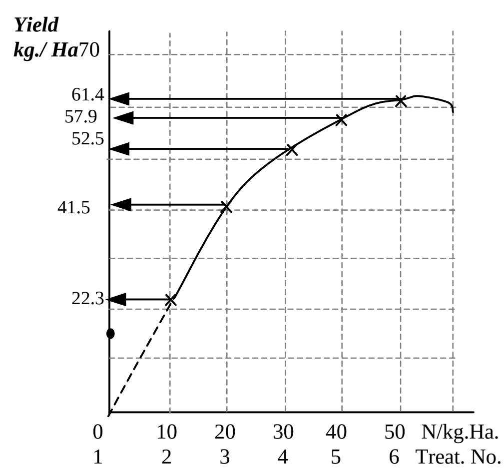
Step 1) First draw a smooth production curve by " eyeing " .

Step 2) Draw a vertical line upwards towards the smoothly drawn production curve from every level of the treatment that was applied.

Step 3) Draw a horizontal line from the point where the vertical line touches the "eyed" production curve. The output levels that we read from the drawn graph are called "check yields". The "check yields" that we get from the graph are written in Table 6.2.

Step 4) For our economic analysis, we will be using the output levels that we get from the production curve we had drawn from "eyeing".

Figure 6.1C.: "Check" Yields Indicated from the production Curve Obtained by Graphing ("eyeing").



The above **"check"** yields are shown in the table below.

TABLE 6.2: "CHECK" YIELDS OBTAINED FROM GRAPHING. (FIG. 6.1C.)					
Treatment No.					
1	2	3	4	5	6
Control	10 N	20 N	30 N	40 N	50 N
15.40	22.30	41.50	52.50	57.90	61.40

When constructing a graph, one must consider which of the two variables should be placed on the horizontal axis and which on the vertical. In the present case, it is apparent that the yield of the crop is dependent upon the level of nitrogen applied and <u>not</u> vice-versa. The variable which is not affected is called the independent variable and should be placed on the horizontal axis. Therefore, since nitrogen is the independent variable (unaffected by the crop yield), it must be placed on the horizontal axis, leaving the yield (or dependent variable) to be placed on the vertical.

A) <u>Biological Maximum Rate of Output</u>

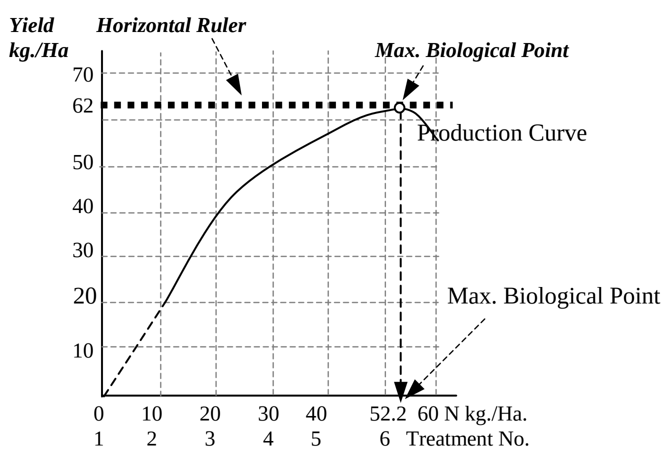
The Biological maximum rate does not really form part of the economic analysis, yet it can be of help in checking our calculations. Because the maximum and the minimum recommended rates will always be less than the rate calculated to produce the biological maximum yield, the latter can be used to detect any errors which may result in calculating the first two quantities. Thus, if any of the first two prove to be greater than the biological maximum, we will know that the calculations must be reevaluated.

In calculating the biological maximum, the prices of the fertilizer nutrients and the crop would be ignored (or, say, reduced to zero).

B) <u>Determining Maximum Biological Rate Determined from Graphing</u>

The easiest way to determine the maximum biological rate is to take a ruler and by placing it on the horizontal axis, move the ruler upwards until it just touches the top most part of the production curve. Or we can say, until the ruler is tangent to the production curve. This is shown in the Figure 6.2.

FIGURE 6.2: DETERMINING THE BIOLOGICAL MAXIMUM FROM GRAPHING



From Figure 6.2 we can see that we obtain the maximum biological yield when the nutrient rate is 52.2 N/ kgs./ha. If the farmer increases his application of the nutrient level above the rate that gives the biological maximum yield, the farmer's yield actually decreases. For example, if the farmer applies 52.2 N/kgs./ha. of the nutrient (the biological/ maximum point) he obtains 62 kgs./ha. of the crop; if however, he applies 60 kgs./ha. of the nutrient (above the biological maximum point) the yield obtained by the farmer actually decreases to 55.00 kgs./ha.

We can see that even if fertilizer is given free to the farmer he should not apply it above the biological maximum point.

Therefore, when the nutrient level is 52.20 kgs/ha., we obtain the highest yield that is biologically possible (62 kg/ha.).

Why do yields decrease after the biological maximum rate? In the presence of excessive nutrients (above the biological maximum rate), a plant grows taller and hence weaker at the base and therefore is more likely to lodge (bend on the ground) due to an even slight amount of wind or rain. Excess of nutrients also encourages greater weed growth, which compete with the crop for light and water. Weeds also increase humidity in the lower level of the crop field, therefore, providing a conducive environment for plant diseases caused by fungi and bacteria to manifest and thus contributing to the reduction of crop yields. Consequently, even if the fertilizer is free, the farmer should not apply it above the biological maximum point.

3. ECONOMIC ANALYSIS : MINIMUM AND MAXIMUM RECOMMENDED RATES

Now that we have discussed the ways in which we can construct a production curve and determine the biological maximum rate, we are prepared to find the range of a fertilizer nutrient (nitrogen, in this case) which a credit agency should recommend. This, of course, is the chief purpose of the present chapter. To find this range, however, we must determine two points on the graph; the minimum recommended rate and the maximum recommended rate. Somewhere between these two points, also called, respectively, the point of the highest average product and the point of the highest profit, lies the correct fertilizer level which the credit agency must recommend.

We can obtain the minimum and maximum recommended levels of fertilizer in the following manner:

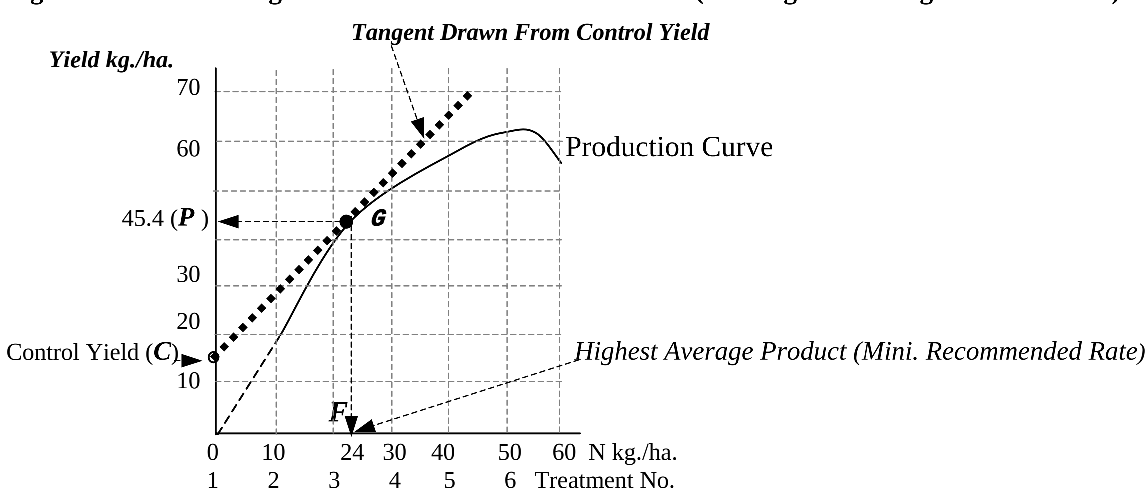
A) Minimum Recommended Rate of Fertilizer (Min. R.R.)

The minimum recommended rate (Min. R.R.) is to be found at the highest average product point.

The highest average product point can be found as follows: First draw the production curve on a graph. Then, using the average yield point of the control treatment, point ***C***, draw a straight line which would be tangential to the production curve. (Tangential means—a line which touches—not crosses—another line. Hence two lines at tangent have only one point of contact.)

Hence the straight line from the average point of the control touches the production curve at the point G, as shown in Figure 6.3.

Figure 6.3: Determining the Minimum Recommended Rate (The Highest Average Product Point)



At the point ***G***, the average product would be the highest. From the point ***G,*** draw a vertical line downward until it touches the horizontal axis at ***F***; and also from ***G*** draw a horizontal line that will touch the vertical axis ***P***. These points indicate that ***0F*** (24) kgs./ha. of nitrogen will produce ***0P*** (45.4) kgs./ha. of the crop.

GF, where the average product point is the highest, gives the ***minimum*** recommended rate for the fertilizer nutrient.

Use of the Average Product Point by the Credit Agency

There are two principle reasons why the credit agency should know the minimum recommended rate of fertilizer or the highest average point:

i) So that the agency may help the farmer obtain higher output from the limited amount of funds, and ii) so that the agency may extend credit to a greater number of farmers, rather than spending too much of the limited funds on fewer individuals. Of course, the correct knowledge of the highest average product point is also important to the farmer so that he should know what is the minimum level of fertilizer he should apply to his crop, and not less that amount should be applied if he is to get any reasonable yields from his fertilizer application.

The credit agency should insist that the farmer apply at least the minimum recommended rate of nitrogen to his crop (or for that matter any other nutrient that we may have been considering), or else not apply nitrogen at all. Since most of the nitrogen is used by the plant in its vegetative growth, and only a small quantity for filling out the grain, the yield will not be notably greater if the amount of nitrogen less than the minimum recommended rate is applied. Thus, not only will a farmer will be disappointed but the credit agency also: how will it recuperate its loan? How can a farmer repay a loan, not to mention the interest, if his yield was no greater than it had been previously?

We can demonstrate the fact that when the level of fertilizer applied is below the minimum recommended rate, the farmer would not even recoup the average cost of the fertilizer applied. (See the appendix of this chapter). As the farmer's average output would increase with additional application of fertilizer, the farmer's average cost of fertilizer applied would decrease. And only when the average output is maximum, would the farmer's average cost of applying fertilizer be at it's minimum. Hence the minimum level of fertilizer (or for that matter, any variable input) that a farmer should apply should be when the average output is it's maximum. See the appendix of this chapter to see the relationship between average output and average variable cost (AVC).

For this reason the minimum recommended rate is always where the average product point is the highest.

Let us assume, for example, that a farmer applies 7 kgs. /ha. of fertilizer (less, that is, than the Min R.R), and that he distributes it uniformly over his land. At this level of fertilizer, the farmer will receive a yield of 15.70 kgs./ha. , only slightly higher than the yield of the control trial (15.40 kgs./ha.) where no fertilizer was applied. The profit the farmer would receive would be:

Yield obtained= 15.7 kgs./ha.; **Price** of crop= $ 88/kg; **Price** of nitrogen=$25/kg.

Total Income =	15.70 x $88 =	$ 1,381.60 /Ha.
Cost of Fertilizer =	7.0 x $25 =	- $ 175.00 /Ha.
Net Profit =	1,381.6 - 175.0	= $ 1,206.60 /Ha.

If the farmer had applied no fertilizer then his income would have been:

Yield obtained= 15.4 kg/ha.; **Price** of crop= $ 88/kg.; **Fertilizer** Expenses= None.

Total Income =	15.4 x $88 =	$ 1,355.20 /Ha.
Cost of Fertilizer =	0 x $25 =	- $ 0.00 /Ha.
Net Profit =	1,355.20 - 0.00	= $ 1,355.20 /Ha.

From the above calculations we can see the farmer obtained higher income when he did not apply any fertilizer than when he applied 7 kgs./ha.

If the farmer had applied 24 kgs./ha. of nitrogen (i.e. the Min.R.R.), and output had been 45.10 kg./ha. the figures would read as follows:

Total Income =	45.41 x $ 88 =	$ 3,996.08 /Ha.
Cost of Fertilizer =	24 x $ 25 =	- $ 600.00 /Ha.
Net Profit =	3,996.08 - 600.00 =	$ 3,396.08 /Ha.

From the above figures it is clear that if the highest average product point (or the Min.R.R.) of fertilizer cannot be applied, then none at all should be applied.

There is, however, a recourse to be taken in the event that the credit agency, or the farmer for that matter, does not have enough funds to offer even the Minimum R.R. to its farmers. If this situation should prevail, then the agency should require that the farmers apply fertilizer to only a part of the land and leave the rest unfertilized.

Let us say, for example, that a farmer is told to apply nitrogen to his crop up to the minimum recommended rate would require a sum of (24 x $25) = $ 600.00/ha. Let us say, also, that the agency can extend only $ 210.00/Ha. In this case, the farmer should apply fertilizer to[(210/600) x 100 =] 35 percent of his land and leave the remaining area unfertilized, as shown in the example below:

$$\frac{210}{600} \times 100 = 35 \text{ percent of the land.}$$

The financial benefits received by the farmer for his partial fertilization are as follows: (farm holding of 1 ha.).

Yield obtained from fertilized part of the land at the minimum recommended rate = 45.41 kgs./ha.
Yield obtained from 35 % (0.35) of the *fertilized* land = 45.41 x 0.35 = 15.89 kgs./ha
Yield from the land when it is unfertilized (control yield) = 15.4 kgs./ha
Yield obtained by the farmer from his *unfertilized* part of the land = (0.65 ha.) = 0.65 x 15.4 = 10.01 kg
Total yield obtained by the farmer = 15.89 + 10.01 = 25.90 kgs./ha.

Gross income of the farmer =	25.90 x $ 88 =	$ 2,279.20/ha.
Cost of Fertilizer =	35% of $ 600 =	- $ 210.00
Net Income =	$ 2,279.20 - $ 2,10.00 =	$ 2,069.20/ha.

If, on the other hand, the farmer had applied the $ 210.00 worth of fertilizer uniformly to all his land (that would be 8.4 kg/ha. of nitrogen), he would have received only slightly higher yield than that of the control, the yield of 18.76 kgs./ha. His net income, in fact would have been:

Gross income of the farmer =	18.76 x $88 =	$ 1,650.88 /ha.
Cost of Fertilizer =	35% of $600 =	- $ 210.00
Net Income =	$ 1,650.88 - $ 2,10.00 =	$ 1,440.88/ha.

At the end of this chapter we will discuss the problems which arise in change in prices. In the example, which follows, however, for the sake of convenience, we will use the above fertilizer and crop prices.

By comparing the net incomes in the two cases, we can see the advantage of applying the fertilizer to only part of the land. By partial fertilization the farmer obtained {[(2069.20 - 1440.88)/1440.88] x 100 =}43 percent higher income than fertilizing the whole land below the Min.R.R.

Let us study another case where knowledge of the minimum recommended level is helpful. Once again we will assume that the credit agency's funds are limited, but this time we will say that the credit agency has enough funds to purchase 48 kgs. of nitrogen. If this credit were allocated to a single farmer (with one hectare of land), then he would produce 59.78 kgs./ha. of the crop (yield read from the check point graph).

But if the credit agency, knowing the highest average product point of the crop which received nitrogen application, were to give this same amount of credit to two farmers for the purchase of 24 kgs./ha., of nitrogen then each farmer would produce 45.41 kgs./ha. Thus the two farmers together would produce 90.88 kgs of the crop, as compared to only 59.78 kgs./ha. which the first farmer produced, even though in each case an equal amount of credit was allocated.

Single farmer applying 48 kgs./ nitrogen, yield obtained is = 1 x 59.78 = 59.78 kgs.
Two farmers, each applying 24 kgs./ nitrogen (at Min. Rec. Rate), yield obtained is = 2 x 45.41 = 90.88 kgs.

To make a fair comparison, even if we add the yield of a second farmer who does not apply fertilizer to his land (yield obtained —15.4 kgs./ha.) to the yield obtained by the farmer who applied 48 kgs./ha. of nitrogen, then the total yield obtained by then is (15.4 + 59.78) = 75.18 kgs.

This yield is still {[(90.82 -75.18)/90.82] x100 }= 17.20 percent less than that was obtained when two farmers received credit for 48 kgs. (24 kgs for each farmer) to apply up to the highest average product point. The fact that there has been greater distribution of income is also a very important point to bear in mind.

B) Maximum Recommended Rate (Max. R. R.)

The maximum recommended rate is to be found at the highest profit point on the graph.

If the yield obtained from each additional unit of fertilizer can be regarded as gain and the cost of nitrogen applied as an expense, then the profit a farmer makes from any level of nitrogen is equal to the value of the outputs minus the cost of the inputs, or as follows:

Net Profit = (Price of Unit Crop x Yield Per Treatment) – (Price of Nitrogen x Quantity of N applied per Treatment)
Net Profit = Value of Outputs – Cost of Inputs

The level of nitrogen application which gives a farmer the maximum financial gain lies at the point where the difference between output and input is greatest. One sure and easy way of finding this point is by drawing an " iso-profit" line: the point where the "*iso-profit*" line touches (is tangential to) the production curve is the point where the level of nitrogen application gives maximum profit.

Since we already know how to draw the production curve, the next step is to draw the " *iso-profit*" line.

"Iso-profit" Line

First we must calculate the "*iso-profit*" fraction : this is simply a fraction made up of the price of a unit input (nitrogen in this case) and the price of a unit output of a crop, as shown here:

Price of Unit Nitrogen (Input)
Price of Unit Crop (Output)

(Input must always be placed on top, and output on the bottom of the fraction).

If the price of nitrogen is $ 25.0 per kg and the price of the crop tested in the field-trails is $ 88.0 per kg, the "iso-profit" fraction would be

$$\frac{25.0}{88.0} = 0.284$$

Once the "iso-profit" fraction has been calculated, mark its corresponding point on the graph of the production curve. In this case of the above fraction, one must move (0.284 x10=) 2.84 units on the vertical scale for every <u>10 units</u> on the horizontal. This procedure will give us point ***A***, as shown in Figure 6.4.

Figure 6.4: Marking the "Iso-profit" line on the Graph

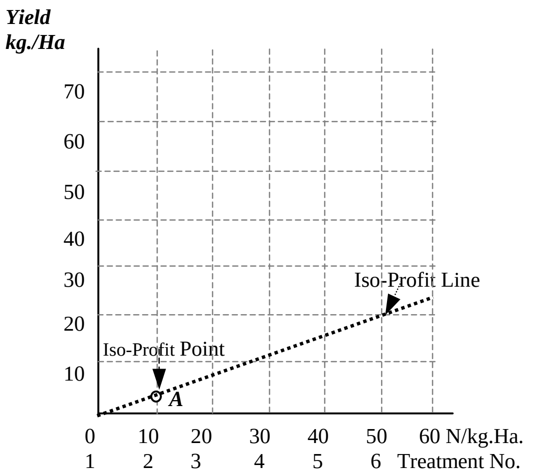
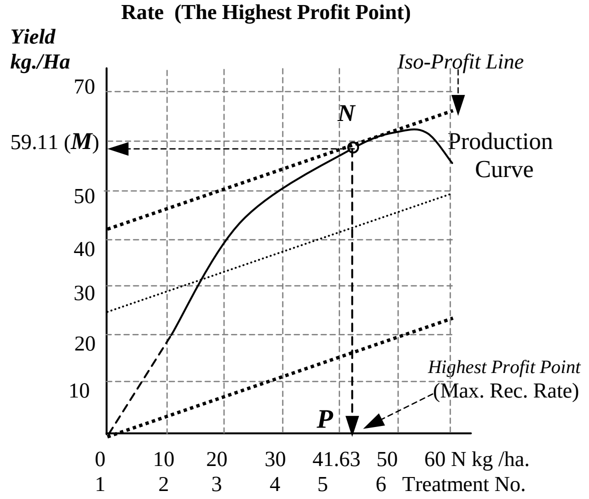


Figure 6.5: Determining the Maximum Recommended Rate (The Highest Profit Point)



Now draw a straight line passing through point ***A*** and the axis ***0***. This gives us the line ***OA***. Now take a ruler and move the ruler parallel to the line ***OA***, until the ruler is tangent to the production curve. When the line is tangent (i.e has only one point of contact) to the production curve, we have found our "*iso-profit*" line.

The point where the "iso-profit" line just touches the production curve is point N: from this point, draw the line ***NP*** and ***MN***. These two lines provide the needed answers: ***OP*** kgs/Ha of nitrogen (in this case 41.63 kgs/Ha) will produce ***OM*** kgs/Ha (59.11 kgs/ha.) of the crop. This level of nitrogen application will be more profitable than any other level at given prices for the particular crop and nitrogen. In other words, we have found the highest profit point and, therefore, the maximum recommended rate. At this level of application, the difference between the cost of applied fertilizer and the net income obtained is the greatest. Below the ***NP*** (41.63 N kg./ha.), the level, the farmer is not making maximum profit, and above ***NP*** (41.63 N kg/ha.), the farmer is wasting money on extra nitrogen, which produces no extra profit. The manner in which profit changes with varying levels of nitrogen can be seen in Table 6. 3.

With the maximum and minimum recommended rates of fertilizer calculated, we obtained the fertilizer range within which the credit agency, according to the availability of funds, can recommend to its farmers. This range of fertilizer is shown in figure 6.6.

The manner in which profit changes with varying levels of nitrogen can be seen in Table 6.3.

TABLE 6.3: NET INCOME FOR VARYING LEVELS OF NITROGEN APPLIED.

-1-	-2-	-3-	-4-	-5-
N applied Kgs/Ha.	Cost of N ($ 25/kg x Col. 1)	Yield obtained Kgs/Ha.	Total Income from Crop (Crop price = $88/kg)	Net Income (4) -(2)
0	25 x 0 =0	15.4	88 x 15.4 = 1179.2	1355.20
10	25 x 10 = 250	22.3	88 x 22.3 = 1962.4	1712.4
20	25 x 20 = 500	41.5	88 x 41.5 = 3652	3152
24	***25 x 224 =600***	***45.41***	***88 x 45.41 = 3,996.08***	***3,396.08 (Min. R.R.)***
30	25 x 30 =750	52.5	88 x 52.5 = 4620	3870
40	25 x 40 =1000	57.9	88 x 57.9 = 5095.2	4095.2
41.63	***25 x 41.63 =1040.75***	***59.11***	***88 x 59.11 = 5,201.84***	***4,161.09 (Highest Profit. Point)***
50	25 x 50 =1250.0	61.4	88 x 61.4 = 5403.2	4153.2

Figure 6.6: The Recommendable Range of the Fertilizer

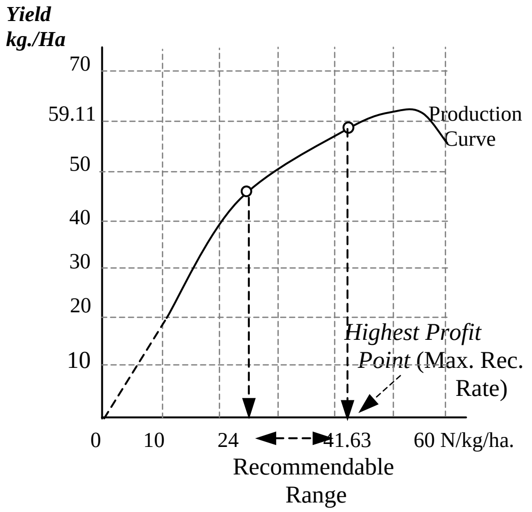
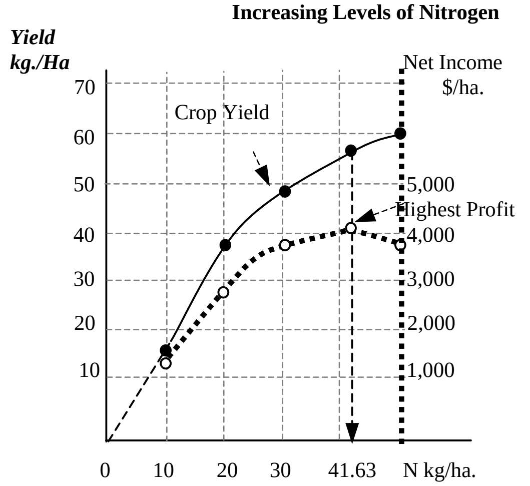


Figure 6.7: Change in Yields and Net Profits with Increasing Levels of Nitrogen



If we draw on a graph the yield and net profit a farmer obtains for increasing levels of nitrogen, we can note that although the yields continue to increase even after 41.63 kgs/ha. of nitrogen is applied, but net profit does not. (see Figure 6.7). At 41.63 kgs/ha. the farmer obtains the highest profit.

With the Max.R.R and Min.R.R of fertilizer calculated, we obtain the fertilizer range within which the credit agency, according to the availability of the funds, can recommend to its farmers. In our example this recommendable fertilizer range lies between 24 kgs/ha. and 41.63kgs/ha.

Use of the Highest Profit Point by the Credit Agency

If a credit agency has sufficient funds, it should extend credit so that farmers may apply fertilizer up to the highest profit point. Under no circumstances, however, should the agency give credit beyond this point. First of all, the farmer would obtain no higher profit from such a superfluous fertilizer application; secondly, the farmer would have a greater loan, with more interest to pay back and with no extra profits to facilitate this payment; and, thirdly the extra credit given to this farmer could have been allocated to other farmers who would have benefited from it.

A) Recommending Fertilizer *above* the Highest Profit Level

Let us assume, for example, that a credit agency has practically unlimited funds but is unaware of the highest profit point. This agency lends $ 41,250 credit to 30 farmers (each farmer having one hectare of land) to apply 50 kgs/ha. of nitrogen. Each farmer receiving (50 x $25) = $ 1,250 credit.

At this level of nitrogen, each farmer would produce 59.53 kgs/ha. of the crop; the profit he would receive would be:

Credit Extended to 30 farmers: *above* the highest profit point. Profit Per Farmer per Ha.		
Total Income =	59.53 x $88 =	$ 5,238.64/Ha
Cost of Fertilizer =	50 x $25 =	$ 1,250.00/Ha
	Net Profit =	$ 3,988.64/Ha

Total crop produced by 30 farmers = 59.53 kg./ha. x 30 = 1785.9 kgs.

If, however, the credit agency had known the highest profit point (41.63 kgs/ha.) and had extended credit only up to that point, the total credit extended to each farmer would have been: 41.63 x $25 = $ 1,040.75/ha.

The total amount of credit extended to these 30 farmers would be: $ 1,040.75 x 30 = $ 31,222.5. The credit agency would have been left with $ 41,250 - $31,222.5 = $ 10,027.5, which they could have lent to 9 (or 10 if they wanted to) other farmers. Moreover, the profit made by each farmer would have been:

Credit Extended to 30 Farmers: <u>*at*</u> Highest Profit Point Profit Per Farmer/ha.		
Total Income =	59.11 x $88 =	$ 5,201.84
Cost of Fertilizer =	41.63 x $25 =	$ 1,040.75
	Net Profit =	**$ 4,161.09 / ha.**

Each farmer made $172.45 extra profit by applying fertilizer up to the highest profit point. The farmer's net profit was even greater than this because he did not borrow money above the highest profit point and thus had less of a loan and less interest to pay back. It is also worth noting that a farmer who makes a greater profit is more disposed to pay a loan than one who makes a lesser profit.

Another important point, on the locality side is : 39 farmers receiving credit up to the Max R.R. would produce 380.79 kgs. more in total yield as compared to 39 farmers of which only 30 received credit up to 50 kgs./ha. of nitrogen and the other 9 not having received any credit at all.

B) <u>Recommending Fertilizer Level *below* Maximum Profit Level when funds are available</u>

Let us now consider another credit agency, equally well endowed with funds and equally ignorant of the use of the highest profit point. This agency gives 40 farmers credit to apply 25 kgs/ha. of nitrogen; the total for each farmer being (25 x 25) = 625.00. At 25.00 kgs/ha. of nitrogen each farmer produces 46.65 kgs/ha. of crop, the total production being (46.65 x 40) = 1866 kgs. The net profit made by each farmer is:

Credit Extended to 40 Farmers: <u>*above*</u> Highest Profit Point: Profit Per Farmer/Ha		
Total Income =	46.65 x $ 88 =	$4,105.20
Cost of Fertilizer =	25 x $ 25 =	$625.00
	Net Profit =	**$3,480.20 per Ha.**

If the credit agency had known the highest profit point, it could have allocated credit to 41.63 kgs./Ha (the highest profit point), and each farmer would have produced 59.11 kgs./ha. of the crop. Each farmer would have produced (59.11 – 46.65 =)12.46 kgs/ha. more of the crop, an increase in production of more than {[(59.11- 46.65) / 46.65]x100=}26 percent. This extra yield would have helped not only the individual farmer but also the country at large. In total 40 farmers would have produced (12.46 kg./ha. x 40=) 498.4 kgs. more of the crop when they received credit up to the Max. R.R. than they would have produced otherwise.

Furthermore, the farmer, by applying fertilizer up to the highest profit point, would have received ($4,161.09 – $3,480.20=) $680.8/ha. more profit than he did by applying only 25 kgs./ha. of nitrogen. Again an increased income for the farmer is an incentive to repay the loan, a fact which should be of interest to a credit agency concerned with improving its rate of recuperation.

4. PRACTICAL FERTILIZER RECOMMENDATIONS

In the course of this chapter we have discussed the means of determining the highest average product point and the highest profit point, on the bases of which a credit agency or foundation can recommend, respectively, the minimum and the maximum fertilizer levels. We know now that a foundation or agency should never provide credit or recommend to a farmer a fertilizer level below the highest average product point; nor should it recommend a level above the highest profit point.

In the example we have used throughout this chapter, 24 kgs./ha. of nitrogen gave the highest average product point on the curve. It is important to note here that if a *recommendation* for *minimum application* is made, it is better to *round up* the figure: in this case, the recommendation would be 25 kgs./ha. of nitrogen.

When, however, a *maximum fertilizer* recommendation is called for, it is better to recommend the exact figure. If the figure is going to be rounded then it is better if the figure is always *rounded down*. If the figure is rounded upwards, then there is a danger of the figure being increased and of the farmer losing money from that level of application rather than benefiting from it.

Minimum Recommendation: round <u>up</u> the fertilizer recommendation.
Maximum Recommendation: round <u>down</u> the fertilizer recommendation

5. EFFECT OF PRICE CHANGES ON FERTILIZER RECOMMENDATIONS

Although we have determined by collections that 41.63 kilos/ha. of nitrogen gives the highest profit, yet this quality is appropriate only for certain price of fertilizer ($25/kg.) and only for certain price of crop ($88/kg.). If the price of either fertilizer or crop should change, then the new " iso- profit" fraction must be recalculated and a new " iso- profit" line must be drawn. If, for example, the price of fertilizer were to increase from $ 25/kg. to $ $259.6/kg. but the price of the crop would to remain constant at 88 /kg. The "iso-profit" fraction would be:

$$\frac{259.6}{88.0} = 2.95$$

The new "iso-profit" line, when drawn would touch the production curve only at a point , i.e. at the axis, as shown in figure 6.8. In this case, it would not be profitable for the farmer to apply any fertilizer at all: he would lose more from the cost of the fertilizer than he would gain from its application. Similarly, no fertilizer should be recommended as long as the " iso- profit" line touches the production curve to the left of point G (which is below the minimum recommended rate): below this point, it is more profitable to apply no fertilizer than it is to apply any fertilizer at all.

Figure 6.8: Fertilizer Recommendations With *High* Fertilizer Prices and *Low* Crop Prices (*No Fertilizer Recommended)*

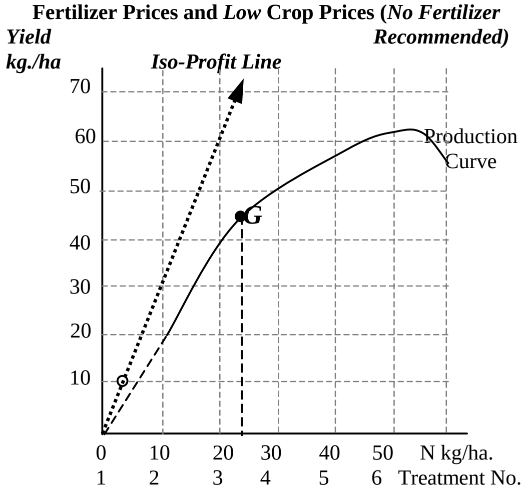
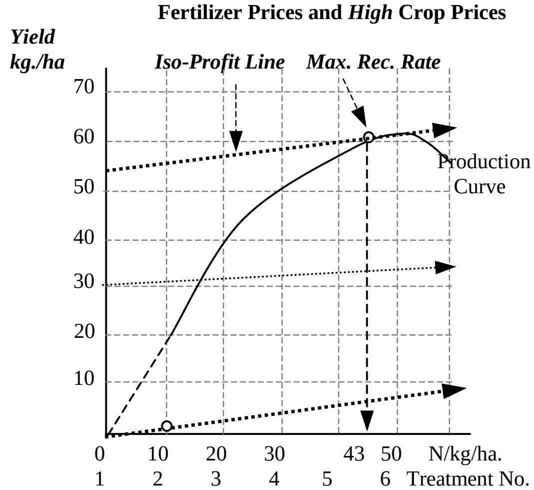


Figure 6.9: Fertilizer Recommendations With *Low* Fertilizer Prices and *High* Crop Prices



On the other hand, if the price of fertilizer were to rise only moderately say up to $28.00/kg. but the price of the crop were to increase considerably, say up to a $140 per kg., then the " iso-profit" fraction would be:

$$\frac{28}{140} = 0.2$$

In this case, the " iso-profit" line would be nearly parallel to the horizontal axis, meaning that, at these prices, the level of fertilizer which would give the maximum biological rate is also the one which would nearly give the highest profit (see figure 6.9). In such a situation, the farmer should be recommended to apply 43.0 kgs/ha. of nitrogen (or very slightly less).

Which Prices to use in calculating the "iso- profit" fraction

Since prices of crops and fertilizer tend to alter more often and more drastically than ever before, one may wonder what prices to use in calculating the " iso- profit" fraction.

As regards fertilizers, the prices that exist two months before the time of application can be used without risk; it is unlikely that prices would alter significantly before the fertilizer is applied.

This rule does not apply, however, to the prices of crop: it will be several months before the crop is harvested and probably more before it is sold. If the price of the crop were to change during that time, the "iso-profit" fraction would also change. This problem is further complicated by the fact that the price at which the farmer sells his crop will vary. A farmer who sells immediately after the harvest is likely to get a lower price than one who sells at a later date.

Where crop prices are fixed by the government- as is the case with rice in the Dominican Republic and Guatemala--, the minimum government prices can be used without risk in the " iso- profit" fraction. A similar situation is found for when a farmer and a buyer have previously agreed on a price, as for example, when a crop has already been contracted for industrial processing.

When neither of the above cases applies, however, the credit agency should ask the government officials to what they think the price of crop in the future would be: they are more likely to be aware of it as they are more likely to be familiar with trends in price changes.

6. WHAT TO DO IF THE MAXIMUM RECOMMENDED RATE IS ABOVE THE NUTRIENT LEVEL IN THE TRIALS?

In our fertilizer field trials, we used levels of nitrogen from 10 kgs/ha. to 50 kgs/ha. For given prices of the crop and fertilizer, we calculated that the maximum recommended rate (also called the highest profit point) which was 41.63 kgs/ha. of nitrogen because this recommendation was within the range of the levels of nutrients be used in the trials.

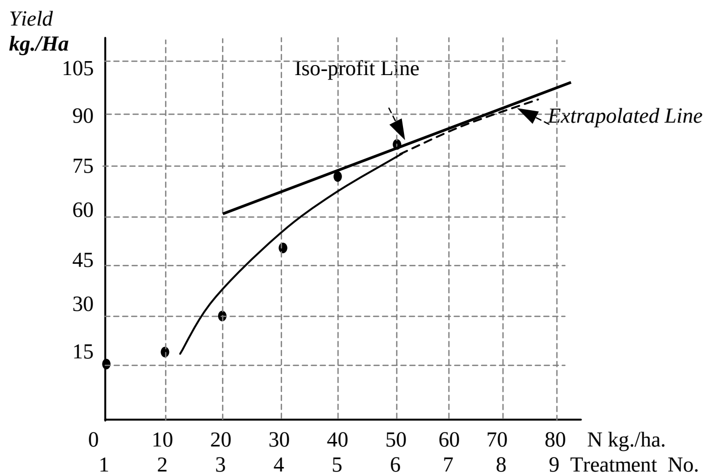
But what would we have recommended if the yields obtained from the trials had been as shown below.

Table 6.4: Yield results (kgs /ha.)

Treatment number	level of nitrogen kg/ha.	Average yield (kg/ha.)
1	0	15.4
2	10	17.5
3	20	30.0
4	30	54.1
5	40	70.3
6	50	83.1

If we wish to determine the maximum recommended rate from the production curve on a graph, we see that the " iso- profit" line cannot be drawn tangential to the curve until it is drawn above levels of 50 kgs/ha. of nitrogen. However, in the field trials, the highest level of fertilizer we used was 50 kgs/ha. If you were going to determine from the graph what the yields would be when the level is above 50 kgs/ha., what we are really doing is trying to determine what the yields may be if the level of nitrogen is above 50 kgs/ha. but we can not be sure of what the yields would be above 50 kgs/ha. of nitrogen because we never had a treatment with nitrogen above that level. How can anyone know whether the actual yield of say 80 kgs/ha. of nitrogen would be considerably higher or even considerably lower than when 50 kgs/ha. of nitrogen were applied. When we try to determine what the yield would be for levels of nutrient above or below what were actually used in the trials it is referred to as the *extrapolation*. For example, in figure 6.9B the broken line part of the production curve is the extrapolated part of the curve.

Figure 6.9B: How to Draw to an Extrapolated Line



What should be done then in such a situation? In this case, recommend for the following year that the farmer use 50 kgs/ha. of nitrogen as its maximum recommended rate. We know for sure that when the level of nitrogen is 50 kgs/ha. the farmer would obtain 83.1 kgs/ha. In spite of the fact that our extrapolated production curve tells us that 65 kgs/ha is the maximum recommended rate (the highest profit point), we just cannot expect the poor farmer to gamble and apply a quantity of fertilizer the yield of which is doubtful even to the credit agency. It is therefore suggested that one never recommend any fertilizer application above the maximum level that was tried in the fertilizer field trials.

But we can use the results of the calculations to know what should be the level of nutrients in the trials in the following year. The maximum recommended rate of fertilizer is calculated from the graph as 83 kgs/ha. So the next year, set up the fertilizer trials using the predicted value of the maximum recommended rate (in this case 83 kgs/ha.) as one of the middle treatments. The following year treatments, therefore, can be as follows:

Table 6.5

Treatment Number	Level of Nitrogen kgs/ha.
1	0.0
2	Farmers Practice
3	83.0
4	93.0
5	103.0
6	113.0

7. ECONOMIC ANALYSIS OF THE STATISTICALLY SIGNIFICANT TREATMENTS WITH TWO OR MORE NUTRIENTS

In the fertilizer field trials conducted on the farms in Chapter 5, only a limited number contained two or more nutrients: treatment 7 with 20 kgs. of nitrogen and 20 kgs of phosphate; treatment 8 with 20 kgs. /Ha. of nitrogen and 20 kgs /Ha. of potassium; and treatment 9 with 20 kgs. /Ha of all the major nutrients (***N,P,K***).

Of the above, treatment 7 (20 kgs /Ha of nitrogen and potassium) and treatment 9 (with 20 kgs. /Ha. of N, P and K) proved to be statistically significant as proved by the "t" test in Chapter 5. In the same chapter, we also noted from the calculations to limits to confidence that a farmer is likely to obtain higher yields from treatment 7 and 9 (as compared to the yields obtained from a treatment 3) 4 out of 5 times unless one chance and 5 comes out. But even such frequent chances of obtaining high yields, treatment 7 or 9 should only be recommended to the farmers after economic analysis of each treatment (that proved to be statistically significant) has first been conducted. In the economic analysis of treatment 7 and 9 that follows, the prices mentioned below have been used throughout:

Price of crop = $ 88.0/kgs.
Price of nitrogen = $25/kg.
Price of phosphate = $5.0/kg.
Price of potassium = $19.0/kg.

A) Economic analysis of treatment 3 (20 kgs/ha.)

Yield obtained by the farmer when applying 20 kgs /Ha of Nitrogen = 43.10 kgs /Ha.		
Gross Income of the farmer =	43.10 x $ 88 =	$ 3,792.80 /Ha
Cost of fertilizer (20 kgs. of nitrogen) =	20 x $25 =	$ 500.00/Ha.
Net profit obtained by the farmer =		$ 3,292.80 /Ha.

B) Economic analysis of treatment 7 (20 kgs. of nitrogen + 20 kgs. of P).

Yield obtained by the farmer when applying treatment 7 = 45.2 kgs. /Ha.		
Gross Income of the farmer =	45.20 x $88 =	$3,977.60 /Ha
Cost of applying treatment 7 (20 kgs. of N + 20 kgs. of P) =	(20 x $25)+(20x $5) =	$ 600 .00/Ha.
Net profit from applying treatment 7 =		$ 3,377.60 /Ha.

The benefit of using treatment 7 rather than treatment 3 is

Net Profit from Treatment 7 =	$ 3,377.6
Net Profit from Treatment 3 =	- $ 3,292.8
	$ 84.8/ Ha

This increase in profit is not much. But for a farmer with small holding even this small increase would be most welcome. As the farmer is likely to obtain this profit more than 19 out of 20 times (95% level of confidence) if he applies treatment 7, the credit agency can safely suggest to the farmers of that community to use treatment 7 the following year.

Treatment 9 (20 N + 20 P + 20 K) also produced yields which were statistically significant at 95% levels of confidence. But, again the agency should not recommend this treatment until the economic analysis have been conducted.

C) Economic analysis of treatment 9 (20 N+ 20 P+ 20 K):

Yields obtained by the farmer by applying treatment **9** = 45.30 kgs. /Ha.		
Gross profit made by the farmer from using treatment 9 =	45.30 x $88 =	$3,986.40
Total cost of treatment 9 =	=(20 x $25)+(20 x $5)+(20 x $19)=	- $980.00/ha.
Net profit made by the farmer from using treatment 9 =$3,986.40 - $980 =		**$3,006.40 /ha**.

The net benefit of using treatment 9 over treatment 3 is shown below.

Net Profit from Treatment **9**:	$ $3,006.40
Net Profit from Treatment **3**:	- $ 3,292.80
	- $ 286.40

By using treatment 9, it can be seen that rather than increasing the farmer's income, it leaves him poorer by $286.00. He would be even poorer if we take into account that the farmer would also have to pay interest on the more expensive fertilizer. The extra nutrient in treatment 9 (potassium in this case) contributed to high crop yields which were statistically significant, but due to a high price of the nutrient it is uneconomical for the farmer to include it in his fertilizer application.

Hence, even if a fertilizer treatment may give yields which are statistically significantly higher, it should not be recommended unless it can be proven to be profitable for the farmer to apply it.

8. ECONOMIC ANALYSIS OF TRIALS WITH 2 OR MORE NUTRIENTS

In some cases we may need to determine the recommendable range of fertilizer when the treatments may contain two or three nutrients. In a particular locality, say for instance, soil tests indicated that potassium (K) was available in abundance in the soil; phosphate (P) was present in the soil but not in nearly sufficient amounts; and nitrogen was considerably lacking in the soil. With this information, the trials containing nitrogen and phosphate where set up: the treatments selected and the average yield of 3 replications were as shown in Table 6.6.

Table 6.6: Fertilizer trials containing 2 nutrients (kg. /ha)

Treatment Number	N	P	Average Yield (kg. /Ha)
1	0	0	18.5 Control and farmer's practice
2	10	20	32.3
3	20	20	49.0
4	30	20	56.4
5	40	20	65.8
6	50	20	62.0

Statistical analysis of the results

The yield results of table 6.6 were statistically tested by the means of analysis of variance (see Chapter 5). The calculations indicated that there **was** a significant difference in the yields indicating that as the nutrient levels were increased, so was the response of the crop to the nutrient. Now we can conduct the economic analysis.

Fitting the graph to the results of the field trials

As the level of phosphate in all the treatments is constant (20 kgs./ha.) and the levels of only nitrogen are varied, then the procedure for fitting the graph to the results is the same as demonstrated earlier. NOTE: that once again the "check" are different from the calculated average yields. (See Fig. 6.10B).

Figure 6.10A: Yields Obtained from the Trials Containing *Two* Nutrients

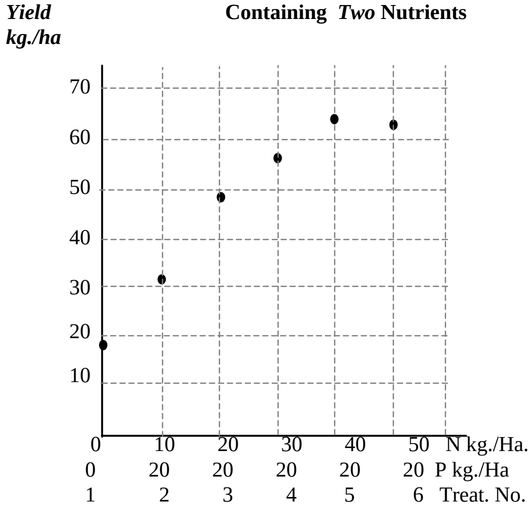
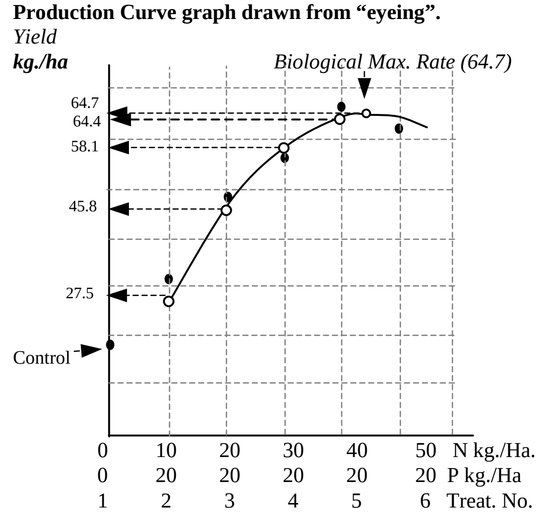


Figure 6.10B.: "Check" yields are read from the Production Curve graph drawn from "eyeing".



A) <u>Biological maximum rate of Fertilizer</u>

When calculating the biological maximum rate the prices of the crop and the fertilizer nutrients are consider zero.

Table 6.7: Yields read from the graph (Figure 6.10 B)for varying levels of nutrients

	Treatment Number					
	1	2	3	4	5	6
Nutrients Contained	0 N 0 P	10 N 20 P	20 N 20 P	30 N 20 P	40 N 20 P	50 N 20 P
"Check Yields"	3.27	27.50	45.8	58.1	64.4	64.7

We can see from figure 6.10B that when the fertilizer contains 45.5 kgs./ha. of nitrogen plus 20 kgs/ha. of phosphate, the maximum biological yield that we can possibly obtain is 64.70 kgs./ha. Hence, even if the fertilizer is given free to the farmer he should not apply more than 45.5 kgs /ha. of nitrogen and 20 kgs./ha. of phosphate in his fertilizer.

B) <u>The minimum recommended rate</u>

To obtain the minimum recommended rate from the average yield of the controlled treatment to the production curve. From the point at which the tangent touches the production curve we obtain the minimum recommended rate (the highest average product point) of the fertilizer mixture. From figure 6.11A it can be seen that the minimum recommended rate of fertilizer which the farmer should apply to his land and to that particular crop must contain at least 21.5 kgs /ha. of nitrogen and 20 kgs /ha. of phosphate.

Figure 6.11A.: Determining the *Minimum* Recommended Rate for Mixed Fertilizers (ie. the Highest Average Product Point)

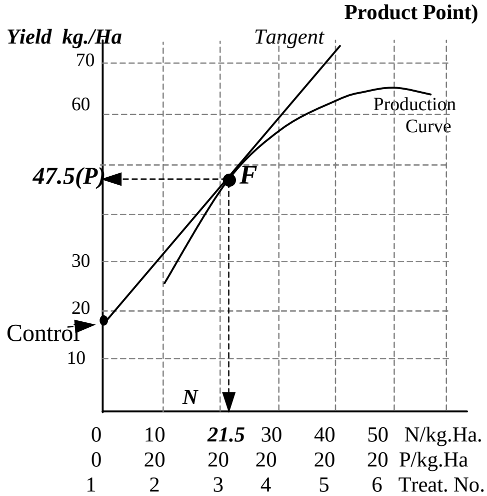
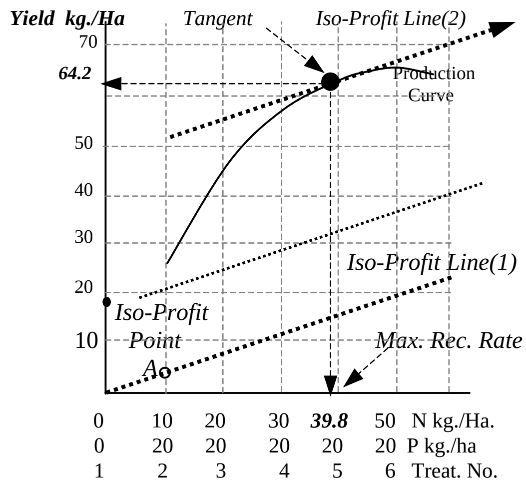


Figure 6.11B: Determining the *Maximum* Recommended Rate for Mixed Fertilizers (ie. the Highest Profit Point)



C) The Maximum Recommended Rate of Fertilizer (Max. R.R.)

The procedure for determining the maximum profit point (the maximum recommended rate) is also the same as for determining the Maximum R.R. for a single nutrient. The only difference is that the "iso-profit" fraction should contain the price of all the nutrients in the fertilizer. For the two nutrients in this experiment the "iso-profit" fraction is:

$$\text{"Iso-profit" Fraction} = \frac{\text{Price of Nitrogen / kg.} + \text{Price of Phosphate / kg.}}{\text{Price of crop / kg.}}$$

If the price of the nutrients and the crop is the same as mentioned earlier ($ 25 for Nitrogen/kg. , $5 for Phosphate/kg. and $88.0 for the crop/kg.) then the "iso-profit" fraction is:

$$\text{"Iso-profit" Fraction} = \frac{\text{Price of Nitrogen / kg.} + \text{Price of Phosphate / kg.}}{\text{Price of crop / kg.}} = \frac{\$\,25 + \$\,5}{\$88} = 0.34$$

To obtain the "iso-profit" point, it means that for every 1 unit we move on the horizontal axis we should move 0.34 on the vertical axis. Or if we move (1 x 10=) 10 units on the horizontal, we should move (3.4 x 10=) 3.4 on the vertical axis.

When the "iso-profit" line is drawn on the production curve, we obtain the maximum recommended rate of the mixed fertilizer which the farmer should apply.

From the graph we can see that to obtain the maximum profit, a farmer should apply 39.8 kgs. /Ha. of nitrogen and 20 kgs /ha. phosphate in his fertilizer to the crop on his land.

To confirm that only 39 kgs/ha. of nitrogen plus 20 kgs/ha. of phosphate would give the highest profit, we can calculate the profits a farmer would make for varying levels of nitrogen plus 20 kgs of phosphate. We did the same type of calculations for six treatments containing only nitrogen. It can be observed that when the level of nitrogen is 39 kgs/ha. plus 20 kgs /ha. phosphate the highest profit to the farmer would result.

If he had three nutrients in the treatments, the procedure for determining the biological, minimum, and maximum recommended rates would be the same as for two nutrients above.

SUMMARY

From this chapter we can see that there is a minimum amount of fertilizer that the farmer should apply if he is to benefit economically. We also see that the level of fertilizer at which the farmer would obtain the maximum output (the maximum biological level) may in fact leave him poorer than before, since the cost of that much fertilizer would be greater than the income the farmer would earn as a result of his larger crop yield. We also noted that there is *maximum* profit level of fertilizer which the farmer should apply that will give him the maximum profit. Finally, in this chapter, we saw how a credit agency, knowing the minimum and the maximum levels of fertilizer, can allocate its credit in such a manner that each farmer maximizes his profits, the community enjoys greater crop yields, and the credit agency is more likely to recoup its loans and hence continue to help farmers the following season.

SUMMARY OF STEPS TO DO THE ECONOMIC ANALYSIS OF FERTILIZER FIELD TRAILS
1) Make a table of the 6 fertilizer treatments for the three blocks as it was done for one nutrient on page 126. If the fertilizer field trails were statistically significant do the next step.
2) Do the *averaging* of the fertilizer treatments.
3) Put the values from the averaging table on to a graph.
4) Draw a graph using the "eyeing" method.
5) Calculating the *Minimum* Rec. Rate (where average is the highest): Draw a tangent to the Production curve from the control yield.
6) Calculating the Maximum Rec. Rate (where profit is maximum): i)*Know the cost of the following*: a) nitrogen, b) potassium, c) phosphate, d) crop that is grown, and e) of any micro-nutrients that needs to be included in the fertilizer.
ii) *Calculate the " iso-profit" fraction:* = Total cost of fertilizer to be applied per kilo. / Total Price of the crop grown per kilo.
iii) Draw the "iso-profit" line until it is tangent to the production curve. This gives us the maximum Rec. Rate of fertilizer.

APPENDIX Ch. 6-1.

1. RELATIONSHIP BETWEEN AVERAGE PRODUCT AND AVERAGE VARIABLE COST CURVES

Naturally, the amount produced (also called yield, output or Total Product (TP)) is related to the number of variable inputs that are used (e.g. the number of bags of fertilizer). The more variable inputs we apply (e.g. the more bags of fertilizer applied), the greater will be the total variable cost (TVC). If TP is linked to inputs, and TVC is also linked to inputs, then the TP curves (average product -AP) must also be linked to the AVC curves (average variable cost). This relation is exactly what we will be looking at here.

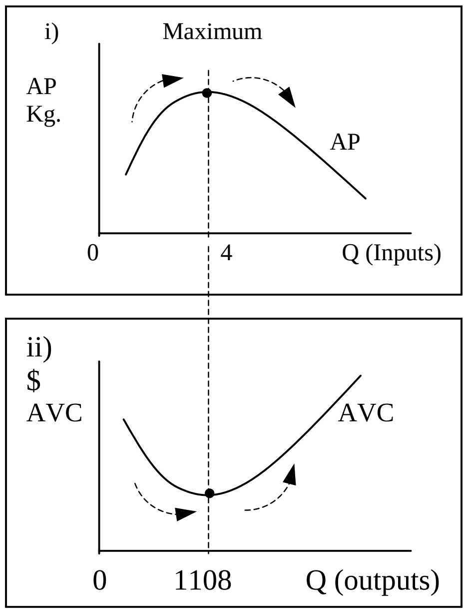
Let us assume that we know only the inputs, the outputs, and the cost of each variable input (bag of fertilizer -$12.20/bag), is as shown in table 1 below. The rest of the information--, average product-AP, TVC, and average variable cost-AVC --can be calculated from just this limited information. Remember, when we draw the production function, we put variable inputs on the horizontal axis and output on the vertical axis. And when we draw cost curves, we put output on the horizontal axis and costs on the vertical axis.

Let us assume that cost of bag of fertilizer is $12.20 (cost of the variable input).

Table 1: Relationship Between AP and AVC

1(Given)	2(Given)	3=(2/1)	4(Given)	5=(1x4)	6=(5/2)
Input	**TP (Output) kg./Ha**	**AP**	$12.2/unit	**TVC**	**AVC**
0	0	---	12.20	0	---
1	106	106.00	12.20	12.20	1.15
2	322	161.00	12.20	24.40	0.76
3	740	246.67	12.20	36.60	0.49
4	***1108***	***277.00***	***12.20***	***48.80***	***0.44***
5	1280	256.00	12.20	61.00	0.48
6	1390	231.67	12.20	73.20	0.53
7	1450	207.14	12.20	85.40	0.59

Figure 1: Mirror Images of AP and AVC .



As AP increases, AVC decreases. When AP reaches its maximum at 277 units and 4 units of inputs, AVC is at its minimum at $0.44 units at 1108 units of output and when AP decreases, AVC increases. In other words, output curves are the mirror images of cost curves--that is, they stand in inverse relation. For this reason, a farmer (or for that matter any firm) should never apply any input below the point where AVC is less than its minimum. (See Table 1 above.)

Ch. 6

STUDY GUIDE QUESTIONS

The yields (kgs./ha.) from the fertilizer field trials were as shown in Table 1.

	Treatment No.					
Block No.	**Control**	**10N**	**20N**	**30N**	**40N**	**50N**
1	12	31	27	42	52	48
2	13	29	25	39	54	51
3	10	33	28	34	49	49

a) Calculate the average yield for each treatment;
b) Draw a production curve using the "eyeing" method; and
c) From the graph drawn read the "check" yields.

	Treatment No.					
Block No.	**Control**	**10N**	**20N**	**30N**	**40N**	**50N**
1	12	31	27	42	52	48
2	13	29	25	39	54	51
3	10	33	28	34	49	49
	35	93	80	115	155	148
	÷ 3 =	÷ 3 =	÷ 3 =	÷ 3 =	÷ 3 =	÷ 3 =
Average	11.67	31.00	26.67	38.33	51.67	49.33

Figure 6.1A: Yields Obtained from the Trials

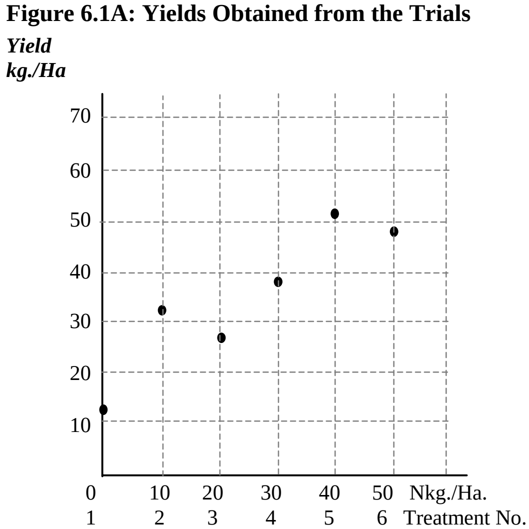
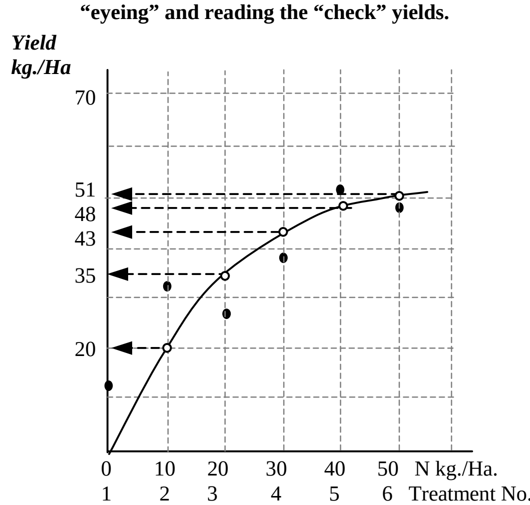


Figure 6.1B. Obtaining of the Production curve by "eyeing" and reading the "check" yields.



C)	Treatment No.					
	Control	**10N**	**20N**	**30N**	**40N**	**50N**
"Check" Yields kg./ha.		20	35	43	48	51

Chapter 7

THE USE OF FERTILIZER ECONOMIC ANALYSIS IN THE CREDIT PROGRAM

1. INTRODUCTION

Having conducted the economic analysis of the fertilizer production functions, the credit agency is in a position to use the results towards more efficient allocation of credit, benefiting in this way not only the farmer but the agency itself and the country as a whole. Equipped with all the information provided by the field trials and the economic and statistical analysis, the agency can now provide credit, knowing that it will:

- **i)** Increase farmers' crop yields and therefore increase national output;
- **ii)** Offer farmers the opportunity to make the maximum profit from the credit;
- **iii)** Finance enough projects to keep the extension agent(s) employed to best advantage;
- **iv)** Create more work-hours for the farmers and other people, thus combating the high unemployment and underemployment in rural areas; and
- **v)** Reduce the chances of bad loans and thus also the rate of delinquent loans.

To demonstrate the way in which the economic analysis of fertilizer production functions fulfills the above objectives, we shall analyze the results of loans in two localities, A and B, first with aid of field-trials and, secondly, without the field-trials, on the basis of general fertilizer recommendations.

The reader should be familiar by now with the procedures for calculating the minimum and maximum recommended rates of fertilizer, and for evaluating fertilizer combinations, by graphic method. In our present analysis, then, to eliminate unnecessary new calculations, we shall assume that the results of the field trials were the same as those obtained in chapters 5 and 6.

In **locality A**, we will say, the field trials showed that nitrogen was lacking in the soil and that, when nitrogen was applied, the yields were those given in chapter 6. But, unlike the case studied in chapter 6, none of the fertilizer treatments containing mixed nutrients gave yields higher than those produced by applying nitrogen alone.

In **locality B**, the field trials showed that two nutrients – nitrogen and phosphate – were lacking. In this case, the yields obtained were the same as those given in chapter 6.

In the absence of fertilizer field-trials, a credit agency usually recommends a fertilizer mixture sold by a commercial firm. As a rule these firms manufacture only one fertilizer for a given crop, regardless of the part of the country where that crop is grown. Let us assume that, in the case of localities A and B, the firm used good judgment in mixing its fertilizer and offered a grade of 30-40-0 (i.e., 30 kgs./ha. of nitrogen and 40 kgs./ha. of phosphate).

Even with good judgment, however, we will soon see how inefficient such recommendations can be when compared to recommendations made on the basis of field-trial results.

The comparison will be made in the context of three distinct situations: when the credit agency has:

- **i)** Limited funds for credit;
- **ii)** Sufficient funds; and

iii) Unlimited funds.

In our comparison of the two lending procedures (shown in detail in Table 1.)– one following field-trials and the other following a general recommendation – we shall make the following assumptions, for convenience:

i) The extension agent can provide effective service to 15 farmers a year.

ii) In both localities, A and B, the average farm holding is 1.0 hectare in area.

iii) The agency has a storage unit of its own, so it can buy the individual nutrients wholesale (in bulk), and equipment to mix the nutrients as required. The costs of storage and personnel for mixing are equal to the money saved by purchasing wholesale.

iv) The process of the crop and nutrients are those used throughout this book (**See Table 1 –Step 1-A to 1-C):**

Price of crop = $88/kg.
Price of nitrogen = $25/kg.
Price of phosphate = $5/kg.

1. COMPARISON OF LENDING PROCEDURES WHEN FUNDS ARE LIMITED: LOCALITY A

We are assuming that the credit agency's funds are limited and that it decides to allocate $10,000 to locality A. Now let us calculate the results of these allocations:

(i) where credit was given on the basis of general fertilizer recommendations and only some farmers got the credit. (**Table 1: Step II - from Step 4 to Step 9**).

(ii) where field-trials had been conducted, and all the 15 farmers received some funds to buy fertilizer. (**See Table 1: Step 10 to Step 12**).

i) <u>Results Of Credit Given Without Field-Trials (Locality A)</u>

(Table 1:Steps 4 to 9B)

Let us look at the consequences when credit is extended for the purchase of the factory-made fertilizer, grade 30-40-0. The price of the fertilizer (**Table 1B: 4-A to 4-D**) is calculated as follows:

Nitrogen 30 kgs. x $25 =	$ 750
Phosphate 40 kgs. x 5 =	$ 200
Total cost =	$ 950

The farmer is advised to apply 30 kgs. of nitrogen and 40 kgs. of phosphate to his 1-hectare holding at a cost of $950. Since the agency only has $10,000 (**Table 1B: Step 3-A**) to spend, it is easy enough to calculate how many hectares it can serve with that amount:

$$\frac{10{,}000}{950} = 10.53 \quad \textbf{(Table 1B: Step 5-A)}$$

In other words, only 10.53 hectares (roughly) can be adequately fertilized. This leaves nearly 4.47 hectares (**Table 1B: Step 5-B**) without fertilizer and an extension agent with time on his hands.

Neither the agency nor the fertilizer firm nor the farmer would know what yield to expect from the application of mixture 30-40-0. We know, however, from the field trials (Figure 6.1C-Chapter 6) that the soil in this locality already has plenty of phosphate and that the only nutrient lacking is nitrogen. And it has already been confirmed that 30 kgs./ha. of nitrogen will produce a yield of <u>52.5 kgs</u>./ha. (Figure 6.1C-Chapter 6). Thus a single farmer's profit will be as follows:

Total Revenue/Ha. = (52.5 x $88 =) $ 4,620 (**See Table 1B: Step 6-A**).

Further calculations show us that the total net profit from 10.53 hectares receiving fertilizer is (10.53 x $ 3,670 =) $38,631, (taking into account rounding error: **Table 1B: Step 6-C**).

The total crop yield from the fertilized part of Has. (10.53 x 52.5 =) is 552.63 kgs.(**Table 1B: Step 8-A**).

But we should not forget to include the yields from the land which, because of lack of funds, received no fertilizer. Of the 15 hectares, only 10.53 received fertilizer, leaving (15-10.53=) 4.47 hectares (Table 1B: Step 5-B). From the latter the yields were 15.4 kgs./ha., according to Table 6.1 (Table 1B: Step 2-A). Therefore the gross income (and the net too, since no fertilizer costs were incurred) would be (15.4 x $88 =) $1355.20 per ha. (Table 1B: Step 7-A) ; and the total income from all the unfertilized land: (4.47 x $1355.20 =) $6,062. (Table 1B: Step 7-A).

All the yields, costs and profits of the 15 farmers who did and did not have the benefit of field-trials, are shown in Table 1B: Steps 8-A to 9-B.

ii) Results of Credit Given on the Basis of Field Trials (Locality A): (Table 1B Steps 10 A to 12 C)

First of all, the agency knows from the field trials that to apply phosphate or potassium in this locality would be a waste of money since none of the trials containing mixed nutrients proved to be statistically significant.

Secondly, the agency knows that its extension agent can supervise 15 farmers in a locality. Thus each farmer can receive

$$\frac{\$\,10{,}000}{15} = \$\,666.67$$ (**Table 1B: Step 10-A**)

Since the field trials clearly showed that only nitrogen was lacking in the soil, then, according to the price of nitrogen given above, each farmer can buy 26.67 kgs. of nitrogen (Read from Ch.6 Fig. 6.1-C).

$$\frac{\$\,666.67}{\$\,25} = 26.67 \text{ kgs. of nitrogen.}$$ (**Table 1B:Step 10-B**)

If we consult Figure 6.1C, in chapter 6, we find that 26.67 kgs./Ha. is above the minimum recommended rate, so there is no need for the farmers to limit their fertilizer application to only a part of their land. Figure 6.1C, in chapter 6, also shows us that when 26.67 kgs./ha. of N is applied, each farmer would produce 48.5 kgs./ha. of the crop (Table 1B: **Step 2-C**). His net profit is shown is in **Table 1B: Step 12-A to 12-C**.

Calculating further, we find that the total net profit of all 15 farmers is (15 x $ 3,601.25=) $54,018 (but for rounding error **- Table 1B: Step 12-C**). Their total crop yield comes to (48.5 x 15=) 727.5 kgs./ha. (**Table 1B: Step 11-A**).

Now we are in a position to compare which of the two credit policies gave the best results. The results for locality A, with and without field-trials, are summarized in Table 1A and Table 1B.

Summary of steps in Table 1A. Results may differ due to rounding error.

Locality A: WHEN FUNDS ARE LIMITED -Table 1A		
Steps: 1A to C	Price of inputs and crop:	
Steps: 2A to C	Yields from different levels of fertilizer applications.	
	Amount of Credit available:	
Steps: 3A	Total amount of funds available from the credit agency = $10,000	
Steps: 3-B	Number of farmers wishing to have loans = 15	
Steps: 4 to 9. **I.**	**RESULTS FROM FACTORY RECOMMEDED FERTILIZER 30N-40P, WITHOUT FERTILIZER TRIALS**	
Steps: 4A to D	Cost of Fertilizer:	
Steps: 5A to B	Amount of Fertilizer that can be bought by $950	
Steps: 6A to C	Net Income /Ha. from 30N-40 factory recommended fertilizer.	
Steps: 7A to C	Net Income /Ha. when no fertilizer was applied.	
Steps: 8A to C	Total Yield from 15 Ha. (With and Without Fertilizer)	
Steps: 9A to B	Total net income from 15 Ha. Average Income from 15 Has.	
Steps 10 to 13 II.	**RESULTS FROM FERTILIZER APPLICATION AFTER FIELD TRIALS.**	
Steps: 10A to B	Amount of Credit available/Ha. :	
Steps: 11	Yield Obtained/Ha.	Total Yield from 15 Ha.
Steps: 12A to C	Net Income/ Ha.:	Total Income from 15 Ha.
III. **Steps: 13A to B**	**COMPARISON OF FERTILIZER APPLICATION WITH FERTILIZER FIELD TRIALS (FFT) AND WITHOUT FERTILIZER FIELD TRIALS.**	

Now the above calculations are shown in detail in Table 1B.(In some calculations figures have been rounded).

Locality A : WHEN FUNDS ARE LIMITED -Table 1B	
Step -1	**Price of inputs and crop:**
Step 1-A	Cost of N = $ 25/kg.
Step 1-B	Cost of P = $5/kg.
Step 1-C	Price of crop = $88 kg.
	Yields from different levels of fertilizer
Step 2-A	i) Yield when no fertilizer is applied = **15.40** kg./ha (from Table 6.1 –Chapter 6)
Step 2-B	ii) Yield from 30N-40P Kgs./Ha. of factory recommended fertilizer = **52.5** kgs/Ha. of (Fig. 6.1C –Chapter 6).
Step 2-C	iii) Yield when applying **26.67** N kgs./Ha. fertilizer = **48.50** kgs./Ha. (Read from Fig. 6.1C -from chapter 6).
	Amount of Credit available :
Step 3-A	Total amount of funds available from the credit agency = $10,000
Step 3-B	Number of farmers wishing to have loans = 15
I. **(Steps 4A to 9B)**	**RESULTS FROM FACTORY RECOMMEDED FERTILIZER 30N-40P, WITHOUT FERTILIZER TRIALS**
	Cost of Fertilizer:
Step 4-A	Factory recommended fertilizer = 30 N and 40 of P
Step 4-B= *(Step 4A x 1A)*	***Quantity* x *Price/kgs.* = *Total Cost*** Nitrogen = 30.00 x $ 25.00 = $ 750.00
Step 4-C= *(Step 4A x 1B)*	Potassium = 40.00 x $ 5.00 = $200.00
Step 4-D= *(Step 4B + 4C)*	**Total cost of fertilizer** = $ 950.00
	Amount of Fertilizer that can be bought by $950

Step 5-A = *(3A/4D)*	Number of Ha. on which fertilizer can be applied = 10,000 / $950 =**<u>10.53</u>** Ha.	
STEP 5-B = *(Step 3B-5A)*	Number of Ha. without fertilizer = 15 – 10.53 = **<u>4.47 Ha</u>**.	
I.A **(Steps 6A to 6C)**	**Net Income /Ha. from 30N-40 factory recommended fertilizer.**	
Step 2-B *(Repeated)*	Yield/Ha. when applying 30N-40P of factory recommended fertilizer = is **<u>52.50</u>** kgs/ha. (Read from Fig. 6.1C -from Chapter 6.)	
	<u>Quantity</u> x **<u>Price</u>** **<u>Total/Ha.</u>**	**<u>Total for 10.53 Ha</u>**.
Step 6-A = *(2B x 1C)*	Total Revenue /Ha = 52.5 x $88 = $ 4,620	4,620 x 10.53 = 48,631
Step 6-B = *(1 x 4D)*	Total cost of the fertilizer/Ha = 1 x $950 = $ <u>950</u>	Total Cost = 10,000
Step 6-C= *(Step 6A + 6B)*	**Net Income of /Ha = $ <u>3,670</u>**	**<u>= $ 38,631</u>**
I.B **(Steps 7A to 7C)**	**Net Income /Ha. when no fertilizer was applied.**	
Step 2-A *(Repeated)*	Yield/Ha. with no fertilizer = **<u>15.40</u>** kgs/Ha. (Read from Fig. 6.1C -from Chapter 6.)	
Step 7-A = *(2A x 1C)*	***<u>Quantity</u>*** *x* ***<u>Price</u>*** ***<u>Total/Ha.</u>*** Total Revenue /Ha = 15.40 x $88 = $ 1,355.20	***<u>Total for 4.47 Ha</u>.*** 1,355 x 4.47 = $6,062
Step 7-B	Total cost of the fertilizer/Ha = 1 x $0.00 = $ <u>0.00</u>	0 x 4.47 = <u>$ 0</u>
Step 7-C = *(Step 7A - 7B)*	**Net Income of /Ha** = $ 1,355.20	**<u>= $ 6,062</u>**
I.C **(Steps 8A to 9B)**	**Total Yield from 15 Ha. (With and Without Fertilizer)**	
Step 8-A = *(2B x 5A)*	***<u>Quantity</u>*** x ***<u>Area</u>*** = ***<u>Total</u>*** Total yield from (10.53 Ha.) of fertilized land = 52.5 x 10.53= 552.63 kgs.	
Step 8-B = *(2A x 5B)*	Total yield from un fertilized land = 15.40 x 4.47= <u>68.89</u> kgs.	
Step 8-C = *(Step 8A+8B)*	Total Yield from 15 Ha. of land = **<u>621.53</u>** kgs	
Step 9-A = *(6C+7C)*	Total net income from 15 Ha. = $ 38,631.58 + $ 6,062.00 = $44,693.58	
Step 9-B = *(9A/3B)*	Average Income from 15 Has. = $44,694.58 / 15 = $2,979.62	
II. **(Steps 10A to 12C)**	**RESULTS FROM FERTILIZER APPLICATION AFTER FIELD TRIALS.** **Amount of Credit available/Ha. :**	
Step 3-A *(Repeated)*	Total amount of funds available from the credit agency = $10,000	
Step 3-B*(Repeated)*	Number of farmers wishing to have loans = 15	
Step 10-A= (Step 3A/3B)	Amount of funds available for each farmer = $10,000 / 15 = $ 666.67	
Step 10-B	Amount of N that can be purchased by $666.67/ $25 = 26.67 kgs.	
	The minimum amount of **<u>N</u>** that should be applied is **<u>24</u> kgs./Ha**. (Read from Fig. 6.3 –Ch.6) . So the farmer can apply **<u>26.67 kgs.Ha.</u>** of N uniformly over all the land.	
	Yield Obtained:	**Total Yield for 15 Ha.**
Step 11-A (Step 2C) *(Repeated)*	i) Yield/Ha. when 26.67 kgs. of **<u>N</u>** is applied = **<u>48.5</u>** kgs./ha. (from Fig.6.1C -Ch.6)	48.5 x 15 = **<u>727.5</u>** kgs.
	Net Income/ Ha.:	**Total for 15 Ha.**
Step 12A =*(Step 2C x 1C)*	<u>Quantity</u> x <u>Price</u> = <u>Total</u> i) Total revenue per/Ha. 48.5 x $ 88= $ 4,268.00	
Step 12B = *(10B x 1A)*	ii) Cost of fertilizer/Ha. 26.67 x $ 25 = $ <u>666.75</u>	
Step 12C= *(Step 12A- 12B)*	iii) Net income /ha. $ **3,601.25**	3,601.25 x 15 =$**54,018.75**

III. **(Steps 13A to 13B)**	**COMPARISON OF FERTILIZER APPLICATION WITH FERTILIZER FIELD TRIALS (FFT) AND WITHOUT FERTILIZER FIELD TRIALS.**			
		With FFT -Without FFT	**Improvement**	**% Improvement**
Step 13-A= *(Step 11A-8C)*	Total yield per Ha.	***<u>Step 11A – 8C</u>*** 727.5 - 621.53 =	105.97 =	17.05
Step 13-B = *(Step 12C-9B)*	Net income /ha.	***<u>Step 12-C – 9B</u>*** 3,601.25 - 2,979.62 =	621.63 =	20.88

The 17.05 percent greater yield shown by the farmers who had the benefit of fertilizer field trials has more than one meaning. Its immediate effect, of course is to raise the standard of living and the nutritional level of the farmers and their families. But it also means more employment in harvesting, transporting and marketing. On a national level, it means a reduction of inflation and of the urban drift of rural peoples so prevalent in developing countries.

The total net income of the farmers with field trials increased by 20.9 percent. Among other things, this encourages the farmers to return the money borrowed, reducing the number of delinquent loans from the agency. The agency also benefited from using its extension agent's time more efficiently. Had he serviced only 10.53 hectares, less than 33.3 percent of his time would have been well employed.

3. COMPARISON OF LENDING PROCEDURES WHEN FUNDS ARE LIMITED: LOCALITY B

All the assumptions made in our study of the credit results with limited funds in locality A, we will make again. The only difference we will encounter in the case of locality B is that the soil, rather than lacking only in nitrogen, has been shown by the field trials to lack both nitrogen and phosphate. And let us assume that fertilizer field trials indicate that the maximum amount of phosphate that needs to be applied to this soil to obtain maximum yield is 20 kgs./ha. However, the fertilizer field trials also indicate that higher amounts of nitrogen would produce higher yields.

i) Result of Credit Given Without Field Trials (Locality B) (Table 2B: Steps 4 to 6)

We are assuming that the credit agency's funds are limited and that it decides to allocate $6,000 to locality B. Of its $6,000, the agency calculates that it can spend, for each of the fifteen farmers, ($6,000 / 15 =) $400 per farmer (**Table 2B : Steps 3-A to 3-C).**

Using the recommended factory-made fertilizer, which has a grade of 30-40-0 and costs $950.00/ha.(**Table 2B: Step 4-D**), only 0.42 kgs. of the fertilizer can be bought (**Table 2B: Step 5-A)**. By using the production function, (Figure 6.10B-Ch.6) we can calculate the yields which will result as 21.00 kg/ha. The details of the costs and yields are shown in **Table 2: Steps 4-A to 6-C.**

ii) Results of Credit Given on the Basis of Field-Trials (Locality B): (Table 2B: Steps 7 to 11)

The fertilizer field-trials have been conducted, and we are assuming that the production function which best fit the data is the same as that of Chapter 6: - Figure 6.10B**.**

The minimum recommended rates of N and P, calculated in chapter 6 (Figure 6.11A) were

21.5 kgs./ha. of N, and
20 kgs./ha. of P.

From the calculations below, we can see that a farmer can apply 21.5 kgs/ha. of nitrogen and 20 kgs./ha of phosphate. And this combination will cost the farmer (21.5 x $25 +20 x $5 =) $637.5 per ha. (**Table 2B: Step 8A-8C).**

21.5 x $25 = 537.5
20 x $5 = 100.00
Total Cost = $637.5

Since the $400 allocated to each farmer, this means that all the farmers would get loans to apply 21.5 kgs of N and 20 kgs of P.

$\frac{\$400}{\$637.5}$ = 0.63 Ha. (Table 2:Step 9-C)

The amount of land left unfertilized would be = (1- 0.63=) 0.37 Ha. (**Table 2B : Step 9-D**).

From Figure 6.11B (Chapter 6) we can see that 47.5 kg/Ha. was the yield obtained when 22.6 kgs. of N and 20 kgs. of P are applied. And the yield from unfertilized part of the land was 21 kgs./Ha. (See Fig. 6.10B –Ch.6).

Now we can calculate that the yield obtained from the fertilized part of the farm will be

0.63 x 47.50 = 29.90 kg. (**Table 2B: Step 10-B**).

And the yield obtained from the unfertilized part of the land would be = (0.37 x 18.5= 6.85 kgs.). (**Table 2-B: Step 10A**).

The total yield the farmer would get from the fertilized and unfertilized land would be (6.89 + 29.80 =) 36.75 kgs./ha. **(Table 2B: Step 10C).**

The profits, then, of each farmer /Ha. will be

Total Revenue = 36.75 x $88 = $3,234

Cost of fertilizer = 1 x 400 = **-** $ 400

Net Income/Ha = $ 2,834 (Table 2B:Step 11-C)

Let us now put all the results for locality B, with and without field trials, in summary in Table 2A and in detail in Table 2B.

Locality B : WHEN FUNDS ARE LIMITED -Table 2A	
Steps:1A to 1C	**Price of inputs and crop:**
Steps: 2A to 2C	**Yields:**
Steps: 3A to 3C	**Amount of Credit available: Total and per farmer.**
I. Steps: 4 to 6	**RESULTS FROM FACTORY RECOMMENDED FERTILIZER WITHOUT FERTILIZER FIELD TRIALS.**
Steps: 4A to 4D	**Cost of Fertilizer:**
Steps: 5A to 5B	**Amount of Fertilizer that be bought by $950**
Steps: 6A to 6C	**Net Income /Ha. from 30N-40P factory recommended fertilizer.**
II. Steps: 7 to 11	**RESULTS FROM FERTILIZER FIELD TRIALS WHEN APPLYING FERTILIZER ON ONLY ON PART OF THE FARM**
Steps: 7A to B	Minimum amount of fertilizer needed to be applied.
Steps: 8A to C	**Cost of applying the minimum amount of recommended fertilizer / Ha.**
Steps: 9A to 9D	Amount of farm that is fertilized and unfertilized.
Steps: 10A to 10D	i) Yield from fertilized and unfertilized part of the farm
Steps: 11A to C	**Net Income/ Ha.:**
III. Steps: 12A to B	**COMPARISON OF FERTILIZER APPLICATION WITH FERTILIZER FIELD TRIALS (FFT) AND WITHOUT FERTILIZER FIELD TRIALS.**

The details of the above table are shown in the table 2B below. (Results may differ slightly due to rounding error).

Locality B : WHEN FUNDS ARE LIMITED -Table 2B		
Step -1	**Price of inputs and crop:**	
Step 1-A	Cost of N = $ 25/kg.	
Step 1-B	Cost of P = $5/kg.	
Step 1-C	Price of crop = $88 kg.	
	Yields from different levels of fertilize applications:	
Step 2-A	i) Yield when no fertilizer is applied = **18.5** kg./Ha. (from Table 6.6 –Chapter 6)	
Step 2-B	ii) Yield from Minimum recommended rate of 21.5 N and 20 P = **47.5** kg./Ha. (Read from Fig. 6.11A –Chapter 6).	
Step 2-C= *(See Step 5-A)*	iii) Yield when applying 0.42 kgs.Ha. of factory recommended 30-40-0 fertilizer is **21** kgs/Ha. (read from 6.10B -from chapter 6).	
	Amount of Credit available :	
Step 3-A	Total amount of funds available from the credit agency = $6000	
Step 3-B	Number of farmers wishing to have loans = 15	
Step 3-C= *(Step 3A/3B)*	Amount of funds available for each farmer = $6000 / 15 = $400	
I. Steps 4 to 6	**RESULTS FROM FACTORY RECOMMENDED FERTILIZER: WITHOUT FERTILIZER FIELD TRIALS**	
	Cost of Fertilizer:	
Step 4-A	Factory recommended fertilizer = 30 N and 40 of P	
Step 4-B = *(Step 4A x 1A)*	***Quantity* x *Price/kgs.* = *Total Cost*** Nitrogen = 30.00 x $ 25.00 = $ 750.00	
Step 4-C= *(Step 4A x 1B)*	Potassium = 40.00 x $ 5.00 = $200.00	
Step 4-D= *(Step 4B + 4C)*	Total cost of fertilizer = $ 950.00	
	Amount of Fertilizer that be bought by $950	
(Step 3-C) *(Repeated)*	Amount of credit available /Ha. (farmer) = $ 400	
STEP 5-A = *(Step 3C/4D)*	Amount of fertilizer each farmer can buy = 400 / 950.00 = **0.42** kgs. Ha.	
	Net Income /Ha. from 30N-40P factory recommended fertilizer.	
Step 5-B	Yield when applying 0.42 kgs./Ha. of factory recommended 30-40-0 fertilizer is **21** kgs/Ha. (read from 6.10B -from chapter 6.)	***Total from 15 Ha.*** 21 x 15 = **315 kgs.**
Step 6-A	***Quantity* x *Price*** ***Total/Ha*.** Total Revenue /Ha. = 21 x $88 = $ 1,848	***Total from 15 Ha.*** 1,848 x 15 = $ 27,720
Step 6-B	Total cost of the fertilizer/Ha. = 1 x $400 = $ 400	400 x 15 = $ 6,000
Step 6-C= *(Step 6A - 6B)*	**Net Income of /Ha. = $ 1,448**	1,448 x 15 = $ **21,720**
II. Steps 7A-11C	**RESULTS FROM FERTILIZER FIELD TRIALS WHEN APPLYING FERTILIZER ON ONLY ON PART OF THE FARM**	
	Minimum amount of fertilizer needed to be applied.	
Step 7-A	21.5 of N kgs./Ha. (From Fig. 6.10B-Ch.6)	
Step 7-B	20.0 of P kgs./Ha. (From Fig. 6.10B- Ch.6)	
Step 8	**Cost of applying the minimum amount of recommended fertilizer / Ha.**	
Step 8-A= *(Step 7A x 1A)*	***Quantity* x *Price* *Total Cost*** Cost of N = 21.5 x $25 = $537.5 cost for N	
Step8-B = *(Step7B x 1B)*	Cost of P = 20 x $ 5 x = $100.0 cost of P	
Step8-C= *(Step 8A+8B)*	Total cost of fertilizer = **$ 637.5**	
	Part of Ha. on which fertilizer was applied.	

Step 9-A	Amount of money available to be given in credit per Ha. = $ 400
Step 9-B	Cost of applying the minimum amount of N and P/Ha.. = $ 637.5
Step 9-C= *(Step 9A/9B)*	i) Part of Ha. that can be fertilized =(400/637.5=) 0.63 Ha.
Step 9-D= *(1- Step 9C)*	ii) Amount of land left unfertilized = (1 - 0.63 =) 0.37 Ha.
	The farmer should apply at least the minimum amount of fertilizer to only part of the land to get the best results and cultivate the rest unfertilized.
	Yield Obtained:
Step 2-A *(Repeated)*	i) Yield when no fertilizer is applied (from Fig.6.10B (Ch.6) = **18.5** kgs./Ha.
Step 2-B*(Repeated)*	ii) Yield from 21.5 N and 20 P from Fig. 6.11A (Ch. 6) = **47.5** kgs./Ha.
Step 10A= *(Step 9D x 2A)*	i) Yield from (0.37) part of Ha. not fertilized = 0.37 x 18.5 = 6.85 kgs.
Step 10-B = *(Step 9C x 2B)*	ii) Yield from applying the minimum amount of fertilizer on 0.63 Ha.. of land = 0.63 x 47.50 = 29.90 kgs.
Step 10C=*(10A +10B)*	**iii) Total yield per Ha.** = **36.75** kgs.
10-D = *(Step 10C x 15)*	Total yield from 15 Ha. = 36.75 x 15 = **551.25 kgs**.
	Net Income/ Ha.:
Step 11A= *(Step 10C x 1C)*	***Quantity*** ***x*** ***Price*** ***Total*** i) Total revenue per/Ha. = 36.75 x $ 88= $ 3234
Step 11B = *(1 x 3C)*	ii) Cost of fertilizer/Ha. = 1.00 x $ 400 = $ 400.
Step 11C	iii) Net income /Ha. = **$ 2,834**
III.	**COMPARISON OF FERTILIZER APPLICATION WITH FERTILIZER FIELD TRIALS (FFT) AND WITHOUT FERTILIZER FIELD TRIALS.**

		With FFT -Without FFT	Improvement	% Improvement
Step 12A= *(Step10D-5B)*	Total yield/Ha.	***Step 10D*** – ***Step 5B*** 551.25 - 315.00 =	236.25 =	75.00
Step 12B= *(Step11C-6C)*	Net income /Ha.	***Step 11C*** - ***6C*** 2834 - 1448 =	1386 =	95.72

The benefits of using field-trials as opposed to general recommendations in the case of locality B are, of course, the same as those for locality A. Locality B, however, presents us with the interesting difference that the fertilizer recommendation was in fact very nearly matched to the actual requirements of the soil. Even under these circumstances, the field trials resulted in a higher average net income of 95.72% and total yield/Ha. increased by more than 75%. In developing countries, an increase of 4 to 5 percent of net income may not seem highly significant, but in developing countries the difference of even 1 percent can determine whether or not a member of the family will eat. It should be remembered also that the increases resulted from a credit base of only $4,000. It is not difficult to imagine how great the increases could be, had greater sums been allocated.

The overall benefits received by the farmer, the agency and the nation, from having conducted field-trials, are by now fairly obvious. The increase in yield averages doubled, and the farmers' average net income was 95% percent higher.

Although we have studied only two localities, and although we have assumed what may be a more-than-usually-intelligent factory-made fertilizer grade, we can see that, without fertilizer field-trials, the credit program is inefficient. Inefficiencies can be much more disastrous than those we have described. But even in the cases described here, the farmers' benefit was over-looked, the extension agent's time was wasted, the agency's rate of recuperation was lowered, and the nation suffered lower yields and more unemployment.

4. GENERAL RECOMMENDATIONS WHEN FUNDS ARE LIMITED

In general, when funds are limited, the credit agency may find the following guidelines helpful:

i) Favor short-term loans and give as few medium- and long-term loans as possible. By reducing the time within which the lent capital and its interest is returned to the agency, this practice allows the capital to be re-lent to more farmers.

ii) Divert funds from social projects – such as home improvement – which are not directly productive, toward more short-term agricultural projects.

iii) Give credit to those farmers or farmer groups which, in the agency's experience, have been shown to be most credit worthy.

iv) Give credit for cultivation of those crops for which there is the greatest chance of loan recuperation. Among the best candidates are crops which have government price support and crops which need processing if there is a pre-established factory contract.

v) Give credit to those farmers who can contribute a large proportion of the total project cost in the form of transportation, labor and the like. (It should be noted that, while this measure may seem to leave out the really poverty-stricken farmer, the agency, while funds are limited, must think of its own solvency first, so that it can help many more farmers later. Otherwise, for all its will to do good, it would soon have no money to help anyone.)

vi) Give credit for fertilizer up to the minimum recommended rate; in the case of one nutrient, to the point where the average product is highest; for two or more nutrients, to the point where the difference of the production function which best fit the field-trials is equal to the ratio of the price of the crop and the price of the fertilizer nutrient. (Please see chap. 7).

5. LENDING PROCEDURE WHEN FUNDS ARE SUFFICIENT

When an agency's funds are sufficient but not abundant, the calculations used up to this point in the chapter still apply. Thus, if an agency had $20,000 instead of $10,000 to give to each of the localities, A and B, it could calculate, by means of the procedures used when funds were limited, to what degree yields and incomes would improve if field-trials were conducted.

When funds are sufficient, however, the guidelines change somewhat:

i) Give fertilizer credit above the minimum recommended rate but not as far as the highest profit point. If the farmer wishes to apply fertilizer to the latter point, he should contribute the additional money necessary.

ii) Credit can be given to poorer farmers whose contribution to the project would be small.

iii) Medium-term loans may be considered for agricultural equipment and animals, but the farmers themselves should contribute a large proportion of the project cost.

iv) The agency should still refrain from funding social projects.

v) The number of farmers to whom credit is extended should not exceed the number which the extension agents can supervise effectively.

6. LENDING PROCEDURE WHEN FUNDS ARE UNLIMITED

Even when funds are unlimited, a credit agency should approve only that number of projects which the extension agents can handle effectively. To approve an exceedingly large number of projects would leave poor supervision, careless evaluation and a higher loan delinquency rate. If the funds are likely to remain abundant over several years, however, the agency may wish to employ one or two additional staff to handle the growing number of projects.

But for the fact that credit can now be given up to the profit point, the calculations used throughout this chapter are still applicable.

Here are additional guidelines for lending when funds are unlimited:

i) Social projects and projects involving agricultural equipment and animal production which were formerly considered too expensive, may now be approved. The agency may also consider long-term loans, such as those needed for tree crops, and loans for crops which have no government price support.

ii) Credit can now be given to the very poor farmers. Even though these farmers are in desperate need of credit, it is imperative that there be some contribution on their part to the project. Experience shows that that loan recuperation rate increases significantly when there is at least a minimal input from the farmer.

iii) Credit can be given to the highest profit point. By giving more credit to each farmer, the total number of farmers receiving credit is kept to a level which the extension agents can supervise, and the farmers' income is maximized.

iv) If funds still remain, other needy groups, which the agency knows to be trustworthy and to have technical know-how to the extent that frequent visits from the extension agent would not be necessary, may also be funded. In this way, money which otherwise would lie idle may help to further the agency's objectives, to increase agricultural production, rural employment and income, with little or no supervision or worry on the part of the central office.

Chapter 8

VISUAL AIDS FOR FARMERS

1. INTRODUCTION

In Chapter 1 we saw that there are a number of measures which a farmer can take, besides the application of fertilizer, to increase his crop yields. From the point of view of economics, these measures can be divided into two categories:

(1) measures which imply extra cost, e.g. the use of herbicides, pesticides, fungicide and irrigation; and

(2) measures which cost nothing, e.g. timeliness of sowing, proper seeding rate and sowing depth and crop rotation.

Although it is very important that the credit agency concentrate on improving its allocation of credit for fertilizer, it is even more important that it help the farmer improve his yields by means which cost him nothing. Having left the discussion of these means in Chapter 1 and devoted the bulk of the book to the methods of improving fertilizer credit programs, it is fitting that we return in this last chapter to certain basic practices which, after so much calculating and analyzing, may stand in danger of being forgotten.

The remote farming areas of developing countries have little access to agricultural publications and the farmers have no way of knowing about new practices by which they could improve their yields. Even were the publications are accessible, the farmers would be unable to read them. In developing countries, the rate of illiteracy is not only high but increasing, according to U.N.O. reports. Bolivia, for example, has a 60 percent illiteracy rate, 90 percent of which is in the rural areas. In Nicaragua the rate of illiteracy is 65% percent, in Haiti 92 percent.

It is the responsibility of the credit agencies to find some means by which to convey an understanding of beneficial agricultural practices to these farmers. The best and most universal means is that of visual illustrations.

The agency's central office should subscribe to important national and international agricultural publications, from which the agronomists can draw news of any agricultural practices which have proven to produce high yields. These practices should be converted into step-by-step illustrations, with timetables indicating exactly when each step should be taken. Wherever possible, measures of land area should be used which are familiar and commonly used by the farmers of a locality. For example, in Guatemala, farmers usually measure their land in *manzanas* (25 m^2) and in Dominican Republic, in *tarea* (20 m^2) .

The extension agent cannot be expected to remember all the agricultural practices for all the crops grown by the farmers he supervises, nor can he be expected to visit the farmers at every stage of crop production.

For these and other reasons, the agency should prepare illustrated sheets regarding each crop for which it extends credit.

At the beginning of the sowing season, the extension agent should take these sheets to the farmers and explain what practices are advised and how, implementing these practices, the crop yields can be increased. Where possible, he should also mention by how much (percentage) the practices have been shown to increase the yield.

The subsistence farmer in developing countries is known to be very reluctant to adopt changes in his agricultural practices, no matter how small the change or how great the impact on crop yield. His reluctance is justified, since, were the suggested practice to result in a crop failure, his family would surely starve. There are simply no other jobs available by which he could earn enough to feed them.

Moreover, tradition is strong. The farmer's mode of farming, like his mode of living in general, was that used by his father, his grandfather, and as far back as memory and imagination reach. To change that mode would constitute a sort of violation of natural law. In Latin America, if asked to explain it, a farmer would say, "*Es nuestro custombre*." "This is our custom."

In the face of such an attitude, there is little point in extending credit for fertilizer or for anything else, since none of the agent's suggestions would be implemented. Still, headway can perhaps be made. To begin with, the agent, without being overbearing, should explain that a certain agricultural practice will increase the farmer's yield by a certain amount. If the farmer is reluctant to adopt this practice over his entire farm, he should be asked to grow only 6 plots, of the same size as the experimental plots in Chapter 4. In three of these plots he should grow the crop using the recommended practice and, in the other three, as tradition dictates. If, upon comparison of the results, the yields of the first three plots show an increase, the farmer will very likely be willing to adopt the new practices of his own accord thereafter.

If the agricultural practice in question has not been tried in the locality, then its impact on yield should be determined by means of field trials, as described in Chapter 4; and the difference in yields analyzed by "t" tests, as in Chapter 5.

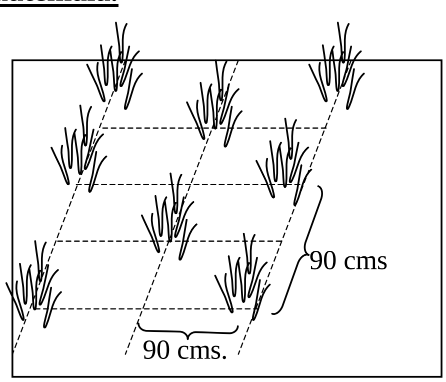
Our first example of the illustrative procedure will be a traditional crop, maize, grown in south-eastern Guatemala, on which ICTA has done considerable research. For our second example, we have chosen tomatoes, an industrial crop. Farmers with small holdings have generally been unable to produce the quality of crop required for industrial processing; because of this, industries have been reluctant to make contracts with these small farmers. In the example, research done by the Ministry of Agriculture of the Dominican Republic and B.A.O. shows how the required quality can be achieved.

2. MAIZE CULTIVATION IN SOUTH-EASTERN GUATEMALA

The Guatemalan peasant farmer in the south-eastern part is accustomed to growing his traditional, unimproved maize by sowing 5 to 6 seeds in one spot. Each spot is equidistant from every other, both in and between the rows, as shown in Figure 8.1 below.

<u>Figure 8.1: Traditional Maize Spacing by the Farmers of the South-Eastern Coast of Guatemala.</u>

Figure 8.1



The above spacing system, without fertilizer, has been shown to produce yields of between 40 and 45 kilos/manzana.

ICTA research has found that there are two varieties of maize which will give higher yields than the traditional variety, and that the best sowing procedure consists of rows 90 cms apart and one seed every 25 cms in the row. It was also discovered that yields were higher when the fertilizer was divided into two applications, one at sowing time and the other just 21 days after seed germination.

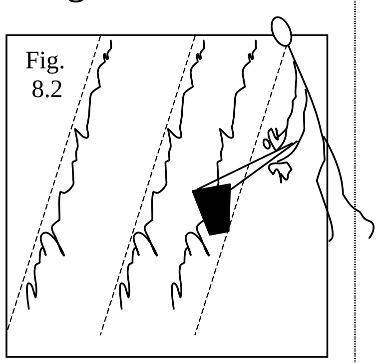
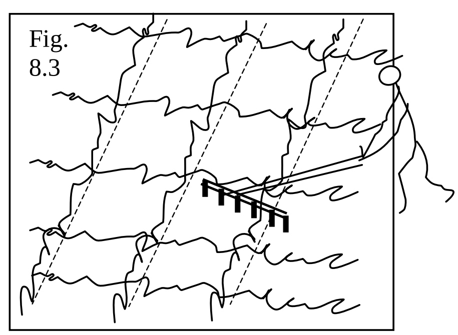
Since the above yield-increasing factors were found through reliable research, they were made into illustrations and given to the extension officers to distribute to the farmers. It will be noticed that the illustrations, shown below, include timetables. If the farmer is unable to count, he should be given a piece of paper on which are written the numbers from one to the day-number on which the crop is harvested. Each day that passes, he can pencil off one of the numbers; when the number on his piece of paper looks like the one on the illustrated sheet, he will know that the activity indicated for that number should be carried out that day.

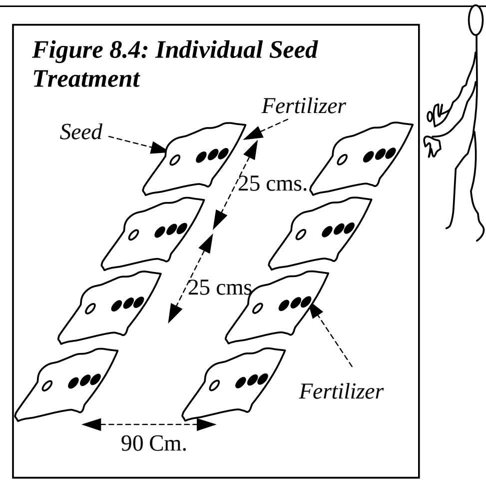
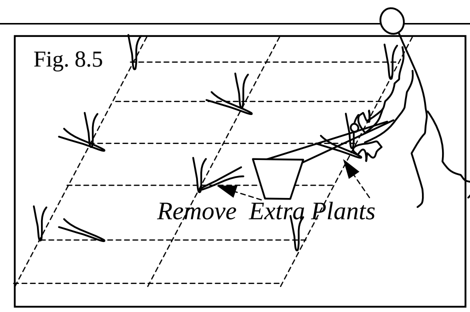
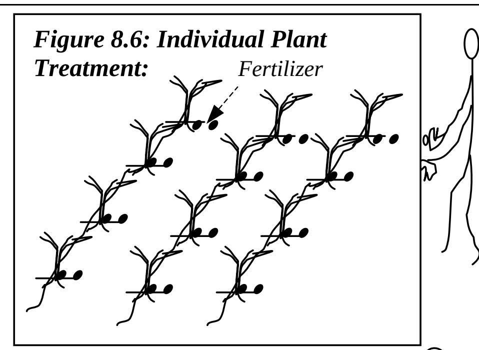
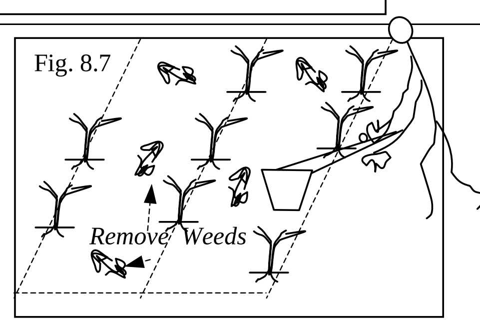
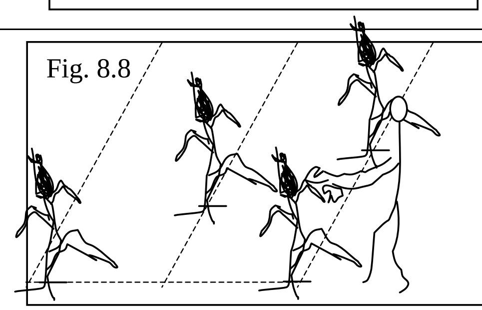
A] Varieties Recommended:

Name	Expected Yield
1) La Maquina	60 quintals/ Manazana (Mn)
2) ICTA T - 101	65 quintals/ Manaza

B] Recommended Sprays if required:

Product	Quantity to be used
1) Yolatan (power) at 2.5%	25 lbs/ Mn
2) Lannate at 24% (liquid)	3 to 4 litres/ Mn

DAY	ACTIVITY	ACTIVITY
1	**Plough and**  Fig. 8.2	**Harrow**  Fig. 8.3

4	**<u>Sow</u>** (**Fig. 8.4**) Keep rows 90 cms. apart. Sow one seed at every 25 cms. in the row. Amount of seed needed : 25 lbs. / manzana.	***Figure 8.4: Individual Seed Treatment***
4	**<u>1st Fertilizer Application:</u>** <u>Type</u>: 20 – 20 – 0 <u>Quantity</u>:2 quintales/ Manazana Drop fertilizer pellets in the same spot as the seed. To avoid seed damage, make sure that the fertilizer is some distance away from the seed.	
19 – 24	**<u>Plant thinning</u>: (Fig. 8.5)** To make sure there is only one plant at each spot, and not more, remove any extra plant that may be there.	Fig. 8.5
21	**<u>2nd Fertilizer Application:</u> (Fig. 8.6)** <u>Type</u>: Urea <u>Quantity</u>: 1 Quintal/ Manazana. Apply fertilizer, should be applied along the row.	***Figure 8.6: Individual Plant Treatment:***
19 – 100	**<u>Weeding</u>: (Fig. 8.7)**	Fig. 8.7
115 onwards	**<u>Harvest</u> (Fig. 8.8)**	Fig. 8.8

Let us now see what financial benefits the farmer would obtain if he adopted the agricultural practices suggested by ICTA as compared to the traditional practices.

In Guatemala the prices of agricultural inputs and outputs (in 1978) were:

Urea = $9.0/qq.
Fertilizer 20-20-0 = $8.90/qq.
Seed: ICTA T 101 = $30/qq.
Maquina = $30/qq.
Maize = $8/qq.

A) Income of farmers from Traditional Practice: (yield 43 qq./ma.)

Gross income = 43 x 8 = $344.0
Cost of land preparation = $50.0
Cost of seed = $7.50
Net income = $286.5

B) Income from Improved Practices (yield obtained – 60 qq./ma.)

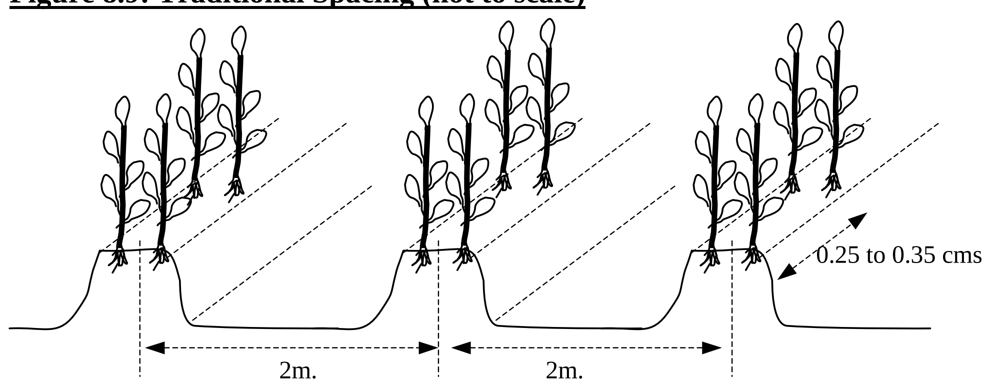
Gross income = 60 x 8 = $480
Cost of urea (one qq.) = $9.0
Cost of 20-20-0 (2.5 qq.) = $22.25
Cost of seed = $7.5
Cost of land preparation = $50.0
Net income = $391.25/ma

We can see that the farmer, by adopting the agricultural practices suggested by ICTA, would have increased his income by $104.75/ma. or he would have increased his income by more than 35%.

3. CULTIVATING INDUSTRIAL TOMATOES IN THE CENTRAL DOMINICAN REPUBLIC

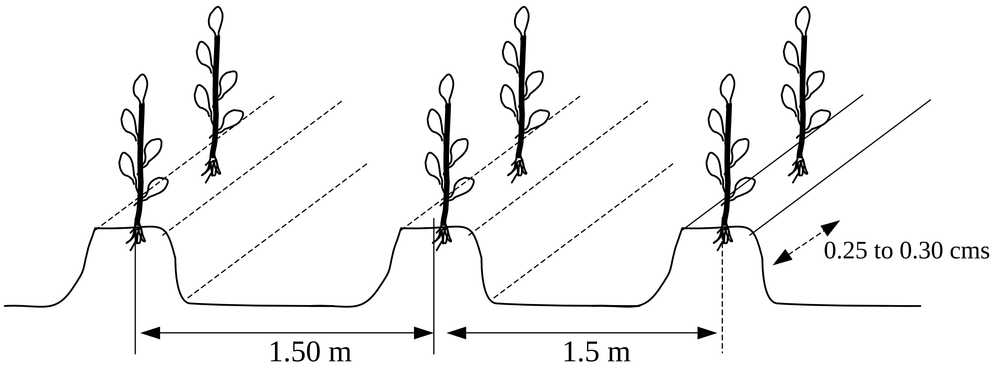
Farmers in the Dominican Republic, whether large or small, usually grow industrial tomatoes by sowing two rows of plants on a single flat ridge (Figure 8.9).

Figure 8.9: Traditional Spacing (not to scale)



The farmers believe that, with more plants per unit area, their yield will be greater. Research by the Ministry of Agriculture and FAO, however, has shown that the farmer's assumption is mistaken, and that where tomatoes are concerned, less is more: By planting a single row of plants on each ridge (Figure 8.10), crop yields increase by an average of 16 percent. Moreover, weeding is facilitated and spraying takes one-fourth less time than it does with the traditional method.

Figure 8.10: Researched Spacing (Not to scale)

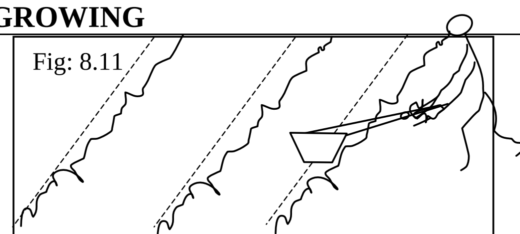
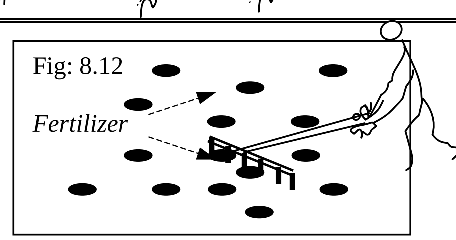


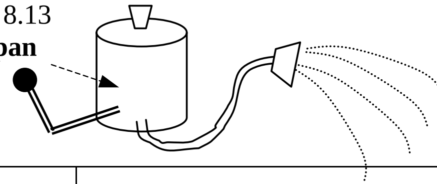
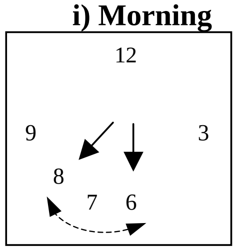
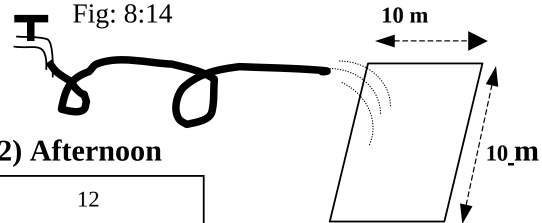
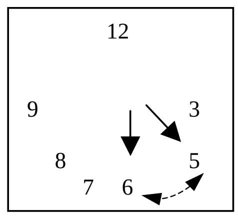
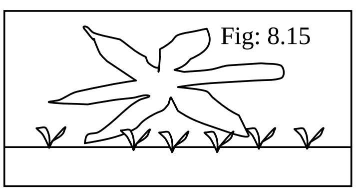
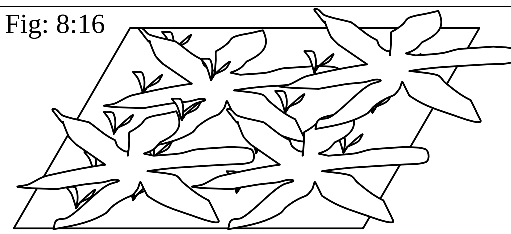
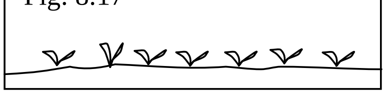
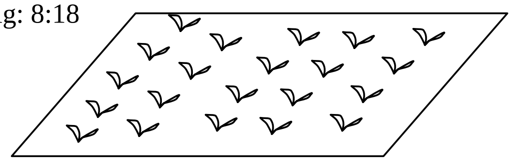
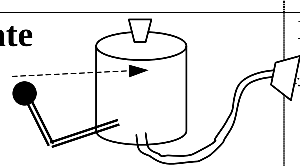
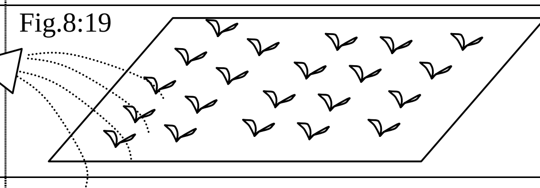
Also, the farmers transplant the seedlings to the land when it is either too young or too mature. When the very young seedling is transplanted, the seedling usually dies, depriving the farmer of a plant from which he could have obtained some crop. When a matured seedling is transplanted root damage results. In this case either the plant dies or its growth is reduced, resulting in less yield. FAO research has determined that the best time to transplant the seedlings is when: a) the seedling is at least 10 to 20 cms. tall and b) the plant should have at least 5 leaves.

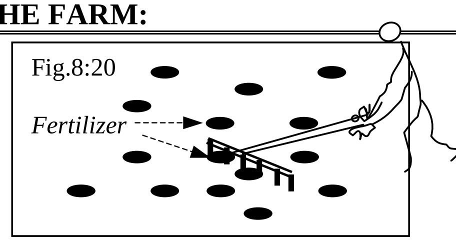
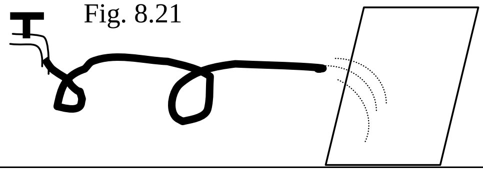
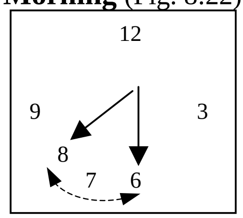
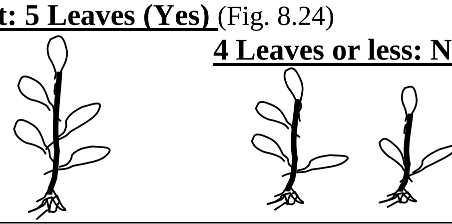
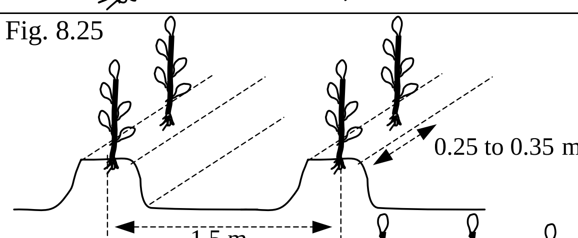
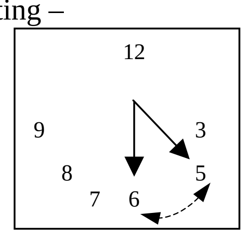
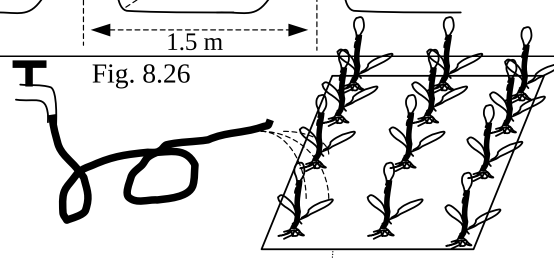
The benefits of this and other research regarding industrial tomatoes are illustrated below.

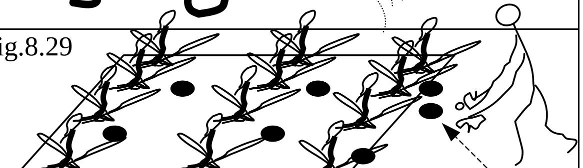
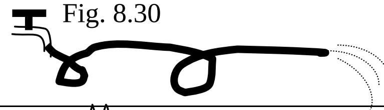
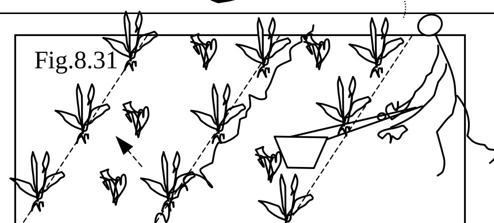
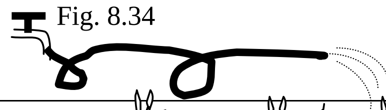
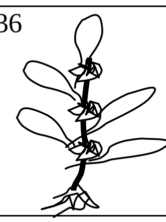
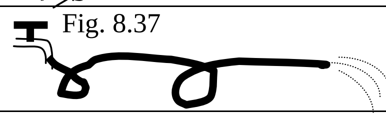
PRODUCTION OF INDUSTRIAL TOMATOES
(as applicable to the Central Dominican Republic)

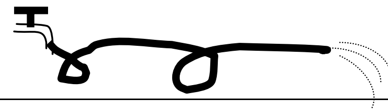
A] Variety Recommended: VF – Nopoli
B] Pesticide Recommended: Manzate 200
C] Fertilizer Recommended: For each tarea
60 lbs of Ammonium sulphate
10.6 lbs of Triple superphosphate

DAY	ACTIVITY : Written	Graphic
	SEED GROWING	
1	**Prepare land** and;	 Fig: 8.11
1	**Incorporate fertilizer** with the soil (uniformly): **Type**: 4 – 12 – 4 **Quantity**: 4 lbs for land 10 by 10 meters.	 Fig: 8.12

1	**Spray** soil with Vapan or Hepatora	Fig: 8.13 **Vapan** 
2	**Sow:** For growing 1 to 1.5 tareas, use 1 ounce of seed in 10 meter by 10 meter area. Extension agent should calculate for each farmer the amount of seed needed for the farmer to sow. For example, if the farmer wishes to grow 3.5 tares with tomatoes, then the amount of seed required would be 3.5 ounces. The area for growing seedlings would be 35 meters 35 meters.	
1 to 25	**Irrigate** **each** day: once in the morning and once in the late afternoon. **i) Morning** 	Fig: 8:14  **2) Afternoon** 
4	**Put leaf covering**  Fig: 8.15	Fig: 8:16 
22	**Remove Cover** Fig: 8:17 	Fig: 8:18 
23	**Fumigate** Vapan 	Fig.8:19 
24	**Fumigate**	
25	**Fumigate**	
27 to 36	**Transplanting Days**	
DAY	**ACTIVITY: Written**	**_Graphic**

TRANSPLANTING ACTIVITIES ON THE FARM:		
1	**Mix Fertilizer Into The Ground.** **<u>Type:</u>** 30 lbs of Nitrogen/ tarea. 6 lbs of Triple super phosphate.	Fig.8:20 
2	**<u>Irrigate</u>** before transplanting	Fig. 8.21 
	TRANSPLANT	
	a) **<u>Transplant</u>** only in the mornings	**Morning** (Fig. 8:22) 
	b) **<u>Transplant</u>** only those plants which are: i) 10 to 20 cm in height, and; ii) have at least 5 leaves.	**<u>Right Height</u>** **<u>Wrong Height</u>** (Fig. 8.23)  **<u>Right: 5 Leaves (Yes)</u>** (Fig. 8.24) **<u>4 Leaves or less: NO</u>** 
2	**<u>Transplant</u>** in simple furrows **Distance** between furrows: 1.50 meter. **Distance** between plants: 0.25 – 0.35 meter .	Fig. 8.25 
2	**Irrigate** in afternoon after transplanting –  	Fig. 8.26 

4-5	**Irrigate**	Fig. 8.27 
10	**Irrigate**	Fig.8.28 
20	**<u>Apply fertilizer</u>** **<u>Type</u>:** **<u>Quantity</u>** Ammonium sulfate 15 lbs/tarea *Triple Phosphate* 5 lbs/tarea	Fig.8.29 
21	**Irrigate**	Fig. 8.30 
22	**1st Weeding**	Fig.8.31 
30	**Irrigate**	Fig. 8.32 
32 to 36	**2nd Weeding**	Fig.8.33 
40	**Irrigate**	Fig. 8.34 
44	**3rd Weeding**	Fig.8.35 
	<u>Fertilize</u> just before flowering **<u>Type:</u>** Sulphate of Ammonia **<u>Quantity:</u>** 15 lb/tarea	Fig. 8.36 
46 to 52	**Irrigate**	Fig. 8.37 

65	**Irrigate** Fig. 8.38	
66 onwards : HARVEST		

As we can see that there are a number of measures which a subsistence farmer can take, besides the application of fertilizer, to increase his crop yields. From the subsistence farmers point of view, measures which cost nothing, e.g. timeliness of sowing, proper seeding rate and sowing depth and crop rotation, and more importantly intercropping with leguminous crops which naturally fixes (increases) nitrogen in the soil, should be recommended to the farmer before application of fertilizer or other expensive inputs.

If this manual has helped a single farmer have a better fed family than before, the job of the extension official would have been worth his/her effort.

For free assistance with Analysis of Variance or “T” tests please visit our website:

GillsConsulting.Com

FLOW-CHART
To Follow Before Making Fertilizer Recommendations To Farmers

As a quick reference each step tells the reader from which page (e.g. page 85), table (e.g. Table 5.3) or figure (e.g. Fig. 6.3) the information is from in the book.

↓

Step 1. ASK FARMERS THE CROP(S) THEY WISH TO GROW.

↓

Step 2. (Ch.1)
GO TO THE LOCAL FAO OFFICE OR LOCAL AGRICULTURAL RESEARCH STATION AND FIND OUT THE FOLLOWING:

a) the best varieties of the crop that the farmers should use;
b) the best spacing that will maximize the farmers profits;
c) the best time for sowing;
d) the best times to irrigate the crops;
e) the best times to fertilize the crops;
f) the price of crop, fertilizer and liming material; and
g) the most suitable pH for that crop.

↓ ↓

Step 3.1. (Ch.1: Section 17) Page 19
If the soil pH **NOT** suitable?

↓

Step 4.1. Whether funds are limited or not.

↓

Step 5.1. (Ch.1: Section 17) Page 19
Give loans only for liming:
i) 12 month loan if it is for calcium oxide or calcium hydroxide.
ii) 18 month loan if the loan is for limestone.
iii) Set up trials with liming and different levels of fertilizer.

Step 3.2. (Ch.1: Section 17) Page 19
If pH is suitable?

↓

Step 4.2. Whether funds are limited or not.

↓

Step 5.2. (Ch.4)

Set up trials with different levels of fertilizer.

↓ ↓

Step 6. INFORMATION PRIOR TO SETTING UP FERTILIZER FIELD TRIALS (Chs. 1 and 4)

A) Are there any pre-existing fertilizer recommendations for this particular crop? If so, what are they?
B) What recommendations exist as to timing of fertilizer application? Should, for example, all of the fertilizer be applied at the sowing time, or all at the flowering time? Or should half be applied at sowing and the other half at flowering?
C)Are the crop varieties which the farmer is presently using susceptible to any diseases?

↓ ↓

Appendix 1 **II**

Step 7.1. (Ch.4 : Section 4) (Table 4.1) Page 65
FERTILIZER TREATMENTS IN THE ABSENCE OF OFFICIAL RECOMMENDATIONS

Treatment No.	N	P	K
1	Farmer's Practice		
2	0	0	0
3	10	0	0
4	20	0	0
5	30	0	0
6	40	0	0
7	20	20	0
8	20	0	20
9	20	20	20

Step 7.2 (Ch 4: Section 4) Page 65

Set up Fertilizer Treatments Based on Official Recommendations.

Step 8. (Ch. 4: Section 7) Page 66
DECIDE ON TRIAL PLOT SIZE :
10 meters by 5 meters a crop with rows spaced 0.8 meters apart would need a plot (0.8 x 7=) 5.6 meters.

Step 9. (Ch. 4:Section 9) Page 66
CALCULATE AMOUNT FERTILIZER TO APPLY PER PLOT
The amount of fertilizer needed can be calculated by using the following formula **(Ch.4: Section 10)**

$$\frac{\text{Nutrient rate per Ha.} \times \text{Area of plot}}{\text{Area of hectare}} \times \frac{1}{\text{Nutrient value of fertilizer}} = \text{Amount to be applied.}$$

Step 10 . (Ch. 4: Section 11) Page 70
CALCULATE AMOUNT OF SEED TO APPLY PER PLOT
In this case, the amounts of seed needed for each plot can be calculated in the same way those amounts of fertilizer nutrients were calculated:

$$\text{Kgs. of seed needed per plot} = \frac{\text{Kgs. of seed recommend per Ha.} \times \text{Area of plot}}{10{,}000\ m^2\ \text{(Area of Ha.)}}$$

Step 11. (Ch. 4: Section 12) Page 74
MARK THE WEIGHT OF THE YIELDS FOR EACH PLOT OF THE FIELD TRIAL AS SHOWN IN TABLE BELOW.

Table 5.2: Field Trial (Sample Yields of Thirty Experimental Plots)

	Treatment Number (kgs./plot)									
	1	2	3	4	5	6	7	8	9	10
Block 1										
Block 2										
Block 3										

Step 12. (Ch. 5 : Section 1) Page 73
CONVERT THE ABOVE EXPERIMENTAL PLOT YIELDS INTO YIELDS PER HECTARE.

$$\frac{\text{Yield obtained from the plot}}{\text{Size of the plot}} \times \text{Area of hectare}$$

Step 13. (Ch. 5 Table 5.3) Page 74
PUT THE CONVERTED YIELDS IN A TABLE AS SHOWN BELOW.

Table 5.3 : Crop Yields of the fertilizer Field Trails Converted to per Hectare (kgs./ha.)

	Treatment No.								
	1	2	3	4	5	6	7	8	9
Block No.	**Control**	**10 N**	**20 N**	**30 N**	**40 N**	**50 N**	**20N, 20P**	**20N,20K**	**20N,20P,20K**
1.									
2.									
3.									

Step14. (Ch. 5: Table 5.5) Page 75 **DO STATISTICAL TESTING ON THE RESULTS**	**Treatment(S)**								
Statistical Testing of Following Treatments **DO ANOVA**	1	2	3	4	5	6			
Statistical Testing of Following Treatments **DO "t" Testing**			3			6	7	8	9
Statistical Testing of Following Treatments **DO "t" Testing**						6	7	8	9
Statistical Testing of Following Treatments **DO "t" Testing**							7	8	9
Statistical Testing of Following Treatments **DO "t" Testing**								8	9

Step 15.1.(Ch.5 : Section 2) Page 75
Do ANOVA test of results using different levels of same fertilizers.
Step 15.2. (Ch. 5: Section 3) Page. 78
Do "t" tests on trails using different fertilizers.

Step 16.1. (Ch. 5: Section 2) Page 75
If **NOT** Statistically significant up to 80% level.

Step 16.2.. (Ch. 5: Section 2) Page 75
If Statistically significant at **80%** significant level, do the economic analysis.

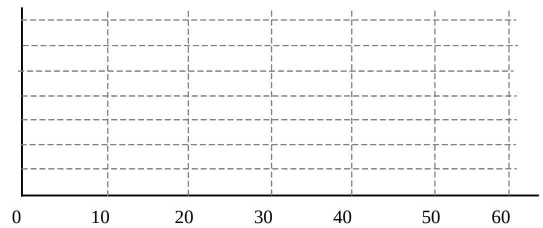
Step 17.1. (Ch. 5)
Set up new trails with higher levels of fertilizers next growing season. Then next season follow from step 5.

Step 17.2. (Ch. 5: Section 2) Page 75
Total the results of each treatment.

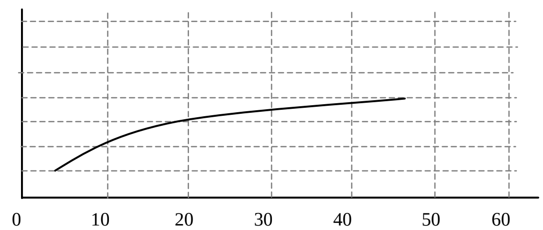
Step 18. (Ch.5 : Section 2) Page 75

	Table 5.6: Yields from treatments 1 to 6 of field trials (kgs. /Ha)						
	Treatment Number						
	Control	10N	20N	30N	40N	50N	Total
Block No.	1	2	3	4	5	6	
1							
2							
3							
Total							
Average							

Step 19. **(Ch.6: Section 2-Fig. 6.1A) Page 96**
PUT THE AVERAGES ON A GRAPH: Fertilizer levels on horizontal axis and outputs on the vertical axis.



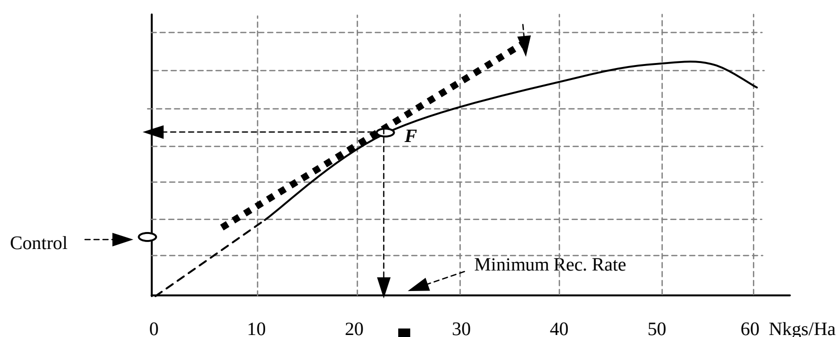
Step 20. **(Ch.6:Section 2-Fig. 6..1B) Page 96**
DRAW A PRODUCTION CURVE USING THE "EYEING" METHOD.



Step 21. **(Ch. 6: Section 2-Fig. 6.1C) Page 96**
READ THE "CHECK" YIELDS FROM THE PRODUCTION CURVE DRAWN.

Step 22. **(Ch. 6: Section 3 –Fig. 6.3) Page 98**
MINIMUM REC. RATE of fertilizer can now be determined by drawing a line tangent to the production curve from the control yield. Where it touches is the minimum R.R. of fertilizer.

Figure 6.3: Determining the Minimum Recommended



Step 23. **(Ch. 6: Section 3-page 101)**
Find out the cost of :
i) output (crop),
ii) Inputs (Nitrogen, Potassium and phosphates)

Step 24. (Ch. 6: Section 3-Page 101)
Standardize the cost of output and inputs to similar units, (e.g. cost the price to dollars per kilo; rupees per ton, etc. for both the output and inputs).

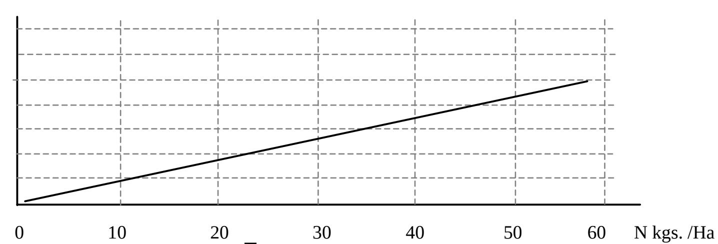
Step 25. 1. (Ch. 6: Section 3-Page 101)
CALCULATE THE "ISO-PROFIT" FRACTION:

$$\frac{\text{Price of Unit Nitrogen (Input)}}{\text{Price of Unit Crop (Output)}}$$

Step 25.2. (Ch.6:Section 3-Page 101)
For the two nutrients in this experiment THE "ISO-PROFIT" fraction is:

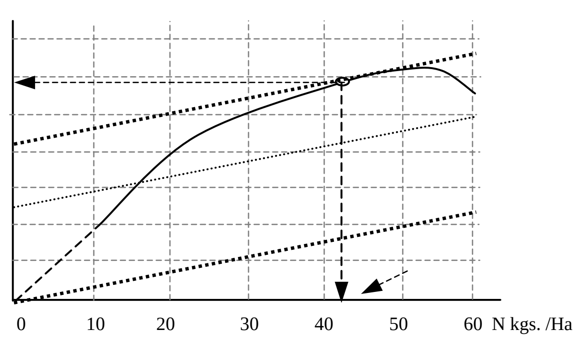
$$\frac{\text{Price of Nitrogen / kg. + Price of Phosphate / kg.}}{\text{Price of crop / kg.}}$$

Step 26. (Ch. 6:Section 3-Fig. 6.4) Page 102
DRAW THE "ISO-PROFIT" LINE on the same graph as the production



Step 27. (Ch.6 : Fig. 6.5) Page 102
Draw a parallel line until it just touches the production curve. Where it touches the production, this gives us the **MAX. R. R. OF FERTILIZER.**

FIGURE 6.5: DETERMINING THE MAXIMUM RECOMMENDED



Step 27.A.
If Funds are LIMITED:
Recommend that each farmer should apply the minimum recommended rate of fertilizer to only part of the farm.

Step 27.B.
If Funds are **UN**LIMITED:
The farmers should be given loans to apply fertilizer to the maximum recommended rate.

Step 28. (Ch.5: Section 3) Page 98
RESULTS OF 1 NUTRIENT AND 2 NUTRIENTS

Step 29.A.
Above 90% level of confidence

Step 29.A.
Conduct economic analysis :
If profits are **above** 15%:
i) Give loan for 2 nutrient fertilizer;
ii) Set up fertilizer trials for next year with higher levels of 2 nutrients.

Step 29.B.
Above 80% level of confidence

Step 29.B.
Conduct economic analysis
If profits are **above** 25%
i)Give loan for 2 nutrient fertilizer;
ii) Set up fertilizer trials for next year with higher levels of 2 nutrients

Step 29.C.
Below 75% level of confidence

Step 29.C
Ignore the results.

Step 30. (Ch.5: Section 3) Page 98
RESULTS OF 1 NUTRIENT AND 3 NUTRIENTS

Step 31.A.
Above 90% level of confidence

Step 31..A.
DO ECONOMIC ANALYSIS:
i) If profits are above 25% make loan for 3 nutrient fertilizer;
ii) Set up fertilizer trails with higher levels of nutrients the next year;
iii) Do statistically analysis between 2 and 3 nutrients treatments.

Step 31.B.
Above **80%** level of confidence.

Step 31.B.
i) Make **NO** fertilizer recommendations this year;
ii) Set fertilizer trails this year with only 1 treatment with 3 treatments.

Step 31.C.
Below **75**% level of confidence.

Step 31.C.
Ignore the results.

Step 32. (Ch. 5: Section 3) Page 98
RESULTS OF 2 NUTRIENTS AND 3 NUTRIENTS

Step 33.A
Above 75% level of confidence

Step 33.A.
DO ECONOMIC ANALYSIS OF TREATMENT
i) if profits are **above 15%** make loans for 3 nutrient fertilizers;
ii) Next year set up fertilizer trials with higher levels of nutrients.

Step 33.B.
Below 75% level of confidence

Step 33.B.
Ignore the results.

Appendix 2.: Blank Forms to Calculate ANOVA and "t" Values.

ANALYSIS OF VARIANCE (ANOVA)

Step 1: Number of Treatments =

Step 2 : Number of times the treatments replicated (blocks) =

Step 3: Put the fertilizer trail results in form a table as shown.		**Treatment Number**								
		1	**2**	**3**	**4**	**5**	**6**	**Total**		**Average**
	Block	*Control*	*10N*	*20N*	*30N*	*40N*	*50N*			
	1	……	……	……	……	……	……	……	÷..	……
	2	……	……	……	……	……	……	……	÷..	……
	3	……	……	……	……	……	……	……	…÷.	……
Step 4: Total the results		……	……	……	……	……	……	……	÷..	……
Step 5: Calculate Averages: (Step **4** ÷ Step **2**)		… ÷ ...	…÷..	…÷..	…÷..	…÷…	…÷…	…÷…	.÷..	…÷…

Step 6

Sum of Squared of Treatments

-1-Yield	-2- Mean	3= 1-2	$4=(3)^2$	
Treatment-1				
……	-……	…	……	
……	-……	…	……	
……	- ……	…	……	
				…
Treatment - 2				
……	- ……	…	……	
……	- ……	…	……	
……	- ……	…	……	
				…
Treatment -3				
……	- ……	…	……	
……	- ……	…	……	
……	- ……	…	……	
				…
Treatment -4				
……	- ……	…	……	
……	- ……	…	……	
……	- ……	…	……	
				…
Treatment -5				
……	- ……	…	……	
……	- ……	…	……	
……	- ……	…	……	
				…
Treatment -6				
……	- ……	…	……	
……	- ……	…	……	
……	- ……	…	……	
				…
			Total	…

Step 7

Squared deviations (weighted by group size)

-1-Yield	-2- Mean	3= 1-2	$4=(3)^2$
Treatment-1			
……	-……	…	……
……	-……	…	……
……	- ……	…	……
Treatment-2			
……	- ……	…	……
……	- ……	…	……
……	- ……	…	……
Treatment-3			
……	- ……	…	……
……	- ……	…	……
……	- ……	…	……
Treatment-4			
……	- ……	…	……
……	- ……	…	……
……	- ……	…	……
Treatment-5			
……	- ……	…	……
……	- ……	…	……
……	- ……	…	……
Treatment-6			
……	- ……	…	……
……	- ……	…	……
……	- ……	…	……
		Total	…

Step 8

Total Sum of Squared Deviations

-1- Yield	-2- Mean	3= 1-2	$4=(3)^2$
……	……	……	……
……	……	……	……
……	……	……	……
……	……	……	……
……	……	……	……
……	……	……	……
……	……	……	……
		Total	……
Multiply by Step 3:			x ……
		Total	…………

Step 9: Calculating Degrees of Freedom for treatments : ***(Step 1 minus 1)*** = (….. - 1) = …….

Step 10: Calculating Degrees of Freedom for blocks ***: [(Step 3 minus 1) x Step 6]*** = (…… - 1) x …… = ……..

Step 11: Calculating Degrees of Freedom for Total (all treatments) ***:[(Step 1 x Step 2) minus 1]*** = (…….. x ……) – 1 = …… - 1= ………

Step 12: Calculating the "***F***" value.

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	*"F" Value*
Between Treatments	**Step 8**: ……..	**Step 9**: ……	**Step 13** = (Step 8/Step 9)	**Step 15** = (Step 13/Step 14)
Within Blocks	**Step 6** : ……..	**Step 10** : ……	**Step 14** = (Step 6/Step 10)	
Total	**Step 7**: ………..	**Step 11**: ……		
Step 16: Reading the "F" Value from the "F" table.	**Step 9 :** we go **across** the "F" table.			80% confidence Level
	Step 10: we go **down** the "F" table .			

	Between ***Treatments***: Follow the ***Top*** of the F Table (Number from STEP 9)	→
Within **Blocks**: Follow the numbers **Below :** (Number from STEP 10)		↓
↓		
	- →	

Memory aid:

i)**Treatment:** can stand for ***Top***: this means follow the F numbers on the top of F table.
ii) **Blocks**: can stand for ***below***: this means follow the F numbers that go ***below***).

If **Calculated** F Number is < than F value in the Table:	Different levels of fertilizer were ***not the responsible*** for the differences in crop output.
If **Calculated** F Number is > than F value in the Table: ………… > ………………	Different levels of fertilizer were ***responsible*** for the differences in crop output.

If statically significant above 80 %	Conduct economic analysis and if needed conduct trials the following year with higher levels of fertilizer.
If not statically significant above 80%	Do not do any economic analysis but repeat fertilizer field trials using greater levels of nitrogen than before.

Go to appendix of this chapter to do one example to see that we really understand how to conduct ANOVA and to see if the results were statically significant.

"t" Tests	**COMPARING TWO TRAILS WITH DIFFERENT FERTILIZER TREATMENTS**			
	Treatment		***Treatment***	
Step 1: Put the fertilizer trail results in form a table as shown.	Block	Yield Kg./ha	Block	Yield Kg./ha
	1	….	1	….
	2	….	2	….
	3	….	3	….
Step 2: Total the results	….		….	
Step 3: Number of blocks.	….		….	
Step 4: ***(Step 2/Step 3)*** Calculate Means:	$\frac{....}{....}$ = ….		$\frac{....}{....}$ = ….	
Step 5: Calculate the variances: S^2_3 and for S^2_7	$(......- ......)^2 = (......)^2 = ...$ $(......- ......)^2 = (......)^2 = ...$ $(......- ......)^2 = (......)^2 = ...$		$(......- ......)^2 = (......)^2 = ...$ $(......- ......)^2 = (......)^2 = ...$ $(......- ......)^2 = (......)^2 = ...$	
	……		……	
Step 6: Number of times each treatment was replicated (No. of blocks)	……		……	
Step 7: ***(Step 6 minus 1)*** Number of times each treatment was replicated minus 1.	$= (n_3 - 1)$ = (…… – 1) = ………		$= (n_7 - 1)$ = (……. – 1) = ………..	
Step 8: ***(Total of Step 7)*** Total Degrees of Freedom:	…… + ……. = …….			
	S_3^2		S_7^2	
Step 9:	Step 5 = $\frac{}{......}$ = $\frac{}{......}$		Step 5 = …… = ……	

(Step 5 ÷ Step 7)	Step 7 ……	Step 7 ……
Step 10: (Step **9** x Step **7**)	(…… x ……) = ……	(…… x ……) = ……
Step 11: Add results of Step **10**	……+ ……= ……	
Step 12: (Step 11/Step 8) Pooled Variance**:** Finding S^2	$\frac{\text{Step 11}}{\text{Step 8}} = \frac{\ldots\ldots}{\ldots\ldots}$ = ……	
Step 13: Square Rt. of Step **12**.	√ Step 12 = √ ……= ……	
Step 14: Differences of Step **4**	…… - ……= ……	
Step 15A: (1/Step 6)	$1/n_3$ 1/…… = ……	$1/n_7$ 1/…… ……
Step 15 B: Total of Step 15A	(…… + ……) = ……	
Step 15C: (Square root of Step 15B). Square Root of the Sum of the inverses of the number of treatment.	√ (……) = ……	
Step 16: (Step **13** x Step **15C**)	(Step 13 x Step 15) = …… x …… = ……	
Step 17: (Step **14**/ Step **16**) "***t***" value	$\frac{\text{Step 14}}{\text{Step 16}} = \frac{\ldots\ldots}{\ldots\ldots}$ = ……	
How to read if yield from **Treatment 7** is statically significantly.(Read next page for more information)		
Step 18A: Degrees of Freedom :***Step 8***	……	
Step 18B: Look at Table ..and Look at Deg. Of Freedom in Step ***18A*** and different levels of Significance.	*Levels of Significance(%)*: 90% / **80%** / 75%	*D of Fred.* …… : 90% …… ; 80% …… …… ; 75%
	The Value in Step 18B (2.0701) is greater than ***80%*** level but smaller than 90 % level. So we can say with ***80%*** level of confidence that 2P in fertilizer in Treatment 7 will give higher yields.	
HOW TO CALCULATE THE RANGE OF YIELD ONE WOULD GET WHEN ***TREATMENT 7*** IS APPLIED:		
		TREATMENT 7
Step 19A: Degrees of Freedom for Treatment 7: from Step 7 (number of blocks for Treatment 7 minus 1)		(…… - 1=)……
Step 19.1B : Level of Confidence read from Step 18B:		80%

Step 19.1B: Read Value Levels of Confidence below.		***80%*** level of Confidence and ***2*** degrees of freedom.			
		Levels of Significance			
			90%	**80%**	75%
		D of Fred. ……	……	……	
Step 19C: Square Root of ***Step 3***: For Treatment 7		√…… = ……			
Step 19D: Square Root of ***Step 9***: For Treatment 7		√……= ……			
Step 19E: (***Step 19D / Step 19C***)		…… ÷……= ……			
Step 19F: (***Step 191.B x Step 19E)***		……x ……**=** ……			
Step 19G: *Minimum* yield from Treatment 7: ***(Step 4 - Step 19F)***		…… **-** …… = ……			
Step 19H: *Maximum* yield from Treatment 7:***(Step 4 + Step 19F)***		…… + …… = ……			
HOW TO CALCULATE THE RANGE OF YIELD WHEN ***TREATMENT 3*** IS APPLIED:					
	TREATMENT 3				
Step 20A:Degrees of Freedom for Treatment 3: from ***Step 7*** (number of blocks for Treatment 3 minus 1)	(…… - 1=) ……				
Step 20B.1 : Level of Confidence read from **Step 18B**:	80%				
	LEVELS OF SIGNIFICANCE				
Step 20B.2: Read Value Levels of Confidence below ***80%*** level of Confidence and ***2*** degrees of freedom.	*D of Fred.* ……	**80%** ……			
Step 20C: Square Root of ***Step 3*** for Treatment 3.	√…… = ……				
Step 20D: Square Root of ***Step 9*** for Treatment 3.	√…… =……				
Step 20E: ***(Step 20D / Step 20C)***	…… ÷ ……= ……				
Step 20F: ***(Step 20B.2 x Step 20E)***	…… x …… **=** ……				
Step 20G: *Minimum* yield from Treatment 3: ***(Step 4 - Step 20E)***	…… **-** …… = ……				
Step 20H: *Maximum* yield from Treatment 3: ***(Step 4 + Step 20E)***	…… + …… = ……				

% Point of the F Distribution ↓	Step10 Page-76. ↓	F DISTRIBUTION TABLE — *Between Treatments (Value from Step 9 –Ch. 5 - page 76)*						
		1	***2***	***3***	***4***	***5***	***6***	***7***
90%	1	39.86	49.5	53.59	55.83	57.24	58.2	58.91
80%	***1***	***9.472***	***12.00***	***13.06***	***13.64***	***14.01***	***14.26***	***14.44***
75%	1	5.83	7.5	8.20	8.58	8.82	8.98	9.10
90%	2	8.53	9	9.16	9.24	9.29	9.33	9.35
80%	***2***	***3.56***	***4.00***	***4.16***	***4.24***	***4.28***	***4.32***	***4.34***
75%	2	2.57	3.00	3.15	3.23	3.28	3.31	3.34
90%	3	5.46	5.39	5.34	5.31	5.28	5.27	5.25
80%	***3***	***2.68***	***2.89***	***2.94***	***2.96***	***2.97***	***2.97***	***2.97***
75%	3	2.02	2.28	2.36	2.39	2.41	2.42	2.43
90%	4	4.54	4.32	4.19	4.11	4.05	4.01	3.98
80%	***4***	***2.35***	***2.47***	***2.48***	***2.48***	***2.47***	***2.47***	***2.47***
75%	4	1.81	2.00	2.05	2.06	2.07	2.08	2.08
90%	5	4.06	3.78	3.62	3.52	3.45	3.4	3.37
80%	***5***	***2.18***	***2.26***	***2.25***	***2.24***	***2.23***	***2.22***	***2.21***
75%	5	1.69	1.85	1.88	1.89	1.89	1.89	1.89
90%	6	3.78	3.46	3.29	3.18	3.11	3.05	3.01
80%	***6***	***2.07***	***2.13***	***2.11***	***2.09***	***2.08***	***2.06***	***2.05***
75%	6	1.62	1.76	1.78	1.79	1.79	1.78	1.78
90%	7	3.59	3.26	3.07	2.96	2.88	2.83	2.78
80%	***7***	***2.00***	***2.04***	***2.02***	***1.99***	***1.97***	***1.96***	***1.94***
75%	7	1.57	1.70	1.72	1.72	1.71	1.71	1.70
90%	8	3.46	3.11	2.92	2.81	2.73	2.67	2.62
80%	***8***	***1.95***	***1.98***	***1.95***	***1.92***	***1.9***	***1.88***	***1.87***
75%	8	1.54	1.66	1.67	1.66	1.66	1.65	1.64
90%	9	3.36	3.01	2.81	2.69	2.61	2.55	2.51
80%	***9***	***1.91***	***1.93***	***1.90***	***1.87***	***1.85***	***1.83***	***1.81***
75%	9	1.51	1.62	1.63	1.63	1.62	1.61	1.60
90%	10	3.29	2.92	2.73	2.61	2.52	2.46	2.41
80%	***10***	***1.88***	***1.90***	***1.86***	***1.83***	***1.80***	***1.78***	***1.77***
75%	10	1.49	1.60	1.60	1.59	1.59	1.58	1.57
90%	11	3.23	2.86	2.66	2.54	2.45	2.39	2.34
80%	***11***	***1.86***	***1.87***	***1.83***	***1.80***	***1.77***	***1.75***	***1.73***
75%	11	1.47	1.58	1.58	1.57	1.56	1.55	1.54
90%	12	3.18	2.81	2.61	2.48	2.39	2.33	2.28
80%	***12***	***1.84***	***1.85***	***1.80***	***1.77***	***1.74***	***1.72***	***1.70***
75%	12	1.46	1.56	1.56	1.55	1.54	1.53	1.52
90%		3.14	2.76	2.56	2.43	2.35	2.28	2.23
80%	***13***	***1.82***	***1.83***	***1.78***	***1.75***	***1.72***	***1.69***	***1.68***
75%	13	1.45	1.55	1.55	1.53	1.52	1.51	1.5
90%		3.1	2.73	2.52	2.39	2.31	2.24	2.19
80%	***14***	***1.81***	***1.81***	***1.76***	***1.73***	***1.70***	***1.67***	***1.65***
75%	14	1.44	1.53	1.53	1.52	1.51	1.50	1.49
90%	15	3.07	2.7	2.49	2.36	2.27	2.21	2.16
80%	***15***	***1.80***	***1.80***	***1.75***	***1.71***	***1.68***	***1.66***	***1.64***
75%	15	1.43	1.52	1.52	1.51	1.49	1.48	1.47
90%	16	3.05	2.67	2.46	2.33	2.24	2.18	2.13
80%	***16***	***1.79***	***1.78***	***1.74***	***1.70***	***1.67***	***1.64***	***1.62***
75%	16	1.42	1.51	1.51	1.50	1.48	1.47	1.46
90%	17	3.03	2.64	2.44	2.031	2.22	2.15	2.1
80%	***17***	***1.78***	***1.77***	***1.72***	***1.68***	***1.65***	***1.63***	***1.61***
75%	17	1.42	1.51	1.50	1.49	1.47	1.46	1.45
90%	18	3.01	2.62	2.42	2.29	2.2	2.13	2.08
80%	***18***	***1.77***	***1.76***	***1.71***	***1.67***	***1.64***	***1.62***	***1.60***
75%	18	1.41	1.50	1.49	1.48	1.46	1.45	1.44
90%	19	2.99	2.61	2.4	2.27	2.18	2.11	2.06
80%	***19***	***1.76***	***1.75***	***1.70***	***1.66***	***1.63***	***1.61***	***1.58***
75%	19	1.41	1.49	1.49	1.47	1.46	1.44	1.43
90%	20	2.97	2.59	2.38	2.25	2.16	2.09	2.04
80%	***20***	***1.76***	***1.75***	***1.70***	***1.65***	***1.62***	***1.60***	***1.58***
75%	20	1.40	1.49	1.48	1.47	1.45	1.44	1.43

“*t*” Table : For Chapter 5:

“*t*” Table					**“*t*” Table**		
TABLE: 2A					***TABLE: 2B***		
Table to Use when comparing: **1** NUTRIENT WITH **2** NUTRIENT TREATMENT; **OR** **2** NUTRIENT WITH **3** NUTRIENT TREATMENT					Table to Use when Comparing: **1** NUTRIENT WITH **3** NUTRIENT TREATMENT		
		Level of Confidence					**Level of Confidence**
	df	***90%***	**80%**	***75%***		***df***	**95%**
Deg. Of	1	*6.314*	3.078	1.000	Deg. Of	1	12.706
Freedom	2	*2.920*	1.886	0.816	Freedom	2	4.303
	3	*2.353*	1.638	0.764		3	3.182
	4	*2.132*	1.533	0.740		4	2.776
	5	*2.015*	1.476	0.726		5	2.571
	6	*1.943*	1.440	0.717		6	2.447
	7	*1.895*	1.415	0.711		7	2.365
	8	*1.860*	1.397	0.706		8	2.306
	9	*1.833*	1.383	0.702		9	2.262
	10	*1.812*	1.372	0.769		10	2.228
	11	*1.796*	1.363	0.697		11	2.201
	12	*1.782*	1.356	0..695		12	2.179
	13	*1.771*	1.350	0.693		13	2.160
	14	*1.761*	1.345	0.692		14	2.145
	15	*1.753*	1.341	0.691		15	2.131
	16	*1.746*	1.337	0.690		16	2.120
	17	*1.740*	1.333	0.689		17	2.110
	18	*1.734*	1.330	0.688		18	2.101
	19	*1.729*	1.328	0.687		19	2.093
	20	*1.725*	1.325	0.686		20	2.086

TABLE 1.17: COMMERCIALLY USED LIMING MATERIALS AND THEIR PROPERTIES

Name of Material	Chemical Formula	NV%	Other Information
1) Calcium Hydroxide (builder's lime)	$Ca(OH)_2$	125-145	**Caustic**: must be handled with care.
2) Calcium Oxide (quicklime)	CaO	150-185	**Quick acting**, for situations where quick results are required. Spread well before sowing to prevent seed damage.
3) Limestone: Impure-	$CaCO_3$	100	Requires at least 12-18 months to reduce soil acidity. Big particles require up to 3 years to be effective. Apply near crop row and mix by plowing and disking. **Dolomite**: recommended where magnesium is lacking.
Pure-	$CaCO_3$	75-95	
Dolomite-	$CaMg(CO_3)_2$	109-119	
4) Marl		90-95	
5) Shells		up to 95	Should be thoroughly ground before use.
6) Wood-ash		30-75	Useful side benefit of wood fuel.

TABLE 2.1: THE PRINCIPAL STRAIGHT FERTILIZERS

COMMON NAME	FORMULA	GRADE OR ANALYSIS PERCENTAGE OF FORMULA		
NITROGEN FERTILIZERS		**N**	**P_2O_5**	**K_2O**
Ammonium chloride	NH_4Cl	24	0	0
Ammonium nitrate	NH_4NO_3	33-34.5	0	0
Ammonium nitrate-limestone	$NH_4NO_3. (NH_4)_2 SO_4$	20.5-26	0	0
Ammonium sulfate	$(NH_4)_2 SO_4$	21	0	0
Ammonium sulfate- nitrate	$NH_4SO_4. (NH_4)_2 NO_3$	26	0	0
Calcium cyanamide	CaN_3	18-22	0	0
Calcium nitrate	$Ca (NO_3)_2$	15-15.5	0	0
Sodium nitrate	$NaNO_3$	16	0	0
Urea	$CO(NH_2)_2$	45-46	0	0
PHOSPHATE FERTILIZERS				
Basic slag		0	16-20	0
Di- Calcium phosphate	$Ca (H_2 PO_4)_2$	0	35-42	0
Ground rock phosphate		0	20-40	0
Single or simple Super phosphate	$Ca (H_2 PO_4)_2 + CaSO_4$	0	16-20	0
Triple or concentrated Super phosphate	$Ca (H_2 PO_4)_2$	0	46	0
POTASH FERTILIZERS				
Marinate of potash or Potassium chloride	KCl	0	0	60
Sulfate of potash		0	0	50
Sulfate of potash-magnesia	$K_2SO_4.MgSO_4$	0	0	21
Sylinite (double)		0	0	40

TABLE 2.2: SOME CHEMICALLY MIXED FERTILIZERS

Common name	Formula	% Nutrient	Method of Application Present *	Advantages	Disadvantages
Ammonium phosphates	$NH_4H_2PO_4$	***N***: 11 P_2O_5: 48	Broadcast or row placement	Good in soils which do not need potassium. Phosphorus is completely water solvable.	Causes high Soil acidity. .
Ammonium phosphate Ammonium nitrate	$NH_4H_2PO_4$ NH_4NO_3	***N***:16 P_2O_5: 20	Broadcast or row placement.	Completely water solvable. N03 immediately available.	$NO3^-$ may be loss through leaching or denitrification. High residual acidity.
Diammonium phosphate	$(NH_4)_2HPO_4$	***N***:18-21 P_2O_5: 46-53	Broadcast	N and P do not separate on bulk blending. Phosphate is completely water solvable.	Danger to seed germination
Potassium nitrate	KNO_3	***N***:13.5 K_2O: 46			

* For methods of fertilizer applications see Section 9 of this chapter.

TABLE 2.3: MICRONUTRIENT FERTILIZERS

Common name	Formula	Micronutrient Contained
Borax	$Na_2B_4O_7.10H_2o$	Boron (B)
Copper Sulfate	$CuSO_4.5H_2o$	Copper (Cu)
Ferrous Sulfate	$FeSO_4.7H_2O$	Iron (Fe)
Manganese Sulfate	$MnSO_4.7H_2o$	Manganese (Mn)
Muriate Of Potash	KCl	Chlorine (Cl)
Sodium Molybdate	$Na_2MoO_4.10H_2O$	Molybdenum (Mo)
Zinc Sulfate	$Zn_2SO_4.7H_2o$	Zinc (Zn)

TABLE 2.7: PROPERTIES OF NITROGEN FERTILIZERS

Common Name	Physical Conditions	Methods Of Application*	Advantages	Disadvantages
Ammonium Nitrate	Pellets	Broadcast or side dressing	$NO3^-$ immediately available	$NO3^-$- maybe easily lost through denitrification or leaching.
Ammonium Sulfate	Pellets Or Granules	Broadcast or side dressing	Acidic in nature. So maybe useful on alkaline soils.	On acidic soils liming would be required to correct acidity.
Calcium Cyanamide	Prills	Broadcast or side dressing	Because of its high toxicity it can be used for weed control.	May cause damage to seed, if applied too closely to it.
Calcium Nitrate	Granules	Broadcast or side dressing	$NO3^-$- is immediately available. Non-acidic.	Expensive for the amount of *N* in it.
Sodium Nitrate	Granules	Broadcast or side dressing	$NO3^-$ --immediately available. Non- acidic.	
Urea	Granules	Side dressing, broadcast, or spray in solutions.	High water solubility. High N content. Non-leachable when converted to NH_4 form.	Can be lost as NH_4 gas or leached, away if rains soon after application.

TABLE 2.8: PROPERTIES OF PHOSPHATE FERTILIZERS

Common Name	% P_2O_5	P available (% of total)	Other Information
Single or Simple Super Phosphate	16 - 20	79-100	May be applied by itself or mixed with other fertilizers. Should be recommended where sulfur is deficient in the soil.
Triple or Concentrated Phosphates	46	96 - 99	High source of P. Should be recommended where transportation is a major cost.
Di-calcium Phosphate	35 - 42	98	See table 2.24 chemically mixed fertilizers.
Ammonium Phosphate	48	100	May be mixed or blended with other fertilizers. See table 2.2 for chemically mixed fertilizers.
Di-ammonium Phosphates	46 - 53	100	(As for above, see table 2.2)
Ground Rock Phosphorate	20 - 40	14 - 65	Slow source of P; so should not be applied on short season crops e.g. Tomatoes.
Basic Slag	16 - 20	62 - 94	Alkaline in nature. So a good source of p on acid soils.
Nitro Phosphate	Variable	0 - 70	Good results on acid soils and good for crops with long growing season.

TABLE 2.9: POTASSIUM FERTILIZERS

Common Name	Formula	% of K_2O	Application
Muriate of Potash or Potassium Chloride	KCl	60	Applied directly or may be bulk blended with other fertilizers. Highly solvable and water so may be used as liquid fertilizer. Chlorine in muriate reduces stalk rot in maize; but potatoes are sensitive to chlorine.
Potassium Sulfate	K_2SO_4	48 - 50	It is relatively expensive fertilizer. Sulfur content of the fertilizer maybe useful where it is lacking.
Sulfate of Potash Magnesia	$K_2SO_4.MgSO_4$	22-23	It is useful where three nutrients -- potassium, magnesium and sulfur are needed.
Potassium Nitrate	KNO_3	46.6	Its application is desirable crops where chlorine is objectionable, e.g. potato crop. It is well-suited for use as liquid fertilizer.

FIG. 3.14: RELIABILITY OF SOIL TESTS IN SHOWING NUTRIENT AVAILABILITY

Test	Good	Fair	Poor	None
Phosphorous	*			
Potassium	*			
Calcium		*		
Zinc		*		
Magnesium			*	
Copper			*	
Nitrogen			*	
Iron				*
Manganese				*
Molybdenum				*
Sulfur				*
Lime Requirement	*			

TABLE 1.16: PREFERRED pH OF SOME CROPS

Crop	pH	Crop	pH
Rice	5.5 - 6.5	Soybean	6.0 -7.5
Wheat	5.5 - 7.5	*Groundnut*	6.0 -7.5
Maize	5.5 - 8.5	*Castor*	6.0 -7.5
Sorghum	6.0 - 7.5	*Rapeseed*	6.0 -7.5
Gram	6.5 - 7.5	*Linseed*	6.0 -7.5
Lentil	6.5 - 8.5	*Sunflower*	7.0 - 8.5
Peas	6.5 - 8.5	*Cotton*	7.0 - 8.5

A

B

C

H

I

K

L

M

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