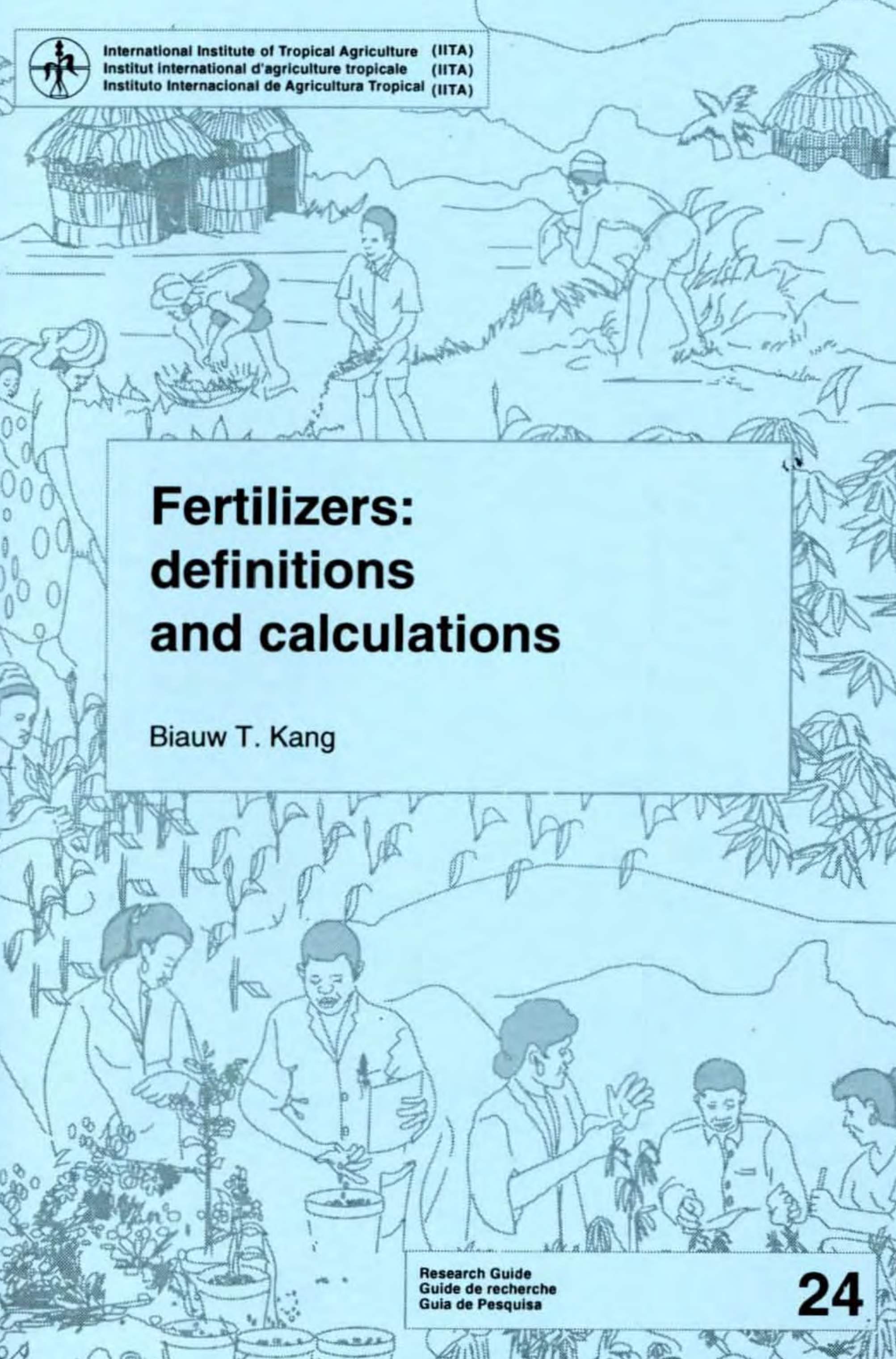

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Fertilizers: definitions and calculations

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IITA Research Guides

IITA Research Guides provide information and guidance to agricultural researchers, technicians, extension specialists, educators and students involved in research and training. The Research Guides are periodically updated to meet advances in scientific knowledge.

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Fertilizers: definitions and calculations

Objectives. This guide is intended to enable you to:

- discuss soil fertility and nutrient availability;
- define different types and grades of fertilizers;
- calculate fertilizer applications;
- mix fertilizers correctly.

Study materials

- Fertilizer samples.
- Examples of fertilizer recommendations.

Practicals

- Practice the identification of common fertilizers.
- Calculate the conversion from oxide to elemental basis, and vice versa.
- Calculate application rates for different levels of recommendations and different types of fertilizers.
- Practice the use of Tables 4, 5 and 6.
- Mix fertilizers.

Questions

1 What are nine macronutrients?
2 What macronutrients are supplied by air and water?
3 What are seven micronutrients?
4 In addition to the 16 essential elements, what are some other elements that are helpful in improving yield and quality of crops?
5 Why can water solubility alone not be used as a measure of nutrient availability?
6 What methods exist for evaluating the availability of phosphate fertilizers?
7 What is the definition of "fertilizer"?
8 What is the definition of "grade" of a fertilizer?
9 What does "10-15-18" indicate?
10 How do most countries express the grade of nitrogen, phosphorus and potassium?
11 What is the chemical residual effect of most nitrogen fertilizers?
12 How are fertilizer recommendations expressed?
13 What are five steps in calculating the amount of fertilizer required for a single-element fertilizer?
14 How should you select a fertilizer?
15 What data are necessary for fertilizer calculations?
16 What do you have to consider when mixing fertilizers?

Fertilizers: definitions and calculations

Abstract. Fertilizers furnish plants with nutrients for growth. Generally, plants take up nutrients dissolved in water. Water solubility, however, cannot be used as the only measure of nutrient availability to plants. Several definitions and terms are important to describe fertilizers. The "grade", for example, describes the N-P_2O_5-K_2O content in weight percentage. The exact amount of fertilizer required has to be calculated depending on type of fertilizer and area to be fertilized. Mixing of fertilizers makes application easier, however, not all fertilizers can be mixed.

1 Soil fertility and nutrient availability

Soil fertility depends on the status of a soil with respect to its ability to supply nutrients essential for plant growth. Soil fertility focuses on adequate and balanced supply of nutrients to satisfy the needs of plants, avoiding toxic concentrations.

Fertilizers, organic or inorganic, natural or synthetic, furnish plants with nutrients. The list of essential elements for plant nutrition has increased over the years and now totals 16 (Table 1).

Table 1. Essential nutrients.

Macronutrients	Available from air and water	carbon hydrogen oxygen
	Primary elements	nitrogen phosphorus potassium
	Secondary elements	calcium magnesium sulfur
Micronutrients		boron chlorine copper iron manganese molybdenum zinc

The first nine elements are required in relatively large amounts and are called macronutrients. Three of them, carbon, hydrogen, and oxygen, are supplied by air and water. The other macronutrients are subdivided into primary elements (nitrogen, phosphorus, potassium) and secondary elements (calcium, magnesium, sulfur). The remaining seven elements are required in small amounts and are known as micronutrients or trace elements.

In addition to the 16 essential elements listed above, some other elements are helpful in improving yield and quality of crops. Examples are sodium, silicon, cobalt and selenium.

Most commercial fertilizers contain at least one of the primary elements in a form available to plants in specified amounts. Generally, plants take up nutrients dissolved in water. Thus, water solubility is a measure of nutrient availability to plants. Unfortunately, the situation is far too complex to use water solubility alone as a measure of availability. All nutrients are soluble in water to some degree, even the most "insoluble" nutrients.

Many partially soluble nutrients are available to plants and, in some cases, are even more effective than readily water-soluble nutrients (e.g. in controlled-release fertilizers). However, some substances are so insoluble that they are not useful as fertilizers. Therefore, most countries specify some degree of nutrient solubility in water or other reagents.

For example, natural organic fertilizers may be acceptable on the basis of their total N, P_2O_5, and K_2O content.

Synthetic organic fertilizers, if partially soluble, may require special methods of analysis, particularly if intended for controlled-release fertilizers. Likewise, special tests may be required for coated controlled-release fertilizers.

Since most common nitrogen and potassium fertilizers are readily water soluble, water solubility is usually accepted as a measure of nutrient availability. Special methods are applied to less soluble elements only when there is evidence that the low (or controlled) solubility may be advantageous.

Phosphate fertilizers have a wide range of water solubility. Several methods exist for evaluating their availability. The most common methods other than water solubility are based on solubility of P_2O_5 in neutral or alkaline ammonium citrate solutions, or in solutions of citric or formic acid. In addition, the total P_2O_5 may be acceptable for some fertilizers. Some examples of quality control of phosphate fertilizers are:

- *Federal Republic of Germany*. Phosphate is expressed as the sum of P_2O_5 soluble in water and (alkaline) ammonium citrate. For superphosphate, at least 90 % of the sum must be soluble in water. For compound fertilizers, at least 30 % of the sum must be soluble in water.

- *Belgium*. For triple superphosphate, only the water-soluble P_2O_5 may be guaranteed. The product must contain at least 38 % water-soluble P_2O_5.

Soft rock phosphate must contain not less than 25 % P_2O_5 soluble in mineral acids, of which not less than 50 % must be soluble in formic acid. It must be ground to such a fineness that at least 90 % passes through a sieve with 0.15 mm sieve openings.

For compound fertilizers, the P_2O_5 content may be expressed as P_2O_5 soluble in water, alkaline ammonium citrate, or both. If the compound fertilizer contains Thomas (basic) slag as the only source of phosphate, the P_2O_5 content is expressed as P_2O_5 soluble in citric acid.

- *United States*. The guaranteed P_2O_5 content of all fertilizers is based on the "available phosphoric acid" (APA) content which is the P_2O_5 content soluble in neutral ammonium citrate including P_2O_5 soluble in water. APA does not state the water-soluble P_2O_5 content separately. The total P_2O_5 may be stated, but it is not stated in the guaranteed APA content.

- *European Economic Community (EEC)*. Regulations adopted in 1977 specify the following permissible solvents as a basis for evaluating phosphate fertilizers:

    - water for those phosphate fertilizers "where applicable",
    - formic acid (2 %) for soft natural phosphates,
    - citric acid (2 %) for basic slag,
    - neutral ammonium citrate solution for all fertilizers.

Since a wide variety of natural and synthetic substances are beneficial to plants, an unlimited number of products could be labeled "fertilizer" and marketed as such. Therefore, it is important to control marketing of fertilizers so that farmers can be sure that each lot of fertilizer has the same effectiveness.

Fertilizer. A fertilizer is a manufactured product containing a substantial amount of one or more of the primary, secondary macronutrients or micronutrients.

In some countries, the terms "chemical fertilizer", "mineral fertilizer", or "inorganic fertilizer" are used to distinguish the manufactured products from natural organic fertilizers of plant or animal origin which are called "organic fertilizers."

Grade. The grade of a fertilizer is the nutrient content in weight percentage of N, P_2O_5, and K_2O in the order N-P-K. The grade is only the amount of nutrient found by prescribed analytical procedures, excluding any nutrient that is unavailable to plants. For example, a grade of "10-15-18" indicates a fertilizer containing 10 % N, 15 % P_2O_5, and 18 % K_2O.

Most countries express the grade as elemental nitrogen (N), phosphorus as pentoxide (P_2O_5), and potassium as oxide (K_2O). Secondary and micronutrients are also expressed on an elemental basis, although calcium and magnesium are sometimes expressed as oxides. Several countries have adopted the elemental basis for all plant nutrients.

Recently, FAO changed to the elemental form, but will use both forms for phosphorus (P and P_2O_5) and potassium (K and K_2O) during a transitional period.

Table 2 shows factors to convert from oxide to elemental basis. For example, the grade 10-15-18 becomes 10-6.5-14.9.

The grade may also be called 'analysis' or 'formula'.

P_2O_5	x	0.44	=	P
P	x	2.29	=	P_2O_5
K_2O	x	0.83	=	K
K	x	1.20	=	K_2O
CaO	x	0.71	=	Ca
Ca	x	1.40	=	CaO
MgO	x	0.60	=	Mg
Mg	x	1.66	=	MgO
SO_2	x	0.50	=	S
S	x	2.00	=	SO_2

Table 2. Conversion factors for plant nutrients.

Straight fertilizer. Fertilizer containing only one nutrient, for example, urea or superphosphate.

Compound fertilizer. Fertilizer containing two or more nutrients.

Granular fertilizer. Fertilizer in the form of particles, with upper and lower size limits, or between two screen sizes, usually between 1-4 mm. In general, the term "granular" does not imply any particular means of preparation. The desired size may be obtained by:

- compacting smaller particles,
- crushing and screening larger particles,
- controlling crystal size in crystallization processes,
- separating a screen fraction of crushed beneficiated potash ore,
- prilling a material.

Often, the name of the product indicates the method of preparation, for example "prilled," "compacted," crystalline," etc.

Prilled fertilizer. A granular fertilizer with round grains.

Coated fertilizer. Granular fertilizer coated with a thin layer of substances, such as clay or sulfur, to prevent caking or to control dissolution rate.

Nongranular (powdered) fertilizer. Fertilizer containing fine particles, usually with some upper limit size such as 3 mm, but no lower limit.

Conditioned fertilizer. Fertilizer treated with an additive to improve physical condition or prevent caking. The conditioning agent may be applied as a coating or incorporated in the product.

Bulk fertilizer. Unpacked fertilizer.

Bulk-blend fertilizer or blended fertilizer. Two or more granular fertilizers of similar size mixed together to form a compound fertilizer.

Liquid or fluid fertilizer. A general term for liquid fertilizers including fertilizers that are readily or partially soluble, clear liquids, liquids containing solids in suspension, and (usually) anhydrous ammonia. However, anhydrous ammonia is sometimes referred to as a gaseous fertilizer even though it is applied as a liquid.

Solution fertilizer. Liquid fertilizer dissolved in water and free of solids.

Reaction of fertilizers. Chemical residual effect of fertilizer. Most nitrogen fertilizers have an acidifying effect [$(NH_4)_2SO_4$ >Urea >CAN]. The effect increases with application rate.

Effectiveness of fertilizers. A measure of efficiency of the applied nutrient. Efficiency depends on application rate, source, timing, and method of fertilizer application.

Table 3 presents abbreviations and grades of common fertilizers.

Table 3. Common fertilizers.

AN	Ammonium nitrate	33 - 34 % N
ANL	Ammonium nitrate-limestone mixture (see CAN)	
AS	Ammonium sulfate	21 % N
ASN	Ammonium sulfate nitrate	26 % N
CN	Calcium nitrate	15 % N
CAN	Ammonium nitrate/calcium carbonate mixture (may contain chalk, marl, dolomite, limestone, or chemically precipitated calcium carbonate. Also called calcium ammonium nitrate and ammonium nitrate limestone (ANL)	20 - 28 % N
UAN	Urea ammonium nitrate (solution)	28 - 32 % N
APN	Ammonium phosphate nitrate	30-10-0 to 18-36-0
APS	Ammonium phosphate sulfate	16-20-0
DAP	Diammonium phosphate	18-46-0
MAP	Monoammonium phosphate	11-55-0
APP	Ammonium polyphosphate (solution)	10-34-0
NK	Nitrate of potash (potassium nitrate)	13-0-44
MOP	Muriate of potash (fertilizer-grade) potassium chloride	60 - 62 % K_20
SOP	Sulfate of potash (fertilizer-grade) potassium sulfate	50 % K_20
SSP	Single superphosphate	16 - 22 % P_20_5
TSP	Triple superphosphate	44 - 48 % P_20_5
KMP	Potassium metaphosphate	0-55-37
MKP	Monopotassium phosphate	0-47-31
KP	Potassium phosphate (see MKP and KMP)	

Fertilizer recommendations are expressed in kilograms of nutrients per hectare (kg/ha) in the order N-P_2O_5-K_2O (or N-P-K). If only nitrogen is needed, for example, the rate is given in kilograms of nitrogen (N) per hectare.

Based on result of field trials or results of soil analysis, fertilizer rates are formulated.

Calculation for a single-element fertilizer:

Step 1. Select a fertilizer that is:

- available locally,
- least expensive,
- suited to the soil conditions (on acidic soil, avoid or minimize use fertilizers with residual acid effect),
- storable,
- applicable with available equipment.

Step 2. List necessary data:

- recommended application rate (R) (kg/ha),
- analysis (C) of the fertilizer (%),
- area to be fertilized (m^2).

Step 3. Calculate amount of fertilizer required per hectare (ha) by dividing application rate (R) by analysis (C).

Equation 1:

$$\text{Fertilizer required (kg/ha)} = \frac{R\ (kg\ /\ ha) \times 100}{C\ (\%)}$$

Step 4. Calculate the amount of fertilizer required per m^2 by dividing the required amount per ha by 10 000 (1 ha = 10 000 m^2).

Step 5. Calculate the amount of fertilizer required for the area to be fertilized. Multiply the required amount per m^2 by the number of m^2 of the area to be fertilized.

Calculation for combinations of single-element fertilizers (example):

For example, a recommended rate of 80N-30P_2O_5-30K_2O kg/ha can be achieved by combining single-nutrient fertilizers, such as urea, triple superphosphate, and muriate of potash.

Calculate first the amount of urea (45 % N) required, then the amount of triple superphosphate (45 % P_2O_5) and muriate of potash (60 % K_2O) to satisfy the recommendation 80-30-30 kg/ha using equation 1:

$$\frac{80 \text{ kg / ha x } 100}{45 \text{ \%}} = 178 \text{ kg / ha of urea}$$

$$\frac{30 \text{ kg / ha x } 100}{45 \text{ \%}} = 67 \text{ kg / ha of triple superphosphate}$$

$$\frac{30 \text{ kg / ha x } 100}{60 \text{ \%}} = 50 \text{ kg / ha of muriate of potash}$$

Calculation for combinations of single-nutrient and compound fertilizers (example):

An application rate of 80-30-30 kg/ha can also be achieved by combining single-nutrient fertilizers with compound fertilizers.

Assumption:

A 15-15-15 fertilizer and urea (45 % N) are recommended for the 80-30-30 kg/ha fertilizer application.

In the recommended rate 80N-30P_2O_5-30K_2O kg/ha, less amounts of phosphorus and potassium are required. Phosphorus and potassium must be calculated first:

$$\frac{30 \text{ kg / ha x } 100}{15 \text{ \%}} = 200 \text{ kg / ha}$$

200 kg of a 15-15-15 compound fertilizer supplies only 30 kg of N per ha. This means that you must yet supply another 50 kg of N by urea:

$$\frac{50 \text{ kg / ha x } 100}{45 \text{ \%}} = 111 \text{ kg / ha}$$

Calculation of fertilizer requirement for a certain area (example):

recommended application rate	120-40-0
area to be fertilized	350 m^2
urea	45 % N
calcium ammonium nitrate	26 % N
single superphosphate	18 % P_2O_5
triple superphosphate	45 % P_2O_5
monoammonium phosphate	11-55-0

If you use urea and triple superphosphate, the amount required for 350 m^2 (0.0350 ha) is:

$$\frac{120 \text{ kg / ha x } 100 \text{ x } 0.0350 \text{ ha}}{45 \%} = 9.1 \text{ kg urea}$$

$$\frac{40 \text{ kg/ha x } 100 \text{ x } 0.0350 \text{ ha}}{45 \%} = 3.1 \text{ kg triple superphosphate}$$

If you use monoammonium phosphate (MAP) and urea, the amount of P_2O_5 required for 350 m^2 is:

$$\frac{40 \text{ kg / ha x } 100 \text{ x } 0.0350 \text{ ha}}{55 \%} = 2.54 \text{ kg MAP}$$

This 2.54 kg of MAP does not only provide the phosphorous required, but also 11 % of nitrogen corresponding to:

$$2.54 \text{ kg} \times 0.11 = 0.2794 \text{ kg N per } 350 \text{ m}^2$$

or:

$$\frac{0.2794 \text{ kg N} \times 10\,000 \text{ m}^2}{350 \text{ m}^2} = 8 \text{ kg N/ha}$$

According to the recommended application rate you still need to add 120-8 = 112 by N/ha. Thus, you must still provide additional urea:

$$(120\text{-}8) \text{ kg N/ha} \times \frac{100 \times 0.0350 \text{ ha}}{45 \%} = 8.7 \text{ kg urea/350 m}^2$$

Table 4. Conversion of pure elements to quantities of **nitrogen** fertilizers (kg/ha).

Rate of N application (kg/ha)	Ammonium sulfate (20 % N)	Urea (45 % N)	Aqua ammonia (25 % N)	Anhydrous ammonia (82 % N)
10	50	22	40	12
20	100	44	80	24
30	150	67	120	37
40	200	89	160	49
50	200	111	200	61
60	300	133	240	73
70	350	156	280	85
80	400	178	320	98
90	450	200	360	110
100	500	222	400	122
110	550	244	440	134
120	600	267	480	146
130	650	289	520	159
140	700	311	560	171
150	750	333	600	183

To calculate the amount of fertilizer required, multiply the rate of N (nitrogen) application by conversion factors of 5.0 for ammonium sulfate, 2.2 for urea, 4.0 for aqua ammonia, 1.2 for anhydrous ammonia.

Table 5. Conversion of pure elements to quantities of **phosphorus** fertilizers (kg/ha).

Rate of P_2O_5 application (kg/ha)	Ordinary superphosphate (20 % P_2O_5)	Triple superphosphate (45 % P_2O_5)
10	50	22
20	100	44
30	150	67
40	200	89
50	250	111
60	300	133
70	350	156
80	400	178
90	450	200
100	500	222
110	550	244
120	600	267
130	650	289
140	700	311
150	750	333

To calculate the amount of fertilizer required, multiply the rate of P_2O_5 (phosphorus) application by conversion factors of 5.0 for ordinary superphosphate, 2.2 for triple superphosphate.

Table 6. Conversion of pure elements to quantities of **potassium** fertilizers (kg/ha).

Rate of K_2O application (kg/ha)	Muriate of potash (60 % K_2O)	Sulfate of potash (50 % K_2O)
10	17	20
20	33	40
30	50	60
40	67	80
50	83	100
60	100	120
70	117	140
80	133	160
90	150	180
100	167	200
110	183	220
120	200	240
130	217	260
140	233	280
150	250	300

To calculate the amount of fertilizer required, multiply the rate of K_2O (potassium) application by conversion factors of 1.7 for muriate of potash, 2.0 for sulfate of potash.

If fertilizer application requires more than one element, it is likely that a combination of single element and compound fertilizers are necessary. You may weigh these fertilizers and apply separately, or mix them together. It is more convenient to mix the fertilizers because application is easier, especially on large mechanized farms.

However, not all fertilizers can be mixed. For example, strong basic fertilizers such as lime, should not be mixed with urea otherwise the nitrogen may be lost as ammonia.

If you need to apply nitrogen and phosphorus, do not mix ammonium sulfate with rock phosphate, or urea with superphosphate. If you mix these fertilizers, the elements react against one another, and one of them becomes less effective (Figure 1).

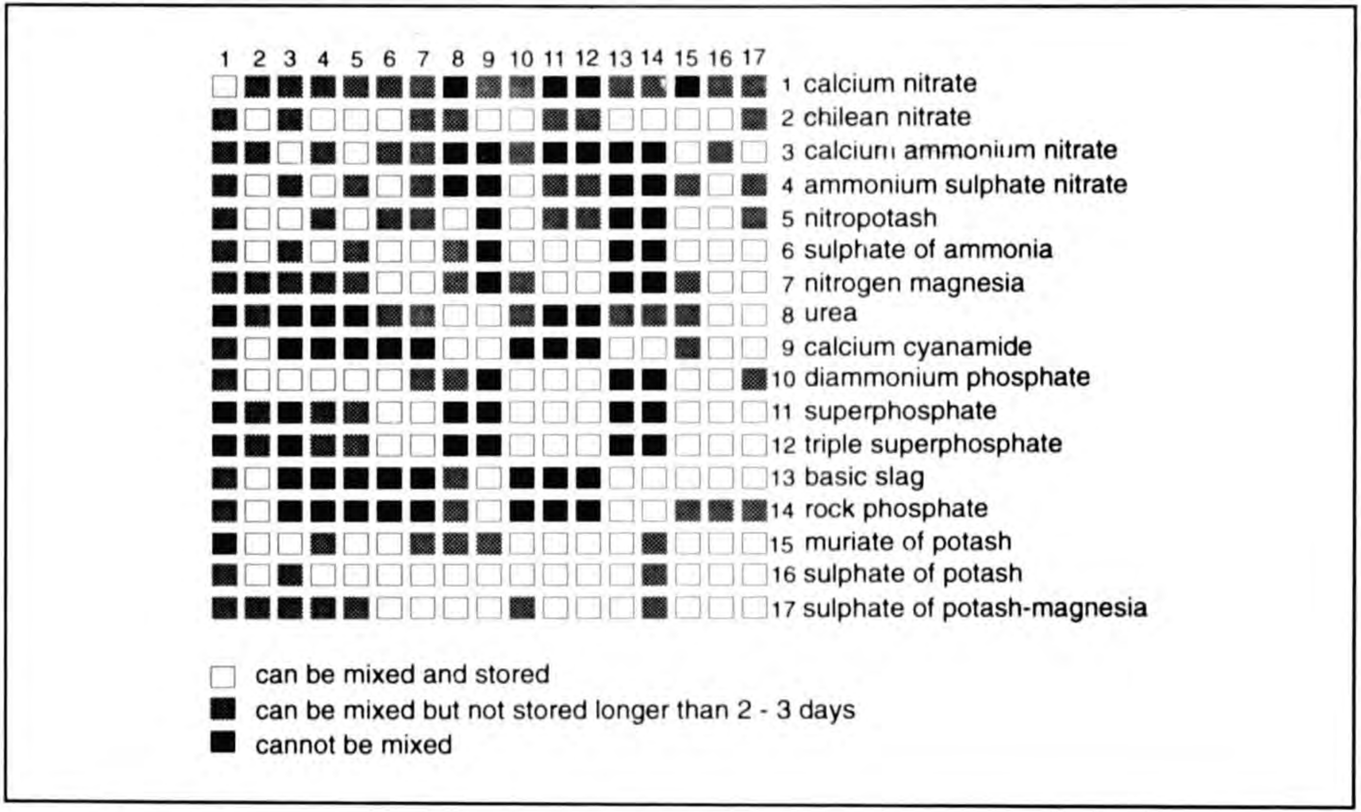

Figure 1. Guide for mixing fertilizers.

5 Bibliography

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6 Suggestions for trainers

If you use this Research Guide in training ...

Generally:

- Distribute handouts (including this Research Guide) to trainees one or several days before your presentation, or distribute them at the end of the presentation.

- Do not distribute handouts at the beginning of a presentation, otherwise trainees will read instead of listen to you.

- Ask trainees not to take notes, but to pay full attention to the training activity. Assure them that your handouts (and this Research Guide) contain all relevant information.

- Keep your training activities practical. Reduce theory to the minimum that is necessary to understand the practical exercises.

- Use the questions on page 4 (or a selection of questions) for examinations (quizzes, periodical tests, etc.). Allow consultation of handouts and books during examinations.

- Promote interaction of trainees. Allow questions, but do not deviate from the subject.

- Respect the time allotted.

Specifically:

- Discuss with trainees about experiences, needs and feasibility of fertilizer application under local farming conditions.

- Present and discuss the content of this Research Guide, using the study materials listed on page 3 (1 ½ hours). You may photocopy the tables, formula, and figure onto transparencies for projection with an overhead projector.

- Conduct the practicals suggested on page 3 in groups (3-4 trainees per group; 2 hours). Make sure that each trainee has the opportunity to practice. Have resource persons available for each group.

  Give each group the same set of data for calculating fertilizer applications. Ask each group to present the results of one example; the other groups should compare the results with their own calculations.

International Institute of Tropical Agriculture (IITA)
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The International Institute of Tropical Agriculture (IITA) is an international agricultural research center in the Consultative Group on International Agricultural Research (CGIAR), which is an association of about 50 countries, international and regional organizations, and private foundations. IITA seeks to increase agricultural production in a sustainable way, in order to improve the nutritional status and well-being of people in tropical sub-Saharan Africa. To achieve this goal, IITA conducts research and training, provides information, collects and exchanges germplasm, and encourages transfer of technology, in partnership with African national agricultural research and development programs.

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