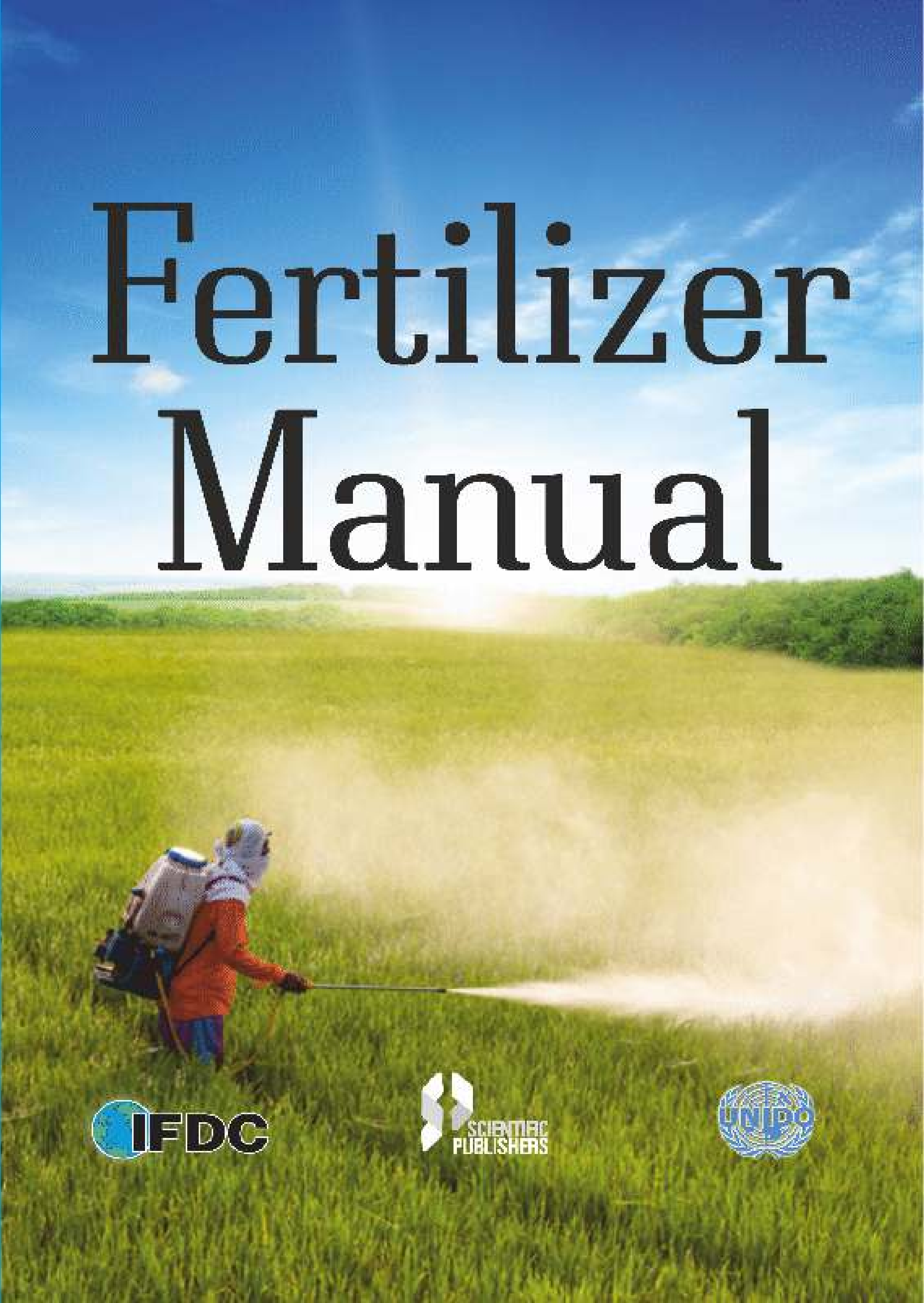
Fertilizer Manual



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Fertilizers Manual

This Manual is a Successor to and in part a revision of the IFDC/UNIDO

Editors:

United Nations Industrial Development Organization (UNIDO) and International Fertilizer Development Center (IFDC).

United Nations Industrial Development Organization (UNIDO)
Vienna, Austria

International Fertilizer Development Center (IFDC).

SCIENTIFIC PUBLISHERS

Scientific Publishers, Jodhpur - Raj. (INDIA)

Reprinted in India by:

SCIENTIFIC PUBLISHERS (INDIA)
5 A, New Pali Road, P.O. Box 91
Jodhpur 342 001 (INDIA)
E-mail: info@scientificpub.com
Website : http://www.scientificpub.com

Print : 2019

ISBN: 978-93-83692-63-7

ISBN: 978-93-88148-26-9 (E-book)

This manual has been prepared by the United Nations Industrial Development Organization (UNIDO) and International Fertilizer Development Center (IFDC) within UNIDO project XP/GL/93/094.

Printed in India

Preface

According to the United Nations, world population will reach 8.5 x 10^9 in 2025. Over 93% of the growth will occur in the developing countries. Such unprecedented growth in population will create equally unprecedented pressures on the natural resource base–land, water, and air–to produce adequate food, fiber, and raw materials to meet the growing demand.

The United Nations projects that the number of people living in absolute poverty will increase from 1.2 x 10^9 today to 1.5 x 10^9 by 2025. Today more than 700 million people in the developing countries do not have access to sufficient food to lead healthy, productive lives. If current trends in population growth and food production continue, by the year 2025, the World Bank estimates that Africa alone will have an annual food shortage of 250 million tonnes.

To solve these seemingly insurmountable problems, the United Nations forecasts that agricultural output must be tripled and people must have the income to buy it. With increasingly limited land under cultivation, sustainable food security cannot be achieved without the benefits of intensified agriculture–the key to alleviating poverty. The adoption of improved technology and the application of modern inputs of agriculture, including inorganic and organic fertilizers, can significantly boost food supply and help to protect the environment. In fact, Dr. Norman Borlaug, 1970 Nobel Peace Prize recipient, has said that "the use of chemical fertilizers must be expanded two- to threefold to maintain soil fertility and productivity in the developing countries over the next 25 years if the world is to feed itself."

The publication of this edition of the *Fertilizer Manual* is timely in that the World Food Summit was held in Rome in November 1996. At this Summit, policymakers from around the world discussed the global challenges created by a burgeoning population, shrinking land area available for food production, and mounting food insecurity.

The last revision of the *Fertilizer Manual* was published in 1979. Since that time major advances in fertilizer technology have occurred whereby more energy-efficient processes and reductions in the cost of production have resulted. This edition of the *Fertilizer Manual* provides planners with information on these new advances.

Editorial Note

In the 3rd edition of the *Fertilizer Manual*, basic information from the 2nd edition has been retained. The contents of the chapters were reviewed by consultants; professionals in the given fields of agronomics, technology, and economics. The names of contributors are as follows: Chapter 1 – D. W. Rutland (IFDC); Chapter 2 – B. H. Byrnes (IFDC); Chapter 3 – W. C. Brummit (IFDC); Chapter 4 – B. L. Bumb (IFDC); Chapter 5 – S. J. Van Kauwenbergh, T.A.B. Lawendy, and J. W. Foster (IFDC); D. E. Garrett, P. Rozwadowski, and B. Groover (UNIDO); Chapters 6 and 7 – B. Groover (UNIDO); Chapter 8 – D. P. Aleinov (UNIDO); Chapter 9 – J. R. Lazo de la Vega and G. R. Coleman (IFDC); Chapter 10 – F. P. Achorn (UNIDO); Chapter 11 – P. Rozwadowski (UNIDO); Chapters 12, 13, and 14 – A. Davister (UNIDO); Chapter 15 – D. E. Garrett (UNIDO); Chapter 16 – J. J. Schultz (IFDC); Chapter 17 – J. Mortvedt and R. G. Lee (IFDC); Chapter 18 – D. W. Rutland (IFDC); Chapters 19, 20, and 22 – J. A. Kopytowski (UNIDO) (S. A. Ahmed from East West Center, Honolulu, Hawaii, contributed with the EWC methodology on projection of fertilizers consumption); Chapter 21 – D. E. Nichols, J. R. Polo, and D. I. Gregory (IFDC). The technical editors of the *Fertilizer Manual* were R. G. Lee (IFDC) and J. A. Kopytowski (UNIDO). Internationally acknowledged fertilizer manufacturers, licensors, and engineering companies were asked to contribute nonconfidential information related to their processes. The following companies responded and their special contribution is appreciated and acknowledged in the *Fertilizer Manual* where needed: Babcock-King-Wilkinson, Chiyoda Corp., Lurgi GmbH, Snamprogetti SpA, M. W. Kellogg, H. Topsoe, Kemira Engineering Oy, Uhde GmbH, Stamicarbon SA, and Raytheon Engineers. Other companies' processes are described on the basis of publicly available information. Also information published by IFDC in workshop proceedings from 1990 to 1995 was used in some chapters, and references to this information are given. The information from these workshops has been especially useful in preparation of Chapters 2, 16, 19, and 21.

IFDC and UNIDO have used their best efforts in development of the information contained in the *Fertilizer Manual*. The use of the information contained herein shall be at the sole discretion of the user. It is unavoidable in a work of this magnitude that some of the information will require frequent updating. Readers should keep in mind that when authors refer to "current" or "present" situations, they usually mean 1996 unless otherwise specified.

Special thanks are extended to the following collaborators in the preparation of this manual.

- R. Rejewski (UNIDO) – preparation of the flow diagrams.
- Marie R. Stribling, Elizabeth N. Roth, and Marie K. Thompson (IFDC) – proofing and editing.
- Lynda F. Young (IFDC) – computer graphics.
- Jane L. Goss, Alicia K. Hall, Janice C. Gautney, and Donna W. Venable (IFDC) – word processing and layout.
- The contribution by Donna W. Venable is especially recognized.

Acronyms of Organizations

AAPFCO .... Association of American Plant Food Control Officials
APC .... Arab Potash Company
APPER .... African Priority Program of Economic Recovery
BASF .... Badische Anilin-und Soda-Fabrik
BFL .... Beladune Fertilizers Limited
BP .... British Petroleum
CERPHOS .... Centre d'Etudes et de Recherches des Phosphates Mineraux
CFCA .... Co-Operative Farm Chemical Association
CFL .... Coromandel Fertilizers Limited
CIL .... Chemetics International Ltd.
CNTIC .... China National Technical Import Corporation
COFAZ .... Compagnie Française de l'Azote
DSM .... Dutch State Mines
EFMA .... European Fertilizer Manufacturers' Association
EPA .... U.S. Environmental Protection Agency
EWC .... East-West Center
FAO .... Food and Agriculture Organization of the United Nations
FERTIMEX .... Fertilizantes Mexicanos
FW .... Foster Wheeler
GIAP .... State Institute of Nitrogen Industry
GNFC .... Gujarat Narmada Valley Fertilizers Company Limited
GSFC .... Gujarat State Fertilizers Company, Limited
HAIL .... Hydro Agri International Licensing
IAALD .... International Association of Agricultural Libraries and Documentalists
ICI .... Imperial Chemical Industries
IDDA .... Industrial Development Decade for Africa
IFA .... International Fertilizer Industry Association
IFDC .... International Fertilizer Development Center
IMI .... Israel Mining Industry
IMO .... International Maritime Organisation
IMPHOS .... Institut Mondial du Phosphate
IPC .... International Potash Company
ISO .... International Organization for Standardization
KT .... Koppers-Totzek
MAPCO .... Mid-America Pipeline Company
OPEC ....
ORNL .... Oak Ridge National Laboratory
PCA .... Potash Company of America
PCS .... Potash Corporation of Saskatchewan
PEQUIVEN .... Petroquímica de Venezuela
ROFOMEX .... Roca Fosfórica Mexicana
SAI .... Scottish Agricultural Industries
SQM .... Sociedad Quimica y Minera de Chile
TEC .... Toyo Engineering Company
TFI .... The Fertilizer Institute
TVA .... Tennessee Valley Authority
UNCED .... United Nations Conference on Environment and Development
UNEP .... United Nations Environment Programme
UNIDO .... United Nations Industrial Development Organization
UNPAAERD .... United Nations Program for Action for African Recovery and Development
USBM .... U.S. Bureau of Mines
USGS .... U.S. Geological Survey
WHO .... World Health Organization of the United Nations

Mathematical Symbols, Abbreviations and Conversion Factors Used in This Manual[a]

Monetary Value

$	U.S. dollar (unless otherwise indicated)
DM	Deutsche mark

Linear Measurement

m	meter = 3.28 feet (ft) = 39.37 inches (in)
cm	centimeter = 0.01 meter = 0.3937 inch (in)
mm	millimeter = 0.001 meter
μm	micrometer or "micron"
km	kilometer = 0.62 mile (mi)

Area Measure

m^2	square meter = 10.76 square feet (ft^2)
cm^2	square centimeter = 0.155 square inch (in^2)
km^2	square kilometer = 0.386 square mile (mi^2)
ha	hectare = 10,000 square meters (m^2) = 2.471 acres (A)

Weight

g	gram = 0.032 troy ounce (oz) = 0.035 avoirdupois ounce (oz)
mg	milligram = 0.001 gram (g)
μg	microgram = 0.000001 gram (g)
kg	kilogram = 1,000 grams (g) = 2.205 pounds (lb)
t	tonne (metric) = 1,000 kg = 2,205 lb = 1.102 short tons (st)
g-mole	gram mole = the molecular weight of a compound multiplied by 1 gram

Volume

gal	U.S. gallons = 3.785 liters
m^3	cubic meter = 35.34 cubic feet (ft^3) = 1,000 liters (l)
cm^3 or cc	cubic centimeter = 0.061 cubic inch (in^3)
l	liter = 0.264 U.S. gallons (gal) = 1.057 quart (qt)
bbl	barrel (of petroleum) = 42 gallons (gal) = 159 liters (l)
ml	milliliter = 1 cubic centimeter (cm^3) approximately
Nm^3	cubic meter (of gas) measured at "normal" temperature
ft^3	cubic foot = 0.0283 m^3

Yields or Application Rates

kg ha^{-1} or kg/ha	kilograms per hectare = 0.892 pounds per acre (lb/A)
g/ha	grams per hectare

Weight Per Unit of Volume (Density)

sp gr	specific gravity = the ratio of the weight of a substance to the weight of an equal volume of water at 4°C; no dimensions; numerically equal to density in g/cm^3
g/cm^3	grams per cubic centimeter = 62.43 pounds per cubic foot (lb/ft^3)
kg/m^3	kilograms per cubic meter = 0.0624 lb/ft^3
t/m^3	tonnes per cubic meter = g/cm^3
°Bé	degrees Baumé

Note: For definitions of true, apparent, and bulk densities or specific gravities, see Chapter 18.

a. Factors for converting metric units to English or SI units (Système International d'Unités) or vice versa.

Concentrations

g/l .... grams per liter
mg/m³ .... milligrams per cubic meter
µg/m³ .... micrograms per cubic meter
ppmw .... parts per million by weight
dm³ .... cubic decimeter = 1 liter

Work-Energy-Heat

MMBtu .... million Btu
cal .... calorie = 4.184 joules (J)
kcal .... kilocalorie = 1,000 cal = 3.968 British thermal units (Btu)
MMcal .... million calories
kJ .... kilojoule = 0.239 kcal
GJ .... gigajoule = 10^9 joules = 0.948 million Btu = 0.239 million kcal
Gcal .... gigacalorie = 10^9 calories = 3.97 million Btu
kWh .... kilowatt-hour = 3,413 Btu = 36,000 joules
mWh .... megawatt hours = 1,000 kWh

Power

W .... watt = 1 joule per second (J/s)
kW .... kilowatt = 1,000 watts (W) = 1.34 horsepower (hp)
MW .... megawatt = 1,000,000 watts

Heating Value Per Unit of Volume or Weight

cal/g .... calories per gram = kilocalories per kilogram (kcal/kg) = 1.8 Btu/lb = 4.187 J/g
kcal/m³ .... kilocalories per cubic meter = 0.1123 Btu/ft³

(Used to denote heating value of fuel gas; the temperature and pressure should be stated; usually 0°C and 1 atm in scientific work. The U.S. natural gas industry uses "standard conditions" of 60°F and 14.7 lb/in²).

Pressure

kg/cm² .... kilograms per square centimeter = 14.2 pounds per square inch (lb/in²)
atm .... atmosphere = 14.7 lb/in²
atm .... 101.325 kilonewtons per square meter (kN/m²) = 101.325 kilopascals (kPa)
mm Hg .... millimeters of mercury = 133.3 Pa = 0.0013 atm
psia .... pounds per square inch absolute
psig .... pounds per square inch gauge
MPa .... megapascal = 1,000 kPa
bar .... 0.987 atm = 100 kPa

Temperature

°C .... degrees Celsius or centigrade; (°C x 1.8) + 32 = °F
°F .... degrees Fahrenheit (°F - 32) 5/9 = °C
°K .... absolute temperature = °C + 273

Plant Capacity or Production Rate

tpd .... tonnes per day
tph .... tonnes per hour
tpy .... tonnes per year

Note: All tonnes are metric unless otherwise specified.

Other Abbreviations

kN/cm .... kilonewtons per centimeter
BL or B/L .... battery limits
pCi/g .... picocuries per gram (a measure of the concentration of a radioactive material)
f.o.b. .... free on board = cost at plant or port including loading on a ship or other conveyance
pH .... logarithm of the reciprocal of the hydrogen ion concentration in grams per liter (pH = log 1/H^+ g/l). A solution of pH 7 is neutral; lower pHs are acidic and higher pHs are alkaline.
gpm .... U.S. gallons per minute
dia .... diameter
CRH .... critical relative humidity
LPG .... liquefied petroleum gas
LNG .... liquefied natural gas
SNG .... substitute (or synthetic) natural gas
HTS .... high temperature shift (catalyst)
LTS .... low temperature shift (catalyst)
LHV .... lower heating value (gas)
CEC .... cation exchange capacity
BPL .... bone phosphate of lime, 1% P_2O_5 = 2.185% BPL
BFW .... boiler feed water

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Chapter 1. General Concepts, Classification, Terminology, and Definitions

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Chapter 1. General Concepts, Classification, Terminology, and Definitions

1.1 Introduction

A fertilizer is a material that furnishes one or more of the chemical elements necessary for the proper development and growth of plants. The most important fertilizers are fertilizer products (also called chemical or mineral fertilizers), manures, and plant residues. A fertilizer product is a material produced by industrial processes with the specific purpose of being used as a fertilizer. Fertilizers are essential in today's agricultural system to replace the elements extracted from the soil in the form of food and other agricultural products.

1.2 Plant Nutrients

Chemical elements that are essential for the proper development and growth of plants are typically referred to as plant nutrients. The list of plant nutrients recognized as being necessary for plant growth has increased over the years and now totals sixteen, as shown in Table 1.1.

Table 1.1. Classification of Elements Essential for Plant Growth

Major elements (macronutrients)	(Available from air or water)	Carbon Hydrogen Oxygen
	Primary nutrients	Nitrogen Phosphorus Potassium
	Secondary nutrients	Calcium Magnesium Sulfur
Minor elements (micronutrients)		Boron Chlorine Copper Iron Manganese Molybdenum Zinc

1.2.1 Classification

Nine plant nutrients are required in relatively large amounts and are referred to as major elements or macronutrients. Of these, carbon, hydrogen, and oxygen are obtained from the carbon dioxide in the atmosphere and water and therefore are not dealt with as nutrients by the fertilizer industry. These three plant nutrients make up 90%-95% of the dry matter of all plants. The other major elements are subdivided into primary nutrients (nitrogen, phosphorus, and potassium) and secondary nutrients (calcium, magnesium, and sulfur). The remaining seven plant nutrients are required in much smaller amounts and are known as micronutrients or minor elements.

In addition to the 16 essential elements listed in Table 1.1, some other elements have been shown, in certain circumstances, to be helpful in increasing crop yields or in improving the value of crops for animal or human nutrition. Examples are sodium, silicon, cobalt, and vanadium.

1.2.2 Expression

Many countries express quantities or percentages of the primary nutrients in terms of elemental nitrogen (N), phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O). Secondary nutrients and micronutrients usually are expressed on an elemental basis although calcium and magnesium sometimes are expressed in the oxide form. However, several countries express all plant nutrients on an elemental basis. Plants actually use neither the pure element nor the pure oxide form, so the difference is largely academic. Conversion factors for those plant nutrients that may be expressed in the elemental or oxide form, depending on the country, are shown in Table 1.2.

1.3 Fertilizer Grade

It is customary to refer to a given fertilizer product by a series of numbers separated by dashes. This set of numbers is called the "grade" of the fertilizer product. Each of the numbers indicates the amount of a nutrient that the manufacturer guarantees is contained in the fertilizer product. This number includes only the amount of nutrient found by prescribed analytical procedures, thereby excluding any nutrient present in a form that is deemed to be unavailable for plant nutrition. The content of each nutrient is always expressed as a percentage by

Table 1.2. Conversion Factors of Plant Nutrients (From Oxide to Elemental and From Elemental to Oxide Form)

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_3	x	0.40	=	S
S	x	2.50	=	SO_3

weight, or in other words as kilograms of nutrient per 100 kg of the fertilizer product. These percentages are guaranteed minimum rather than actual content, which is usually slightly higher.

Usually, three numbers are used when giving the grade of a fertilizer product, and these three numbers always refer, in order, to the content of the primary nutrients: nitrogen, phosphorus, and potassium. If other nutrients are present, their content can also be indicated in the grade of the fertilizer product; each extra number is followed by the chemical symbol of the nutrient it represents. Many countries indicate the content of phosphorus and potassium not in the elemental form but in the oxide form, P_2O_5 and K_2O. When references are made to the phosphorus content of a fertilizer product, it is common to call it phosphate, which is the form in which it is mostly present within the fertilizer products, although all calculations and expressions of content are made using either the oxide form (P_2O_5) or the elemental form (P).

Some examples of fertilizer grades follow:

- A fertilizer product with a grade of 18-46-0 is guaranteed by the manufacturer to have the following content:

  18% N, or 18 kg of N in every 100 kg

  46% P_2O_5, or 46 kg of P_2O_5 in every 100 kg

  0% K_2O, or no K_2O

- A fertilizer product with a grade of 12-6-22-2MgO is guaranteed by the manufacturer to contain:

  12% N, or 12 kg of N in every 100 kg

  6% P_2O_5, or 6 kg of P_2O_5 in every 100 kg

  22% K_2O, or 22 kg of K_2O in every 100 kg

  2% MgO, or 2 kg of MgO in every 100 kg

Expressed on an elemental basis, the fertilizer grade of this product would be 12-2.6-18.3-1.2Mg (Table 1.2).

In this manual, the oxide form will be used unless otherwise specified.

The value of using fertilizer grades in identifying a fertilizer product cannot be overemphasized. This is a constant reminder to the consumer that he is purchasing plant nutrients, not a named fertilizer product. For example, the fertilizer product single superphosphate (SSP) is known worldwide by that name or acronym. However, the P_2O_5 content in commercially available SSP products around the world ranges from 14% to 20%.

1.4 Nutrient Availability

A commercial fertilizer is a material containing at least one of the plant nutrients in a form assimilable or "available" to plants in known amounts. Generally, a plant nutrient is taken up by plant roots or foliage in the form of a solution in water. Plant nutrients form many different chemical compounds having varying degrees of solubility in water. Thus, it would seem that water solubility should provide a simple conclusive measure of the availability to plants. Unfortunately, the situation is far too complex for water solubility alone to serve as a measure of availability. All materials are soluble in water to some extent, even the most "insoluble."

Many sparingly soluble materials have been found to be available to plants and, in some cases, even more effective than readily water-soluble materials. However, some materials are so insoluble as to be virtually worthless as fertilizers. Therefore, most countries specify some degree of solubility of the nutrient content in water or other reagents or alternatively require identification and approval of the source of the material.

For example, natural organic materials may be acceptable on the basis of total N, P_2O_5, and K_2O content, provided the source of the material is identified and approved. Synthetic organic materials, if sparingly 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.

Because most common nitrogen and potassium fertilizers are readily water-soluble, water solubility usually is accepted as evidence of plant availability, and special methods are applied to less soluble materials only when there is some evidence to indicate that the low (or controlled) solubility may be advantageous.

In the case of phosphate fertilizers, there is a wide variety of both readily water-soluble materials and