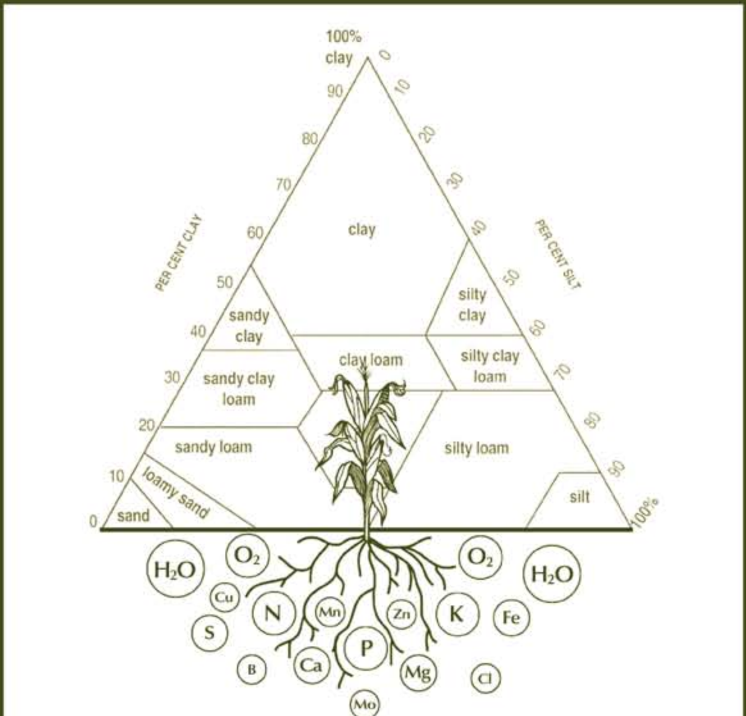
AGRONOMIC HANDBOOK

Management of Crops, Soils, and Their Fertility



J. Benton Jones, Jr.

CRC PRESS

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Preface

Agronomy is defined as that "branch of agriculture that deals with the theory and practice of field crop production and soil management." This agronomic handbook contains information on the cultures of some of the world's major agronomic grain, oil, fiber, and sugar crops and provides data on the characteristics and management of these crops and the soils on which they are grown.

The handbook is divided into multiple parts, each dealing with a specific aspect of agronomy: the major field crops; soils, their classification and characteristics; pH, liming and liming materials; fertilizers; mineral nutrition; diagnostic procedures for assessing the fertility status of soils and the nutrient element status of plants; and units and measures. This handbook is unique in that it covers both crop and soil topics and focuses on their significant aspects. Although some of the information presented is dated and will change with time, most of it will not. The appendices include a list of definitions, a glossary of botanical terms, data on nutrient requirements for major agronomic crops, a list of troublesome weeds, a key to nutrient deficiency symptoms of legumes, and a summary of the characteristics of the major elements and micronutrients.

The information in this book came from government publications, university bulletins and circulars, textbooks, journal articles, industry publications, and the Internet. The objectives are to focus on accepted basic principles and procedures and present only those aspects of each subject that will enhance knowledge of crops and soils. For example, fertilizer recommendations are not included since they are based on a range of inputs such as soil status, cropping procedures, and climatic, economic, and cultural conditions that will change with time and circumstances. Similarly, specific cultural crop practices are not included because most of them are based on local and regional climatic, economic, cultural, and other factors that will also change with time and circumstances. However, this book contains the basic information needed to develop cultural, liming, and fertilizer recommendations.

Most agronomic reference books focus on a single crop or several related crops or on a specific soil topic. They do not cover a full range of both crop and soil topics as this book does. The major objective is to cover both crops and soils, so that the reader will need only one book to locate important and useful information on both aspects of agronomy. This handbook contains a wide range of fundamental information on crops and soils. It should serve as a valuable resource for all those engaged in agronomic production, study, and research, whether as farmers, agricultural consultants or advisors, researchers, or students.

Author

J. Benton Jones, Jr., Ph.D., is professor emeritus at the University of Georgia (UGA). He retired in 1989 after completing 21 years of service. He spent 10 years as a professor of agronomy at the Ohio Agricultural Research and Development Center where he established the Ohio Plant Analysis Laboratory, the first of its kind to provide analytical and interpretive services dealing with agronomic crops. Dr. Jones joined UGA in 1968 and supervised construction of the Georgia Soil Testing and Plant Analysis Laboratory. He served as its first director until he became chairman of the Department of Horticulture in 1974. He also assisted in establishing the analytical laboratory of UGA's Institute of Ecology.

Dr. Jones has written extensively about analytical methods and developed many procedures for assaying soil and plant tissue and interpreting soil and plant analyses to aid in crop production decision making.

He was first president and later served as secretary-treasurer of the Soil and Plant Analysis Council. He has written more than 200 scientific articles, 15 book chapters, and 5 books. He established two international journals, *Communications in Soil Science and Plant Analysis* and the *Journal of Plant Nutrition,* and served as their editor for many years.

Dr. Jones earned a B.S. in agricultural science from the University of Illinois and an M.S. and Ph.D. in agronomy from Pennsylvania State University. He has traveled widely in connection with consultancies in the former Soviet Union, China, Taiwan, South Korea, Saudi Arabia, Egypt, Costa Rica, Cape Verde, India, Hungary, Kuwait, and Indonesia.

He has received many awards and recognitions for his work in soil testing and plant analysis. He is a Fellow of the American Association for the Advancement of Science, the American Society of Agronomy, and the Soil Science Society of America. The Soil and Plant Analysis Council established the J. Benton Jones, Jr. Award in his honor in 1989. The University of Horticulture in Budapest conferred an Honorary Doctorate on Dr. Jones. He is a member of Sigma Xi, Gamma Sigma Delta, and Phi Kappi Phi, and is listed in *Who's Who in America* and in several similar biographical listings.

Dr. Jones resides in Anderson, SC. He continues to write and advise growers and is experimenting with hydroponic growing systems for use in the field and greenhouse.

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Part I

Agronomic Crops

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1. Smith, C.W., Crop Production: Evolution, History, and Technology, 1995, John Wiley & Sons, New York. TABLE 2.8 Barley Seeds/Pound, Weight/Bushel, and Germination Time Seeds (1,000/lb) No. Seeds/g Weight (lb/bu) Germination Time (days) 13 30 48 7 TABLE 2.9 Weight and Standard Yield of Full (Level) Bushel of Barley Grain Weight of 1 bu (measured) Multiplication factor to yield standard bushels (lb) 52 1.08 50 1.04 48 1.00 46 0.96 44 0.92 42 0.87 40 0.83

2.2 CORN (Zea mays L.)

2.2.1 I NTRODUCTION

Corn (known as mais in France, Germany, and Italy and maiz in Spain) belongs to the Poaceae

or Gramineae grass family. It is a cereal grass grown in more countries than any other crop and

is the most important crop grown. It has a wide variety of food uses and ranks second (after

wheat) in world grain production. The kernels can be eaten directly and used as components

of many food products. Kernels and plants are used as livestock feed. Yellow dent is used

primarily as livestock feed; white dent is used for human consumption as meal and cereals.

Corn is also used in the manufacture of nonfood products including ceramics, drugs, paints,

paper goods, and textiles.

In developing countries in Latin America, Africa, and Asia, corn forms a major part of human

diets. Corn kernels are rich in starch carbohydrates. They contain small quantities of fats and

proteins but lack some important amino acids. Therefore, diets based primarily on corn-based foods can lead to protein malnutrition if other sources of protein are not added to diets.

Corn has been used as a food for over 10,000 years. Indians first gathered it from wild plants

in Mexico. They learned how to grown corn around 5000 B.C. By the late 1500s, corn was a well

established crop in Africa, Asia, southern Europe, and the Middle East. It was the basic food in

the American Colonies in the 1600s and 1700s.

Corn can be grown in most mild and tropical regions (30 to 55° latitude) — mainly in latitudes

below 47°. A warm weather crop, corn grows best when air temperatures range from 21 to 27°C

and the optimum mean air temperature is below 19°C. Evapotranspiration ranges from 0.20 to 0.25

cm per day for young plants and up to 0.48 cm per day during the reproduction stage. Corn produces

best when rotated with other crops, particularly legumes that can add N to the soil for the next

corn crop and reduce the potential for pests and diseases.

Corn can be bred and selected to fit growing seasons with maturities ranging from 60 days to

over 40 weeks. Plant densities vary from 15,000 to 25,000 plants per ha, with higher densities up

to 75,000 plants per ha in humid or irrigated areas when optimum production is required. Spacing

between rows ranges from 50 to 100 cm.

The best plant growth occurs on soils with pH levels from 6.0 to 7.0 and moderate to high

fertility. Over half of the N and P and 80% of the K for best growth is required before the

reproductive stage. The N requirement for corn planted after a legume crop varies from 45 to 100 kg per ha and, for corn planted after a nonleguminous crop, 145 to 170 kg per ha in the Corn Belt.

Under irrigation, a 50 to 70% portion of the N is preplanted and the remainder is applied in

20 to 25 kg per ha increments through irrigation systems. Fertilizer N rates are frequently adjusted

based on yield goal and expected climatic conditions. For P and K, fertilizer rates should be based

on soil test recommendations. Based on surveys, PK fertilizer rates range from 54 to 84 kg P_2O_5

per

ha and from 56 to 84 kg K_2O per ha. For some soils, B and Zn are included in fertilizer

recommendations.

In 1999, the highest verifiable corn grain yield of 393.7 bu per acre was recorded in Iowa. In

the U.S. 2000, the average corn grain yield was 137.1 bu per acre.

2.2.2 KINDS OF CORN

2.2.2.1 Dent Corn

Dent corn forms when the soft floury starch in the kernels dries and shrinks. Most kernels are

yellow or white. Dent corn is most widely grown in North America and is used chiefly for livestock

feed and in manufacturing processed foods and industrial products.

Flint corn has hard round kernels with smooth coats. Its color ranges from white to red. It grows

well in cool climates and reaches maturity early. It is used for food and livestock feed and grown

widely in Asia, Europe, and Central and South America.

2.2.2.3 Flour Corn

Flour corn kernels are white, blue, or variegated. Flour corn is the oldest type; it was grown in central Mexico and western South America more than 5,000 years ago. It is grown primarily for food.

2.2.2.4 Pod Corn

Pod corn is the most primitive and possibly oldest form of corn. Each kernel is enclosed in a pod or husk and the entire ear is surrounded by husk. Pod corn has no commercial value; it is used in scientific research.

2.2.2.5 Popcorn

Popcorn is one of the oldest varieties. The two types are pearl popcorn (kernels are rounded and usually yellow or orange) and rice popcorn (kernels are pointed and white). The kernels have hard endosperms with small amounts of white starch in their centers. Steam is created inside the kernels when they are heated. This causes them to explode, turn inside out, and become light, fluffy masses.

2.2.2.6 Sweet Corn

Sweet corn kernels are soft and may be white or yellow. The kernels are the sweetest and may be eaten directly from cooked cobs or removed from the cobs.

2.2.2.7 Waxy Corn

The endosperm of a waxy kernel has a wax-like appearance. The corn consists mostly of starch (amylopectin). This quality makes it useful as a thickener in instant pudding mixes, gravies, and sauces, and glues.

2.2.3 CORN GLOSSARY

Aflatoxin Any of a number of mycotoxins produced by the Aspergillus flavus fungus.

Amylase Enzyme that accelerates the hydrolysis of starch.

Amylopectin Heavy molecular weight component of starch that has a branched structure of glucose subunits. Amylopectin and amylose are the components of corn starch.

Amylose Component of starch; has straight chains of glucose subunits.

Blending Mixing two or more grain lots to establish an overall quality that may or may not be different from any single lot.

Country elevator Grain elevator that serves as the first collection point in the marketing of corn. Grain elevators accept, dry, and store corn from producers. It is then delivered to terminal elevators.

Cultivar (cultivated variety) International term denoting certain cultivated plants that are clearly distinguishable from others by one or more characteristics. A cultivar will retain those characteristics when reproduced.

Dockage Materials such as stems, weeds, dirt, and stones that are removed readily by ordinary grain cleaning equipment; also called foreign material.

Double-cross hybrid Hybrid developed by crossing the F1s of two single cross-hybrids.

Embryo Undeveloped plant within a seed.

Endosperm Dead but nutritive tissue in seeds found in the inner bulk of kernel consisting primarily of carhohydrates, but also containing protein, riboflavin, and B vitamins. The endosperm provides nutrients to the seedling plant during germination-emergence and early seedling growth.

Enzyme Group of catalytic proteins produced by living cells that mediate the chemical processes of life without being destroyed or altered.

Federal Grain Inspection Service (FGIS) U.S. Department of Agriculture branch responsible for setting grain standards and developing the technology to measure factors affecting grain quality; also develops sampling and inspection procedures, evaluates and approves equipment monitor inspection accuracy, and oversees mandatory export inspection of grain.

Feed grain Grain characterized as high-energy because of high levels of carbohydrates and low levels of crude fiber.

Germ See embryo.

Genotype Hereditary makeup of an individual plant or animal.

Germplasm Genotype of crop species or related species used or of potential use in developing cultivars; also called race stocks, breeding lines, inbred lines, or germplasm lines.

Grain Seed or fruit of various food or feed plants including cereal grains (wheat, corn, barley, oats, and rye) and other plants in commercial and statutory use, such as soybeans.

Hybrid Cultivar resulting from crossing two genetically unlike inbred lines of corn.

Inbred line Parent in the development of a hybrid cultivar developed by repeated generations of self-pollination.

Intrinsic quality Characteristic important to the end use of grain. A characteristic is nonvisual and can only be determined by analytical tests to determine, for example, protein, ash, oil content, or starch.

Millfeed Material remaining after all food-grade flour and other components have been extracted from grain used in animal feed and feed supplements.

Modified single-cross Scheme of hybrid production where the female parent is the F1 from the cross of two genetically similar parents. The F1 is crossed with a genetically dissimilar pollen parent to produce hybrid seed sold to the farmer.

Open pollinated Seed produced on plants or to cultivars maintained with no control over which individual plants pollinate other plants within the seed increase blocks.

Pericarp Seed covering derived from the ovary wall.

Phenotype Plant as seen; the outward expression of the genotype of a plant within the limits of its environment.

Protein Complex organic compound composed of nitrogen (N), carbon (C), hydrogen (H), and oxygen (O) essential to the functionings and structures of all organic cells.

Shrinkage Loss of grain weight due to the removal of water.

Single-cross Production of hybrid cultivars by crossing two genetically dissimilar inbred lines of corn.

Starch Primary fraction of corn endosperm composed of straight and branched chains of glucose molecules. Starch is an important component of animal diets. It reacts with enzymes to form dextrose, maltose, and other sugars required for energy and growth.

Steepwater Water used to soak corn during wet milling.

Tempering Addition of water to corn and wheat during dry milling to aid in removing bran from the endosperm. to other terminal elevators.

Three-way cross Hybrid production scheme by which the F1 of two genetically dissimilar inbred lines of corn are crossed with a genetically dissimilar inbred to produce hybrid corn seed.

Variety See cultivar.

Wet milling Process of using water in which corn is tempered, steeped, and milled to separate the grain into its germ, hull, gluten, and starch components. Oil is extracted from the germ; the hulls are dried and may be added to gluten to produce corn gluten feed; gluten may be purified and used in several industrial products; and the starch is converted into corn syrups and corn sugars.

TABLE 2.10

Growth Stages of Corn, Cumulative Growing Degree Days, and Calendar Days Required

to Reach Successive Stages

State No. Stage Stage Description Growing Degree Days a Calendar Days

0.0 Emergence Tips of leaves emerged from the coleoptile 120 10

0.5 Two-leaf Two leaves fully emerged with collars visible 200 17

1.0 Four-leaf Four leaves fully emerged

1.5 Six-leaf Six leaves fully emerged; tassel initiation 475 30

2.0 Eight-leaf Eight leaves fully emerged; tassel developing rapidly — —

2.5 Ten-leaf Ten leaves fully emerged; tassel developing rapidly; ear shoots developing at 6 to 8 nodes 740 50

3.0 Twelve-leaf Twelve leaves fully emerged; ears developing rapidly; number of ovules determined — —

3.5 Fourteen-ear Fourteen leaves fully emerged; tassel near full size; 1 to 2 ears developing rapidly; silks developing 1,000 60

4.0. Sixteen-leaf Sixteen leaves fully emerged; ears and silks developing rapidly; tassel emerges 1,150 75

5.0 Silking Leaves and tassel fully emerged; elongation of stem ceases; cob and silks growing rapidly; silks continue to grow until fertilized 1,480 75

6.0 Blister Cob and husks fully developed; starch begins to accumulate in kernels — 8

7.0 Dough Kernels growing rapidly; consistency like bread dough 1,925 95

8.0 Beginning dent A few kernels showing dents — —

9.0 Dent Kernels fully dented; dry matter accumulation almost complete 2,450 105

10.0 Physiological maturity Dry matter accumulation is complete; grain moisture is 35% 2,765 120

a Growing degree days based on a minimum temperature of 50˚F and a maximum of 86˚F; may be referred to as DD 50

units.

Source: Adapted from Illinois Agronomy Handbook, 1991–1992, University of Illinois, Urbana, IL.

2.2.4 COMPOSITION OF WHOLE-GRAIN FIELD CORN

The germ contains about 35% oil, 20% protein, and 10% ash.

2.2.4.1 Composition of Whole Grain, Ground

2.2.5 ETHANOL PRODUCTION

In the U.S., nearly 500 million bu corn (about 7% of the crop) goes into ethanol production annually,

adding about $3 billion annually to farm income. One bushel of corn will produce 2.5 gal ethanol. Component % Carbohydrate 72.2 Water 13.8 Protein 8.9 Fat 3.9 Ash 1.2 Component Value Digestible energy 3,610 kcal/kg Protein 10.0% Lysine 0.13% Methionine + cystine 0.18% Tryptophan 0.09% Calcium 0.01% Phosphorus 0.31% Fiber 2.0% Ether extract 3.9% Component % Water 13.5 Protein 10.0 Oil 4.0 Starch 61.0 Sugars 1.4 Pentosans 6.0 Crude fiber 2.3 Ash 1.4 Potassium 0.40 Phosphorus 0.43 Magnesium 0.16 Sulfur 0.14 Other minerals 0.27 Other substances (organic acids, etc.) 0.4 Total 100.0 Component Value Calories/100 g 355 Protein (%) 9.2 Fat (%) 3.9 Total calcium (mg/lb) 20 Total phosphorus (mg/lb) 256 Total potassium (mg/lb) 284 Carbohydrates (%) 73.7

2.2.6 CORN PRODUCTION STATISTICS TABLE 2.11 U.S. Corn Acreage, Grain Yield, and Production, 1950–2000 Year Planted Acres (millions) Harvested Acres (millions) Grain Production (million bu) Grain Yield (bu/acre) 1950 82,900 72,400 2,764 38.2 1951 83,275 71,191 2,629 36.9 1952 82,230 71,353 2,981 41.8 1953 81,574 70,738 2,882 40.7 1954 82,185 68,668 2,708 39.4 1955 80,932 68,462 2,873 42.0 1956 77,828 64,877 3,075 47.4 1957 73,180 63,065 3,045 48.3 1958 73,351 63,549 3,356 52.8 1959 82,742 72,091 3,825 53.1 1960 81,425 71,422 3,907 54.7 1961 65,919 57,634 3,598 62.4 1962 65,017 55,726 3,606 64.7 1963 68,771 59,227 4,019 67.9 1964 65,823 55,367 3,484 62.9 1965 65,171 55,392 4,103 74.1 1966 66,347 57,002 4,168 73.1 1967 71,156 60,694 4,860 80.1 1968 65,126 55,980 4,450 79.5 1969 64,264 54,574 4,687 85.9 1970 66,863 57,358 4,152 72.4 1971 74,179 64,123 5,646 88.1 1972 67,513 57,513 5,580 97.0 1973 72,253 62,143 5,671 91.3 1974 77,935 65,405 4,701 71.9 1975 78,719 67,625 5,841 86.4 1976 84,588 71,506 6,289 88.0 1977 84,328 71,614 6,505 90.8 1978 81,675 71,930 7,268 101.0 1979 81,394 72,400 7,928 109.5 1980 84,043 72,961 6,639 91.0 1981 84,097 74,524 8,119 108.9 1982 81,857 72,719 8,235 113.2 1983 60,207 51,479 4,174 81.1 1984 80,517 71,897 7,672 106.7 1985 83,398 75,209 8,875 118.0 1986 76,580 68,907 8,226 119.4 1987 66,200 59,505 7,131 119.8 1988 67,717 58,250 4,929 84.6 1989

72,322 64,783 7,532 116.3 1990 74,166 66,952 7,934 118.5 1991 75,957 68,822 7,475 108.6 continued 1992 79,311 72,077 9,477 131.5 1993 73,239 62,933 6,338 100.7 1994 78,921 72,514 10,051 138.6 1995 71,479 65,210 7,400 113.5 1996 79,229 72,644 9,233 127.1 1997 76,537 72,671 9,207 126.7 1998 80,187 72,604 9,761 134.4 1999 74,386 70,487 9,430 133.8 2000 74,545 72,732 9,968 137.1 Source: Department of Agricultural Economics, Kansas State University, Manhattan. With permission.

TABLE 2.12

U.S. Acreage, Yield, Production, and Value for Corn Grain and Silage, 1991–2000 Year Area Planted (1,000 acres) Area Harvested (1,000 acres) Yield/Harvested Acre a Production b Marketing Year Average Price/bu ($) Corn Grain 1991 75,957 66,822 108.7 7,474,765 2.37 1992 79,311 72,077 131.5 9,476,689 2.07 1993 73,239 62,933 100.7 6,337,730 2.50 1994 78,921 72,514 138.6 10,050,520 2.26 1995 71,479 55,210 113.5 7,400,051 3.24 1996 79,229 72,644 127.1 9,232,557 2.71 1997 79,537 72,671 126.7 9,206,632 2.43 1998 60,165 72,569 134.4 9,756,665 1.94 1999 77,366 70,467 133.6 9,430,612 1.62 2000 c 74,545 72,732 137.1 9,968,356 1.85 Corn for Silage 1991 6,140 13.2 61,216 1992 6,069 14.4 87,663 1993 6,823 11.9 61,131 1994 5,717 15.8 90,170 1995 5,321 14.7 76,181 1996 5.607 15.4 86,561 1997 6,054 16.1 97,192 1998 5,913 16.1 95,479 1999 6,037 15.8 95,633 2000 c 5,866 16.8 96,536

a

Yield/harvested acre shown in bushels for corn grain and tons for corn for silage.

b

Production shown in 1,000 bu for corn grain and 1,000 tons for corn for silage.

c

Preliminary.

Source: National Agricultural Statistics Service, Crops Branch, Washington, D.C., 2001. U.S. Corn Acreage, Grain Yield, and Production, 1950–2000 Year Planted Acres (millions) Harvested Acres (millions) Grain Production (million bu) Grain Yield (bu/acre) Corn Planted in the U.S. (1,000 acres), 1998–2000 State 1998 1999 2000 Alabama 300 220 230 Arizona 50 50 56 Arkansas 235 105 180

California 600 525 540 Colorado 500 350 400 Connecticut 35
38 38 Delaware 169 169 165 Florida 160 90 85 Georgia 500
350 400 Idaho 145 165 195 Illinois 10,600 10,600 11,200
Indiana 5,800 5,600 5,700 Iowa 12,500 12,100 12,300 Kansas
3,000 3,150 3,450 Kentucky 1,300 1,320 1,330 Louisiana 700
340 360 Maine 34 33 28 Maryland 470 470 400 Massachusetts
25 26 25 Michigan 2,300 2,200 2,200 Minnesota 7,300 7,100
7,100 Mississippi 550 340 410 Missouri 2,650 2,650 2,650
Montana 60 65 60 Nebraska 8,800 8,600 8,500 Nevada — — 4
New Hampshire 15 15 15 New Jersey 120 110 90 New Mexico 140
150 150 New York 1,130 1,150 980 North Carolina 860 750 730
North Dakota 970 600 1,060 Ohio 3,550 3,450 3,550 Oklahoma
270 430 300 Oregon 55 45 55 Pennsylvania 1,550 1,500 1,550
Rhode Island 3 3 2 South Carolina 350 300 310 South Dakota
3,900 3,600 4,300 Tennessee 700 630 650 Texas 2,400 1,950
2,100 Utah 62 61 64 Vermont 112 106 90 Virginia 500 500 470
Washington 160 155 155 West Virginia 60 60 55 Wisconsin
3,700 3,600 3,500 Wyoming 95 65 95 U.S. Total 80,165 77,366
79,545 Source: Crops Branch, National Agricultural
Statistics Service, Washington, D.C., 2001. T A B L E 2 . 1
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0 2 6 0 2 7 0 1 3 0 . 0 1 4 5 . 0 1 4 0 . 0 2 6 , 6 0 0 4 0
, 6 0 0 3 7 , 6 0 0 O r e g o n 3 3 3 0 2 9 1 9 0 . 0 1 7 5
. 0 1 8 0 . 0 6 , 2 7 0 5 , 2 5 0 5 , 2 2 0 P e n n s y l v
a n i a 1 , 0 5 0 6 6 0 1 , 0 6 0 1 1 1 . 0 7 0 . 0 1 2 7 .
0 1 1 6 , 5 5 0 6 1 , 6 0 0 1 3 7 , 1 6 0 S o u t h C a r o
l i n a 2 7 5 2 7 5 2 8 0 4 0 . 0 7 0 . 0 6 5 . 0 1 1 , 0 0
0 1 9 , 2 5 0 1 8 , 2 0 0 S o u t h D a k o t a 3 , 5 5 0 3
, 2 5 0 3 , 6 5 0 1 2 1 . 0 1 1 3 . 0 1 1 2 . 0 4 2 9 , 5 5
0 3 6 7 , 2 5 0 4 3 1 , 2 0 0 T e n n e s s e e 6 2 0 5 7 0
5 9 0 9 6 . 0 1 0 2 . 0 1 1 4 . 0 5 9 , 5 2 0 5 6 , 1 4 0 6
7 , 2 6 0 T e x a s 1 , 6 5 0 1 , 7 7 0 1 , 9 0 0 1 0 0 . 0
1 2 9 . 0 1 2 4 . 0 1 6 5 , 0 0 0 2 2 6 , 3 3 0 2 3 5 , 6 0
0 U t a h 2 4 2 0 2 1 1 4 1 . 0 1 4 3 . 0 1 4 4 . 0 3 , 3 6
4 2 , 6 6 0 3 , 0 2 4 V i r g i n i a 3 0 0 2 8 0 3 3 0 8 4
. 0 7 8 . 0 1 4 6 . 0 2 5 , 2 0 0 2 1 , 8 4 0 4 8 , 1 8 0 W
a s h i n g t o n 1 0 0 1 0 0 1 0 0 1 9 0 . 0 1 6 0 . 0 1 6
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n i a 3 4 2 0 3 5 6 0 . 0 6 5 . 0 1 3 0 . 0 2 , 7 2 0 1 , 3
0 0 4 , 5 5 0 W i s c o n s i n 2 , 9 5 0 2 , 8 5 0 2 , 7 5
0 1 3 7 . 0 1 4 3 . 0 1 3 2 . 0 4 0 4 , 1 5 0 4 0 7 , 5 5 0
3 6 3 , 0 0 0 W y o m i n g 6 0 5 2 6 2 1 2 7 . 0 1 1 6 . 0
1 3 2 . 0 7 , 6 2 0 6 , 1 3 6 6 , 1 6 4 U . S . T o t a l 7

2 , 5 6 9 7 0 , 4 6 7 7 2 , 7 3 2 1 3 4 . 4 1 3 3 . 6 1 3 7 . 1 9 , 7 5 6 , 6 6 5 9 , 4 3 0 , 6 1 2 9 , 9 6 8 , 3 5 6 a P r e l i m i n a r y S o u r c e : C r o p s B r a n c h , N a t i o n a l A g r i c u l t u r a l S t a t i s t i c s S e r v i c e , W a s h i n g t o n , D . C . , 2 0 0 1 .

U.S. Total and Per Capita Civilian Consumption of Corn and Corn Products as Food,

1990–1999

Calendar year a	Total Consumed (million bu) b	Per Capita Consumption of Food Products Flour and Meal (lb)	Hominy and Grits (lb)	Syrup (lb)	Sugar (lb)	Starch (lb)
1990	736	14.4	2.9	67.3	3.8	4.0
1991	763	14.9	2.8	72.0	3.9	4.0
1992	791	15.4	2.6	72.9	3.9	4.2
1993	834	15.8	3.1	76.2	3.9	4.4
1994	868	16.1	3.6	78.4	3.9	4.6
1995	895	16.4	4.1	80.2	4.0	4.8
1996	939	18.8	4.6	82.0	4.0	5.0
1997	968	17.1	5.0	85.9	3.8	4.9
1998	976	17.4	5.5	87.3	3.7	4.8
1999 c	990	17.7	5.9	88.0	3.6	4.8

a

Data shown for marketing year, September 1 to August 31.

b

Includes allowance for quantities used as hominy and grits.

c

Preliminary.

Source: Economics Research Service, Washington, D.C., 2001.

With permission. All figures are estimates based on data

from private industry sources, the U.S. Department of Commerce, the Internal Revenue Service, and other government

agencies. TABLE 2.16 World Corn Production by Country shown as Percent of Total, 2000 Country % India 2 Argentina 3 Brazil 6 European Union 7 China 10 U.S. 43 Others 18 Source: Foreign Agriculture Service, Washington, D.C., 2001. TABLE 2.17 World Corn Consumption by Country, 2000 Country Million Bu Romania 214.6 Canada 350.3 Egypt 405.5 India 472.4 Japan 631.9 Mexico 956.6 Brazil 1,393.6 European Union 1,606.5 China 4,724.1 U.S. 7,739.9 Others 5,300.8 Total 23,796.3 Source: Foreign Agriculture Service, Washington, D.C., 2001. TABLE 2.18 World Corn Exports by Country Shown as Percent of Total, 2000 Country % Ukraine 1 South Africa 2 China 6 Argentina 14 U.S. 75 Others 2 Source: Foreign Agriculture Service, Washington, D.C., 2001. TABLE 2.19 Annual Percent Change in World Corn Yields, 1950–1995 (3-year average) Year % Change 1950–1960 2.6 1960–1970 2.4 1970–1980 2.7 1980–1990 1.3 1990–1995 1.7 Source: Foreign Agriculture Service, Washington, D.C., unpublished printout, 1996; updated 1997.

TABLE 2.20

U.S. Corn Acreage, Yield, and Production for Grain and Silage, 1991–2000 Corn for Grain Corn for Silage

Year Area Harvested (1,000 acres) Yield (bu/acre) Production (1,000 tons) Area Harvested (1,000 acres) Yield (bu/acre) Production (1,000 tons)

1991 68,822 108.6 7,474765 6,140 13.2 81,216

1992 72,077 131.5 9,476,698 6,069 14.4 87,663

1993 62,933 100.7 6,337,730 6,823 11.9 81,131

1994 72,514 138.6 10,050,520 5,717 15.8 90,170

1995 65,210 113.5 7,400,051 5,321 14.7 78,181

1996 72,644 127.1 9,232,557 5,607 15.4 86,581

1997 72,671 126.7 9,206,632 6,054 16.1 97,192

1998 72,589 134.4 9,756,685 5,913 16.1 95,479

1999 70,487 133.6 9,430,612 6,037 15.8 95,633

2000 a 72,732 137.1 9,968,358 5,868 16.8 98,538

a Preliminary.

Source: Crops Branch, National Agricultural Statistics Service, Washington, D.C., 2001. Corn Grain Acreage, Yield, and Production by Continent and Country, 1999–2000 Location Area Harvested (10,000 ha) Grain Yield (metric tons/ha) Production (1,000 metric tons) Continent North America 37,375 7.18 267,645 Central America 1,863 1.49 2,775 South America 18,050 2.99 53,995 European Union 4,145 8.92 36,762 Eastern Europe 7,028 4.39 30,840 USSR 2,155 2.30 4,946 Africa 23,959 1.67 40,042 Asia 43,971 3.71 163,289 Middle East 1,012 3.47 3,507 Oceania 76 6.71 510 World total 140,119 4.32 605,147 Country U.S. 28,528 8.40 239,549 China 25,704 4.94 128,086 Brazil 12,500 2.53 31,600 Mexico 7,900 2.47 17,000 India 6,510 1.76 11,470 South Africa 3,868 2.74 10,584 Source: Foreign Agriculture Service, Washington, D.C., 2001. TABLE 2.22 Corn: Percent of Areas Receiving Fertilizer Applications, All States Surveyed, 1995–1999 a Year Nitrogen (%) Phosphate (%) Potash (%) 1995 97 81 70 1996 98 85 73 1997 99 84 72 1998 98 63 66 1999 98 82 67 a All values shown as percents and based on number of acres receiving one or more applications of a specific fertilizer ingredient. Source: Environmental, Economics and Demographics Branch, National Agriculture Statistics Service, Washington, D.C., 2001.

2.2.7 CORN PLANT NUTRITION

TABLE 2.23

Nutrient Elements Contained in the Stovers, Grains, and Roots of a 150-Bu Corn Crop

Compound or Element Approximate (lb/acre) Supplied by or Approximate Equivalent

Water 6,500,000 to 8,250,000 29 to 36 inches of rain

Oxygen 10,200 Air is about 20% oxygen

Carbon 7,800 carbon or 28,500 CO_2 Carbon contained in 6 tons of coal

Nitrogen 310 Nitrogen, phosphorus, and potassium are the three nutrient elements contained in most mixed fertilizers

Phosphorus (P ×

2.29 = phosphate) 120 lb as phosphate or 52 lb as P Approx. equivalent is 1,200 lb of 25-10-20 fertilizer

Potassium (K x 120

= potash) 245 lb as potash or 205 lb K

Calcium 58 Approx. 150 lb agricultural limestone or equivalent

Sulfur 33 33 lb sulfur or equivalent

Magnesium 50 Approx. 215 lb epsom salt or 550 lb sulfate of potashmagnesia

Iron 3 15 lb iron sulfate or equivalent

Manganese 0.45 Approx. 1.3 lb manganese sulfate or equivalent

Boron 0.10 Approx. 1.0 lb borax or equivalent

Zinc Trace Small amount of zinc sulfate or equivalent

Copper Trace Small amount of copper sulfate or oxide

Molybdenum Trace Very small amount of sodium or ammonium molybdate

Note: Corn roots contain 75 lb N, 30 lb P 2 O 5 , 60 lb K 2 O, and 9 lb S.

TABLE 2.24

Nutrient Elements Required to Produce 150 bu (8400 lb at 56 lb/bu) of Corn Element Grain Stover Total (lb/acre) (lb/bu) (lb/acre) (lb/bu) (lb/acre) (lb/bu)

Nitrogen 115 0.77 55 0.37 170 1.13

Phosphorus as phosphate 28 0.19 7 0.05 35 0.55

Potassium as potash 35 0.23 140 0.93 175 1.40

Calcium 1.3 0.01 35 0.23 36 0.24

Magnesium 10 0.07 29 0.19 39 0.26

Sulfur 11 0.07 8 0.05 19 0.13

Chlorine 4 0.03 68 0.45 72 0.48

Iron 0.1 — a 1.8 0.01 1.9 0.01

Manganese 0.05 — 0.25 — 0.30 —

Copper 0.02 — 0.08 — 0.10 —

Zinc 0.17 — 0.17 — 0.34 —

Boron 0.04 — 0.12 — 0.16 —

Molybdenum (mo) 0.005 — 0.003 — 0.008 —

a Less than 0.0005.

Source: Changing Patterns in Fertilizer Use, 1968, Soil Society of America, Madison, WI. With permission. TABLE 2.25 Corn Crop Nutrient Element Utilization (lb/acre) Yield Nitrogen Phosphorus Potassium Magnesium Sulfur 100 bu/acre 150 60 125 30 18 150 bu/acre 220 80 195 40 25 180 bu/acre 240 100 240 50 30 200 bu/acre 266 114 266 65 33 TABLE 2.26 Uptake of Major Elements and Micronutrients by a 10-Ton/Acre Corn Crop Major Elements kg Nitrogen 240 Phosphorus as phosphate 102 Potassium as potash 120 Calcium 43 Magnesium 58 Sulfur 30 Micronutrients mg Boron 36 Copper 20 Iron 120 Manganese 36 Zinc 60 Source: International Soil Fertility Manual, 1995, Potash & Phosphate Institute, Norcross, GA. TABLE 2.27 Major Element and Micronutrient Removal by Corn Grain and Stover at Two Grain Yields Yield 9.5 tons/ha 6.3 tons/ha Element Grain Stover Grain Stover kg/ha Nitrogen 129 62 100 63 Phosphorus as phosphate 71 18 40 23 Potassium as potash 47 188 29 92 Calcium as oxide 2.1 55 1.5 15 Magnesium as oxide 18 55 9.3 28 Sulfur 12 9 7.8 9 g/ha Boron 50 140 — — Copper 20 90 40 30 Iron 110 2020 — — Manganese 60 280 70 940 Zinc 190 190 110 200 Source: International Fertilizer Association World Fertilizer Use Manual, 2000, Paris. TABLE 2.28 Major Requirements of Corn during Growing Season (Yield = 11.8 tons/ha) Plant Age (days) Major Amount Absorbed (kg/ha/day) N P 2 O 5 K 2 O 20–30 1.7 0.39 1.7 30–40 6.7 1.55 9.95 40–50 8.3 2.32 11.56 50–60 5.3 2.06 4.42 Source: International Fertilizer Association World Fertilizer Use Manual, 2000, Paris. Increase Elemental Content of Corn Plants Produced by Nitrogen Fertilization Element No Fertilizer 180 N kg/ha Nitrogen, % 2.36 3.02 Phosphorus, % 0.18 0.26 Potassium, % 2.22 2.44 Calcium, % 0.66 0.68

Magnesium, % 0.24 0.26 Boron, ppm 12 18 Copper, ppm 10 14 Iron, ppm 163 162 Manganese, ppm 40 47 Zinc, ppm 22 36 Yield, tons/ha 7.4 8.7 Source: International Soil Fertility Manual, Potash & Phosphate Institute, Norcross, GA. TABLE 2.30 Plant Nutrient Elements Absorbed by 180-Bu/Acre Corn Crop during Successive 25-day Growing Periods (%) Nutrient First (Early) Second (Growth) Third (Silk) Fourth (Grain) Fifth (Mature) Nitrogen 8 35 31 20 6 Phosphate 4 27 36 25 8 Potash 9 44 31 14 2 Source: Efficienct Fertilizer Use Manual — Soil Fertility, IMC Global, Inc., Lake Forest, IL., 2001.

FIGURE 2.1 Corn yields in the U.S., China, and Brazil, 1950–1996. (Source: The Agricultural Link, 1997,

Worldwatch Paper 136, Worldwatch Institute.) FIGURE 2.2 Nitrogen uptake and distribution in corn. FIGURE 2.3 Phosphorus uptake and distribution in corn. FIGURE 2.4 Potassium uptake and distribution in corn.

FIGURE 2.5 Normal ears on well fertilized, high-producing corn often weigh 5 oz to 8 oz.

FIGURE 2.6 Big ears (in excess of 8 oz), with kernels covering the tips of the cobs.

FIGURE 2.7 Small ears may be signs of low fertility.

FIGURE 2.8 Poorly filled tips and loose, chaffy kernels may indicate potassium deficiency.

FIGURE 2.9 Phosphorus deficiency results in small, twisted ears and underdeveloped kernels from lack of

pollination.

FIGURE 2.10 Nitrogen deficiency at critical times results in small ears; kernels at the tips do not fill.

2.2.8 NUTRIENT ELEMENT DEFICIENCIES 1

2.2.8.1 Boron (B)

2.2.8.1.1 Deficiency Symptoms

Boron-deficient plants are stunted; they have short, stout stems that appear oval in cross-section.

Leaves are pale green, short, and more erect than normal. Boron deficiency reduces the numbers and sizes of ears and also affects pollination by preventing the growth of the pollen tube. As a

result, barren ears are commonly produced by B-deficient plants and grain yields are severely

reduced.

Yellow interveinal lesions on younger leaves: Because B is not readily transferred from old to

young leaves, symptoms of deficiency appear first and are more severe on young leaves. Old leaves

usually remain green and appear healthy. The youngest leaves are affected before unrolling fully

from the sheaths of previous leaves. Affected leaves are short and held erect. They are pale green,

with short, yellow interveinal lesions throughout their laminae. The chlorotic lesions produce no

definite patterns.

2.2.8.1.2 Problem Soils

Boron deficiency is likely to occur in: • Soils derived from parent material low in B such as acid igneous rocks or fresh water sediments • Sandy soils from which boron has been leached • Alkaline soils, especially those containing free lime • Soils low in organic matter • Acid peat and muck soils

2.2.8.1.3 Correcting Deficiency

Boron deficiency can be corrected by soil applications or foliar sprays of boron fertilizers. Soil

applications are more effective if broadcast and mixed into the soil some months before sowing.

Borax, boric acid, and chelated B compounds are suitable soil applications but only boric acid or

chelated B compounds are suitable as foliar sprays. Foliar sprays should be applied about 5 to 6 weeks

after seedling emergence or as soon as symptoms appear.

While soil applications often remain effective

for many years, foliar sprays have little residual value and must be applied to every crop.

Soil tests can be used to estimate the amount of available B in a soil and predict whether

fertilizer is needed. The best prediction can be obtained by seeking advice on fertilizer practices

used on similar soils in the region.

2.2.8.2 Calcium (Ca)

2.2.8.2.1 Deficiency Symptoms

Calcium deficiency produces very stunted plants. Stems very short and stout; the foliage is green,

often distorted, and appears torn and ragged. If the deficiency persists, young leaves have difficulty

emerging fully and unrolling, and shoots may die before reaching maturity. Calcium deficiency

FIGURE 2.11 Dry weather slows silking; kernels are not well pollinated.

Torn or malformed young leaves: Because Ca is not readily transferred from old to young

tissues, symptoms appear first and are more severe on young leaves. If the deficiency persists,

young leaves become very short and are held erect. Symptoms begin with young leaves that turn

pale green and develop yellow to white interveinal lesions. The chlorotic areas grow and the laminae

tear easily at those points. When new leaves develop, they often have holes in the laminae. The

torn, malformed leaves give the plants a ragged appearance. When the deficiency is very severe,

the youngest leaves do not fully unroll. They remain joined at their tips and produce a ladder-like appearance. In extreme cases, the youngest leaves die before emerging. Old leaves remain green

and appear healthy.

Fan-shaped stems: Calcium deficiency produces short, stout stems that appear flattened in cross

section. The sheaths of old leaves often pull away from the stems, producing a fan-shaped appear

ance after the leaves crowd together at the tops.

2.2.8.2.2 Problem Soils

Calcium deficiency is likely to occur in: • Acid sandy soils where Ca is leached by heavy rainfall • Strongly acid peat and muck soils in which total Ca is low • Alkaline or sodic soils in which high exchangeable sodium (Na) and pH depress the uptake of Ca • Soils with high levels of soluble aluminum (Al) and low levels of exchangeable Ca

2.2.8.2.3 Correcting Deficiency

Calcium deficiency can be corrected by broadcasting a suitable fertilizer onto the soil and mixing

it in some months before sowing. Where the chief problem is simply a lack of Ca, suitable fertilizers

are gypsum (calcium sulfate) and calcium nitrate or chloride. However, if the pH is low, lime or

limestone (calcium carbonate) and dolomite (a mixture of calcium and magnesium carbonates) are

more suitable.

A soil test can be used to determine the lime or Ca requirement. However, since the correct

rate of application depends on soil type and the crop to be grown, advice should be sought on

fertilizer practices used on similar soils in the region. The excessive use of lime may induce

deficiencies of K, Mg, Fe, Mn, Zn, or Cu; and care should be taken to prevent over-liming.

2.2.8.3 Copper (Cu)

2.2.8.3.1 Deficiency Symptoms

Copper-deficient corn plants appear patchy. In copper-poor areas, plants are stunted; they have thin,

spindly stems and pale green foliage. Affected plants often appear limp and wilted. Copper-deficient

plants produce small ears that set few grains because Cu deficiency interferes with the production

of fertile pollen. If a deficiency is very severe, many plants die before reaching maturity.

Weather-tipped young leaves: Because Cu is not readily transferred from old to young leaves,

symptoms appear first and are more severe on young leaves. Old leaves usually remain green and

appear healthy. Young leaves become limp and turn pale green. Pale yellow to white, interveinal

and marginal chlorosis then develops at the leaf tips. If the deficiency persists, the affected tissue

dies, turns pale brown, and twists or rolls into a tube, giving the leaves a weather-tipped appearance.

Deaths of shoots: When the deficiency persists and becomes very severe, the youngest leaves

often die before emerging from the sheaths of older leaves. The affected plants seldom mature.

Tillers may develop but they die before maturity. • Peat and muck soils in which organic matter ties up soluble Cu in forms less available to plants • Alkaline sands in which total Cu is low • Leached acid soils in which total Cu is low • Soils formed from rocks low in Cu

2.2.8.3.3 Correcting Deficiency

Foliar sprays and soil applications of Cu salts such as copper sulfate (bluestone) or copper chelates

have corrected Cu deficiencies. Soil applications should be mixed into the soil some weeks before sowing. However, soil applications may fail to correct the deficiencies in some seasons and

symptoms may reappear in the crop. If this occurs, foliar sprays should be applied immediately.

A reliable remedy is to apply foliar sprays of 0.5 to 1% solutions of soluble Cu salts (for

example, 0.5 to 1 kg copper sulfate per 100 L water per ha); the first application should occur 4

to 6 weeks after seedling emergence. Additional sprays should be applied as soon as symptoms

reappear.

Tests can be used to estimate the amount of available Cu in a soil and predict whether fertilizer

is needed. The best prediction can be obtained by seeking advice on fertilizer practices used on

similar soils in the region.

2.2.8.4 Iron (Fe)

2.2.8.4.1 Deficiency Symptoms

Iron-deficient plants are stunted and have pale green to yellow leaves. Stems are thin and spindly

and usually green, although faint red-purple stripes may appear on the lower stems and older leaf

sheaths when the deficiency is severe. Affected plants develop small ears that set fewer grains than

normal. Kernel size may be reduced also if the deficiency is severe. As a result, grain yields may

be severely reduced.

Interveinal chlorosis on younger leaves: Because Fe is not readily transferred from old to young

leaves, symptoms develop first and are more severe on young leaves. Symptoms begin when young leaves turn pale green. Pale yellow chlorosis then develops throughout the interveinal tissues of

whole leaves. The veins become green and prominent. When the deficiency persists or becomes

severe, the interveinal tissue turns dark yellow and the veins become pale green. At this stage,

interveinal yellowing is often seen also on the youngest, unrolled leaves.

2.2.8.4.2 Problem Soils

Iron deficiency is likely to occur in: • Calcareous soils in which levels of soluble Fe are low • Waterlogged soils • Acid soils that have excessively high levels of soluble Mn, Zn, Cu, or Ni that depress plant uptake of Fe • Sandy soils low in total Fe • Peat and muck soils in which organic matter ties up Fe

2.2.8.4.3 Correcting Deficiency

While soil applications of inorganic Fe salts such as iron sulfates or chlorides have corrected the

deficiencies in some soils, the applied Fe quickly becomes insoluble and less available to plants.

Iron salts of various organic chelates show promise as soil applications because the chelates have

effective, large amounts of chelates may be required and may prove too costly.

Another effective remedy is to apply solutions of inorganic salts or chelates to the foliage (1%

solutions or 1 kg salt per 100 L water per ha). Because Fe is so immobile in plants, sprays must

be applied every 10 to 15 days to provide Fe to new leaves. Advice on fertilizer practices used on

similar soils in the region should be sought to obtain the best remedies for local conditions.

2.2.8.5 Magnesium (Mg)

2.2.8.5.1 Deficiency Symptoms

Magnesium-deficient corn plants are stunted. They have thin, spindly stems, pale green to yellow

foliage, and rust-brown lesions. Magnesium-deficient crops develop small ears and kernel size may

also be reduced, causing low grain yields.

Interveinal chlorosis on older leaves: Because Mg is readily transferred from old to young

leaves, symptoms appear first and are more severe on old leaves. Symptoms work their way up the

plants to younger leaves if the deficiency persists. Old leaves turn pale green. Pale yellow, interveinal

chlorosis develops in the mid-sections of the leaves and advances toward the bases and the tips.

The chlorotic tissue dies and leaves intermittent, pale brown, necrotic lesions between the veins.

The youngest leaves usually remain green and appear healthy.

Rust-brown striped leaves: As a deficiency becomes more severe, rust-brown stripes appear on

the margins and in adjacent interveinal areas on old leaves. Eventually, the brown striping extends

completely over leaves and combines with the brown necrotic lesions developed in interveinal

areas. Soon afterward, the margins and tips die and turn dark brown. In severe cases, the lower

leaves die and hang down around the stems.

2.2.8.5.2 Problem Soils

Magnesium deficiency is likely to occur in: • Acid sandy soils from which Mg has been leached • Strongly acid peat and muck soils in which total Mg is low • Soils over-fertilized with Ca (for example, lime) or K, thus inhibiting uptake of Mg

2.2.8.5.3 Correcting Deficiency

Magnesium deficiency on acid soils is best corrected by broadcasting dolomite (a mixture of calcium

and magnesium carbonates) and mixing it into the soil some months before sowing. When the

problem is strictly a deficiency of Mg, hand applications of magnesium sulfate or chloride can be

made at or before planting. Tests can be used to estimate the amount of soluble and exchangeable

Mg in the soil and predict the amount of fertilizer required. The best prediction can be obtained

by seeking advice on fertilizer practices used on similar soils in the region.

Magnesium deficiency in existing crops can be corrected by applying soluble salts such as

magnesium sulfate, chloride, or nitrate with irrigation water. Foliar sprays of similar salts are usually

not recommended because of the large number needed to supply the requirements of the crop.

2.2.8.6 Manganese (Mn)

2.2.8.6.1 Deficiency Symptoms

Crops suffering from Mn deficiency often appear patchy. Within Mn-poor areas, plants are stunted;

they have thin, short stems and pale green to yellow foliage. Mild deficiencies of Mn do not appear

to affect grain yields greatly. However, if the deficiency persists and becomes severe, the numbers

and sizes of ears and kernels are reduced, thereby reducing grain yields.

appear first on middle leaves and spread mainly to older leaves. Younger leaves are also affected

if the deficiency persists and becomes severe. Middle leaves turn pale green and develop a pale

yellow interveinal chlorosis that extends the full lengths of the leaves. The veins remain pale green

and are easily recognizable. As the deficiency becomes more severe, this symptom develops on old

leaves. It rarely appears on the youngest leaves, which remain pale green.

White interveinal flecks: When the deficiency is severe, crystalline, white flecks appear within

the interveinal chloroses. Eventually, all chlorotic tissue dies and turns white, leaving the veins

green and very prominent. Necrosis develops near the margins and tips of old leaves and extends

toward the bases until whole leaves die and turn pale brown.

Wavy leaf margins: Affected leaves often appear limp or wilted. Leaf margins curl down and

appear excessively wavy.

2.2.8.6.2 Problem Soils

Manganese deficiency is likely to occur in: • Strongly alkaline soils in which Mn is less available to plants • Poorly drained, peaty soils in which Mn occurs in forms less available to plants • Strongly acid, sandy soils from which soluble Mn has been leached • Soils formed from rocks low in Mn

2.2.8.6.3 Correcting Deficiency

Foliar sprays and soil applications of Mn salts and oxides have been used to correct Mn deficiency.

Soil applications are more effective when broadcast and mixed into the soil some weeks before

sowing. However, foliar applications have generally been more successful than soil applications.

One or more foliar sprays of 0.5 to 1% solutions of soluble Mn salts (for example, 0.5 to 1 kg

manganese sulfate per 100 L water per ha) usually correct the deficiency. The first should be applied

5 to 6 weeks after seedling emergence. If the symptoms reappear, the spray should be repeated

immediately. While soil applications usually last 5 to 6 years before fresh applications are needed,

foliar sprays must be applied to every crop.

Soil tests can be used to estimate the amounts of available Mn in a soil and predict whether

fertilizer is needed. The best prediction can be obtained by seeking advice on fertilizer practices

used on similar soils in the region.

2.2.8.7 Nitrogen (N)

2.2.8.7.1 Deficiency Symptoms

Corn is very sensitive to N supply and even mild deficiencies severely reduce growth. Nitrogen

deficient young plants are stunted and have thin, spindly stems and pale green to yellow, short,

erect leaves. If the deficiency persists or occurs in more mature crops, the old leaves become pale

yellow while young leaves remain green. Nitrogen-deficient plants usually produce single small

ears. The small ears and the depression of kernel size severely reduce grain yields. Furthermore,

the grain will be low in protein because N plays a central role in the formation of proteins.

Pale yellow older leaves: Because N is readily transferred from old to young leaves, symptoms

appear first and are more severe on old leaves. Symptoms work their way up the plants to young

leaves if the deficiency persists. Old leaves turn pale green. Pale yellow chlorosis then develops at

the tips and advances down the leaves, usually along the mid-veins, producing V-shaped patterns.

The chlorosis is followed by pale brown necrosis until entire leaves are affected and die, often

hanging down around the lower stems.

2.2.8.7.2 Problem Soils

Nitrogen deficiency is likely to occur in: • Sandy soils leached by heavy rainfall or excessive irrigation • Soils low in organic matter • Soils with a long history of cropping and depleted of N supplies

However, even fertile soils may suffer temporary N deficiency when double-cropped, heavily

leached, or waterlogged.

2.2.8.7.3 Correcting Deficiency

Nitrogen deficiency is corrected by increasing the level of available N in the soil by fallowing,

which allows organic N to be converted to mineral N; by growing cover or cash crops of legumes,

which can fix atmospheric N_2; or by adding nitrogenous fertilizers. Suitable fertilizers are urea,

gaseous ammonia or ammonium sulfate, nitrates, or phosphates. Crop growth depends on the

amount of N already in the soil.

A test can measure the amount of total N or nitrate (NO_3)-N in the soil and predict the amount

of fertilizer required. The best prediction can be obtained by seeking advice on fertilizer practices

used on similar soils in the region.

Nitrogen deficiency in existing crops can be corrected by applying soluble salts such as urea with

irrigation water or as a foliar spray. Spray applications usually result in a rapid response of short

duration, and additional sprays 10 to 14 days apart may be needed to supply enough N to the crop.

2.2.8.8 Phosphorus (P)

2.2.8.8.1 Deficiency Symptoms

Mild deficiencies cause reduced growth but few clearly recognizable leaf symptoms. When the

deficiency is severe, plants are stunted and have short, stout stems and dark green, short, erect

leaves. Some varieties may develop purple or red areas on leaves and stems. A deficient plant

may produce only one small ear containing fewer, smaller kernels than usual. Grain yield is

often severely reduced.

Purple older leaves: Because P is readily transferred from old to young leaves, symptoms

appear first and are more severe on old leaves. They work their way up the plants to young leaves

if the deficiency persists. In many varieties, purple or purple-red areas develop on the old dark

green leaves. In some varieties, the purple is restricted to the mid-sections of leaves and may

develop interveinal patterns. In other varieties, entire leaves are suffused with purple. Young leaves

usually remain unaffected.

Dark yellow leaf tips: Yellow chlorosis develops at the tips of old leaves and advances toward

the bases, usually in a broad front but sometimes along the margins. The chlorosis turns dark brown

as the tissue dies.

Purple stems: Many varieties develop red or purple areas on the lower stems and old leaf

sheaths. The colors are more intense on areas exposed to sunlight; stems are green beneath protecting

leaf sheaths.

2.2.8.8.2 Problem Soils

Phosphorus deficiency is likely to occur in: • Soils low in organic matter • Soils in which cropping has depleted P supplies • Calcareous soils that contain P in forms that are less available to plants

2.2.8.8.3 Correcting Deficiency

Phosphorus deficiency can be corrected by applying phosphatic fertilizers at or before sowing.

Suitable fertilizers are single or triple superphosphates or ammonium phosphates. The growth of

crops depends on the amount of water-soluble phosphates and the rate of exchange between

insoluble and soluble forms of P in the soil.

A test can be used to estimate the amount of available phosphate in a soil and predict the

amount of fertilizer needed. The best prediction can be obtained by seeking advice on fertilizer

practices used on similar soils in the region.

Phosphorus deficiency in existing crops can be corrected by applying soluble salts such as

ammonium phosphates with irrigation water. Spray applications of similar salts are usually not rec

ommended because of the large number of applications needed to supply the requirements of the crop.

2.2.8.9 Potassium (K)

2.2.8.9.1 Deficiency Symptoms

Mild deficiencies of K cause stunted growth; plants have short, thin stems and pale green foliage.

In severe deficiencies, plants become very stunted with short, spindly stems, pale green young

leaves, and dead old leaves that hang down around the lower stems. Potassium deficiency severely reduces grain yield. An affected plant may produce a single small ear that is often very pointed

and underdeveloped at the tip. Kernel size is smaller than normal.

Marginal necrosis on older leaves: Because K is readily transferred from old to young leaves,

symptoms develop first and are more severe on old leaves. They work their way up the plants to

younger leaves if the deficiency persists. Symptoms begin as a pale yellow chlorosis on the tips of

old leaves. The chlorosis is followed rapidly by pale brown necrosis and both symptoms advance

down the margins toward the bases, usually leaving the mid-veins and surrounding tissues pale

green. Young leaves usually remain green and appear healthy.

Red stems: When the deficiency is mild, stems are usually pale green, but prominent red stripes

develop on the lower stems and leaf sheaths if the deficiency persists or becomes severe.

2.2.9.9.2 Problem Soils

Potassium deficiency is likely to occur in: • Soils low in organic matter • Sandy soils formed from parent material low in K • Light textured soils leached of K by heavy rainfall

2.2.8.9.2 Correcting Deficiency

Potassium deficiency is corrected by applying potassium nitrate, sulfate, or chloride to the soil at

or before sowing. Crop yield depends on the amounts of water-soluble and exchangeable K in the

soil. A test can measure the amount of available K in the soil and predict the amount of fertilizer

needed. The best prediction can be obtained by seeking advice on fertilizer practices used on similar soils in the region.

Potassium deficiency in existing crops can be corrected by applying soluble salts such as

potassium sulfate, chloride, or nitrate with irrigation water. Foliar sprays of similar salts are not

recommended because of the large number needed to meet crop requirements.

2.2.8.10.1 Deficiency Symptoms

Sulfur-deficient plants are stunted and have stout, short stems and yellow foliage. Mild deficiencies

in young crops cause whole plants to change color from pale green to yellow-green. In more mature

crops or if the deficiency persists and becomes severe, older leaves are pale green and younger

leaves are yellow. Sulfur deficiency reduces grain yield because affected plants produce fewer,

smaller ears with fewer kernels. The grain may be low in protein because S is required for the

formation of amino acids used in protein synthesis.

Yellow young leaves: Because S is not readily transferred from old to young leaves, symptoms

develop first and are more severe on young leaves. Symptoms begin with all leaves turning pale

green; the young leaves are the palest. Young leaves then turn pale yellow while old leaves remain

pale green. The veins and interveinal tissues usually turn pale yellow, but in some varieties, the

veins in the lower halves of the leaves may remain pale green during the early stages of deficiency.

Red-purple suffusion on leaves: On severely deficient young plants, red-purple color sometimes

develops as a suffusion over the yellow areas of the youngest leaves and red striping may develop

on the sheaths of old leaves.

2.2.8.10.2 Problem Soils

Sulfur deficiency is likely to occur in: • Soils low in organic matter after many years of cropping • Soils formed from parent material low in S (for example, certain volcanic rocks and ash) • Acid sandy soils from which sulfates have been leached

2.2.8.10.3 Correcting Deficiency

Soil applications of any S fertilizer will correct deficiencies. Elemental S (flowers of S) can be

broadcast and thoroughly mixed into the soil about 4 months before sowing. Gypsum (calcium

sulfate) is another useful source of S. Tests can measure the amounts of available sulfate in the

soil before sowing and predict the amounts of fertilizer required. The best prediction can be obtained

by seeking advice on fertilizer practices used on similar soils in the region.

Sulfur deficiency in existing crops can be corrected by applying soluble sulfate salts, such as

magnesium, ammonium, or potassium sulfate, in irrigation water. Foliar sprays of similar salts are

usually not recommended because of the large numbers needed to meet crop requirements.

2.2.8.11 Zinc (Zn)

2.2.8.11.1 Deficiency Symptoms

Zinc-deficient corn crops often appear patchy. Within Zn-poor areas, plants can be very stunted

and have short, stout stems and pale green to yellow foliage. Zinc deficiency affects both ear and

tassel development. Affected crops produce small ears that set few grains. Tassels are often distorted and may be devoid of pollen when the deficiency is very severe. As a result, grain yields are severely

reduced even by mild deficiencies.

White bands in younger leaves: Because Zn is not readily transferred from old to young leaves,

symptoms develop first and are more severe on young leaves. Often, the youngest leaves are the

most severely affected. Old leaves usually remain green and appear healthy. The youngest leaves

turn pale green. White to yellow bands or streaks appear between the margins and mid-veins in

the lower halves of the leaves. Eventually, the affected tissue dies and turns pale grey, leaving the

margins and mid-veins green.

shaped appearance with the leaves crowded together at the tops.

2.2.8.11.2 Problem Soils

Zinc deficiency is likely to occur in: • Strongly alkaline soils with depressed Zn availability • Leached sandy soils with low total Zn • Leveled soils that may have Zn-deficient subsoils exposed on their surfaces • Soils in which heavy applications of phosphate fertilizers may reduce crop use of Zn

2.2.8.11.3 Correcting Deficiency

Foliar and soil applications of Zn salts have been used to correct deficiencies. Soil applications

of zinc chelates, sulfates, or oxides should be broadcast and mixed into the soil 2 to 3 months

before sowing. Soil applications are effective for 6 to 8 years before fresh applications may

be needed.

Foliar sprays exert no residual effects and fresh applications must be made to each crop. Best results are obtained when a 0.5 to 1% solution of a soluble Zn salt (for example, 0.5 to 1 kg zinc

sulfate heptahydrate ($ZnSO_4 \cdot 7H_2O$) per 100 L of water per ha) is applied 2 to 3 weeks after seedling

emergence. Additional sprays should be applied as soon as symptoms reappear.

Soil tests can be used to estimate the amounts of available Zn in a soil and predict whether

fertilizer is needed. The best prediction can be obtained by seeking advice on fertilizer practices

used on similar soils in the region. TABLE 2.31 Key to Nutrient Deficiency Symptoms of Corn Symptom Deficient Nutrient Color changes in lower leaves Yellow discoloration from tip backward in form of a V Nitrogen Brown discoloration and scorching along outer margin from tip to base Potassium Yellow discoloration between veins; edges become reddish-purple Magnesium Purpling and browning that extend in waves backward from tip Phosphorus Uniform yellowing of upper and lower leaves Sulfur Color changes in upper leaves Emerging leaves show yellow to white bleached bands in lower parts of leaves Zinc Young leaves show interveinal chlorosis along entire length Iron Young leaves are uniformly pale and yellow; older leaves die starting from the tips Copper White, irregular spots between veins Boron Young leaves show pale green to yellow discoloration between veins Manganese Young leaves wilt and die along the margins Molybdenum Note: Stunted plants and loss of green color are common for all deficiencies.

2.2.8.12.1 Problem Soils

Sodium cloride toxicity is more likely to occur in: • Saline soils formed from salt water sediments • Previously fertile soils flooded or heavily irrigated with water containing a high concentration of NaCl

2.2.8.12.2 Correcting Toxicity

Leaching with good quality irrigation water is the most effective means of removing excess Na

and Cl from soil. The water table may have to be lowered to make the treatment effective. Permeable soils such as well structured sandy soils are often easily reclaimed, but the problem is more difficult

in less permeable soils such as poorly structured heavy clays.

If exchangeable Na in the soil is high, reclamation involves replacement of the adsorbed Na

by Ca via application of gypsum (calcium sulfate) and then leaching the dissolved Na and Cl

beyond the rooting depths of the plants. If irrigation water is to be used to leach the Na, the quality

of the water should be checked before use to make sure it is not saline. Where excess NaCl cannot

be wholly corrected by soil leaching, a more tolerant species may have to be grown.

TABLE 2.32

Effects of Salinity on Corn 1 Appearance Causal Condition

Unthrifty, low-yielding

crops When sodium chloride (NaCl) is only moderately toxic, affected plants have a droughty appearance and grow poorly. As the toxicity becomes more severe, plants become stunted and develop short, thick stems and erect, grey-green foliage. Although the number of ears developed may not be affected, ear and kernel sizes are reduced and affected crops usually produce less grain than normal.

Droughty appearance Sodium chloride is carried in the transpiration stream and accumulates to high concentrations in old leaves. Symptoms appear first in old leaves and work up the plant to younger leaves if the toxicity persists. Affected plants have harsh, droughty appearance. Foliage is dull grey-green and leaves are shorter and held more erect than normal. The margins of all leaves are often rolled in, as if the leaves had wilted.

Weather-tipped older

leaves As the toxicity develops, grey necrosis appears on the margins near the tips of old leaves. The necrosis spreads down the leaves, usually along the margins, making them appear weather-tipped.

2.2.8.13.1 Problem Soils

Manganese toxicity is likely to occur in: • Strongly acid soils with increased solubility of Mn • Waterlogged soils in which poor aeration causes unavailable manganic (Mn^{3+}) ions to be reduced to manganous (Mn^{2+}) ions that can be taken up by plants

2.2.8.13.2 Correcting Toxicity

Manganese toxicity is usually corrected by adopting management practices that reduce the levels

of soluble Mn in soils. If soils are strongly acid, liming to an alkaline reaction will reduce excessive

levels of soluble Mn. Drainage of waterlogged soils prevents anaerobic conditions in which soluble

Mn^{2+} ions are produced. If soils have been over-fertilized with Mn^{2+}, heavy leaching with low Mn

irrigation waters or mulching with organic materials will remove soluble Mn from the soil solutions.

TABLE 2.33

Effects of Manganese Toxicity on Corn Appearance Causal Condition

Unthrifty, low-yielding

crops On some soils or under certain conditions, soluble Mn can reach levels that are toxic for plant growth. In corn, such toxicity causes stunted plants with thin stems and yellow-green foliage. Grain yield is depressed, mainly by reducing the numbers and sizes of ears produced. If the toxicity is very severe, small, distorted plants that produce little grain or die before maturity may develop.

Interveinal chlorosis on

older leaves Excess Mn accumulates in older tissues and symptoms appear first and are usually more severe on old leaves. However, if the toxicity persists, symptoms spread rapidly to young leaves until entire plants are affected. Leaves turn pale green and pale yellow flecks and mottles develop between the veins in the mid-sections of the leaves. The chlorotic tissue dies, turns pale brown or grey, and the lesions join to produce streaks of necrotic tissue running between the veins in the mid-sections of the leaves.

Weather-tipped older

leaves When the deficiency persists, the margins and tips of old leaves turn dark grey-green, then brown. The mid-veins and surrounding tissues appear silver-green and the dead brown tips appear weather-tipped.

TABLE 2.34
Critical Plant Nutrient Element Levels in Corn Leaves Opposite to and below the Ear at Tasseling

Major Element	%	Micronutrient	ppm
Nitrogen	2.90	Boron	10
Phosphorus	0.25	Copper	5
Potassium	1.90	Iron	25
Calcium	0.40	Manganese	15
Magnesium	0.15	Zinc	15
Sulfur	0.15		

TABLE 2.35

Normal Expected Ranges in Nutrient Elements Concentrations for Parts of Corn Plants

	Average Range in Concentration				
Element	Whole plant at 3- to 4-leaf stage	Ear leaf at silk	Stalk at silk above ear node	Stalk at silk below ear node	Grain at maturity
	g/kg				
Nitrogen	35–50	27–365	—	—	10–25
Phosphorus	4–8	2–4	1–2	1–2	2–6
Potassium	35–50	17–25	10–20	20–30	2–4
Calcium	9–16	4–10	1–3	1–3	0.1–0.2
Magnesium	3–8	2–4	1–3	1–3	0.9–2.0
Sulfur	2–3	1–3	—	—	—
	mg/kg				
Aluminum	100–200	10–200	10–25	50–100	—
Boron	7–25	4–15	4–12	4–9	1–10
Barium	—	0.50	5–20	2–15	—
Copper	7–20	3–15	3–15	3–10	1–5
Iron	50–300	50–200	50–75	50–100	30–50
Manganese	50–160	20–250	20–70	50–100	5–15
Sodium	—	1–400	1–100	1–100	—

Strontium — 10–100 10–50 10–30 — TABLE 2.36 Sufficiency Ranges for Major Elements and Micronutrients in Corn Plants Time of Sampling and Plant Part Element 15 whole tops of plants 12 in. tall 12 leaves below whorl prior to tasseling 12 ear leaves at initial silk % Nitrogen 3.50–5.00 3.00–5.00 2.70–4.00 Phosphorus 0.30–0.50 0.25–0.45 0.25–0.50 Potassium 2.50–4.00 2.00–2.50 1.70–3.00 Calcium 0.30–0.70 0.25–0.50 0.21–1.00 Magnesium 0.15–0.45 0.13–0.30 0.20–1.00 Sulfur 0.15–0.50 0.15–0.50 0.21–0.50 ppm Boron 5–25 4–25 5–25 Copper 5–20 3–15 6–20 Iron 50–250 10–100 20–250 Manganese 20–300 15–300 20–200 Molybdenum 0.10–10.0 0.10–0.30 0.10–0.20 Zinc 20–60 15–60 25–100 Source: Plant Analysis Handbook II: A Practical Sampling, Preparation, Analysis, and Interpretation Guide, 1996, MicroMacro Publishing, Athens, GA.

FIGURE 2.12 Relative yield of corn grain versus concentration of total nitrogen in a basal segment of a stalk.

2.2.9 CHLOROPHYLL METER READINGS OF CORN LEAVES

Chlorophyll meter readings taken in the field are compared to the average readings from a high N

reference area. The field to be tested should have received no fertilizer N beyond a normal amount

of starter N and the N applied to the high N reference area.

The manual accompanying the chlorophyll meter should provide detailed instructions for

operating the meter. What follows is a brief explanation of how to use a chlorophyll meter to take

leaf readings for an early season test:

Internal calibration — This is the first step in the procedure. Turn the meter on. CAL will appear

in the window. With no sample in the sample slot, press the measuring head down. The meter will

beep when calibration is complete. The display will then show N = 0 (N is the sample number).

If the display flashes CAL and beeps, the calibration was not performed correctly, probably because the sample head was not closed completely. Repeat the procedure. If the meter beeps and EU

appears at the top of the display, the top and bottom windows of the measuring head may be dirty.

Wipe them clean and repeat the procedure.

Leaf reading — Place a leaf in the slot of the meter head. Use the center line on the measuring

head to align the measuring head window and the spot on the leaf to be read. When the head is

closed on the leaf, the meter will beep, a digital reading will appear on the display, and the reading

will be stored in the meter. Sometimes the meter will beep and not give a reading. When this

happens, try changing the alignment of the leaf slightly before closing the head again.

Standardization — Meter readings of corn leaves are affected by the part of the leaf and the

position of the leaf on the plant that is sampled. Therefore, it is necessary to standardize the part

of the corn plant to be read with the chlorophyll meter. For this test, chlorophyll meter readings

should always be done on leaf 5 of a plant to be tested. The reading is done at a point on the leaf

approximately 1/2 inch from the edge of the leaf and 3/4 of the length of the leaf from the leaf

base. Do not take readings on the midrib or too near the edge.

Pick representative plants in the field for meter readings. Care should be taken to avoid unusual

or damaged parts of leaves when reading the chlorophyll meter. Plants chosen should be relatively

evenly spaced rather than separate from others or in clusters. Use your body to shield the meter from direct sunlight. Wet leaves may be read if beaded water is shaken or rubbed off before the

leaf is inserted into the meter.

Questionable readings — Occasionally you may get readings that seem incorrect or are very

different from others in the field. Such a reading can be deleted by pressing the 1 DATA DELETE

button to remove the last reading. Be careful not to press ALL DATA CLEAR because it will delete

all readings taken to that point. If you want to look over all of existing readings at any time, use

the DATA RECALL button to scan them. During the scan, you may use the DELETE button to

remove a reading and then replace it by taking another reading.

Determining average — A chlorophyll meter will store up to 30 readings. At any point, pressing

the AVERAGE button will display the average of the readings taken. When you are ready to begin

a new set of readings, press ALL DATA CLEAR to delete all the readings saved to that point.

Once an operator is familiar with meter operation and leaf stage identification, readings can

be done very quickly. Since the meter memory will store up to 30 readings and calculate an average,

at least 30 readings should be taken. If a field is very variable, more readings may be necessary

for an accurate field average or to determine whether several different N rates would be appropriate.

At least 25 to 30 readings should be taken from plants in the high N reference sections.

Advantages of early season chlorophyll meter testing — • Chlorophyll meter readings are quick, easy, and provide instantaneous values. • No samples need to be collected, processed, and sent to a laboratory for analysis. • The only cost of sampling is labor. • Nitrogen recommendations are accurate (comparable to the pre-side-dress soil nitrate test). • Initial expense is high; the meter costs about $1,400. • Early season corn leaf chlorophyll levels are affected by hybrid selection and environmental stresses. Thus, high N reference plots must be established. • This test is not applicable to fields that have received preplant or at-plant N fertilizer applications beyond starter N.

2.2.10 PLANTING RATES

2.2.11 CORRECTION TABLES

TABLE 2.37

Corn Plants/Acre at Various Planting Rates

Distance between Rows	Checked Corn			Drilled Corn			
	2/hill	3/hill	4/hill	8 in.	10 in.	12 in.	14 in.
2 ft. 8 in.				24,502	19,600	16,335	14,001
2 ft. 10 in.				23,061	18,449	15,374	13,178
3 feet	9,680	14,520	19,360	21,780	17,424	14,520	12,447
3 ft. 2 in.	8,690	13,030	17,380	20,634	16,507	13,756	11,791
3 ft. 4 in.	7,840	11,760	15,680	19,602	15,682	13,068	11,201
3 ft. 6 in.	7,110	10,670	14,220	18,669	14,935	12,446	10,688
3 ft. 8 in.				17,820	14,256	11,880	10,183
3 ft. 10 in.				17,045	13,636	11,363	9,740

TABLE 2.38

Corn Grain Moisture Yield Correction

% Moisture	lb Ears to Equal 1 bu	% Moisture	lb Ears to Equal 1 bu
14	66.9	25	81.3
15	67.9	26	82.8
16	68.9	27	84.2
17	70.0	28	85.6
18	71.3	29	87.0
19	72.6	30	88.5
20	74.0	31	89.9
21	75.4	32	91.4
22	76.8	33	92.9
23	78.3	34	94.3
24	79.8	35	95.7

2.2.12 WEIGHTS AND MEASURES

Conversion factor — 1 bu (56 lb) shelled corn is approximately equal to 2 bu (70 lb) husked ear corn.

Percentage of Shelled Corn to Add or Subtract to Correct to 15.5% Moisture Content

% Moisture in Corn	% to Add	% Moisture in Corn	% to Subtract	%Moisture in Corn	% to Subtract
10.5	5.9	15.5	0.0	20.5	5.9
11.0	5.3	16.0	0.6	21.0	6.5
11.5	4.7	16.5	1.2	22.0	7.7
12.0	4.1	17.0	1.8	23.0	8.9
12.5	3.6	17.5	2.4	24.0	10.1
13.0	3.0	18.0	3.0	25.5	11.8
13.5	2.4	18.5	3.6	30.5	17.8
14.0	1.8	19.0	4.1	35.5	23.7
14.5	1.2	19.5	4.7	40.5	29.6
15.0	0.6	20.0	5.3	50.5	41.4

TABLE 2.40 Weights and Measures of Corn Commodities

		Approximate Net Weight	
Commodity	Unit	lb	kg
Ear, husked	bu	70	31.8
Shelled	bu	56	25.4
Meal	bu	50	22.7
Oil	gal	7.7	3.5

TABLE 2.41 Weight of Grain and Standard Yield of Level Full Bushel of Corn

Weight (lb) of 1 Measured bu	Multiplication Factor to Yield 1 Standard bu Shelled Corn
60	1.07
58	1.04
56	1.00
54	0.96
52	0.93
50	0.89
48	0.86
46	0.82
44	0.79
42	0.75
40	0.71

1. Grundon, N.J., Hungry Crops: A Guide to Nutrient Deficiencies in Field Crops, 1987, Information Series QI87002, Queensland Department of Primary Industries, Brisbane, Australia.

2. The Early-Season Chlorophyll Meter Test for Corn, 1997, Agronomy Facts 53, Pennsylvania State University, University Park, PA.

2.3 GRAIN SORGHUM [Sorghum bicolor (L.) Moench]

2.3.1 I NTRODUCTION

Some question surrounds whether the early cultivation of sorghum began in the Nile Valley or elsewhere in Africa, but its domestication is certainly tied to the origin and evolution of African agriculture. Sorghum is known as sorgho in France, sorgo in Spain and Italy, mohrenhirse and sorghum in Germany, jowar in India, and durra in Arabian countries. The five races of grain sorgum are bicolor, guinea, caudatum, kafir, and durra.

Sorghum has a wide range of uses: as grain, sweetener (sugar sorghum), animal feed, silage, fuel, building material, and in broom making. Sorghum can grow at rainfall levels over 250 mm, but grows best with 800 to 1,200 mm of rain during the vegetative season. Under very dry conditions,

recommended densities range from 0.5 to 3 plants per m 2 under dry conditions to 10 plants per m 2

when irrigated or grown for forage. Seed germinates at temperatures >15°C, with optimum growth

between 25 and 30°C. Early maturing varieties can be harvested 3 to 4 months after sowing and

late varieties, 8 to 10 months after sowing. Sorghum can grow on light sandy soils, but best yields

are obtained from high fertility soils. Corn Seeds per Pound, Weight per Bushel, and Germination Time Corn Seeds/lb (1,000) Seeds/g (no.) Weight/bu Germination Time (days) 62 3 56 7

2.3.2 PRODUCTION STATISTICS

TABLE 2.43

U.S. Sorghum Grain and Silage Acreage, Yield, and Production, 1991–2000. a Sorghum for Grain b Sorghum for Silage

Year	Harvested Acres (1,000)	Yield (bu/acre)	Production (1,000 bu)	Harvested Acres (1,000)	Yield (tons/acre)	Production (1,000)
1991	9,670	59.3	584,860	463	10.0	4,846
1992	12,050	72.6	675,022	453	12.1	5,468
1993	6,916	59.9	534,172	351	11.2	3,914
1994	8,882	72.7	645,741	362	11.9	4,316
1995	6,253	55.6	458,648	413	10.3	4,242
1996	11,811	67.3	795,274	423	11.8	4,976
1997	9,158	69.2	633,545	412	13.1	5,365
1998	7,723	67.3	519,933	306	11.4	3,526
1999	6,544	69.7	595,166	320	11.6	3,716

2000 c 7,723 60.9 470,070 265 10.8 2,663

a Grain and sweet sorghum for all uses including syrup.

b Includes both sorghum for grain, and sweet sorghum forage or seed.

c Preliminary.

Source: Crops Branch, National Agriculture Statistics Service, Washington, D.C., 2001. TABLE 2.44 U.S. Grain Sorghum Acreage and Production, 2000 State Area Harvested (1,000 acres) Yield (bu/acre) Production (1,000 bu) Kansas 3,200 59 188,800 Texas 2,350 61 143,350 Maryland 756 84 756 Arizona 720 80 720 California 600 75 600 Nebraska 500 70 35,000 U.S. Total 7,723 60.9 470,070 Source: Crops Branch, National Agricultural Statistics Service, Washington, D.C., 2001. TABLE 2.45 U.S. Utilization of Sorghum for Silage, 2000 State Area Harvested (1,000 acres) Yield (tons/acre) Production (1,000 tons) Kansas 65 10 650 Texas 60 10 600 Nebraska 20 11 220 South Dakota 20 9 180 Oklahoma 17 12 204 Georgia 15 9 135 Source: Crops Branch National Agriculture Statistics Service, Washington, D.C., 2001.

2.3.3 CHARACTERISTICS OF GROWTH

TABLE 2.46

Stages of Growth of Grain Sorghum Stage Days after Emergence a Stage Name and Description 0 0 Emergence — usually occurs 3 to 10 days after planting. 1 10 Three-leaf stage — three fully developed leaves; collar of each leaf is visible without tearing the blade or sheath; the growing point or meristem is still below the soil surface. 2 20 Five-leaf stage — five leaves are fully developed; the root system is developing rapidly; disease at lower nodes may cause loss of leaves at the nodes; rate of growth is increased and remains almost constant until physiological maturity. 3 30 Stage has no descriptive name; plant normally has 7 to 10 fully developed leaves; reproductive development is initiated; the final number of leaves has been determined; potential panicle size will be established; three lower leaves may be lost; culm or stalk growth is rapid. 4 40 Stage has no descriptive name; flag leaf is visible in the whorl; all leaves except the final three or four are fully expanded; 80% of total leaf area is present, light interception is approaching maximum; reference to the number of leaves or leaf number should be from the top; because a variable number of leaves were lost from the base of the culm, the flag leaf is numbered

1; about 20% of the final dry weight is present. 5 50 Boot — leaves are fully expanded; panicle is near full size and enclosed in the flag leaf sheath; culm elongation is essentially complete; peduncle elongation begins; boot stage of inflorescence development occurs during this stage. 6 60 Half-bloom — peduncle has grown rapidly during stage 5 and the panicle is extended from the flag leaf sheath; half the plants in a field are in some stage of bloom; for some, flowering has progressed half-way down the panicle; time required to reach half bloom depends upon maturity of the hybrid and environmental conditions. 7 70 Soft-dough — between stage 6 and the point at which grains are at soft-dough stage, about half the total dry weight of the grain is accumulated; culm weight is decreased by about 10% during grain filling; lower leaves continue to be lost and only 8 to 12 functional leaves remain. 8 85 Hard-dough — About 75% of the grain dry weight has accumulated; grain contents are more solid; culm weight has declined to its lowest dry matter weight. 9 95 Physiological maturity — Plant and panicle reach maximum total dry weight; the time from flowering to physiological maturity varies by hybrid but represents about a third of the total time from planting; grain moisture is usually 25 to 35%; remaining functional leaves may remain green; branches may develop from upper nodes if temperature and moisture are adequate.

a Approximate number of days for hybrids of RS 610 maturity grown at Manhattan, KS.

Source: Growth stages of sorghum, Agron J., 64, 13, 1972.

2.3.4 SORGHUM GRAIN CHARACTERISTICS TABLE 2.47 Nutritive Values of Whole Sorghum Grain Component Value Calories/100 g 332 Protein, % 11.0 Fat, % 3.3 Total calcium, mg/lb 28 Total phosphorus, mg/lb 287 Total potassium, mg/lb 350 Carbohydrates, % 73.0 TABLE 2.48 Levels and Degrees of Toxicity of Prussic Acid in Grain Sorghum Level (ppm dry weight) Relative Degree of Toxicity 0–250 Very low (safe to pasture) 250–500 Low (safe to pasture) 500–750 Medium (doubtful to pasture) 750–1,000 High (dangerous to pasture) >1,000 Very high (very dangerous to pasture) Source: Modern Grain Sorghum Production, 1990, Iowa State University Press, Ames. TABLE 2.49 Levels and Degree of Toxicity of Nitrates in Grain Sorghum Nitrate-Nitrogen Content (ppm dry weight) Toxicity 0–1,000 Safe under all feeding conditions 1,000–1,500 Safe for all except pregnant animals 1,500–4,000 Risk of poisoning: should not constitute more than 50% of ration >4,000 Potentially toxic: should not be fed Source: Modern Grain Sorghum Production, 1990, Iowa

State University Press, Ames. Average Mineral Composition of Grain Sorghum Element Content (%) Nitrogen 1.80 Phosphorus 0.30 Potassium 0.40 Sulfur 0.15 Calcium 0.04 Magnesium 0.15 Iron 0.005 Manganese 0.001 Copper 0.001 Source: Modern Grain Sorghum Production, 1990, Iowa State University Press, Ames. TABLE 2.51 Influence of Nitrogen Application on Protein Content of Grain Sorghum Nitrogen Rate (lb/acre) Yield (lb/acre) Protein (%) 0 3,100 6.8 40 4,300 6.9 80 5,100 7.8 160 6,200 10.3 320 6,500 12.4 Source: Modern Grain Sorghum Production, 1990, Iowa State University Press, Ames. TABLE 2.52 Quality Components of Sorghum Grain Component Content Digestible energy, kcal/kg 3,453 Protein, % 11.0 Lysine, % 0.27 Methionine + cystine, % 0.27 Tryptophan, % 0.09 Calcium, % 0.04 Phosphorus, % 0.30 Fiber, % 2.0 Ether extract, % 2.8 Source: Modern Grain Sorghum Production, 1990, Iowa State University Press, Ames.

2.3.5 SORGHUM PLANT NUTRITION

TABLE 2.53

Nutrient Element Contents of Above-Ground Parts of Grain Sorghum Plant

Yield

(lb/acre) Plant Part Dry Matter (lb) N (lb) P 2 O 5 (lb) K 2 O (lb) Ca (lb) Mg (lb) S (lb)

6,000 Grain 5,100 95 30 25 3 10 7 Stover 6,800 70 12 100 15 8 13

8,000 Grain 6,800 120 60 30 5 14 10 Stover 8,000 80 16 120 20 12 10

10,000 Grain 8,500 145 70 35 7 18 13 Stover 9,500 95 20 135 25 20 18

Source: Modern Grain Sorghum Production, 1990, Iowa State University Press, Ames.

TABLE 2.54

Normal Ranges in Composition of

Leaves and Grain of Grain Sorghum Range Element Leaf Grain %

Nitrogen 2.0–3.0 1.0–2.0

Phosphorus 0.2-0.4 0.2-0.4

Potassium 1.5-3.0 0.3-0.5

Calcium 0.3-0.5 0.03-0.05

Magnesium 0.2-0.4 0.1-0.2 ppm

Boron 10-75 1-3

Copper 5-10 5-15

Iron 15-150 40-60

Manganese 10-100 5-15

Zinc 10-75 5-15

Source: Modern Grain Sorghum Production,

1990, Iowa State University Press, Ames. TABLE 2.55 Critical Nutrient Element Concentrations for Grain Sorghum a Nutrient Element Concentration % Nitrogen 2.40 Phosphorus 0.20 Potassium 2.20 Calcium 0.40 Magnesium 0.25 ppm Boron 15 Copper 5 Iron 25 Manganese 15 Molybdenum 0.2 Zinc 15 a Based on the leaf immediately below the flag leaf during booting and flowering. Source: Modern Grain Sorghum Production, 1990, Iowa State University Press, Ames.

2.3.6 NUTRIENT ELEMENT UPTAKE BY GRAIN SORGHUM TABLE 2.56 Approximate Amounts of Nutrient Elements Removed by 5,600 Pounds Grain Sorghum Element Grain (lb) Stover (lb) a Nitrogen 90 76 Phosphorus as phosphate 35 20 Potassium as potash 22 110 Sulfur 9 10 Magnesium 7 10 Calcium 1.4 18.9 Copper 0.014 0.02 Manganese 0.056 0.11 Zinc 0.07 0.14 a The amount of stover is not linearly related to grain yield. Source: Adapted from Changing Patterns in Fertilizer Use, 1968, Soil Science Society of America, Madison, WI. TABLE 2.57 Fertilizer Nutrient Element Demand/Uptake/Removal (kg/ha) by Grain Sorghum kg/ha Plant Condition Nitrogen Phosphorus as Phosphate Potassium as Potash Dryland, low yield 40 20 40 Wet, medium yield 60 35 75 Irrigated, high yield 100 50 125 Green forage 80 30 70 Silage 150 40 150 Top yield, grain and forage 250 60 250 Source: IFA World Fertilizer Use Manual., 2000, International Fertilizer Industry Association, Paris. TABLE 2.58 Cumulative Estimated Amounts of Primary Nutrient Elements Absorbed by Grain Sorghum during the Georgia Growing Season (5,600 lb/acre) Nutrient Element Stage of Growth 0-2 3 5 8 9 Nitogen, % 5 38 70 85 100 Phosphorus as phosphate, % 3 27 60 87 100 Potassium as potash, % 8 48 80 95 100 Nitrogen, lb 5 38 70 85 100 Phosphorus as phosphate, lb 2 16 36 52 60 Potassium as potash, lb 6 38 64 76 80

2.3.7 NUTRIENT ELEMENT DEFICIENCIES 1

2.3.7.1 Boron (B)

2.3.7.1.1 Deficiency Symptoms

Boron-deficient crops are very stunted, lack vigour and yield poorly. Affected plants have short,

stout stems and dark green foliage. Leaves are shorter and held more erect than usual. Deficient

plants produce small heads that may be partly barren, resulting in low grain yields.

White interveinal lesions on younger leaves: Because B is not readily transferred from old to

young leaves, symptoms appear first and are more severe on young leaves. Old leaves usually remain

green and appear healthy. The youngest leaves remain dark green but develop intermittent, white

interveinal lesions, often over their entire lengths. Tissue next to such lesions is brittle and easily torn.

The edges of the torn laminae may turn brown but necrosis of the remaining tissue is rare.

Fan-shaped stems: Because B plays a role in the elongation of internodes and leaves, stems

on deficient plants are very short, often flattened or oval in cross-section, with leaves crowded

together at the top. As the leaf sheaths pull away from the stem, they resemble a partly opened fan.

2.3.7.1.2 Problem Soils

Boron deficiency is likely to occur in: • Soils derived from parent material low in B such as acid igneous rocks or freshwater sediments • Sandy soils from which B has been leached by heavy rainfall Nutrient Element Utilization by Grain Sorghum Crop (8,000 lb/acre) Nutrient Element Uptake (lb/acre) Nitrogen 250 Phosphorus as phosphate 90 Potassium as potash 240 Magnesium 44 Sulfur 38

TABLE 2.60

Key to Nutrient Element Deficiencies for Sorghum Symptom Deficiency

Color changes in lower leaves

Yellow discoloration extending from tip backward in form of V along midrib Nitrogen

Brown discoloration or firing along outer margin from tip to base Potassium

Purpling and browning from tip backward; in young plants entire plant shows general purpling Phosphorus

Color changes in upper leaves

Yellow to white bleached bands appear on lower parts of emerging leaves Zinc

Entire lengths of young leaves show interveinal chlorosis; leaves may eventually turn white Iron

Uniform yellowing of upper leaves Sulfur

Note: Stunted plants and loss of green color are common to all deficiencies.

Source: Modern Grain Sorghum Production, 1990, Iowa State University Press, Ames. • Acid peat and muck soils

2.3.7.1.3 Correcting Deficiency

Boron deficiency can be corrected by applying soil dressings or foliar sprays of fertilizers. Soil

dressings are more effective if broadcast and mixed into the soil some months before sowing.

Borax, boric acid, and chelated B compounds are suitable for soil application, but only boric acid

and chelated B compounds are suitable for foliar sprays. Foliar sprays should be applied about 5

to 6 weeks after seedling emergence or as soon as symptoms appear. While soil dressings often

remain effective for many years before fresh applications are needed, foliar sprays have little residual

value and must be applied to every crop.

Tests can estimate the amount of available B in a soil and predict whether fertilizer is needed.

The best prediction can be obtained by seeking advice on fertilizer practices used on similar soils

in the region.

2.3.7.2 Calcium (Ca)

2.3.7.2.1 Deficiency Symptoms

Sorghum is very sensitive to Ca deficiency and even mild deficiencies can severely reduce growth

and grain yields. Affected plants are stunted and have short, stout stems and dark green, often

ragged foliage. If the deficiency is severe, whole plants may die or the heads may be malformed

and partly or completely barren.

Malformed younger leaves: Because Ca is not readily transferred from old to young leaves,

symptoms develop and are more severe on young leaves. Affected leaves are dark green, short,

brittle, and held more erect than usual. Pale yellow chlorotic areas develop near the margins and

these are easily torn, giving the leaves a malformed appearance.

Brown necrosis on younger leaves: If the deficiency persists, leaves missing sections of lamina

may be produced. Tissue adjacent to the affected areas is usually chlorotic, then quickly dies and

turns dark brown.

Flattened stems: Calcium deficiency prevents the elongation of the internodes. Affected plants

have very short stems that are oval in cross-section. Leaves are crowded together at the top of the plants.

2.3.7.2.2 Problem Soils

Calcium deficiency is likely to occur in: • Acid sandy soils from which Ca has been leached by heavy rainfall • Strongly acid peat and muck soils that have low total Ca • Sodic soils in which exchangeable Na and pH are high, thus depressing the Ca uptake • Soils with high levels of soluble Al and low levels of exchangeable Ca

2.3.7.2.3 Correcting Deficiency

Calcium deficiency can be corrected by broadcasting a suitable fertilizer and mixing it into the

soil some months before sowing. Where the chief problem is a lack of Ca, suitable fertilizers

are gypsum (calcium sulfate) and calcium nitrate or chloride. However, if the soil pH is low,

lime or limestone (calcium carbonate) and dolomite (a mixture of calcium and magnesium

carbonates) are more suitable.

A soil test can be used to determine the lime or Ca requirement of a soil. However, since the

correct rate of application depends on soil type and the crop to be grown, advice should be sought

on fertilizer practices used on similar soils in the district. Excessive use of lime may induce K,

Mg, Fe, Mn, Zn, or Cu deficiencies so care should be taken to prevent over-liming.

2.3.7.3.1 Deficiency Symptoms

Mild deficiencies usually exhibit no clearly recognizable symptoms, but cause unthriftiness, delayed

maturity, and stunted plants. Definite symptoms are associated with severe deficiencies only.

Affected plants are very short and have thin, spindly stems, pale green foliage, and smaller heads

on which many flowers are barren.

Weather-tipped younger leaves: Because Cu is not readily transferred from old to young leaves,

symptoms develop first and are more severe on young leaves. Frequently, the youngest leaves are

the most affected, while old leaves remain dark green and appear healthy. Symptoms develop on

the youngest leaves before they are unrolled from the whorls. They turn pale green and pale yellow

chlorosis develops at the tips. The chlorosis is followed rapidly by pale brown necrosis and both

symptoms advance down the margins towards the bases. The dead leaf tips usually roll or twist

tightly into tubes. This symptom is known as weather tipping.

2.3.7.3.2 Problem Soils

Copper deficiency is likely to occur in: • Peat and muck soils in which organic matter ties up soluble Cu in forms less available to plants • Alkaline soils in which total Cu is low • Leached acid soils containing low total Cu • Soils formed from rocks low in Cu

2.3.7.3.3 Correcting Deficiency

Foliar sprays and soil dressings of Cu salts such as copper sulfate (bluestone) or copper chelates

will correct Cu deficiency. Soil dressings should be broadcast and mixed into the soil some weeks

before sowing. However, soil dressings may fail to correct deficiencies in some seasons and

symptoms may reappear. If this occurs, foliar sprays should be applied immediately.

A reliable remedy is to apply foliar sprays of 0.5 to 1%

solutions of soluble Cu salts (for

example, 0.5 to 1 kg copper sulfate per 100 L water per ha), the first to be applied 4 to 6

weeks after seedling emergence. Additional sprays should be applied as soon as symptoms

reappear.

Tests can be used to estimate the amount of available Cu in a soil and predict whether fertilizer

is needed. The best prediction can be obtained by seeking advice on fertilizer practices used on

similar soils in the region.

2.3.7.4 Iron (Fe)

2.3.7.4.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Sorghum is relatively sensitive to Fe deficiency, and temporary

environmental conditions such as waterlogging may cause symptoms to appear, then disappear

when conditions return to normal. Prolonged or severe deficiencies produce stunted plants with

thin, spindly stems and pale yellow foliage. Mild or temporary deficiencies usually have few effects

on grain yields. However, prolonged or severe deficiencies reduce head size and the number of

grains set per head and result in low grain yields.

Yellow interveinal chlorosis on younger leaves: Because Fe is not transferred from old to young

leaves, symptoms develop first and are more severe on young leaves. The youngest leaves are

usually the most affected. Old leaves remain dark green and appear healthy. Young leaves turn pale

green and develop pale yellow interveinal chlorosis over their entire lengths. Veins remain dark green and prominent. • Alkaline soils that have low levels of soluble Fe • Waterlogged soils • Acid soils with excessively high levels of soluble Mn, Zn, Cu, or Ni that depress Fe uptake • Sandy soils low in total Fe • Peat and muck soils whose organic matter ties up Fe

2.3.7.4.3 Correcting Deficiency

While soil dressings of inorganic Fe salts, such as iron sulfates or chlorides, have corrected

deficiencies in some soils, the applied Fe quickly becomes insoluble and less available to plants.

Iron salts of various organic chelates have proved promising as soil dressings because the chelate

keeps the Fe in solution. For acid soils, FeEDTA is the most effective chelate, while FeHEDTA

and FeDTPA are best on neutral soils. FeEDDHA is best for alkaline soils. However, to be effective,

large amounts of chelates may be required.

An equally effective remedy is to apply solutions of inorganic salts or chelates to the foliage

(1% solutions or 1 kg salt per 100 L water per ha). Because Fe is so immobile in plants, sprays

need to be applied every 10 to 15 days to provide Fe to new leaves. Advice on fertilizer practices

used on similar soils in the district should be sought to obtain the best remedy for the affected crop

under local conditions.

2.3.7.5 Magnesium (Mg)

2.3.7.5.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Magnesium-deficient crops are unthrifty, lack vigor, and yield poorly.

Deficient plants are stunted and have short, thin stems and pale green to yellow foliage. Severely deficient plants usually produce small heads that set few grains; grain yields are severely reduced.

Interveinal chlorosis of older leaves: Because Mg is readily transferred from old to young

leaves, symptoms develop first and are more severe on old leaves. Symptoms then advance up the

plants to younger leaves if the deficiency persists. Young leaves usually remain pale green and

appear healthy. Pale yellow interveinal chlorosis develops on the mid-sections of old leaves and

and extends rapidly over their entire lengths. As the symptoms progress, the chlorosis darkens to

yellow-orange. The veins remain green and easily seen.

Brown necrosis on older leaves: When a deficiency is very severe, irregular, linear, rust-brown

necrotic lesions develop on and adjacent to the veins in the chlorotic tissues. Eventually these

lesions join to form rust-brown streaks running almost the full lengths of affected leaves.

2.3.7.5.2 Problem Soils

Magnesium deficiency is likely to occur in: • Acid sandy soils from which Mg has been leached • Strongly acidic peat and muck soils whose total Mg is low • Soils that have been over-fertilized with Ca (for example, with lime) or K

2.3.7.5.3 Correcting Deficiency

Magnesium deficiency on acid soils is corrected by broadcasting dolomite (a mixture of calcium

and magnesium carbonates) onto the surface and mixing it into the soil some months before sowing.

When the problem is strictly Mg deficiency, band applications of magnesium sulfate or chloride

can be made at planting. A soil test can be used to estimate the amounts of soluble and exchangeable

Magnesium deficiency in existing crops can be corrected by applying soluble salts, such as magnesium sulfate, chloride, or nitrate, with irrigation water. Foliar sprays of similar salts are usually not recommended because of the large number of applications needed to supply crop requirements.

2.3.7.6. Manganese (Mn)

2.3.7.6.1 Deficiency Symptoms

Patchy, low-yielding crops: Affected crops often appear patchy. Within the Mn-poor area, plants are very stunted and have thin, spindly stems and dark green foliage marked by red-brown necrotic areas. Affected plants produce small heads that set few grains and produce low yields. When the deficiency is very severe, many plants die before developing heads.

Interveinal white lesions on younger leaves: Because Mn is not readily transferred from old to young leaves, symptoms develop first and are more severe on young leaves. Old leaves remain dark green and appear healthy. Young leaves turn pale green and develop intermittent, white lesions between the veins around their mid-sections. If the deficiency persists, these lesions spread toward the base — not toward the tips.

Necrotic lesions on younger leaves: When a deficiency becomes severe, brown necrotic lesions develop in interveinal tissues adjacent to the white lesions. Initially, the main veins and leaf tips remain green. When the vein dies, the death of the leaf follows. In extreme deficiencies, young, still-unrolling leaves die, followed by the death of the main shoot.

2.3.7.6.2 Problem Soils

Manganese deficiency is likely to occur in: • Strongly alkaline soils whose Mn is less available to plants • Poorly drained peaty soils whose Mn is in forms less available to plants • Strongly acid sandy soils whose soluble Mn has been leached by heavy rain • Soils formed from rocks low in Mn

2.3.7.6.3 Correcting Deficiency

Foliar sprays and soil dressings of Mn salts and oxides have been used to correct Mn deficiencies.

Soil dressings are more effective when broadcast and mixed into the soil some weeks before sowing.

However, foliar applications have generally been more successful. One or more foliar sprays of 0.5

to 1% solutions of soluble Mn salts (for example, 0.5 to 1 kg of manganese sulfate per 100 L of water

per ha) usually correct the deficiency, the first applied 5 to 6 weeks after seedling emergence. If the

symptoms reappear, sprays should be repeated immediately. While soil dressings usually last 5 to 6

years before fresh applications are needed, foliar sprays must be reapplied to every crop.

Tests can estimate the amount of available Mn in a soil and predict whether fertilizer is needed.

The best prediction can be obtained by seeking advice on fertilizer practices used on similar soils

in the region.

2.3.7.7 Nitrogen (N)

2.3.7.7.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Nitrogen-deficient crops are unthrifty, mature more slowly, and yield

poorly. Deficient young plants are stunted and have thin, spindly stems and pale green foliage. In mature crops, affected plants have pale green upper leaves and pale yellow or brown lower leaves.

Head size and the number of grains set per head are low. Because N plays a vital role in the

formation of protein, grain from deficient plants may also be low in protein.

deficiency persists. Young leaves are pale green and smaller than usual. Old leaves turn pale

green and develop pale yellow chlorosis at the tips. The chlorosis is followed by pale brown

necrosis and both symptoms advance down the main veins creating V-notch patterns while the

margins remain green. Eventually, affected leaves die and form thatches of dead leaves around

the bases of the stems.

Red stems: Some varieties often develop red stripes on the lower stems and old leaf sheaths

when the deficiency is very severe. The red color is more intense on areas exposed to sunlight.

2.3.7.7.2 Problem Soils

Nitrogen deficiency is likely to occur in: • Sandy soils that have been leached by heavy rainfall or excessive irrigation • Soils low in organic matter • Soils with a long history of cropping whose supplies of N have been exhausted

However, even fertile soils may suffer temporary N deficiencies when double-cropped, heavily

leached, or waterlogged.

2.3.7.7.3 Correcting Symptoms

Nitrogen deficiency is corrected by increasing the level of available N in the soil by fallowing,

which allows organic N to be converted to mineral N; by growing cover or cash crops of legumes, which can fix atmospheric N_2; or by adding nitrogenous fertilizers. Suitable fertilizers are urea,

gaseous ammonia or ammonium sulfate, nitrate, and phosphates. Crop growth depends on the

amount of N already in the soil.

A soil test can measure the amount of total N or nitrate (NO_3)-N in the soil and predict the

amount of fertilizer required. The best prediction can be obtained by seeking advice on fertilizer

practices used on similar soils in the district.

Nitrogen deficiency in existing crops can sometimes be corrected by applying soluble salts

such as urea with irrigation water or as a foliar spray. Spray applications usually result in a rapid

response of short duration, and additional sprays 10 to 14 days apart may be needed to supply

enough N for crop.

2.3.7.8 Phosphorus (P)

2.3.7.8.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Sorghum is not a good indicator of P deficiency. Mild deficiencies

cause unthriftiness and delayed maturity but exert no recognizable symptoms. If a deficiency is

severe, plants are very stunted and have stout stems and dark green-purple foliage. Severely deficient

plants produce small heads that set few grains.

Dark yellow older leaves: Because P is readily transferred from old to young leaves, symptoms

develop first and are more severe on old leaves, working up the stems to younger leaves if the

deficiency persists. Old leaves remain dark green and develop dark yellow chlorosis at the tips.

The chlorosis is followed by dark brown necrosis and both symptoms advance down the leaves,

usually along the margins. Eventually, affected leaves die and turn brown to form thatches of dead

leaves around the bases of the stems. Young leaves remain dark green but may be shorter and more

erect than usual.

Purple leaves and stems: In some varieties, purple pigmentation develops on old leaves, leaf

sheaths, and lower stems. The colors are more intense on areas exposed to sunlight, developing on

the upper surfaces of the leaves and on parts of the stems that are not protected by the leaf sheaths.

These lesions do not increase in size as symptoms develop further.

2.3.7.8.2 Problem Soils

Phosphorus deficiency is likely to occur in: • Soils low in organic matter • Soils with a long history of cropping and exhausted P supplies • Highly weathered, Fe-rich acid soils whose phosphate is fixed in less available forms • Soils that have lost their topsoil through erosion • Akaline soils whose P may be insoluble and less available.

2.3.7.8.2 Correcting Deficiency

Phosphorus deficiency can be corrected by applying fertilizers to the soil at or before sowing.

Suitable fertilizers are single or triple superphosphates or ammonium phosphates. The growth of

crops depends on the amount of water-soluble phosphate available and the rate of exchange between

soluble and insoluble forms of P in the soil. Tests can estimate the available phosphate in a soil

and predict the amount of fertilizer needed. The best prediction can be obtained by seeking advice on fertilizer practices used on similar soils in the district.

Phosphorus deficiency in existing crops can be corrected by applying soluble salts, such as

ammonium phosphates, with irrigation water. Spray applications of similar salts are usually not

recommended because of the large number of applications needed to supply crop requirements.

2.3.7.9 Potassium (K)

2.3.7.9.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Sorghum is a good indicator of K deficiency. Affected crops lack

vigor, mature slowly, and yield poorly. Deficient plants are very stunted and have short, thick stems

and pale green to bronze-yellow foliage. As the deficiency increases, old leaves develop marginal

necrosis, often called firing. Affected plants develop small heads that set few grains.

Interveinal and marginal necrosis on older leaves: Because K is easily transferred from old to

young leaves, symptoms develop first and are more severe on old leaves, working up the stems to

younger leaves if the deficiency persists. In some varieties, mild deficiencies cause faint, pale yellow

interveinal chlorosis to develop over the entire lengths of middle leaves, followed rapidly by

intermittent, necrotic lesions concentrated near the leaf tips and margins. Severely deficient plants

develop marginal necrosis on old leaves. The pale brown necrosis develops near the leaf tips and

advances down the margins, leaving the main veins and surrounding tissues green. Eventually, entire leaves die and form thatches of dead leaves around the lower stems.

2.3.7.9.2 Problem Soils

Potassium deficiency is likely to occur in: • Soils low in organic matter after many years of cropping • Sandy soils formed from parent material low in K • Light textured soils whose K has been leached by heavy rainfall

2.3.7.9.3 Correcting Deficiency

Potassium deficiency is corrected by applying potassium nitrate, sulfate, or chloride to the soil

at or before sowing. Crop yield depends on the amount of water-soluble and exchangeable K in

the soil. Tests can measure the available K in the soil and predict the amount of fertilizer needed.

Potassium deficiency in existing crops can be corrected by applying soluble K salts, such as

sulfate, chloride, or nitrate, with irrigation water. The foliar application of similar salts is usually

not recommended because of the large number of applications needed to supply crop requirements.

2.3.7.10 Sulfur (S)

2.3.7.10.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Mild deficiencies of S in young crops cause poorer growth and lack

of color. Whole plants appear pale green. In more mature crops, the plants are short and have thin,

spindly stems, pale green old leaves, and yellow young leaves. Mildly deficient plants may not

suffer much yield loss, but the protein content of the grain may be lower than usual because S

deficiency prevents the conversion of N into many proteins. If a deficiency is severe, plants often

develop small heads that set few grains, and yields are greatly reduced.

Pale yellow younger leaves: Because S is not readily transferred from old to young leaves

when a deficiency occurs, symptoms develop first and are more severe on young leaves. Fre

quently, the youngest leaves are the most severely affected. Old leaves usually remain green and

appear healthy. Young leaves first turn pale green, then pale yellow. Entire leaves are affected

and veins are never prominent.

2.3.7.10.2 Problem Soils

Sulfur deficiency is likely to occur in: • Soils low in organic matter after many years of cropping • Soils formed from parent material low in S (for example, volcanic rocks and ash) • Acid sandy soils from which sulfates have been leached

2.3.7.10.3 Correcting Deficiency

The application of soil dressings of any S fertilizer will correct the deficiency. On alkaline soils,

elemental S (flowers of S) may be broadcast and thoroughly mixed into the soil about 4 months

before sowing. On neutral or acid soils, gypsum (calcium sulfate) is a useful source of S.

Soil tests can measure the amount of available sulfate in soil before sowing and predict the

amount of fertilizer required. The best prediction can be obtained by seeking advice on fertilizer

practices used on similar soils in the region.

Sulfur deficiency in existing crops can be corrected by applying soluble sulfate salts such as

magnesium, ammonium, or potassium sulfate in irrigation water. Foliar sprays of similar salts are

usually not recommended because of the large number of applications needed to supply crop

requirements.

2.3.7.11 Zinc (Zn)

2.3.7.11.1 Deficiency Symptoms

Patchy, low-yielding crops: Affected crops lack vigor, are unthrifty, yield poorly, and often appear

patchy. Affected plants are stunted and have very short stems and pale green foliage. On mature

plants, heads are smaller than usual and may be partly barren.

Pale yellow bands on younger leaves: Because Zn is not readily transferred from old to

young leaves, symptoms develop first and are more severe on young leaves. The most severe

symptoms appear on the youngest unrolling leaves (thus called white buds). Old leaves remain

dark green and appear healthy. Young leaves turn pale green and broad bands of pale yellow

Necrotic lesions on younger leaves: If a deficiency persists, the chlorotic areas die and turn

pale brown. Initially, the mid-veins remain green but eventually they are affected and die.

Interveinal chlorosis and necrosis on middle leaves: When a deficiency is prolonged, middle

leaves develop pale yellow interveinal chlorosis near their tips followed rapidly by pale brown

interveinal necrosis that becomes general as the necrotic lesions join in the tip halves of the leaves.

Fan-shaped stems: Zinc deficiency prevents the elongation of internodes and leaves. As a result,

stems are short, often flattened or oval in cross-section, with the leaves crowded at the top to produce a fan-shaped appearance.

2.3.7.11.2 Problem Soils

Zinc deficiency is likely to occur in: • Strongly alkaline soils whose availability of Zn is depressed • Leached sandy soils whose total Zn is low • Leveled soils whose Zn-deficient subsoils may be exposed on the surface • Soils in which heavy, frequent applications of phosphatic fertilizers may have reduced crop use of Zn

2.3.7.11.3 Correcting Deficiency

Foliar and soil applications of Zn salts have been used to correct deficiencies. Soil dressings of

zinc chelates, sulfates, or oxides should be broadcast and mixed into the soil 2 to 3 months before

sowing. While soil dressings of Zn have residual effects for 6 to 8 years before fresh applications

are needed, foliar sprays have no residual effects and fresh applications must be made to each crop.

Best results are obtained when a 0.5 to 1% solution of a soluble Zn salt (for example, 0.5 to 1 kg

zinc sulfate heptahydrate per 100 L water per ha) is applied 2 to 3 weeks after seedling emergence.

Additional sprays should be applied as soon as symptoms reappear.

Tests can estimate the amount of available Zn in a soil and predict whether fertilizer is needed.

The best prediction can be obtained by seeking advice on fertilizer practices used on similar soils

in the region.

2.3.7.12 Salinity 1

2.3.7.12.1 Deficiency Symptoms

Unthrifty, low-yielding crops: High levels of NaCl in soils or irrigation water cause unthrifty, low

yielding crops. Affected plants are stunted and have short, stout stems and dull grey-green foliage.

Plants often have a harsh, droughty appearance and leaves are shorter and more erect than usual.

The plants develop small heads that set few grains and produce low grain yields.

Grey necrosis on older leaves: Because NaCl is carried in the transpiration stream, symptoms

appear first and are more severe on older leaves. Symptoms work up the stems to young leaves if

the toxicity persists. Young leaves usually remain green but may be shorter and more erect than

usual. Old leaves turn dull green and appear wilted; their margins roll inward. As NaCl accumulates

to toxic concentrations, the leaf tips and margins die and turn grey-green then pale brown. The

dead tissue rolls into tubes.

2.3.7.12.2 Problem Soils

Sodium chloride toxicity is more likely to occur in: concentrations of NaCl

2.3.7.12.3 Correcting Toxicity

Leaching with good quality irrigation water is the most effective means of removing excess Na

and Cl from the soil. The water table may have to be lowered. Permeable soils such as well structured

sandy soils are often easily reclaimed, but the problem is more difficult in less permeable soils (for

example, poorly structured heavy clays).

If exchangeable Na in the soil is high, reclamation involves replacing Na with Ca by applying

gypsum (calcium sulfate) and then leaching the dissolved Na and Cl beyond the rooting depths of

the plants. If irrigation water is to be used to leach the

Na, the water quality should be checked

before use to make sure it is not saline. If excess NaCl cannot be wholly corrected by soil leaching,

a more tolerant species may have to be grown.

2.3.8 WEIGHTS AND MEASURES

The net weight of 1 bu sorghum grain is approximately 56 lb or 25.4 kg.

1. Grundon, N.J., Hungry Crops: A Guide to Nutrient Deficiencies in Field Crops, 1987, Queensland Department of Primary Industries, Brisbane, Australia. TABLE 2.61 Weight and Standard Yield of Level Full Bushel of Sorghum Weight of 1 bu (lb) Multiplication Factor to Yield Standard bu 60 1.07 58 1.04 56 1.00 54 0.96 52 0.93 50 0.89 48 0.86 46 0.82 44 0.79 42 0.75 40 0.71 TABLE 2.62 Sorghum Seeds/Pound, Weight/Bushel, and Germination Time Seeds/lb (1,000) Seeds/g (no.) Weight/bu (lb) Germination Time (days) 15 33 56 10

2.4 OATS (Avena sativa L.)

2.4.1 I NTRODUCTION

The oat belongs to the grass family (Poaceae or Gramineae). The oat is known as avoine in French,

avena in Spanish and Italian, and hafer in German. Oats were some of the earliest cereals cultivated

by man. They were known in ancient China as early as 7000 B.C. The oat belongs to the same

plant family as barley, corn, rice, and wheat. It has higher food values (rich in starch and high

quality protein and a good source of vitamin B) than any other cereal grain. The grain is primarily

used as livestock feed (90% in the U.S.) and processed for making oatmeal, oatcakes, cookies, and

ready-to-eat breakfast foods. Oat straw is commonly used as animal bedding.

The chief kinds of oats are common (most commonly grown in the U.S.), red, side, and hull less. Oats grow especially well in cool, moist climates, and on fertile soil. They may be autumn sown (winter oats in areas with mild winters) or spring-sown.

Yields are dependent on rainfall and range from 1.5 tons per ha with 350 mm rainfall to a high of 6.5 tons per ha with 750 mm rainfall. At a yield of 5.0 tons per ha, ear density is 350 per m^2, with a single ear weight of 1.43 g. Average oat yield in the U.S. in 2000 was 64.2 bu per acre; the highest was 98.0 and the lowest was 42.0 bu per acre. The fertilizer elements required to produce a 3.5-ton per ha grain yield are 70 kg N per ha, 35 kg P_2O_5 per ha, and 105 kg K_2O per ha.

2.4.2 PRODUCTION STATISTICS

TABLE 2.63 Harvested Area, Yield, and Production of Oats by Continents and Specified Countries, 1999–2000

Continent/Country	Harvested Area (1,000 ha)	Yield (metric tons/ha)	Production (1,000 metric tons)
Continent			
North America	2,491	2.35	5,863
South America	720	1.47	1,058
Europe	1,934	3.16	6,115
Eastern Europe	1,149	2.21	2,541
USSR	5,634	1.10	6,195
Africa	840	0.17	148
Asia	501	1.20	602
Oceania	598	1.95	1,167
World Total	14,116	1.73	24,383
Country			
Russia	4,500	0.98	4,400
Canada	1,398	2.60	3,641
U.S.	993	2.14	2,122
South Africa	700	0.06	45
Australia	578	1.89	1,092
Poland	572	2.53	1,446
Ukraine	530	1.43	760
China	500	1.20	600

Source: Foreign Agriculture Service, Washington, D.C.

TABLE 2.64 U.S. Oat Acreage, Yield, and Production, 1991–2000

Year	Area Harvested (1,000 acres)	Yield (bu/acre)	Production (1,000 bu)
1991	4,816	50.6	243,851
1992	4.496	65.4	294,229
1993	3,803	54.4	206,731
1994	4.008	57.1	228,844
1995	2,952	54.6	161,094
1996	2,655	57.7	153,245
1997	2,813	59.5	167,246
1998	2,755	60.2	165,981
1999	2,453	59.6	146,193
2000 a	2,324	64.2	149,195

a Preliminary.

Source: Crops Branch, National Agriculture Statistics Service, Washington, D.C., 2001.

TABLE 2.65 Leading Oat-Producing States, 2000

State	Area Harvested (1,000 acres)	Yield (bu/acre)	Production (1,000 bu)
North Dakota	315	63.0	19,845
Minnesota	310	59.0	22,320
Wisconsin	280	62.0	19,040
South Dakota	220	64.0	13,420
Iowa	180	65.0	12,060
Pennsylvania	145	55.0	8,265
Texas	100	44.0	4,300
U.S. Total	2,324	64.2	149,195

Source: Crops Branch, National

Agriculture Statistics Service, Washington, D.C., 2001. TABLE 2.66 U.S. Total and Per Capita Civilian Consumption of Oat and Oat Products as Food, 1990–1999 Calendar Year a Total Consumed (million bu) b Per Capita Consumption of Food products (lb) 1990 75.3 6.5 1991 76.6 6.5 1992 77.4 6.5 1993 73.0 6.1 1994 70.0 5.8 1995 67.0 5.5 1996 63.0 5.1 1997 59.0 4.7 1998 59.0 4.5 1999 c 58.8 4.5 a Data shown for marketing year, June 1 to May 3. b Oats used in oatmeal, prepared breakfast foods, infant foods, and other food products. c Preliminary. Source: Economics Research Service, Washington, D.C., 2001. All figures are estimates based on data from private industry sources, the U.S. Department of Commerce, the Internal Revenue Service, and other government agencies. TABLE 2.67 Leading Oat-Producing States and Provinces State or Province 1,000 Short Tons Alberta 1,734 Saskatchewan 794 Iowa 639 Minnesota 638 South Dakota 625 Wisconsin 609 Manitoba 357 Quebec 328 Ontario 310 North Dakota 309

2.4.3 NUTRIENT ELEMENT CHARACTERISTICS TABLE 2.68 Relative Nutrient Element Uptake (% of Maximum) of Oats in Relation to Plant Development Growth Stage Dry Matter Nitrogen Phosphorus as Phosphate Potassium as Potash Early growth 0 0 0 0 Tillering 1 16 10 11 Jointing 1 31 14 19 Booting 3 34 20 31 Ear emergence 5 68 60 88 Flowering 7 85 74 100 Grain formation 10 97 100 98 Physiological Maturity Biomass (dry) 90 100 100 94 Grain 5 74 64 18 Source: IFA World Fertilizer Use Manual, 2000, International Fertilizer Industry Association, Paris. TABLE 2.69 Nutrient Element Utilization (lb/acre) by 100-bu/acre Oat Crop Nutrient Element Nitrogen Phosphorus as Phosphate Potassium as Potash Magnesium Sulfur 115 40 145 20 19 TABLE 2.70 Nutrient Element Sufficiency Ranges for Oats Major Elements % Micronutrients ppm Nitrogen 2.00–3.00 Copper 5–25 Phosphorus 0.20–0.50 Iron 40–150 Potassium 1.50–3.00 Manganese 25–100 Calcium 0.20–0.50 Molybdenum 0.20–0.30 Magnesium 0.15–0.50 Zinc 15–70 Sulfur 0.15–0.40 Note: Sampling procedure: 25 whole tops as head emerges from boot. Source: Plant Analysis Handbook II: A Practical Sampling, Preparation, Analysis, and Interpretation Guide, 1996, MicroMacro Publishing, Athens, GA.

2.4.4 NUTRIENT ELEMENT DEFICIENCIES

2.4.4.1 Boron (B)

2.4.4.1.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Boron-deficient plants are stunted and have dull yellow-green foliage.

Although tiller production is usually not affected, many tiers die before maturity if a deficiency

persists. Whole plants may die before producing heads if a deficiency is very severe. As a result,

both forage and grain yields are reduced.

Chlorotic tips on younger leaves: Boron is immobile in plants and symptoms develop first and

are more severe on young leaves. Old leaves remain dark green. They appear healthy, but may turn

a dull orange-green when a deficiency is severe. Marginal, dull yellow chlorosis develops at the

tips of young leaves. The remainders of the leaves turn dull green-yellow. As the symptoms develop,

leaf tips turn dull orange-green and pale brown necrotic lesions appear between the mid-veins and

margins in the upper halves of the leaves. The chlorotic leaf tips die and turn pale orange-brown.

Fan-shaped stems: Because B plays a major role in the elongation of stems and leaves, stems

of deficient plants are very short and stout. The leaves are often crowded at the tops of the stems,

forcing the leaf sheaths apart so the stems appear fan-shaped.

2.4.4.1.2 Problem Soils

Boron deficiency is likely to occur in: • Soils derived from parent material low in B, such as acid igneous rocks or freshwater sediments • Sandy soils from which B has been leached • Calcareous soils, especially those containing free lime • Soils low in organic matter • Acid peat and muck soils

2.4.4.1.3 Correcting Deficiency

Boron deficiency can be corrected by applying soil dressings or foliar sprays of B fertilizers. Soil dressings are more effective if broadcast and mixed into the soil some months before sowing.

Borax, boric acid, and chelated B compounds are suitable for soil application, but only boric acid

and chelated B are suitable for foliar sprays because of the low solubility of borax. Sprays should

be applied within the first 5 weeks of seedling emergence or as soon as foliar symptoms appear.

While foliar sprays are often beneficial, they have little residual value. Soil dressings can remain

effective for many years.

Soil tests can estimate the amount of available B and predict whether fertilizer is needed. The

best prediction can be obtained by seeking advice on fertilizer practices used on similar soils in

the district.

2.4.4.2 Calcium (Ca)

2.4.4.2.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Calcium-deficient oat plants are very stunted and have short, dark

green foliage. Tillering is not affected if the deficiency is mild. If it persists, many tillers die before

producing heads. Forage and grain production are much reduced and, in some instances, whole

plants die when the deficiency is severe.

Weather-tipped younger leaves: The symptoms begin and are more severe on young leaves

because Ca is not readily transferred from old to young leaves when a deficiency occurs. Old leaves

usually remain dark green and appear healthy. Young leaves cease growth and become erect, short,

and pale green. The leaf tips wilt and hang down, often with the margins rolled inward into tubes.

Ragged leaf margins on younger leaves: When a deficiency is very severe, the youngest leaves

become brittle and are easily torn as they emerge. Hence, the margins of young leaves often appear

ragged.

Death of shoots: As the deficiency persists, growing points of shoots die. The youngest leaves

may die before emerging fully from the sheaths of previous leaves.

2.4.4.2.2 Problem Soils

Calcium deficiency is likely to occur in: • Acid sandy soils from which Ca has been removed by heavy rainfall • Strongly acid peat and muck soils whose total Ca is low • Alkaline or sodic soils in which high exchangeable Na and pH inhibit Ca uptake • Soils with high levels of soluble Al and low levels of exchangeable Ca

2.4.4.2.2 Correcting Deficiency

Calcium deficiency can be corrected by broadcasting a suitable fertilizer onto the soil some months

before sowing. Subsequent tillage operations will thoroughly mix the fertilizer and soil. Where the

chief problem is a lack of Ca, suitable fertilizers are gypsum (calcium sulfate) and calcium nitrate

or chloride. However, if the soil pH is low, lime or limestone (calcium carbonate) and dolomite (a

mixture of calcium and magnesium carbonates) are more suitable.

A soil test can be used to determine lime or Ca requirements. However, since the correct rate

of application depends on the soil type and the crop to be grown, advice should be sought on

fertilizer practices used on similar soils in the district. The excessive use of lime may induce deficiencies of K, Mg, Fe, Mn, Zn, and Cu, and care should be taken to prevent over-liming.

2.4.4.3 Copper (Cu)

2.4.4.3.1 Deficiency Symptoms

Patchy, low-yielding crops: Even in mild deficiencies, affected crops often have a patchy appearance.

Within Cu-poor areas, plants are stunted and pale green and appear limp or wilted. If the deficiency

is severe, young leaves may be dead while old leaves remain green. If the deficiency is mild, tiller

production is usually unaffected and additional late tillers may develop at nodes or joints above ground

level. However, severe deficiency causes many tillers to die before maturing. Because Cu deficiency

leads to production of sterile pollen, heads on apparently healthy plants may set few grains and yields

are reduced. When easily recognizable symptoms are present, little or no grain may be set.

Weather-tipped younger leaves: Because Cu is immobile in plants, the symptoms develop first

and are more severe on young leaves. Old leaves remain green and apparently healthy. The

symptoms begin when young leaves turn pale green and appear to wilt even when ample water is

available. If the deficiency persists, the tips of young leaves develop pale yellow chlorosis, then

die and turn dark brown (weather-tipped). The dead tissue usually rolls or twists tightly into tubes

or spirals.

2.4.4.3.2 Problem Soils

Copper deficiency is likely to occur in: • Peat and muck soils in which organic matter ties up Cu in forms unavailable to plants • Calcareous sands whose total Cu is low • Leached acid soils whose total Cu is low • Soils formed from rocks low in Cu

corrected deficiencies. Soil dressings should be broadcast and mixed into the soil some months

before planting. However, such dressings sometimes fail to correct the deficiencies or symptoms

reappear. If this occurs, foliar sprays should be applied immediately.

A reliable remedy is to apply two or three foliar sprays (for example, 0.5 to 1 kg copper sulfate

per 100 L water per ha). The first spray should be applied 5 to 6 weeks after seedlings emerge and

the second when the first or oldest heads reach the boot stage. An optional third spray may be

applied 7 to 10 days after the second spray.

Tests can estimate the amount of available Cu in the soil and predict whether fertilizer is needed.

The best prediction can be obtained by seeking advice on fertilizer practices used on similar soils

in the district.

2.4.4.4 Iron (Fe)

2.4.4.4.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Iron deficiency causes stunted growth and pale green to yellow

foliage. If the deficiency is mild, tillering may be relatively unaffected. In severely deficient plants

it is very reduced, and forage and grain yields are greatly reduced.

Interveinal yellow chlorosis on younger leaves: Iron is not easily transferred from old to young

leaves when a deficiency occurs. Hence, symptoms begin and are more severe on young leaves, often on leaves that have not fully unrolled. Old leaves usually remain dark green and appear

healthy. The symptoms begin when young leaves turn pale green. As the deficiency becomes more

severe, the interveinal areas of affected leaves become bright yellow while the veins remain green

and stand out prominently. If the deficiency persists, the interveinal areas may turn white and the

veins become pale green to yellow.

2.4.4.4.2 Problem Soils

Iron deficiency is likely to occur in: • Calcareous soils whose levels of soluble Fe are low • Waterlogged soils • Acid soils excessively high in soluble Mn, Zn, Cu, and Ni that inhibit Fe uptake • Sandy soils low in total Fe • Peat and muck soils in which organic matter ties up Fe

2.4.4.4.3 Correcting Deficiency

While soil dressings of inorganic iron salts such as iron sulfates or chlorides correct deficiencies

in some soils, it appears that applied Fe quickly becomes insoluble and less available. Iron salts

of various organic chelates appear more promising because the chelate form keeps the Fe in solution.

For acid soils, FeEDTA is the most effective chelate, while FeHEDTA and FeDTPA are best on

neutral soils and FeEPDHA is best for calcareous soils. However, large amounts of chelates may

be required and may prove too costly.

An equally effective remedy is applying solutions of inorganic salts or chelates to the foliage

(1% solution or 1 kg salt per 100 L water per ha). Because Fe is so immobile in plants, the sprays

may need to be applied every 10 to 15 days to provide Fe to new leaves. Advice on local fertilizer practices should be sought.

2.4.4.5.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Magnesium deficiency causes stunted plants with pale green foliage

that often turns orange-purple. Tillering can be greatly reduced when the deficiency appears in

young plants. If the deficiency persists or becomes severe, young tillers die before producing heads

and mature tillers develop small heads. Yields of forage and grain are reduced.

Interveinal chlorosis on older leaves: Because Mg is easily transferred from old to young leaves

when a deficiency occurs, symptoms begin and are more severe on old leaves, working up the plant

to young leaves if it persists. The youngest leaves usually remain green to pale green and appear

healthy. On very young plants, old leaves turn pale green and develop yellow chlorosis near the

margins around the middles of the leaves. On more mature plants, linear yellow or white lesions

develop in interveinal tissue in the mid-sections. The chlorosis and lesions advance toward the tips

and bases of the leaves, developing into yellow or yellow-red, interveinal chlorosis. If the deficiency

is severe, affected leaves develop generalized orange-red chlorosis, die, and turn pale brown.

2.4.4.5.2 Problem Soils

Magnesium deficiency is likely to occur in: • Acid sandy soils from which Mg has been removed by leaching • Strongly acid peat and muck soils whose total Mg is low • Soils that have been over-fertilized with Ca (for example, lime) or K, thus inhibiting Mg uptake

2.4.4.5.3 Correcting Deficiency

Magnesium deficiency on acid soils is corrected by broadcasting dolomite (a mixture of calcium

and magnesium carbonates) onto the surface some months before sowing and mixing it thoroughly

throughout the topsoil. When the problem is strictly Mg deficiency, band applications of magnesium

sulfate or chloride can be made at or before planting. A test can estimate the amount of soluble

and exchangeable Mg in the soil and predict the amount of fertilizer required. The best prediction

can be obtained by seeking advice on fertilizer practices used on similar soils in the district.

Magnesium deficiency in existing crops can be corrected by applying soluble salts such as

magnesium sulfate, chloride, or nitrate with irrigation water. Foliar sprays of similar salts are usually

not recommended because of the large number of applications needed to meet crop requirements.

2.4.4.6 Manganese (Mn)

2.4.4.6.1 Deficiency Symptoms

Patchy, low-yielding crops: Magnesium deficiency may cause areas of poor growth and give a

crop a patchy appearance. Within Mn-poor areas, plants are stunted and have short, stout stems

and pale green to brown foliage. If the deficiency becomes severe or persists, plants in these

areas may die. Deficient plants produce few tillers and many die. As a result, both forage and

grain yields are reduced.

Grey flecks in older leaves: Because Mn is partly mobile in oats, the symptoms first appear

and become more severe on mature leaves about halfway up the shoots. If the deficiency persists,

symptoms spread rapidly to older leaves, then up the shoots to younger leaves until whole plants

are affected. Small, linear, grey flecks appear in interveinal tissues in the basal halves of old leaves,

extending toward the tips as symptoms develop. The flecks join to form large grey lesions in the

basal halves of the leaves between the margins and mid-veins, eventually affecting the veins and

causing the leaves to collapse. The necrotic areas finally turn pale brown. • Calcareous soils in which Mn is less available to plants • Poorly drained peaty soils • Strongly acid sandy soils whose soluble Mn has been leached by heavy rain • Soils formed from rocks low in Mn

2.4.4.6.3 Correcting Deficiency

Foliar sprays and soil dressings of Mn salts and oxides have been used to correct deficiencies. Soil

dressings are more effective when broadcast and mixed into the soil some months before sowing.

However, foliar sprays have generally been more successful. One or more foliar sprays of 0.5 to

1% solutions of manganese sulfate (0.5 to 1 kg manganese sulfate per 100 L water per ha) usually

correct the deficiency, the first spray to be applied 5 to 6 weeks after seedling emergence. If

symptoms reappear, the spray should be repeated immediately.

Tests can estimate the amount of available Mn in a soil and predict whether fertilizer is needed.

The best prediction can be obtained by seeking advice on fertilizer practices used on similar soils

in the district.

2.4.4.7 Nitrogen (N)

2.4.4.7.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Nitrogen-deficient oats lack vigor and yield poorly. In young crops,

stems are short and thin and the foliage is pale green. Mature plants are stunted and appear

multicolored. Upper leaves are pale green, short, and erect. Middle leaves are usually yellow to

pale green with red tips. The oldest leaves may be dead and brown and lie in the soil around the

bases of the plants. Even mild deficiency reduces the number of tillers produced. When a

deficiency persists, many young tillers die before producing heads. As a result, forage and grain

yields are reduced. Furthermore, the protein concentration is low because of the central role N

plays in protein formation.

Pale yellow older leaves: When a deficiency occurs, N is transferred from old to young leaves.

Symptoms appear first on old leaves and work up the plant to younger leaves if the deficiency

persists. Old leaves turn pale green. Pale yellow chlorosis develops at the tips and advances toward

the bases until entire leaves are pale yellow.

Red leaf tips: When a deficiency persists or becomes severe, the tips of the leaves become

orange-red. As the tissue dies, it turns dark brown and the leaf margins often roll upward to form

tubes.

Red stems: Stems are thin and spindly. Leaf sheaths are usually pale green but red striping

often develops in cold weather.

2.4.4.7.2 Problem Soils

Nitrogen deficiency is likely to occur in: • Sandy soils leached by heavy rainfall or excessive irrigation • Soils low in organic matter • Soils with a long history of cropping where N stores have been used up

Even fertile soils may suffer temporary N deficiencies when double-cropped, heavily leached,

or waterlogged.

allow organic N to be converted to mineral N; by growing cover or cash crops of legumes, which

can fix atmospheric N_2; or by adding nitrogenous fertilizers such as urea, gaseous ammonia, or

ammonium sulfate, nitrate or phosphates. Crop growth depends on the amount of N already in the

soil.

A soil test can measure the amount of total N or nitrate-N in soil and predict the amount of

fertilizer required. The best prediction is obtained by seeking advice on fertilizer practices used on

similar soils in the district. Nitrogen deficiency in existing crops can be corrected by applying

soluble salts such as urea as solids or with irrigation water.

2.4.4.8 Phosphorus (P)

2.4.4.8.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Phosphorus-deficient crops are unthrifty and yield poorly. Affected

plants are stunted and have erect, short, dark green leaves with bright red-purple tips. In severe

deficiencies, the oldest leaves may be brown and dead and lie on the soil around the bases of the

plants. Tiller production is reduced and the youngest tillers usually die before maturity. As a result,

yields of both foliage and grain are severely depressed.

Dark yellow-orange chlorosis on older leaves: Phosphorus deficiency symptoms are more

severe on old leaves, working up the plants to younger leaves if the deficiency persists because P

is transferred from old to young leaves when a deficiency occurs. Dark orange-yellow chlorosis

begins at the tips of affected leaves and advances toward the bases, usually along the leaf margins.

Red or purple tips on older leaves: If the deficiency persists or becomes severe, chlorotic tissue

dies and turns red or purple. Affected leaves often have green bases, orange-yellow mid-sections,

and bright red or purple tips. The margins of the leaf tips often roll inward to form tubes. Eventually,

entire leaves die and turn dark brown.

Purple stems: The leaf sheaths and stems of affected plants often turn purple, especially if the

season is cold.

2.4.4.8.2 Problem Soils

Phosphorus deficiency is likely to occur in: • Soils low in organic matter • Soils in which cropping has exhausted the stores of P • Highly weathered, Fe-rich acid soils in which phosphate is fixed in unavailable forms • Soils whose topsoil has been lost through erosion • Calcareous soils in which much of the P is tied up in insoluble phosphates that are less available to plants

2.4.4.8.3 Correcting Deficiency

Phosphorus deficiency can be corrected by applying phosphatic fertilizers to the soil at or before

sowing. Suitable fertilizers are single or triple superphosphates or ammonium phosphates. The

growth of crops depends on the amount of available water-soluble phosphate and the rate of exchange between insoluble and soluble forms of P in the soil. Tests can estimate the amount of

available P in the soil and predict the amount of fertilizer required. The best prediction can be

obtained by seeking advice on fertilizer practices in the district.

Phosphorus deficiency in existing crops can be corrected by applying soluble salts such as

ammonium phosphates with irrigation water. Spray applications of similar salts are usually not

recommended because of the large number needed to satisfy crop requirements.

2.4.4.9.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Potassium-deficient oat plants are stunted and exhibit sprawling

growth. Foliage is green with brownish-yellow lesions. Stems are short and stout and leaf sheaths

often develop brownish lesions similar to those on the leaf laminae. As affected leaves die, plants

develop a three-tone appearance. Younger leaves are green, middle leaves are green with yellow to

bronze areas, and older leaves are brown and dead. Tiller production may be unaffected but when

a deficiency persists, many tiers die before maturity. Because of the severe stunting and deaths of

tillers, K deficiency greatly reduces forage and grain yields.

Bronze-yellow older leaves: Because K is readily transferred from old to young leaves when

a deficiency occurs, symptoms appear first and are more severe on old leaves, working up the plant

to younger leaves if it persists. Affected leaves turn pale green and develop bronze-yellow chlorosis in their mid-sections between the margins and mid-veins. The chlorosis rapidly extends toward the

tips until two thirds of the leaves turn bronze-yellow. In some varieties, the chlorosis may be orange

red.

Necrotic lesions on older leaves: Grey-brown necrotic lesions develop in the chlorotic tissues

of old leaves, usually beginning in the mid-sections between the mid-veins and margins. Eventually

the lesions join and affect the mid-veins, causing the leaves to bend downward. Similar lesions

develop on the sheaths of old leaves. Affected leaves die, turn brown, and form thatches of dead

leaves at the plant bases.

2.4.4.9.2 Problem Soils

Potassium deficiency is likely to occur in: • Soils whose organic matter was depleted by many years of cropping, and particularly where hay was cut • Sandy soils formed from parent material low in K • Light textured soils whose K has been leached by rainfall

2.4.4.9.3 Correcting Deficiency

Potassium deficiency is corrected by applying potassium nitrate, sulfate, or chloride to the soil at

or before sowing. Yield depends on the amount of water-soluble and exchangeable K in the soil.

Tests can estimate the amount of available K in the soil and predict the amount of fertilizer

required. The best prediction can be obtained by seeking advice on fertilizer practices used on

similar soils in the district. Potassium deficiency in existing crops can be corrected by applying

soluble salts such as potassium sulfate, chloride, or nitrate with irrigation water. The foliar appli cation of similar salts is usually not recommended because of the large number of sprays required.

2.4.4.10 Sulfur (S)

2.4.4.10.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Sulfur deficiency leads to stunted plants with yellow to pale green

foliage. In young crops, the whole plant is often pale green. In more mature crops, young leaves

are pale green to yellow, giving the field a distinct yellow appearance. Tiller production is severely

reduced and heads are smaller than normal. As a result, both forage and grain yields are depressed.

Forage and grain from affected plants are usually low in protein because S deficiency depresses

the conversion of N into protein.

Yellow or white younger leaves: Because S is not readily transferred from old to young leaves

when a deficiency occurs, the first and more severe symptoms occur on younger leaves. Symptoms

begin with the youngest leaves turning pale green, then pale yellow. The chlorosis is not confined

green if the deficiency persists or becomes severe. When a deficiency is very severe, old leaves

may develop orange-red margins.

Purple streaked stems: Stems are short and thin. Leaf sheaths are usually pale green, but purple

streaks often develop when a deficiency is very severe.

2.4.4.10.2 Problem Soils

Sulfur deficiency is likely to occur in: • Soils whose organic matter has been depleted by many years of cropping • Soils formed from parent material low in S (for example, some volcanic rocks and ash) • Acid sandy soils whose sulfates have been leached

2.4.4.10.3 Correcting Deficiency

Soil dressings of any S fertilizer will correct deficiencies. Elemental S (flowers of sulfur) may be

broadcast onto the soil and thoroughly mixed in, about 4 months before sowing. Gypsum (calcium

sulfate) is another useful source of S.

Tests can estimate the amount of available sulfate in a soil before sowing and predict the amount

of fertilizer required. The best prediction can be obtained by seeking advice on fertilizer practices

used on similar soils in the district.

Sulfur deficiency in existing crops can be corrected by applying soluble sulfate salts such as

magnesium, ammonium, or potassium sulfate in irrigation water. Foliar sprays of similar salts are

usually not recommended because of the large number of applications needed.

2.4.4.11 Zinc (Zn)

2.4.4.11.1 Deficiency Symptoms

Patchy, low-yielding crops: Zinc deficiency often causes patchy growth. In Zn-poor areas, plants

are stunted and have pale green foliage and yellow or orange-red leaf tips. Tiller production may

not be affected, but if a deficiency is severe or persists, many tillers die before producing heads.

As a result, forage and grain yields can be reduced greatly.

Yellow, orange, purple, or black tips on older leaves: Zinc is only partly mobile in oats and symptoms

appear first and are more severe on middle and old leaves, working up the plant to younger leaves if

deficiency persists. The youngest leaves usually remain green and appear healthy. Initially, middle and

older leaves turn pale green and develop pale yellow chlorosis between the margins and mid-veins at

the tips. As the deficiency progresses, the chlorosis becomes more extensive and general, turning dark

yellow, orange-red, or purple. Brown necrotic lesions appear in the chlorotic tissues and increase in size

until the leaf tips die, often turning red-brown to black. Frequently, the basal portions of leaves remain

green while the mid-sections are chlorotic and the leaf tips turn dark brown or black.

Crowded leaves: When a deficiency is very severe, stems are short and the youngest leaves

sometimes have difficulty emerging fully from the sheaths of older leaves. This leads to the crowding

of leaves on top of the short stems.

2.4.4.11.2 Problem Soils

Zinc deficiency is likely to occur in: • Calcareous soils in which the availability of Zn is depressed • Leached sandy soils whose total Zn is low • Leveled soils in which Zn-deficient subsoils may be exposed on the surface • Soils in which heavy, frequent applications of phosphate fertilizers may have reduced Zn uptake

chelates, sulfates, or oxides should be broadcast and mixed into the soil 2 to 3 months before sowing.

While soil applications have residual effects lasting 6 to 8 years, foliar sprays have no residual effects

and fresh applications must be made to each crop. Best results are obtained when two sprays of a 0.5

to 1% solution of zinc sulfate heptahydrate (0.5 to 1 kg zinc salt per 100 L water per ha) are applied

about 2 weeks apart, the first sprayed 2 to 3 weeks after seedling emergence.

Tests can estimate the amount of available Zn in the soil and predict whether fertilizer is needed.

The best prediction can be obtained by seeking advice on fertilizer practices used on similar soils

in the district.

2.4.4.12 Manganese Toxicity 1

2.4.4.12.1 Toxicity Symptoms

Unthrifty, low-yielding crops: Manganese toxicity causes stunted plants to produce stout stems

and dull green foliage. If the toxicity becomes severe or persists, the leaves develop bronze

orange areas. Tiller production is usually not affected initially, but some may die if the toxicity

persists. Mature tillers often produce small heads. As a result, forage and grain yields can be

greatly reduced.

Dull-colored leaves: Excess Mn accumulates in old leaves. Hence symptoms appear first and

are more severe on old leaves, working up the plant to younger leaves if the toxicity persists. All

leaves present a dull appearance, ranging from dull green in young leaves to dull bronze-green in

old leaves. If the toxicity persists, entire plants appear dull bronze-green.

Chlorosis on older leaves: Bronze-orange chlorosis develops on old leaves between the margins

and the mid-veins near the points of attachment of the laminae and leaf sheaths. The chlorosis

advances up the leaves between the margins and mid-veins, eventually affecting whole leaves. As

the concentration of Mn becomes toxic, affected tissues die and turn brown.

Broken leaves: When the toxicity is severe, the mid-veins die near the points of attachment of

the laminae and leaf sheaths, thus weakening the leaves and allowing the laminae to bend down

and lie on the soil.

2.4.4.12.2 Problem Soils

Manganese toxicity is likely to occur in: • Strongly acid soils that have increased solubility of Mn • Waterlogged soils in which poor aeration causes unavailable manganic (Mn^{3+}) ions to reduce to manganous (Mn^{2+}) ions that can be taken up by plants

2.4.4.12.3 Correcting Toxicity

Manganese toxicity is usually corrected by adopting management practices that reduce the level

of soluble Mn in the soil. Liming of strongly acid soils and drainage of waterlogged soils are

effective measures. If soils have been over-fertilized with Mn, heavy leaching with low Mn irrigation

water or mulching with organic materials removes soluble Mn from the root zones of plants. Acid

reacting fertilizers should not be used on acid soils high in Mn. Care should be taken also when

applying Mn fertilizers to prevent over-fertilization.

2.4.4.13 Salinity 1

2.4.4.13.1 Salinity Symptoms

Unthrifty, low-yielding crops: When sodium chloride (NaCl) levels in soils or irrigation water

become excessive, oat plants become stunted and develop harsh, droughty appearance. The foliage

Wilted appearance: High levels of NaCl in soil make it difficult for plants to take up water.

Hence, they develop a harsh, droughty appearance even when ample water is available. They often wilt on hot days and recover overnight.

Dull-colored leaves: Sodium chloride is carried in the transpiration stream to the margins

and tips of leaves. Because older leaves had more time to accumulate NaCl, their symptoms

are more severe. The foliage has a dull appearance, ranging from dull green in young leaves

to dull, bluish yellow-green in old leaves. If the toxicity persists, the whole plant develops a

bluish-green color.

Yellow tips on older leaves: As NaCl accumulates in the leaf tips, it eventually reaches con

centrations that kill tissues. Dull yellow chlorosis develops on the tips of old leaves, followed by

yellow-grey necrosis when the tissues die. The chlorosis and necrosis advance down the margins

until entire leaves are dead.

2.4.4.13.2 Problem Soils

Sodium chloride toxicity is more likely to occur in: • Saline soils formed from salt water sediments • Previously fertile soils flooded or heavily irrigated with water containing high concentrations of NaCl

2.4.4.13.3 Correcting Toxicity

Leaching with good quality irrigation water is the most effective means of removing excess Na or

Cl from the soil. The water table may have to be lowered. Permeable soils such as well structured

sandy soils are often easily reclaimed, but the problem is more difficult in less permeable soils (for

example, poorly structured heavy clays).

If exchangeable Na in the soil is high, reclamation involves replacement of the adsorbed Na with Ca by applying gypsum (calcium sulfate) and then leaching the dissolved Na and Cl beyond

the rooting depths of the plants. If irrigation water is to be used to leach the Na, its quality should

be checked before use to make sure it is not saline. Where excess NaCl cannot be wholly corrected

by soil leaching, a more tolerant species may have to be grown.

2.4.5 WEIGHTS AND MEASURES

The net weight of 1 bu of oat grain is approximately 32 lb or 14.5 kg.

1. Grundon, N.J., Hungry Crops: A Guide to Nutrient Deficiencies in Field Crops, 1987, Queensland Department of Primary Industries, Brisbane, Australia. TABLE 2.71 Crop Seeds/Pound, Weight/Bushel, and Germination Time Seeds/lb (1,000) Seeds/g (number) Weight/bu Germination Time (days) 14 30 32 10

2.5 RICE (Oryza sativa L.)

2.5.1 I NTRODUCTION

Rice belongs to the Gramineae grass family. It is known as riz in France, arroz in Spain, riso in

Italy, and reirs in Germany. It is a vital food crop because half the world’s population eats rice

as a main part of their diets. Rice ranks second only to wheat in terms of area harvested. It

provides more calories per hectare than any other cereal grain. Most people who depend heavily

on rice live in Asia. Asian farmers grow about 90% of the world’s rice. It grows during the wet

season that starts in June or July. Rice grows best in warm temperatures with plentiful moisture

from rainfall or irrigation, and is most frequently grown in valley and river deltas. It grows in

more than 100 countries. Crops cover about 360 million acres and production is about 580 million

short tons.

The three Asian rice groups are Indica, grown in India and other tropical regions; Japonica,

cultivated in cooler Asian regions (China, Japan, and Korea), Europe, North America, and Australia;

and Javanica, grown in Indonesia. Rice is also classified by the method of culture. Lowland rice

is grown in flat fields that are flooded by irrigation and in enclosed fields called paddies. Upland

rice depends on rainfall for moisture and accounts for only 6% of all rice grown. Highest grain

yields for irrigated rice range from 7 to 10 tons per ha in dry seasons when well irrigated and 5

to 8 tons per ha in wet seasons. Rain-fed rice yields an average of 1 ton per ha. Each ripened rice

panicle contains 80 to 120 grains.

Evidence indicates that rice was cultivated about 5,000 B.C. in southern China and northern

Thailand, Laos, and Vietnam. Cultivation later spread to northern China, Japan, and Korea, west

to India, and south to Indonesia. Rice reached the American Colonies during the 1600s, and was

grown commercially in South Carolina as early as 1685. Rice production moved west. By 1900,

about 70% of the rice grown in the U.S. was from Louisiana. It became an established crop in

California around the same time.

In the 1960s, the worldwide Green Revolution brought, through plant breeding and production

trials, higher yielding varieties that had shorter, sturdier stems and responded to fertilization. The

International Rice Institute, established in 1960 and located in the Philippines, is devoted to

improving cultivation. It conducts research and provides extension services in an effort to increase

food production throughout the developing world.

2.5.2 CLASSIFICATION AND TERMINOLOGY

2.5.2.1 Classes

Classes are based mainly on type of rice. All class designations are explained in the Definitions

section. The four main classes of rice are:

1. Long-grain rice

2. Medium-grain rice

3. Short-grain rice

4. Mixed rice

The following additional classes apply only to milled rice and are based on the percentages of

whole kernels and broken kernels of different sizes they contain:

1. Second head milled rice

2. Screenings milled rice

3. Brewers milled rice

Rice types are based on the length:width ratios of unbroken kernels of rice and the widths,

thicknesses, and shapes of broken kernels, as set forth in the Rice Inspection Handbook. 1 All type

designations are explained in the Definitions section. The types are:

1. Long grain

2. Medium grain

3. Short grain

2.5.2.3 Special Grades

A special grade designation is supplemental to the grade assigned and includes the following terms:

coated, granulated, parboiled, parboiled light, parboiled dark, and/or undermilled. 2 Special grades

for milled rice are:

Coated milled rice

Granulated brewers milled rice

Parboiled milled rice

Undermilled milled rice

2.5.2.4 Definitions 2

Brewers milled rice Milled rice containing not more than 25% whole kernels and that does not meet the kernel size requirements of the second head milled rice or screenings milled rice class.

Brown rice for processing Rice consisting of more than 50% kernels of brown rice and is intended for processing to milled rice.

Coated milled rice Special grade of rice that is coated in whole or in part with safe and suitable substances according to commercially accepted practice.

Damaged kernels Whole or large broken kernels that are distinctly discolored or damaged by water, insects, heat, or other means, and whole or large broken kernels of parboiled rice in nonparboiled rice. Heat-damaged kernels (see below) shall not function as damaged kernels.

Granulated brewers milled rice Special grade of milled rice that is crushed or granulated so that 95% or more will pass through a 5 sieve, 70% or more will pass through a 4 sieve, and not more than 15% will pass through a 2 1/2 sieve.

Heat-damaged kernels Whole or large broken kernels of rice that are materially discolored and damaged as a result of heating, and whole or large broken kernels of parboiled rice in nonparboiled rice that are as dark as or darker than the interpretive line for heatdamaged kernels.

Long-grain brown rice for processing Brown rice for processing that contains more than 25% whole kernels of brown rice and not more than 10% whole or broken kernels of mediumor short-grain rice.

Long-grain milled rice Milled rice that contains more than 25% whole kernels of milled rice; in U.S. Nos. 1 through 4, not more than 10% whole or broken kernels of medium- or short-grain rice. U.S. Nos. 5 and 6 long-grain milled rice shall contain not more than 10% whole kernels of medium- or short-grain milled rice. Broken kernels do not apply.

Long-grain rough rice Rough rice that contains more than 25% whole kernels and after milling to a well-milled degree, contains not more than 10% whole or large broken kernels of medium- or short-grain rice. long-grain or short-grain rice.

Medium-grain milled rice Milled rice that contains more than 25% whole kernels of milled rice; in U.S. Nos. 1 through 4, not more than 10% whole or broken kernels of long-grain rice or whole kernels of short-grain rice. U.S. Nos. 5 and 6 medium-grain milled rice shall contain not more than 10% whole kernels of long- or short-grain milled rice. Broken kernels do not apply.

Medium-grain rough rice Rough rice that contains more than 25% whole kernels and after milling to a well-milled degree, contains not more than 10% whole or large broken kernels of long-grain rice or whole kernels of short-grain rice.

Milled rice Whole or broken kernels from which the hulls or at least the outer bran layers have been removed; contains not more than 10% seeds, paddy kernels, or foreign material, either singly or combined.

Milling yield Estimate of the quantity of whole kernels and total milled rice (whole and broken kernels combined) produced in the milling of rough rice to a well-milled degree.

Mixed brown rice for processing Brown rice for processing that contains more than 25% whole kernels of brown rice and more than 10% other types (see below).

Mixed milled rice Milled rice that contains more than 25% whole kernels of milled rice and more than 10% other types.

U.S. Nos. 5 and 6 mixed milled rice shall contain more than 10% whole kernels of other types. Broken kernels do not apply.

Mixed rough rice Rough rice that contains more than 25% whole kernels; after milling to a well-milled degree, contains more than 10% other types (see below).

Objectionable seeds Seeds other than rice, except seeds of Echinochloa crusgalli (commonly known as barnyard grass, water grass, and Japanese millet).

Other types (A) Whole kernels of (i) long grain rice in medium- or short-grain rice, (ii) medium-grain rice in long- or short-grain rice, (iii) short-grain rice in long- or mediumgrain rice; (B) large broken kernels of long grain rice in medium- or short-grain rice and large broken kernels of medium- or short-grain rice in long-grain rice. Large broken kernels of medium-grain rice in short-grain rice and large broken kernels of short-grain rice in medium-grain rice shall not be considered other types.

Paddy kernels Whole or broken unhulled kernels.

Parboiled milled rice Special grade of milled rice in which the starch has been gelatinized by soaking, steaming, and drying. U.S. Nos. 1 through 6 shall contain not more than 10% ungelatinized kernels. U.S. Nos. 1 and 2 shall contain not more than 0.1%. U.S. Nos. 3 and 4 shall contain not more than 0.2%. U.S. Nos. 5 and 6 shall contain not more than 0.5% nonparboiled rice. If the rice is (A) not distinctly colored by parboiling, it shall be considered parboiled light; (B) distinctly but not materially colored by parboiling, it shall be considered parboiled; (3) materially colored by parboiling, it shall be considered parboiled dark. Color levels for parboiled light, parboiled, and parboiled dark shall be in accordance with interpretive line samples for parboiled rice. The maximum limits for chalky kernels, heat-damaged kernels, kernels damaged by heat, and color requirements are not applicable to the parboiled milled special grade.

Red rice Whole or large broken kernels that contain appreciable amounts of red bran.

Rough rice Consists of 50% or more paddy kernels.

Screenings milled rice Milled rice that contains (A) not more than (i) 25% whole kernels, (ii) 10% broken kernels removed by a 5 plate, and (iii) 0.2% broken kernels passing through a 4 sieve (southern production); or (B) not more than (i) 25% whole kernels, (ii) 15% broken kernels passing through a 5 1/2 sieve, (iii) more than 50% broken kernels passing through a 6 1/2 sieve, and (iv) 10% broken kernels passing through a 6 sieve (western production). 5 plate, and (iv) 0.05% broken kernels passing through a 4 sieve (southern production); or (B) not more than (i) 25% whole kernels, (ii) 50% broken kernels passing through a 6 1/2 sieve, and (iii) 10% broken kernels.

Seeds Whole or broken seeds of any plant other than rice.

Short-grain brown rice for processing Brown rice for processing that contains more than 25% whole kernels of brown rice and not more than 10% whole or broken kernels of long-grain rice or whole kernels of medium-grain rice.

Short-grain milled rice Milled rice that contains more than 25% whole kernels of milled rice; in U.S. Nos. 1 through 4, not more than 10% whole or broken kernels of long-grain rice or whole kernels of medium-grain rice. U.S. Nos. 5 and 6 short-grain milled rice shall contain not more than 10% whole kernels of long- or medium-grain milled rice. Broken kernels do not apply.

Short-grain rough rice Rough rice that contains more than 25% whole kernels; after milling to a well-milled degree, contains not more than 10% whole or large broken kernels of long-grain rice or whole kernels of medium-grain rice.

Smutty kernels Whole or broken kernels of rice that are distinctly infected by smut.

Undermilled milled rice Special grade of milled rice that does not meet the requirements for well milled, reasonably well milled, or lightly milled rice, U.S. Nos. 1 and 2 shall contain not more than 5%, U.S. Nos. 3 and 4 shall contain not more than 5%, U.S. No. 5 shall contain not more than 10%, and U.S. No. 6 shall contain not more than 15% well milled kernels. U.S. No. 5 shall contain not more than 10% red rice and damaged kernels (singly or combined), and in no case, more than 6% damaged kernels. Color and milling requirements are not applicable to the undermilled milled rice special grade.

Ungelatinized kernels Whole or large broken kernels of parboiled rice with distinct white or chalky areas resulting from incomplete gelatinization of starch.

Whole kernels Unbroken kernels of rice that comprise at least 3/4 of an unbroken kernel.

Whole and large broken kernels Rice (including seeds) that (A) passes over a 6 plate (southern production) or (B) remains on top of a 6 sieve (western production).

2.5.2.5 Glossary 2

Adventitious Plant structure arising from an unusual place.

Anaerobic Without oxygen.

Auricle Narrow extension of the collar in grasses; may completely clasp the culm; may be absent.

Blank Individual floret of rice that produces no grain.

Boot Growth stage identified by the bulge within the flag leaf sheath caused by the enlarging panicle.

Borrow pit Depression on each side of a rice levee created when soil is embanked.

Brewers Smallest size of broken milled rice, less than 1/4 of a whole kernel.

Broken Milled rice containing less than 3/4 whole kernels; includes second heads, screenings, and brewers.

Broken yield Broken grain resulting from milling 100 lb of rough rice; equals total mill yield minus head yield.

Brown rice Rice with the hull removed; bran and embryo remain.

Carbohydrate Organic chemical composed of carbon (C), hydrogen (H), and oxygen (O); photosynthetically produced sugar and starch found in plants.

Chlorosis Yellowing of normally green tissue resulting from chlorophyll destruction or failure to develop.

Collar Juncture of leaf blade and sheath; may be used to identify grass species.

Commingled rice Blend of rice of similar grain type, quality, and grade.

Culm Stem of a grass plant; rice plants have main culms and tiller culms.

Dough stage Stage of maturity when a grain develops from a thick liquid to a soft dough consistency.

Embryo Microscopic plant attached to the endosperm of a seed; often called the germ.

Endosperm Stored food, primarily a carbohydrate in the form of starch, comprising most of a monocot seed such as rice; the endosperm serves as food for the embryo and developing seedling during germination and early growth.

Flag leaf Topmost leaf of the rice plant immediately below the panicle.

Floret Grass flower, including the lemma, palea, and sex organs.

Green rice High moisture (18.5 to 22.5%) rough rice.

Hailing Removal of the lemma and palea (husks or hulls) from rough rice.

Head milling yield Pounds of head rice milled from 100 lb of rough rice.

Head rice Milled rice kernel comprising more than 3/4 of the whole kernel.

Hull Lemma and palea parts of rough rice that are usually waste products but may be used in rice millfeed and as filler in feed products.

Inflorescence Flowering structure of a plant.

Instant rice Milled rice that has been cooked, cooled, and dried under controlled conditions and packaged in dehydrated form; requires little preparation time before eating; enriched with thianline, riboflavin, niacin, and iron.

Internode Area of a stem between two nodes.

Jointing Internode elongation in grasses.

Lemma The larger of two structures enclosing a rice seed; with the palea, it forms the hard outer covering of rough rice.

Ligule Short membranous projection on the inner side of a leaf blade at the junction of blade and sheath in many grasses.

Long-grain rice Long slender rice; when milled, measures typically from 0.26 to 0.28 in. (6.7 to 7.0 mm) or longer; has length:width ratio from 3.27 to 3.41:1.

Main culm or shoot Stem or above-ground portion of a plant originating directly from seed.

Medium-grain rice Rice that, when milled, measures typically from 0.22 to 0.23 inches (5.5 to 5.8 mm); has length:width ratio of 2.09 to 2.49:1.

Milk stage Early stage of grain development when milky liquid fills the grain.

Milled rice Grain with husks, bran, and germ removed.

Milling Converting rough rice into milled or brown rice.

Necrotic Dead.

Nematode Unsegmented, round, thread-like, usually microscopic worm that may be free-living or parasitic on plants and animals; soil-inhibiting nematodes may be parasitic on rice.

Node Solid portion of the rice stem from which leaves arise.

Paddy Subdivision of a rice field; bounded by levees.

Palea The smaller of two enclosing structures forming a hard outer covering of unmilled rice.

Panicle Many-branched inflorescence composed of few to many spikelets containing one to several florets.

Parboiled rice Rough rice steeped in warm water under pressure, steamed, dried, and milled; improves head milling yield.

Pathogen Living organism that causes infectious disease.

Precooked rice Milled rice processed to make it cook quickly.

Processed rice Rice used in breakfast cereals, soups, baby foods, packaged mixes, etc. crop before planting.

Rice bran Outer layer of the caryopsis just beneath the hull containing the outer bran layer and parts of the germ; rich in protein and vitamin B; used as livestock feed and in vitamin concentrates.

Rice polish Layer composed of the inner white bran and perhaps aleurone cells that are high in protein and fat; used in livestock feed and baby food; sometimes removed at the final stage of milling.

Rough or paddy rice Rice grains with hulls but without stalk parts; consists of 50% or more whole or broken unhulled kernels.

Screenings Broken milled rice kernels containing less than 1/2 and more than 1/4 of the whole kernel.

Second heads Broken milled rice kernels containing more than 1/2 and less than 3/4 of the whole kernel.

Senescence Stage of growth from maturity to death.

Sheath Portion of a complete grass leaf below the collar that may enclose the stem.

Shoot Above-ground portion of a plant; in rice, the portion above the crown.

Short-grain rice Rice that is almost round and when milled measures typically from 0.20 to 0.22 inches (5.2 to 5.4 mm); has a length:width ratio of 1.66 to 1.77:1.

Spikelet Subdivision of a spike consisting of one to several flowers.

Tiller Vegetative shoot, not the main culm.

Total milling yield Pounds of heads, second heads, brewers, and screenings milled from 100 lb rough rice.

White rice Kernel remaining after hull, bran layer, and germ are removed; includes head rice and brokens.

Y leaf Most recently matured leaf.

2.5.3 PRODUCTION STATISTICS TABLE 2.72 Leading Rice-Growing Countries, 1999–2000 Country 1,000 Short Tons China 206,335 India 121,418 Indonesia 31,740 Bangladesh 30,451 Vietnam 22,337 Thailand 21,708 Myanmar 16,708 Japan 12,865 Brazil 10,908 Philippines 10,410 Source: United Nations

Food and Agriculture Organization, Rome. TABLE 2.73 Milled Rice: Acreage, Yield, and Production in Continents and Specified Countries, 2000 a Location Harvested Area (1,000 ha) Yield (metric tons/ha) Production (1,000 metric tons) Continent North America 1,511 4.50 6,802 South America 5,452 2.41 13,122 Central America 255 2.22 567 Caribbean 220 2.34 514 European Union 396 4.36 1,725 Eastern Europe 23 1.52 35 Soviet Union 473 1.63 773 Middle East 750 2.57 1,930 Africa 7,160 1.48 10,581 Asia 137,860 2.68 369,376 Oceania 134 5.78 775 Country India 44,500 2.01 89,480 China 31,284 4.44 138,936 Indonesia 11,650 2.87 33,445 Bangladesh 10,700 2.01 21,530 Thailand 10,080 1.64 16,500 Vietnam 7,660 2.71 20,750 Myanmar 5,800 1.70 9,860 Philippines 3,995 1.95 7,772 Brazil 3,650 2.15 7,843 Pakistan 2,515 2.05 5,156 Cambodia 2,120 1.13 2,400 World Total 154,234 2.63 406,200 a Crop yield beginning August 1. Source: Estimate and Crop Assessment Division, Foreign Agriculture Service, Washington, D.C. TABLE 2.74 Rice by Length of Grain: U.S. Acreage, Yield, and Production, 1999–2000 State Area Harvested (1,000 acres) Yield (lb/acre) Production (1,000 cwt) Long Grain Arkansas 1,175 6,060 71,205 California 5 7,100 365 Louisiana 455 5,080 23,114 Mississippi 218 5,900 12,862 Missouri 173 5,700 9,861 Texas 209 6,740 14,087 Medium Grain Arkansas 233 6,300 14,679 California 513 8,000 41,040 Louisiana 25 5,150 1,288 Missouri 1 5,700 57 Texas 5 5,100 255 Short Grain Arkansas 2 6,000 120 California 30 7,300 2,190 Source: Crops Branch, National Agriculture Security Service, Washington, D.C., 2001. TABLE 2.75 Rough Rice: U.S. Acreage, Yield, and Production, 1991–2000 Year Area Harvested (1,000 acres) Yield (lb/acre) Production (1,000 cwt) 1991 2,761 5,731 159,367 1992 3,132 5,736 179,658 1993 2,833 5,510 156,110 1994 3,316 5,964 197,779 1995 3,093 5,621 173,871 1996 2,604 6,120 171,599 1997 3,103 5,897 182,992 1996 3,257 5,663 184,443 1999 3,512 5,866 206,027 2000 3,044 6,276 191,113 Source: Crops Branch, National Agriculture Security Service, Washington, D.C., 2001. TABLE 2.76 Rice and Milled Rice Products: U.S. Total and Per Capita Civilian Consumption, 1990–1999 Marketing Year (August 1–July 1) Total Consumed (cwt) Per Capita Consumption (lb) 1990 42.7 17.0 1991 43.7 17.2 1992 45.4 17.7 1993 49.6 19.1 1994 51.5 19.7 1995 52.6 19.9 1996 53.7 20.1 1997 55.0 20.4 1998 56.8 20.9 1999 a 59.3 21.6 a Preliminary. Source: Economics Research Service, Washington, D.C., 2001. All figures are estimates based on data from private industry sources, the U.S. Department of Commerce, the Internal Revenue Service, and other government agencies.

FIGURE 2.13 Rough rice: Production and value of production, 1991–2000.

2.5.4 GRAIN QUALITY TABLE 2.77 Food Value of White Rice Component % Carbohydrate 80.4 Water 12.0 Protein 6.7 Ash 0.5 Fat 0.4 Nutritive Value of Whole Grain Component Value Calories/100 g 363 Protein,% 6.7 Fat,% 0.2 Total calcium, mg/lb 24 Total phosphorus, mg/lb 94 Total potassium, mg/lb 92 Carbohydrates,% 80.4

2.5.5 NUTRIENT ELEMENT DEFICIENCIES TABLE 2.79 Nutrient Element Deficiency Symptoms and Effects on Rice Growth Nutrient Element Symptoms and Effects on Growth Nitrogen Stunted, yellowish plants; yellowish green older leaves or whole plants Phosphorus Stunted dark green plans with erect leaves and reduced tillering Potassium Dark green plants with yellowish brown leaf margins or dark brown necrotic spots first appearing on the tips of older leaves Calcium Chlorotic-necrotic split leaves or rolled tips on younger leaves Magnesium Orange-yellow interveinal chlorosis on older leaves Sulfur Pale green plants; light green-colored young leaves Silicon Soft, droopy leaves and culms Boron White, rolled tips of young leaves Copper Chlorotic streaks and bluish green leaves that become chlorotic near the tips Iron Interveinal yellowing and chlorosis Zinc Dusty brown spots on upper leaves of stunted plants appearing 2 to 4 weeks after transplanting Source: Rice: Nutrient Disorders and Nutrient Management, 2000, Potash & Phosphate Institute, Norcross, GA. TABLE 2.80 Element Toxicity Symptoms and Effects on Growth Element Symptoms and Effect on Growth Aluminum Orange-yellow interveinal chlorosis on leaves; poor growth, stunted plants Boron Brownish leaf tips and dark brown elliptical spots on leaves Iron Tiny brown spots on lower leaves starting from the tips or whole leaves colored orange-yellow to brown; black coating on root surfaces Manganese Yellowish brown spots between leaf veins, extending to interveinal areas Sulfide Interveinal chlorosis of emerging leaves; coarse, sparse, and blackened roots Source: Rice: Nutrient Disorders and Nutrient Management, 2000, Potash & Phosphate Institute, Norcross, GA.

2.5.6 FERTILIZER AND NUTRIENT ELEMENT STATUS

Silicon Fertilizer Sources Substance Formula Silicon Content Comment

Blast furnace slag $CaSiO_3$, $MgSiO_3$ 14–19% Si, 25–32% Ca, 2–4% Mg

Convertor slag $CaSiO_3$, $MgSiO_3$ 4–10% Si, 26–46% Ca, 0.5–9% Mg

Silico-manganese slag $CaSiO_3$, $MnSiO_3$ 16–21% Si, 21–25% Ca, 0.5–2% Mn

Fused magnesium

phosphate 9% Si, 9% P, 7–9% Mg Granular

Calcium silicate Si, Ca, Mg 14–19% Si, 1–4% Mg Granular, slow-release fertilizer

Potassium silicate K, Si 14% Si, 17% K, 2.5% Mg Granular, slow-release fertilizer

Source: Rice: Nutrient Disorders and Nutrient Management, 2000, Potash & Phosphate Institute, Norcross, GA.

TABLE 2.82

General Soil- and Season-Specific Fertilizer Recommendations (kg/ha) for Irrigated Rice Target Yield Dry Season (Y max ~ 10 tons/ha) Wet Season (Y max ~7.5 tons/ha) N P K N P K

Low Soil Fertility 4 60–80 8–12 a 20–40 60–80 8–12 a 20–25 5 90–110 15–25 50–60 90–120 15–25 50–60 6 120–150 25–40 80–100 Yield target not applicable 7 150–200 b 35–60 110–140

Medium Soil Fertility 4 0 a 8–12 a 10–40 a 0 a 8–12 a 10–40 a 5 50–70 10–15 a 15–50 a 50–70 10–15 a 15–50 a 6 90–110 12–18 30–60 100–120 12–18 40–60 7 120–150 15–30 60–80 Yield target not applicable 8 160–200 b 35–50 110–130

High Soil Fertility 4 0 a 8–12 a 10–40 a 0a 8–12 a 10–40 a 5 0 a 10–15 a 15–50 a 20–30 10–15 a 15–50 a 6 50–60 12–18 a 20–60 a 60–80 12–18 a 20–60 a 7 80–100 14–21 a 20–70 a Yield target not applicable 8 120–150 15–25 60–80

a Indigenous supply of P and K sufficient to achieve this yield level with smaller or no fertilizer application. For N, this

is a situation where input from other sources such as biological N_2 fixation is large enough to sustain the INS at this

level. For P and K, we recommend applying amounts of P and K at least equivalent to the net P and K removal from the field with grain and straw to maintain soil P and K supplies. The values given assume a replenishment dose equivalent

to P removal of 2–3 kg P/ha and K removal of 3–10 kg K/ha/ton of grain yield. The smaller value applies to systems in

which most of the P and K in straw remains in the field, either incorporated or burned. The larger value applies to systems

with large removals of crop residues.

b

Caution: N dose recommended is very large and could cause lodging and increased pest incidence.

Source: QUBFTS model modified for rice. For each yield target, the model was run using the INS, IPS, and IKS assumed

for each soil type and the ranges of recovery effciencies of N, P, and K specified above. Effect of Nutrient Availability on the Removal of N, P, and K (kg Nutrient/ton of Rice Grain) for the Linear Part of the Relationship of Grain Yield and Nutrient Uptake (<80% of Potential Yield) Nutrient Element Availability Nitrogen Phosphorus Potassium Maximum nutrient limitation 10 1.6 9 Nutrient limitation 11–13 1.7–2.3 10–13 Nutritional optimum 14–16 2.4–2.8 14–16 Nutrient surplus 17–23 2.9–4.8 17–27 Maximum nutrient surplus 24 4.9 28 Source: Rice: Nutrient Disorders and Nutrient Management, 2000, Potash & Phosphate Institute, Norcross, GA. TABLE 2.84 Optimal Internal Efficiency (kg/grain/kg Element) of N, P, and K in Irrigated Rice N P K 68 385 69 Source: Rice: Nutrient Disorders and Nutrient Management, 2000, Potash & Phosphate Institute, Norcross, GA. TABLE 2.85 Uptake of Major Elements and Micronutrients for 7.8 Tons/Acre Crop Major Elements kg Nitrogen 125 Phosphorus as phosphate 67 Potassium as potash 130 Calcium 23 Magnesium 16 Sulfur 21 Micronutrients g Boron 60 Copper 20 Iron 810 Manganese 600 Molybdenum 2 Zinc 215 Source: International Soil Fertility Manual. 1995. Potash & Phosphate Institute, Norcross, GA. TABLE 2.86 Nitrogen, Phosphorus, and Potassium Uptake and Content in Modern Rice Varieties Plant Part Typical Observed Range a Observed Average b kg N uptake/ton grain yield Grain + straw 15–20 17.5 Grain 9–12 10.5 Straw 6–8

7.0 % N content Grain 0.93–1.20 1.06 Straw 0.51–0.76 0.63 Unfilled spikelets 0.76–1.02 0.89 kg P uptake/ton grain yield Grain + straw 2.5–3.5 3.0 Grain 1.7–2.3 2.0 Straw 0.8–1.2 1.0 % P content Grain 0.18–0.26 0.21 Straw 0.07–0.12 0.10 Unfilled spikelets 0.13–0.20 0.17 kg K uptake/ton grain yield Grain + straw 14–20 17.0 Grain 2–3 2.5 Straw 12–17 14.5 % K content Grain 0.22–0.31 0.27 Straw 1.17–1.68 1.39 Unfilled spikelets 0.61–1.20 1.07 a 25–75% interquartile range of farmers' fields and field experiments in Asia (n = 1,300). b Median of farmers' fields and field experiments in Asia (n = 1,300). Source: Rice: Nutrient Disorders and Nutrient Management, 2000, Potash & Phosphate Institute, Norcross, GA.

2.5.7 NUTRIENT ELEMENT SUFFICIENCY TABLE 2.87 Optimal Ranges and Critical Levels for Occurrence of Mineral Deficiencies or Toxicities in Tissue Nutrient Element Growth Plant Stage Plant Part Optimum Range Critical Level for Deficiency Critical Level for Excess or Toxicity % Nitrogen Tillering-PI Y leaf 2.9–4.2 <2.5 >4.5 Flowering Flag leaf 2.2–2.5 <2.0 Maturity Straw 0.6–0.8 Phosphorus Tillering-PI Y leaf 0.20–0.40 <0.10 >0.50 Flowering Flag leaf 0.20–0.30 <0.18 Maturity Straw 0.10–0.15 <0.06 Potassium Tillering-PI Y leaf 1.8–2.6 <1.5 >3.0 Flowering Flag leaf 1.4–2.0 <1.2 Maturity Straw 1.5–2.0 <1.2 Calcium Tillering Y leaf 0.2–0.6 <0.15 >0.7 Tillering-PI Shoot 0.3–0.6 <0.15 Maturity Straw 0.3–0.5 <0.15 Magnesium Tillering-PI Y leaf 0.15–0.30 <0.12 >0.50 Tillering-PI Shoot 0.15–0.30 <0.13 Maturity Straw 0.20–0.30 <0.10 Sulfur Tillering Y leaf <0.15 Tillering Shoot 0.15–0.30 <0.11 Flowering Flag leaf 0.10–0.15 <0.10 Flowering Shoot <0.07 Maturity Straw <0.06 Silicon Tillering Y leaf <5 Maturity Straw 8–10 <5 mg/kg Boron Tillering Y leaf 6–15 <5 >100 Maturity Straw <3 >100 Copper Tillering Y leaf 7–15 <5 >25 Maturity Straw <6 >30 Iron Tillering Y leaf 75–150 <70 >300 Tillering Shoot 60–100 <50 Manganese Tillering Y leaf 40–700 <40 >800 Tillering Shoot 50–150 <20 Zinc Tillering-PI Y leaf 25–50 <20 >500 Tillering Shoot 25–50 <10 >500 Aluminum Tillering Shoot 15–18 <5 >100 Note: PI = panicle initiation. Source: Rice: Nutrient Disorders and Nutrient Management, 2000, Potash & Phosphate Institute, Norcross, GA. TABLE 2.88 Nutrient Element Sufficiency Ranges Nutrient Element Sufficiency Range Panicle Initiation Maximum Tillering % Nitrogen 2.60–3.20 2.80–3.60 Phosphorus 0.09–0.18 0.10–0.18 Potassium 1.00–2.20 1.20–2.40 Calcium 0.20–0.40 0.15–0.30 Magnesium 0.20–0.30 0.15–0.30 ppm Boron 6–10 5–15 Copper 8–25 8–25 Iron 70–150 75–200 Manganese 150–800 200–800 Zinc 18–50 25–50 Note: Sampling procedure = 25 mature leaves from new growth. Source: Plant Analysis Handbook II: A

Practical Sampling, Preparation, Analysis, and Interpretation Guide, 1996, MicroMacro Publishing, Athens, GA.

TABLE 2.89

Typical Symptoms Associated with Most Common Deficiencies

Nutrient Element	Mobility	Symptoms
Nitrogen	Mobile	Older leaves become pale green to yellow; younger leaves greener and may be narrow, short, and erect; plants are stunted with few tillers
Phosphorus	Mobile	Leaves become dark green to purple, narrow, short and erect; later become necrotic; plants are stunted with few tillers
Potassium	Mobile	Leaves become dark green followed by interveinal chlorosis and small necrotic spots coalescing from tips; leaves are shortened and slightly smaller
Sulfur	Mobile	Similar to N
Iron	Immobile	Starts as interveinal chlorosis on young leaves; entire leaves become pale yellow to whitish; older leaves remain green
Zinc	Immobile	Midribs of younger leaves turn yellow and droop, stunted growth and delayed maturity

Source: Crop Production: Evolution, History, and Technology, 1995, John Wiley & Sons, New York.

2.5.8 WEIGHTS AND MEASURES

1. Rice Inspection Handbook.

2. Smith, C.W., Crop Production: Evolution, History, and Technology, 1995, John Wiley & Sons, New York.

2.6 WHEAT (Triticum aestivum L., T. durum Desf.)

2.6.1 I NTRODUCTION

Wheat is a member of the Poaceae or Graminae grass family. It is known as blé in France, trigo

in Spain, frumento in Italy, and wreizen in Germany. It was one of the earliest crops cultivated and dates back to 11,000 B.C. in the Middle East. By about 4,000 B.C., wheat farming had spread to

Asia, Europe, and northern Africa. In 1493, wheat was brought to the Americas. It reached Mexico

in 1519 and Argentina by 1527. The spread of cultivation followed the movements of missionaries,

colonists, pioneers, and religious groups into Canada and the U.S. The introduction of winter wheat

in the U.S. in the 1870s greatly increased production.

`In 1988, the highest verifiable winter wheat grain yield of 190 bu per acre was recorded in

British Columbia, Canada. In the U.S. in 2000, the average winter wheat yield was 41.9 bu per

acre and the highest average state yield was 61.8 bu per acre in the state of Washington.

Wheat covers more cultivated land (232 million ha) than any other food crop and is one of the

most important (595 million tons). It grows in a wide range of climates (best in fairly dry and mild

climates) and soils (best grown on clay and silt loams). In most wheat-growing areas, farmers grow TABLE 2.90 Rice Seeds/Pound, Weight/Bushel, and Germination Time Seeds/lb (1,000) Seeds/g (no.) Weight/bu Germination Time (days) 15 65 45 14 TABLE 2.91 Weights and Measures Approximate Net Weight Unit lb kg Rough rice Bu 45 20.4 Bag 100 45.4 Bbl 162 73.5 Milled rice Cook-in-bag 100 45.4 Source: U.S. Department of Agriculture, Agricultural Statistics, 2001, U.S. Government Printing Office, Washington, D.C.

Harvested products include or are made into bran, bread, flour, gluten, pasta, starch, and straw

for litter and bedding. Plants are sometimes harvested for grazing or fodder. Hard red wheats

generally make excellent bread flour, cakes, cookies, and pastries, Durum wheats are best in pasta

products, and white wheats are used in breakfast foods and pastries.

2.6.2 GLOSSARY 1

Blending Combining measured amounts of different lots from bins and mixing them into a uniform blend with grain assemblers or millers.

Bolt Sift through a cloth or sieve.

Bran Outer covering of a wheat kernel composed of seed coat, nuclear tissue, tube and cross cells, hypodermis, and endodermis, which are separated from the endosperm and embryo or germ during commercial milling.

Break flour Flour produced by break rolls during commercial milling; particles of endosperm are also reduced to flour.

Break system Stage in the milling process in which kernels are broken by a series of successively closer-set pairs of rollers to separate the endosperm from the bran coat.

Broken kernel Kernel separated into two or more pieces, exclusive of insect boring or surface consumption.

Clear flour Flour remaining after a patent flour has been removed; normally higher in ash and protein than patent but of lower market value because of color.

Club wheat Triticum aestivum subsp. compactum: usually white wheat cultivars; may be winter or spring; heads are usually awnless, elliptical, oblong, or clavate in shape, and short, compact, or laterally compressed.

Coarse break Break roll that grinds larger particles in a classified break system in which break stock is classified as coarse and fine by size and ground on separate rolls.

Crop year U.S. officially designated production–marketing year for a commodity; the wheat crop year is June 1 to May 31.

Durum wheat Triticum turgidum subsp. durum; has 14 pairs of chromosomes; spring growth habit; very hard; high protein; used primarily for pasta.

Elevator Point of accumulation and distribution in the movement of grain; terminal elevators usually receive grain by railroad carloads; country elevators receive grain by trucks, usually from farmers.

Endosperm Starchy portion of the wheat kernel that is ground into flour; the seed-stored nutrient supply for the embryo during germination and early seedling growth.

Ethanol Grain alcohol made from almost any kind of grain containing a reasonable amount of starch.

Family flour Commonly called all-purpose flour; used for baking bread, cakes, biscuits, etc.

Fancy patent flour Most finely ground flour.

Farina Very pure endosperm of nondurum wheat ground to about medium screen size; maybe used in pasta, but will overcook more easily than pasta made from durum wheat

Fine break Break roll used to further reduce smaller particles in a classified break system of milling.

First clear Portion of straight run flour remaining after patent flour has been removed; higher in protein than the patent flour produced but poorer in color and thus has lower commercial value; about 20 to 25% of the flour produced in hard wheat mills may be first clear.

Flour extraction rate Percent of flour produced from milling 100 lb of wheat kernels. protein content of the flour.

Grain reserve Wheat stored by the U.S. government.

Hard red spring (HRS) Triticum aestivum subsp. aesrivum; also called common or bread wheat; has 21 chromosome pairs — A, B, and D genomes; spring seeded; not winter hardy; does not require vernalization for reproduction; may be referred to as red, dark northern, or northern; high protein; hard endosperm; primarily used to produce bread flour.

Hard red winter (HRW) Triticum aestium subsp. aestivum, also called common or break wheat; has 21 chromosome pairs — A, B, and D genomes; fall seeded; winter hardiness varies; requires vernalization for reproduction; may be referred to as dark hard, hard, or yellow hard; medium to high protein; hard endosperm; primarily used to produce bread flour.

Hard wheat Generic term for wheat having a vitreous endosperm suitable for bread flour or semolina; yields coarse, gritty flour that is free-flowing and easily sifted; flour consists of regular shaped particles that are mostly whole endosperm cells.

Middlings Pieces of endosperm not ground into flour; a byproduct of commercial milling produced during break reduction and composed of coarse material; usually used for animal feed.

Middlings rolls Pair of smooth rolls used to reduce middlings to flour particle size; may be called reduction rolls.

Millfeed Any byproduct of the milling industry used as livestock feed.

Pasta Product made principally from durum wheat flour; includes macaroni, spaghetti, and noodles.

Patent flour Highest value grade flour with good dress and color.

Product stream Any of 125 to 150 mill streams in the flour manufacturing process; different grades of flour are produced by blending individual streams.

Semolina Coarse endosperm extracted from durum wheat; used for pasta.

Short An inseparable mixture of bran, endosperm, and wheat germ remaining after flour extraction in milling; used for animal feed.

Soft red winter (SRW) Triticum aestivum subsp. aestium; a common wheat; has 21 chromosome pairs — A, B, and D genomes; fall seeded; winter hardiness varies; requires vernalization for reproduction; low to medium protein; soft or floury endosperrn; used primarily for cakes, pastries, and products whose tenderness is important.

Soft wheat Generic term for wheat having a chalky, nonvitreous endosperrn suitable for pastry flour; yields a very fine flour consisting of irregular-shaped fragments of endosperm cells that cling together and are difficult to shift.

Spring wheat Wheat seeded in the spring and harvested the following summer or fall; does not require vernalization to reproduce.

Stock Wheat in storage or transit; stock sometimes includes processed products in inventory.

Straight flour Flour extracted from a blend or mill mix of wheat without division or addition of flour from other runs.

Test weight Quality test used to determine weight per bushel; bushel weight standard for wheat is 60 pounds.

Vernalization Low temperature-triggered, hormonal-controlled conversion from vegetative growth to reproductive growth in winter wheat; requires temperatures below 50˚F; length of exposure required is cultivar-dependent.

2.6.3 PRODUCTION STATISTICS TABLE 2.92 Wheat: Area, Yield, and Production, 1999–2000 a Continent Harvested Area (1,000 ha) b Yield (metric tons/ha) Production (1,000 metric tons) North America 32,845 2.82 92,519 South America 8,132 2.48 20,179 Europe 17,016 5.71 97,115 Eastern Europe 8,346 3.47 28,951 Western Europe 158 5.64 891 Soviet Union 42,225 1.58 66,510 Middle East 17,690 1.72 30,482 Africa 9,295 1.78 16,583 Asia 68,724 3.05 209,422 Oceania 12,393 2.04 25,287 World Total 216,827 2.71 587,944 a Year of harvest. b Harvested area. Source: Foreign Agriculture Service, Washington, D.C. TABLE 2.93 Area, Yield, and Production of Leading Wheat-Growing Countries, 1999–2000 a Country Harvested Area (1,000 ha) b Yield (metric tons/ha) Production (1,000 metric tons) China 28,855 3.95 113,880 India 27,400 2.58 70,780 Russia 23,000 1.36 31,000 U.S. 21,781 2.87 62,569 Australia 12,338 2.03 25,012 Canada 10,364 2.59 26,850 Kazakhstan 8,730 1.28 11,200 Turkey 8,650 1.91 16,500 Pakistan 8,231 2.17 17,854 Iran 6,000 1.42 8,500 Ukraine 5,900 2.29 13,599 France 5,116 7.28 37,232 World Total 216,827 2.71 587,944 a Year of harvest. b Harvested area. Source: Foreign Agriculture Service, Washington, D.C. TABLE 2.94 Area, Yield, and Production of Leading States, 2000 State Harvested Area (1,000 acres) Yield (bu/acre) Production (1,000 bu) North Dakota 9,413 33.3 313,785 Kansas 9,400 37.0 347,800 Montana 4,920 27.5 135,250 Oklahoma 4,200 34.0 142,800 South Dakota 2,878 39.7 114,268 Washington 2,420 68.1 164,880 Colorado 2,396 29.8 71,370 Texas 2,200 30.0 66,000 Minnesota 1,971 49.0 96,926 Nebraska 1,650 36.0 59,400 U.S. Total 53,028 41.9 2,223,440 Source: Crops Branch, National Agriculture Statistics Service, Washington, D.C. TABLE 2.95 U.S. Total and Per Capita Civilian Consumption of Wheat and Wheat Products, 1990–1999 Per Capita Consumption of Food Products Calendar Year Total Consumed (million bu) a Flour (lb) b Cereal (lb) 1990 773 136 4.3 1991 791 137 4.5 1992 817 139 4.7 1993 853 143 5.0 1994 871 144 5.2 1995 858 142 5.4 1996 896 149 5.4 1997 902 150 5.4 1998 911 148 5.4 1999 919 147 5.3 a Excludes quantities used alcoholic beverages. b Includes white, whole wheat, and semolina flour. Source: Economics Research Service, Washington, D.C. All figures are estimates based on data from private industry sources, the U.S. Department of Commerce, the Internal Revenue Service, and other government agencies. U.S. Wheat Acreage, Yield, and Production, 1991–2000 a Year Harvested Acres (1,000) Yield (bu/acre) b Production (1,000 bu) 1991 57,803 34.3 1,980,139 1992 62,761 39.3 2,466,798 1993 62,712 38.2 2,396,440 1994 61,770 37.8 2,320,981 1995 60,955 35.8 2,182,706 1996 62,819 38.3 2,277,388 1997 62,640 39.5 2,461,466 1998 59,002 43.2 2,547,321 1999 53,823 42.7 2,299,010 2000 53,028 41.9 2,223,440 a Includes area seeded in preceding fall for winter wheat. b Includes allowance for loans outstanding and purchases by the government valued at the average loan and purchase rate by state where applicable. Source: Crops Branch, National Agriculture Statistics Service, Washington, D.C., 2001. TABLE 2.97 Harvest Times for Wheat Crops January Argentina, Australia. Chile, New Zealand February Myanmar, Chile, New Zealand, Uruguay March India, Upper Egypt April Lower Egypt, India, Iran, Mexico, Morocco May Algeria, China, Japan, Spain, southwestern U.S. June China, southern France, Greece, Italy, Portugal, Spain, Tunisia, Turkey, southern U.S. July Bulgaria, Croatia, southern England, France, Germany, Hungary, Kazakhstan, Moldova, Romania, Russia, Urkaine, northern U.S. August Belgium, Canada, Denmark, northern England, Kazahkstan, Moldova, Netherlands, Russia, Ukraine, northern U.S. September and October Canada, Kazakhstan, Russia, Scandinavia, Scotland November Argentina, Brazil, Venezuela, South Africa December Argentina, Australia TABLE 2.98 Varieties of U.S.-Grown Wheat Variety States Where Grown Hard red winter Texas, Oklahoma, Kansas, Colorado, Nebraska Hard red spring Minnesota, South Dakota, North Dakota, Montana Spring durum Northern Great Plains, Arizona, California Soft red winter Missouri, Illinois, Indiana, Ohio, Pennsylvania White Michigan, New York, California, Washington, Oregon, Idaho

2.6.4 GRAIN QUALITY

FIGURE 2.14 Wheat production and value of production in the U.S., 1991–2000. TABLE 2.99 Average Composition (%) of Wheat Flour, Bran, and Germ Containing about 13% Moisture Composition Wheat or Graham Flour White Flour Bran Germ Carbohydrates Nitrogen-free extract 68 74 50 18 Starch 55 70 10 — Pentosans 6 3.5 25 — Dextrins — — 4 —

Sugars 2 1.5 1.5 15 Crude fiber 2.3 0.4 9 2 Fat 2 1 4 11 Crude protein 13 11 17 30 Ash (mineral matter) 2 0.45 7 5 TABLE 2.100 Quality Components of Wheat Grain Component Value Digestible energy, kcal/kg 3,520 Protein, % 13.7 Lysine, % 0.45 Methionine + cystine, % 0.36 Tryptophan, % 0.18 Calcium, % 0.05 Phosphorus, % 0.36 Fiber, % 3.0 Ether extract, % 1.7

2.6.5 FERTILIZER USE

2.6.6 ELEMENTAL UPTAKE AND UTILIZATION TABLE 2.101 Fertilizer, Total Acreage, and Area Receiving Applications (%), All States Surveyed, 1995–1999 a Crop Type Nitrogen Phosphate Potash 1995 Wheat, winter 86 54 16 Wheat, durum 92 78 10 Wheat, other spring 87 78 23 1996 Wheat, winter 86 51 6 Wheat, durum 93 73 8 Wheat, other spring 89 79 24 1997 Wheat, winter 84 53 15 Wheat, durum 95 77 8 Wheat, other spring 92 82 25 1998 Wheat, winter 89 63 22 Wheat, durum 94 76 5 Wheat, other spring 87 77 25 a Acres receiving one or more applications of a specific fertilizer ingredient. Source: National Agriculture Statistics Service, Washington, D.C. TABLE 2.102 Nutrient Elements Removed by a Bushel of Wheat Amount Removed Nutrient Element Grain Grain + Straw Nitrogen, lb/bu 1.20 1.52 Phosphorus as phosphate, lb/bu 0.56 0.70 Potassium as potash, lb/bu 0.31 1.03 Sulfur, lb/bu 0.12 0.22 Calcium, lb/bu 0.05 0.25 Magnesium, lb/bu 0.13 0.35 Copper, oz/bu 0.012 — Manganese, oz/bu 0.036 — Zinc, oz/bu 0.055 — Source: Crop Production: Evolution, History, and Technology, 1995, John Wiley & Sons, New York. Nutrient Elements (lb/acre) Removed by Wheat Crop Nutrient Element Grain (60 bu/acre) Straw (2 tons/acre) Nitrogen 75 30 Phosphate 39 9 Potash 24 65 Sulfur 5 7 Calcium 2 9 Magnesium 9 5 Boron 0.06 0.02 Copper 0.05 0.03 Iron 0.45 0.15 Manganese 0.14 0.26 Zinc 0.2 0.08 TABLE 2.104 Uptake of Major Elements and Micronutrients for 4-Ton/Acre Wheat Crop Major Element kg Micronutrient g Nitrogen 130 Boron 36 Phosphorus as phosphate 46 Copper 43 Potassium as potash 180 Iron 380 Calcium 18 Manganese 120 Magnesium 20 Zinc 180 Sulfur 17 Source: International Soil Fertility Manual, 1995, Potash & Phosphate Institute, Norcross, GA. With permission. TABLE 2.105 Nutrient Element Utilization by 40-Bu/Acre Wheat Crop Nutrient Element Content (lb) Nitrogen 160 Phosphorus as phosphate 54 Potassium as potash 184 Magnesium 24 Sulfur 20

2.6.7 NUTRIENT ELEMENT SUFFICIENCY

2.6.8 NUTRIENT ELEMENT DEFICIENCIES

2.6.8.1 Calcium (Ca)

2.6.8.1.1 Deficiency Symptoms

Calcium-deficient plants are very stunted with short, stout stems and dark green leaves that are

held erect. Although tiller production does not appear to be affected by mild deficiencies, few tillers

may mature and produce heads. When a deficiency is severe, plants die before heads are produced.

As a result, grain yields can be greatly reduced.

Weather-tipped young leaves: Because Ca is not transferred from old to young leaves when a

deficiency occurs, symptoms appear first and are more severe on young leaves. They are often most

severe on the youngest, still unrolling leaves. All leaves are dark green and the tips of the youngest

leaves turn yellow, then grey or pale brown, and die. The dead tissue becomes tightly rolled into

tubes and may twist into circles. Affected leaves are very brittle and the laminae may tear while

emerging or the dead tips may break off to produce squared ends of the leaves. The bases of affected

leaves remain dark green and appear healthy. Mature leaves remain unaffected and retain their

healthy, dark green appearance.

Fan-shaped stems: Stems are short and stout. As a plant matures, young leaves have difficulty

emerging fully and this causes the stem to become flattened in cross-section and develop a fan

like appearance.

2.6.8.1.2 Problem Soils

Calcium deficiency is likely to occur in: • Acidic, sandy soils whose original Ca has been removed by heavy rainfall • Strongly acid peat and muck soils that have low total Ca

TABLE 2.106 Nutrient Element Sufficiency Ranges for Wheat

Nutrient Element	Sufficiency Range Spring Wheat a	Sufficiency Range Winter Wheat b
Nitrogen, %	2.00–3.00	1.75–3.00
Phosphorus, %	0.20–0.50	0.20–0.50
Potassium, %	1.50–3.00	1.50–3.00
Calcium, %	0.20–0.50	0.20–1.00
Magnesium, %	0.15–0.50	0.15–1.00
Boron, ppm	6–10	—
Copper, ppm	5–25	5–50
Iron, ppm	25–00	10–300
Manganese, ppm	25–100	16–200
Molybdenum, ppm	0.09–0.18	—
Zinc, ppm	15–70	20–70

a As head emerges from boot; 50 leaves, top 2 leaves. b Just before heading; 25 whole tops. Source: Plant Analysis Handbook II: A Practical Sampling, Preparation, Analysis, and Interpretation Guide, 1996, MicroMacro Publishing, Athens, GA. With permission.

• Soil with high levels of soluble Al and low levels of exchangeable Ca

2.6.8.1.3 Correcting Deficiency

Calcium deficiency can be corrected by broadcasting suitable fertilizer onto the soil some months before sowing. Subsequent tillage operations then thoroughly mix the fertilizer with the soil. Where the chief problem is simply a lack of Ca, suitable fertilizers are gypsum (calcium sulfate) and calcium nitrate or chloride. If the soil pH is low, lime or limestone (calcium carbonate) and dolomite (a mixture of calcium and magnesium carbonates) are more suitable.

A soil test can determine soil lime or Ca requirement. However, since the correct rate of application depends on the soil type and crop to be grown, advice should be sought on fertilizer practices used on similar soils in the district. The excessive use of lime may induce deficiencies of K, Mg, Fe, Mn, Zn, and Cu, so care should be taken to prevent overliming.

2.6.8.2 Copper (Cu)

2.6.8.2.1 Deficiency Symptoms

The first signs of Cu deficiency may be areas of poor growth within an apparently healthy crop.

Deficient plants appear limp and wilted even when ample water is available in the soil. If the deficiency

persists and becomes severe, affected plants are shorter and develop thin, spindly stems and pale green

to yellow foliage. When the deficiency is very severe, affected plants appear to die from the tops

down, resulting in plants with dark green old leaves and crowns of dead leaves at the tops.

Copper deficiency affects the amount of live pollen formed. As a result, partly filled or even

empty heads can be produced by plants that appear healthy. Heads without grain often turn white

but remain firmly attached to the plants. A similar symptom is associated with frost, fungal, or

mouse damage; the white heads are easily pulled from the stems in those situations.

Weather-tipped younger leaves: Because Cu is not readily transferred from old to young leaves

when a deficiency occurs, symptoms develop first and are more severe on young leaves. Old leaves

usually remain dark green and appear healthy. Affected leaves turn pale green to yellow and appear

limp or wilted. If the deficiency persists, the tips of young leaves wilt, hang down, and turn yellow.

The leaf tips eventually die and turn pale brown, rolling or twisting into tight tubes. The bases of

the affected leaves may remain green when a deficiency is mild, but entire leaves are affected and

die if a deficiency is very severe.

Increased tillering: In mild deficiencies, tiller production may be increased by the development

of late tillers around the boot stage of growth. The new tillers are usually formed from nodes or joints that are well above ground level.

Delayed maturity and black straw: Copper deficiency delays crop maturity. When plants

eventually ripen, their straw is usually much darker than normal and may be black or dark grey.

2.6.8.2.2 Problem Soils

Copper deficiency is likely to occur in: • Peat and muck soils in which organic matter ties up soluble Cu in forms less available to plants • Calcareous sands whose total Cu is low • Leached acid soils whose total Cu is low • Soils formed from rocks low in Cu

2.6.8.2.3 Correcting Deficiency

Foliar sprays and soil dressings of salts such as copper sulfate (bluestone) or copper chelates have

corrected deficiencies. Dressings should be broadcast and mixed into the soil some weeks before

A reliable remedy is to apply two or more foliage sprays of 0.5 to 1% solutions of soluble Cu

salts (for example, 0.5 to 1 kg copper sulfate per 100 L water per ha), the first to be applied 5 to

8 weeks after seedling emergence when the crop is in the tillering stage. The second spray is applied

when the first or oldest heads reach the boot stage of growth; an optional third spray can be applied

7 to 10 days later.

Soil tests can estimate the amount of available Cu in a soil and predict the amount of fertilizer

needed for most seasons. The best prediction can be obtained by seeking advice on fertilizer

practices used on similar soils in the district.

2.6.8.3 Iron (Fe)

2.6.8.3.1 Deficiency Symptoms

Iron-deficient plants are stunted and have short, spindly stems and pale green to yellow foliage.

Because the symptoms are more severe on upper leaves, the crop has a distinct yellow color. Tiller

production is reduced even by mild deficiencies. If a deficiency persists or becomes severe, many

young tillers die without producing heads and mature tillers develop small heads. Grain yields can

be severely reduced.

Interveinal chlorosis on younger leaves: Because Fe is not transferred from old to young leaves

when a deficiency occurs, symptoms appear first and are more severe on young leaves. Old leaves

usually remain dark green and appear healthy. During the early stages of symptom development,

the youngest leaves turn pale green or yellow and the veins remain dark green and clearly visible.

If the deficiency persists or becomes severe, the veins may lose their green color and the youngest

leaves often turn dark or pale yellow, but rarely white. At this stage, it can be difficult to distinguish

between S and Fe deficiencies, although Fe-deficient plants usually have a greener overall appear

ance than those deficient in S.

2.6.8.3.2 Problem Soils

Iron deficiency is likely to occur in: • Calcareous soils whose levels of soluble Fe are low • Waterlogged soils • Acid soils with excessively high levels of soluble Mn, Zn, Cu, and Ni that depress plant uptake of Fe • Sandy soils low in total Fe • Peat and muck soils in which organic matter ties up Fe

2.6.8.3.3 Correcting Deficiency

While dressings of inorganic salts such as iron sulfates or chlorides have corrected deficiencies in

some soils, the applied Fe quickly becomes insoluble and less available to plants. Fe salts of organic

chelates have proved more promising because the chelate has the ability to keep Fe in solution in

soils. For acid soils, FeEDTA is the most effective chelate. FeHEDTA and FeDTPA are best on

neutral soils and FeEDDHA is best on alkaline, calcareous soils. However, to be effective, large

amounts of chelates may be required and may prove too costly.

An equally effective remedy is to apply solutions of inorganic salts or chelates to the foliage

(1% solution or 1 kg salt per 100 L water per ha). Because Fe is so immobile in plants, sprays

may need to be applied every 10 to 15 days to provide Fe to new leaves. Advice on fertilizer

practices used on similar soils in the district should be sought to obtain the best remedy for the

affected crop under local conditions.

2.6.8.4.1 Deficiency Symptoms

Magnesium-deficient wheat and triticale plants are stunted and have short, spindly stems and pale

green to yellow foliage. Although tiller production may not be affected, many young tillers die

before reaching maturity if a deficiency persists or becomes severe. Extremely deficient plants

develop only a few heads that set few grains.

Interveinal chlorosis on older leaves: Because Mg is readily transferred from old to young

leaves when a deficiency occurs, symptoms appear first and are more severe on old leaves, working up the plants to younger leaves as the deficiency develops. Pale yellow interveinal chlorosis begins

between the leaf tips and the mid-sections of middle and old leaves and rapidly expands toward

the bases until whole leaves are affected. During early stages, the veins remain green and prominent.

As the deficiency becomes more severe, the veins become less distinct and the interveinal tissue

may die and turn pale or dark brown. Necrosis of interveinal tissue is more common on old leaves

and usually occurs toward the tips. The youngest leaves remain green and appear healthy.

2.6.8.4.2 Problem Soils

Magnesium deficiency is likely to occur in: • Acid sandy soils whose Mg has been removed by leaching • Strongly acid peat and muck soils whose total Mg is low • Soils that have been over-fertilized with Ca (for example, lime) or K, thus inhibiting uptake of Mg

2.6.8.4.3 Correcting Deficiency

Magnesium deficiency on acid soils is best corrected by broadcasting dolomite (a mixture of calcium

and magnesium carbonates) onto the surface some months before sowing. The dolomite is then

mixed thoroughly with the topsoil during seedbed preparation. When the problem is simply a

deficiency of Mg, applications of magnesium sulfate or chloride can be made at or before planting.

A soil test can estimate the amounts of soluble and exchangeable Mg in the soil and predict

the amount of fertilizer required. The best prediction can be obtained by seeking advice on fertilizer

practices used on similar soils in the district.

Magnesium deficiency in existing crops can be corrected by applying soluble salts such as magnesium sulfate, chloride, or nitrate with irrigation water. Foliar sprays of soluble magnesium

salts such as magnesium sulfate are usually not recommended because of the large number of

applications required to supply crop requirements.

2.6.8.5 Manganese (Mn)

2.6.8.5.1 Deficiency Symptoms

Manganese-deficient crops often appear patchy and exhibit areas of poorer growth adjacent to

apparently healthy plants. Within the Mn-poor area, plants are stunted and have short, thin,

spindly stems and pale green to yellow foliage. Affected plants often have wilted appearance

and prostrate growth. Even mild deficiencies cause plants to produce few tillers. When a defi

ciency is severe, many young tillers and sometimes whole plants die before maturity. As a result,

grain yields may be greatly reduced.

White flecks in younger leaves: Because Mn is not readily transferred from old to young leaves

when a deficiency occurs, symptoms develop first and are more severe on young leaves. When the

deficiency persists, the severest symptoms appear on the youngest leaves. The oldest leaves may

show mild symptoms. Affected leaves turn pale green and appear limp or wilted. Mild interveinal

chlorosis develops in the mid-sections of leaves and spreads rapidly. Whole leaves turn pale yellow

green. Small, linear grey to white flecks or streaks appear in interveinal tissues toward the bases.

at the bases of the leaves. The basal tissue then dies and turns pale brown. Initially, the leaf tips remain green and appear healthy but eventually whole leaves die.

Deaths of shoots: Severe deficiency causes the youngest leaves to die before they emerge fully

from the sheaths of the previous leaves. When this occurs, the apical microstem soon dies and then

the whole shoot dies.

2.6.8.5.2 Problem Soils

Manganese deficiency is likely to occur in: • Calcareous soils whose Mn is less available to plants • Poorly drained soils with high organic matter content in which Mn is tied up in forms less available to plants • Strongly acid sandy soils whose soluble Mn has been leached by heavy rain • Soils formed from rocks low in Mn

2.6.8.5.3 Correcting Deficiency

Foliar sprays and soil dressings of Mn salts and oxides have been used to correct deficiencies. Soil

dressings are more effective when broadcast and mixed into the soil some weeks before sowing.

Foliar applications have generally been more successful. One or more sprays of 0.5 to 1% solutions

of soluble Mn salts (for example, 0.5 to 1 kg manganese sulfate per 100 L water per ha) usually

correct the deficiency, the first to be applied 5 to 6 weeks after seedling emergence. If symptoms

reappear, the spray should be repeated immediately. While soil dressings usually last 5 to 6 years,

foliar sprays must be reapplied to every crop.

Tests can estimate the amount of available Mn in the soil and predict whether fertilizer is

needed. The best prediction can be obtained by seeking advice on fertilizer practices used on similar

soils in the district.

2.6.8.6 Nitrogen (N)

2.6.8.6.1 Deficiency Symptoms

Nitrogen deficiency leads to stunted plants with thin, spindly stems and short, erect leaves. In young

crops, all leaves are pale green to yellow. Mature crops often take on a three-tone appearance: the

oldest leaves are pale lemon yellow or pale brown; the middle leaves are yellow; and the youngest

are pale green. Tiller production is reduced and if the deficiency is severe, many die before maturing,

forming thatches of dead leaves around the bases of the plants. Grain yields are severely reduced.

Mottled grain: An early warning sign is the production of low protein grain. In bread wheats,

such grain is only partly vitreous and has opaque patches or mottles.

Pale yellow older leaves: Because N is readily transferred from old to young leaves as soil

supplies become deficient, symptoms appear first and are more severe on old leaves, working up

the plants to younger leaves if the deficiency persists. The youngest leaves remain pale to dark

green and appear healthy but may be short and more erect than usual. Old leaves turn pale green.

Pale yellow chlorosis develops at the leaf tips and advances in broad fronts down the leaves. The

chlorotic tissues die and turn pale brown. Affected leaves can be green at the bases and develop

yellow mid-sections and brown leaf tips.

Red stems: Deficient plants usually have green, thin, spindly stems. However, in cold

weather, stems, leaf sheaths and auricles may develop red stripes, a symptom usually associated

with P deficiency. • Sandy soils that have been leached by heavy rainfall or excessive irrigation • Mineral soils low in organic matter • Soils with a long history of cropping, where the supplies of N are exhausted

Even fertile soils may suffer temporary N deficiency when double-cropped, heavily leached or

waterlogged.

2.6.8.6.3 Correcting Deficiency

Nitrogen deficiency is corrected by increasing the available N in the soil by fallowing, which allows

organic N to be converted to mineral N; by growing cover or cash crops of legumes, which can

fix atmospheric N_2; or by adding nitrogenous fertilizers. Suitable fertilizers are urea, gaseous

ammonia or ammonium sulfate, nitrate, or phosphates. Crop growth depends on the amount of N

already in the soil. A soil test can measure the amount of total N or (NO_3)-N in the soil prior to

sowing, and predict the amount of fertilizer required. The best prediction can be obtained by seeking

advice on fertilizer practices used on similar soils in the district.

Nitrogen deficiency in existing crops is sometimes corrected by applying soluble salts such as

urea with irrigation water or as a foliar spray. Spray applications usually result in a rapid response

of short duration, and additional sprays 10 to 14 days apart may be needed to supply enough N

for crop requirements.

2.6.8.7 Phosphorus (P)

2.6.8.7.1 Deficiency Symptoms

Symptoms are more noticeable in young plants, which have greater relative demands for P than more mature plants. Mild deficiencies cause stunted growth but no obvious leaf symptoms. More severe deficiencies produce small, dark green plants that have short, erect leaves, stout stems, and often develop orange, red, or purple areas. Tiller production and grain yield are reduced even by mild deficiencies. When a deficiency persists or becomes severe, little grain is produced because many young tillers die before maturity and the surviving tillers produce small heads that set few grains.

Dark yellow older leaves: Because P is readily transferred from old to young leaves when a deficiency occurs, symptoms develop first and are more severe on old leaves, working up the plants to younger leaves if the deficiency persists. The youngest leaves remain dark green and appear healthy but may be short and more erect than usual. Old leaves remain dark green and dark yellow chlorosis develops on the leaf tips and advances in broad fronts down the leaves. If the deficiency is severe or persists, purple suffusion combines with the yellow to produce orange-yellow to orange-purple chlorosis. Even tually the affected leaves die, turn dark brown, and form thatches around the bases of the plants.

Purple stems: Red-purple or purple striping develops on stems and leaf sheaths even when a deficiency is mild.

2.6.8.7.2 Problem Soils

Phosphorus deficiency is likely to occur in: • Mineral soils low in organic matter • Soils with a long history of cropping, whose supplies of P are depleted • Highly weathered, Fe-rich acid soils whose phosphate is fixed in less available forms • Soils whose P-rich topsoil has been lost through erosion • Alkaline soils in which much of the P may be tied up in insoluble phosphates that are less available to plants

Suitable fertilizers are single or triple superphosphates or ammonium phosphates. Crop growth

depends on the amounts of water-soluble phosphates and the rates of exchange between insoluble

and soluble forms of P in the soil. Soil tests can estimate the amounts of available phosphate in

soils and predict the amounts of fertilizer needed. The best prediction can be obtained by seeking

advice on fertilizer practices used on similar soils in the district.

Phosphorus deficiency in existing crops can be corrected by applying soluble salts such as

ammonium phosphates with irrigation water. Spray applications of similar salts are usually not

recommended because of the large number required to supply enough P.

2.6.8.8 Potassium (K)

2.6.8.8.1 Deficiency Symptoms

Deficient plants are stunted and have thin, spindly stems and pale green, yellow-tipped foliage.

The lower leaves may wilt and lie on the surface of the soil or may die and turn brown if the

deficiency is severe. Tiller production is usually not affected by mild deficiency. However, if it

persists or becomes severe, many young tillers die before producing heads, while mature tillers

produce small heads that set few grains.

Marginal yellowing on older leaves: Because K is readily transferred from old to young leaves when a deficiency occurs, symptoms appear first and are more severe on old leaves, working up

the plants to younger leaves if the deficiency persists. The youngest leaves usually remain green

and appear healthy. On old leaves, symptoms appear on the tips and advance along the margins

toward the bases, usually leaving the mid-veins alive and green. The symptoms become clearly

recognizable only when a deficiency is severe. In mild deficiencies, leaves may be pale green and

appear limp or wilted and lack other signs of disorder. When a deficiency is severe, the tips and

margins of older leaves become bright yellow or dull yellow-brown. Eventually the affected tissue

dies and turns dark brown, giving the leaf margins a ragged appearance.

2.6.8.8.2 Problem Soils

Potassium deficiency is likely to occur in: • Mineral soils low in organic matter after many years of cropping • Sandy soils formed from parent material low in K • Light textured soils whose original K has been leached by rainfall

2.6.8.8.3 Correcting Deficiency

Potassium deficiency is corrected by applying potassium nitrate, sulfate, or chloride to the soil at or before

sowing. Crop yield depends on the amounts of water-soluble and exchangeable K in the soil. Tests can

estimate the amount of available K in the soil and predict the amount of fertilizer required. The best

prediction can be obtained by seeking advice on fertilizer practices used on similar soils in the district.

Potassium deficiency in existing crops can be corrected by applying soluble K salts such as

potassium sulfate, chloride, or nitrate with irrigation water. The foliar application of similar salts is usually not recommended because of the large number of sprays needed to supply crop requirements.

2.6.8.9 Sulfur (S)

2.6.8.9.1 Deficiency Symptoms

Sulfur deficiency causes stunted growth, delayed maturity, and yellowing of leaves. In young crops

or when the deficiency is mild, stunting is limited. The first symptom of a deficiency is general

yellowing over the whole plant followed by severe symptoms developing on upper leaves. In the

green. The yellowing is not confined to areas between the veins and affects entire leaves. Leaf

tissue usually does not die even when the leaves have turned white.

2.6.8.9.2 Problem Soils

Sulfur deficiency is likely to occur in: • Mineral soils low in organic matter after many years of cropping • Soils formed from parent material low in S (for example, some volcanic rocks and ash) • Acid sandy soils whose original sulfates have been removed by leaching

2.6.8.9.3 Correcting Deficiency

Soil dressings of any S fertilizer will correct deficiencies. Elemental S (flowers of sulfur) can be

broadcast and thoroughly mixed into the soil about 4 months before sowing. Gypsum (calcium

sulfate) is another useful source of S.

In soils not subject to heavy leaching, tests can estimate the amount of available sulfate before

sowing and predict the amount of fertilizer required. The best prediction can be obtained by seeking

advice on fertilizer practices used on similar soils in the district.

Sulfur deficiency in existing crops can be corrected by applying soluble sulfate salts such as mag

nesium, ammonium, or potassium sulfate in irrigation water. Foliar sprays of similar salts are usually not

recommended because of the large number of applications needed to supply crop requirements.

2.6.8.10 Zinc

2.6.8.10.1 Deficiency Symptoms

Zinc-deficient crops often appear patchy, with deficient plants adjacent to well grown, apparently

healthy plants. Deficient plants are stunted and have short, thin stems and usually pale green foliage.

If the deficiency continues and becomes severe, plants cease growth and often develop a grass

tufted appearance. Tiller production is usually normal in mild deficiencies but many young tiers

die without developing heads if the deficiency persists. When it is severe, tillering is greatly reduced

and the few heads produced may have little or no grain.

Chlorosis and necrosis of middle leaves: Zinc is partly mobile in wheat and triticale and the

first symptoms originate halfway up the middle leaves. The youngest leaves at the top and the oldest

at the base of the shoots may be unaffected initially, but will develop symptoms if the deficiency

persists. Symptoms appear in the lower halves of the leaves, commencing as yellow chlorotic areas

between the mid-veins and leaf margins and extending outward toward the tips and bases. These

chlorotic areas eventually die and turn pale grey or brown. The affected areas may remain discrete,

producing separate, linear brown or grey lesions or they may join, involve the mid-veins, and result in the deaths of the central areas of the leaves, leaving the tips, bases, and margins green.

Chlorotic and necrotic lesions on the leaf sheath: Similar chlorotic areas and grey lesions may

develop on the leaf sheaths when a deficiency is severe.

2.6.8.10.2 Problem Soils

Zinc deficiency is likely to occur in: • Strongly alkaline soils whose availability of Zn is depressed • Leached sandy soils whose total Zn is low • Leveled soils whose Zn-deficient subsoils may be exposed on the surface • Soils in which heavy, frequent applications of phosphatic fertilizers may have reduced crop use of Zn

zinc chelates, sulfates or oxides should be broadcast and mixed into soil 2 to 3 months before

sowing. While soil dressings usually remain effective for 6 to 8 years before more are needed,

foliar sprays have no residual effects and fresh applications must be made to each crop. Best results

are obtained when two sprays of a 0.5 to 1% solution of a soluble Zn salt such as zinc sulfate

heptahydrate (0.5 to 1 kg Zn salt per 100 L water per ha) are applied about 2 weeks apart, the first

applied 2 to 3 weeks after seedling emergence.

Soil tests estimate the amount of available Zn in a soil and predict whether fertilizer is needed.

The best prediction can be obtained by seeking advice on fertilizer practices used on similar soils

in the district.

2.6.9 SALINITY 2

2.6.9.1 Saline Toxicity

2.6.9.2 Problem Soils

Sodium chloride toxicity is more likely to occur in: •

Saline soils formed from salt water sediments • Previously fertile soils that were flooded or heavily irrigated with water containing high concentrations of NaCl

2.6.9.3 Correcting Toxicity

Leaching with good quality irrigation water is the most effective means of removing excess Na

and Cl from the soil. The water table may have to be lowered. Permeable soils such as well structured

sandy soils are often easily reclaimed, but the problem is more difficult in less permeable soils (for

example, poorly structured heavy clays).

TABLE 2.107

Effects of Salinity on Wheat Appearance Causal Factors

Unthrifty, low-yielding

crops Excessive NaCl leads to short, stunted plants that have generally short, erect leaves. Affected plants have a harsh, droughty appearance, short, spindly stems, and bluish-green foliage. Young plants may appear only droughted. Older leaves of more mature plants may be brown and dead and lie on the soil surface around the bases of the plants. Tiller production may not be affected but if the toxicity persists, many young tillers die before maturity. On mature tillers, heads are small and set few grains.

Dull yellow leaf tips on

older leaves The leaf tips of old leaves turn dull yellow due to the accumulation of excess NaCl in tissues that transpired the greatest amounts of water during the life of the plant. Symptoms appear first and are more severe on the oldest leaves, working up the plants to younger leaves as the toxicity persists. The leaves are shorter than normal and appear harsh and wilted. They are carried erect and are dark green or dull bluish-green. The tips of the oldest leaves turn dull, dark yellow then die and turn pale brown. As the toxicity worsens, the chlorosis and necrosis advance down the leaves, usually along the margins, until entire leaves die.

Red-purple awns In awned wheats, the glumes and awns may develop reddish-purple areas.

rooting depths of the plants. If irrigation water is to be used to leach the Na, the quality of the

water should be checked before use to make sure it is not saline. Where excess NaCl cannot be

wholly corrected by leaching, a more tolerant species may have to be grown.

2.6.10 WEIGHTS AND MEASURES

A bushel of wheat grain weighs 60 lb (27.2 kg).

1. U.S. Department of Commerce, U.S. Wheat History, 1979, U.S. Government Printing Office, Washington, D.C.

2. Grundon, N.J., Hungry Crops: A Guide to Nutrient Deficiencies in Field Crops, 1987, Queensland Department of Primary Industries, Brisbane, Australia.

TABLE 2.108 Wheat Seeds/Pound, Weight/Bushel, and Germination Time

Seeds/lb (1,000)	Seeds/g (no.)	Weight/bu (lb)	Germination time (days)
12–20	35	60	7

TABLE 2.109 Weight and Standard Yield of Level Full Bushel of Wheat Grain

Weight of 1 Measured Bushel (lb)	Multiplication Factor to Yield Standard Bushel
64	1.07
62	1.03
60	1.00
58	0.97
56	0.93
54	0.90
52	0.87
50	0.83
48	0.80
46	0.77
44	0.73
42	0.70
40	0.67

3 Chapter 3. Nut, Bean, and Oil Crops

3.2 SOYBEAN [Glycine max (L.) Merr.]

3.2.1 I NTRODUCTION

Soybeans belong to the Fabaceae or Leguminosae pea family. The soybean is known as soya in

French, soja in Spanish and Italian, and sojaböhne in German. Soybean culture dates back to 2,500

B.C. The plant is native to eastern Asia, Australia, and several Pacific Islands and is also called

Chinese pea, Manchurian bean, Japan pea, Japan bean, and Japanese fodder plant. The soybean was introduced to Europe in the early 1700s and to North America in 1765. It

was grown as a forage crop in the U.S. until World War II. The acreage harvested for seed (beans)

by 1930 was less than 25% of total acres planted; it increased to 40% by 1939. By 1944, the

acreage harvested for the beans had increased to 74%. Today, most plants are harvested for their

beans to be used primarily for meal and oil. In 1999, 171 million short tons of soybean oil were

produced and represented 52% of all vegetable oil produced. Soybean adapts to a wide range of climatic conditions, but is very susceptible to drought damage

during flowering and grain filling. The U.S. is the leading soybean-growing country (72.7 million acres in 2000). It provides about

two-thirds of the world's soybeans, followed by China, India, and Indonesia. Other major soybean

growing countries are Nigeria, Russia, North Korea, Italy, and Thailand. In 1983, the highest

verifiable soybean grain yield of 118 bu per acre was recorded in New Jersey. The U.S. average

yield in 2000 was 38.1 bu per acre. Soybean oil contains no cholesterol and has one of lowest levels of saturated fat among

vegetable oils. The soy foods business in the United States is a $2.5 billion industry and growing.

The products are soy milks, cheeses, and yogurts as dairy subsitutes, soy butter, corn dogs, and

soyburgers. They require 6.5 million bu of soybeans and the number is projected to rise to 12.29

million bu by 2010. Speciality items, such as infant formula, nutritional supplements and bars,

beverages and nutraceuticals or functional foods use 12.4 million bu and are projected to require

50 million bu by 2010.

3.2.2 VEGETATIVE AND PRODUCTIVE STAGES

TABLE 3.12

Vegetative Stages

Stage Abbreviated Title Description VE Emergence Cotyledons above the soil surface VC Cotyledon Unifoliolate leaves unrolled sufficiently so the leaf edges do not touch. V1 First node Fully developed leaves at unifoliolate nodes V2 Second node Fully developed trifoliolate leaf at node above unifoliolate nodes V3 Third node Three nodes on the main stem with fully developed leaves beginning with the unifoliolate nodes V(n) nth node Number of nodes on the main stem with fully developed leaves beginning with the unifoliolate nodes; n can be any number beginning with 1 for V1, first node stage

Source: Stages of Soybean Development, Iowa State University, Ames. Reproductive Stages Stage Abbreviated Title Description R1 Beginning bloom One open flower at any node on the main stem R2 Full bloom Open flower at one of the two uppermost nodes on the main stem with a fully developed leaf R3 Beginning pod Pod 5 mm (3/16 in.) long at one of the uppermost nodes on the main stem with a fully developed leaf R4 Full pod Pod 2 cm (3/4 in.) long at one of the four uppermost nodes on the main stem with a fully developed leaf. R5 Beginning seed Seed 3 mm (1/8 in.) long in pod at one of the four uppermost nodes on the main stem with a fully developed leaf. R6 Full seed Pod containing a green seed that fills the pod cavity at one of the four uppermost nodes on the main stem with a fully developed leaf R7 Beginning maturity One normal pod on the main stem that has reached its mature pod color R8 Full maturity 95% of the pods have reached their mature pod color; 5 to 10 days of drying weather are required after R8, before the soybeans have less than 15% moisture Source: Stages of Soybean Development, Iowa State University, Ames. TABLE 3.14 Comparison of Determinate and Indeterminate Soybeans Determinate Indeterminate Little growth in height after flowering Will usually double in height during flowering Flowers occur about the same time throughout the plant Will flower at new nodes; flowering, pod, and seed development occur at same time Pods and seeds develop uniformly throughout the plant Pods and seeds develop from lower nodes upward Terminal leaves are approximately the same size as lower leaves Terminal leaves are smaller than lower leaves Terminal nodes on main stem usually have long, flowering stalks and several pods Few pods at terminal node

3.2.3 SOYBEAN PRODUCTS, STANDARDS, AND GRADES

3.2.3.1 Soybean Processing Products

The National Soybean Processors Association defined product standards as follows:

Soybean cake or chip The product remaining after extraction of part of the oil by pressure or solvents. A term descriptive of the process of manufacture, such as expelled, hydraulic, or solvent-extracted shall be used in the brand name. The product is designated and sold according to its protein content.

Soybean meal Ground soybean cake, ground soybean chips, or ground soybean flakes. A term descriptive of the process of manufacture, such as expelled, hydraulic, or solventextracted, shall be used in the brand name. The product is designated and sold according to its protein content.

Soybean mill feed The by-product resulting from the manufacture of soybean flour or grits; composed of soybean hulls and the offal from the tail of the mill. A typical analysis is 13% crude protein, 32% crude fiber, and 13% moisture.

Soybean mill run The product resulting from the manufacture of dehulled soybean meal; composed of soybean hulls and bean meals that adhere to the hull in normal milling operations. A typical analysis is 11% crude protein, 35% crude fiber, and 13% moisture.

Soybean hull The product consisting primarily of the outer covering of the bean.

Solvent-extracted soybean flake The product obtained after extracting part of the oil by using hexane or homologous hydrocarbon solvents. The product is designated and sold according to its protein content.

Soybean flake and 44% protein soybean meal These are produced by cracking and heating soybeans and reducing the oil content of the conditioned product by using hexane or homologous hydrocarbon solvents. The extracted flakes are cooked and marketed as flakes or ground into meal. Typical analysis is minimum protein, 44%; minimum fat, 0.5%; maximum fiber, 7%; and maximum moisture, 12%.

Ground soybean Product obtained by grinding whole soybeans without cooking or removing any oil.

Ground soybean hay Ground plant that includes leaves and beans. It must be reasonably free of other crop plants and weeds and contain not more than 33% crude fiber.

Soybean feed, solvent-extracted The product remaining after partial removal of protein and nitrogen-free extract from dehulled solvent-extracted soybean flakes.

Heat processed (dry roasted) soybeans The product resulting from heating whole soybeans without removing any of the component parts. The product may be ground, pelleted, flaked, or powdered and must be sold according to its crude protein content.

Soy protein concentrate Concentrate prepared from high quality sound, clean, dehulled soybean seeds by removing most of the oil and water-soluble nonprotein constituents; must contain not less than 70% protein on a moisture-free basis.

Kibbled soybean meal The product obtained by cooking ground, solvent-extracted soybean meal under pressure and extruding from an expeller or other mechanical pressure device. It must be designated and sold according to its protein content and contain not more than 7% crude fiber. sold according to its crude protein, fat, and fiber content.

Soy grits Granu!ar material remaining from the screened and graded product after removal of most of the oil from selected, sound, clean, and dehulled soybeans by a mechanical or solvent extraction process.

Soy flour Finely powdered material resulting from the screened and graded product after removal of most of the oil from selected, sound, cleaned, and dehulled soybeans by a mechanical or solvent extraction process.

3.2.3.2 U.S. Standards and Grades

3.2.3.2.1 Definition of Soybean

Grain that consists of 50% or more of whole or broken soybeans (Glycine max (L.) Merr.) that

will not pass through an 8/64 round-hole sieve and not more than 10% of other grains for which

standards have been established under the U.S. Grain Standards Act.

3.2.3.2.2 Other Terms

Classes The two classes of soybeans are yellow and mixed.

Yellow soybeans Soybeans that have yellow or green seed coats. In cross-section, they are yellow or have a yellow tinge, and may include not more than 10% soybeans of other colors.

Mixed soybeans Soybeans that do not meet the requirements of the yellow soybean class.

Damaged kernels Soybeans and pieces of soybeans that are badly ground damaged, badly weather damaged, diseased, frost damaged, germ damaged, heat damaged, insect bored, mold damaged, sprout damaged, stinkbug stung, or otherwise materially damaged. Stinkbug stung kernels are considered damaged at the rate of 1/4 of the actual percentage of the stung kernels.

Foreign material All matter that passes through an 8/64 round-hole sieve and all matter other than soybeans remaining in the sample after sieving according to procedures prescribed in Federal Grain Inspection Service instructions.

Heat damaged kernels Soybeans and pieces of soybeans that are materially discolored and damaged by heat.

Purple mottled or stained kernels Soybeans that are discolored by the growth of fungus or by dirt or dirt-like substances, including nontoxic inoculants or other nontoxic substances.

Sieve (8/64 round-hole) Metal sieve 0.032 in. thick; perforated with 0.125 in. diameter round holes.

Soybeans of other colors Soybeans that have green, black, brown, or bicolored seed coats. Soybeans with green seed coats will also be green in cross-section. Bicolored soybeans will have seed coats of two colors, one of which is brown or black and covers 50% of the seed coats. The hilum of a soybean is not considered a part of the seed coat for this determination.

Split Undamaged soybean with more than 1/4 of the bean removed.

3.2.4 PRODUCTION STATISTICS TABLE 3.15 U.S. Soybean Acreage, Yield, and Production, 1991–2000 Year Harvested Area (1,000 acres) Yield (bu/acre) Production (1,000 bu) 1991 56,011 34.2 1,986,539 1992 58,233 37.6 2,190,354 1993 57,307 32.6 1,669,718 1994 60,809 41.4 2,514,669 1995 61,544 35.3 2,174,254 1996 63,349 37.6 2,380,274 1997 69,110 38.9 2,686,750 1998 70,441 38.9 2,741,014 1999 72,446 36.6 2,653,758 2000 72,718 36.1 2,769,665 Source: National Agriculture Statistics Service, Washington, D.C., 2001. TABLE 3.16 World Soybean Production, 1950–2000 Year Total (million tons) Per Person (kg) Year Total (million tons) Per Person (kg) 1950 17 6.5 1984 93 19.5 1955 19 7.0 1985 97 20.0 1960 25 8.2 1986 98 19.8 1965 32 9.5 1987 103 20.6 1970 44 11.9 1988 96 18.7 1971 47 12.5 1989 107 20.6 1972 49 12.7 1990 104 19.7 1973 62 15.9 1991 107 20.0 1974 55 13.6 1992 117 21.5 1975 66 16.1 1993 118 21.3 1976 59 14.3 1994 138 24.5 1977 72 17.1 1995 125 22.0 1978 78 18.0 1996 132 22.9 1980 81 18.1 1997 158 27.0 1981 86 19.0 1998 160 27.0 1982 94 20.3 1999 158 26.3 1983 83 17.7 2000 167 27.5 Note: Preliminary. Source: U.S. Department of Agriculture electronic database, December 2000. Leading Soybean-Growing States: Acreage, Yield, and Production, 2000 State Acres Harvested (1,000) Yield (bu/acre) Production (1,000 bu) Iowa 10,680 43.0 459,240 Illinois 10,450 44.0 459,800 Minnesota 7,150 41.0 293,150 Indiana 5,630 46.0 258,980 Missouri 5,000 35.0 175,000 Nebraska 4,575 38.0 173,850 Ohio 4,440 42.0 186,480 South Dakota 4,370 35.0 152,950 Arkansas 3,200 26.0 83,200 U.S. Total 72,718 38.1 2,769,665 Source: National Agriculture

Statistics Service, Washington, D.C., 2001. TABLE 3.18 Soybeans: Area, Yield, and Production by Continent and Country, 1999–2000 Location Area (1,000 ha) Yield (metric tons/ha) Production (1,000 metric tons) Continent North America 30,399 2.47 75,124 South America 23,769 2.42 57,413 Central America 27 2.63 71 European Union 365 3.12 1,140 Eastern Europe 270 2.47 666 Soviet Union 481 0.79 379 Middle East 113 1.65 186 Africa 830 0.71 586 Asia 15,883 1.39 21,999 Oceania 50 2.20 110 Country China 8,180 1.78 14,290 India 5,645 0.92 5,200 Indonesia 1,140 1.19 1,360 Nigeria 550 0.29 160 Russia 439 0.76 334 North Korea 300 1.00 300 Italy 239 3.41 814 Thailand 220 1.50 330 World Total 72,189 2.18 157,682 Source: Foreign Agriculture Service, Washington, D.C.

FIGURE 3.2 World soybean production, 1930–2000. (Source: Vital Signs 2001, Worldwatch Institute, W.W.

Norton, New York.)

FIGURE 3.3 World soybean production per person, 1950–2000. (Source: Vital Signs 2001, Worldwatch

Institute, W.W. Norton, New York.)

FIGURE 3.3 World soybean area harvested, 1950–2000. (Source: Vital Signs 2001, Worldwatch Institute,

W.W. Norton, New York.)

3.2.5 FERTILIZER AND NUTRIENT ELEMENT UPTAKE

FIGURE 3.4 Production of soybeans and value of production, 1991–2000. TABLE 3.19 Percentages of Areas Receiving Fertilizer Applications, All States Surveyed, 1995–1999 a Year Nitrogen Phosphate Potash 1995 17 22 25 1996 15 25 27 1997 20 26 33 1998 17 24 27 1999 18 26 28 a Acres receiving one or more applications of a specific fertilizer ingredient. Source: National Agriculture Statistics Service, Washington, D.C., 2001. TABLE 3.20 Uptake of Major Nutrient Elements for a 4-Ton/Acre Soybean Crop Major Element Weight (kg) Nitrogen 350 Phosphorus as phosphate 65 Potassium as potash 180 Calcium 29 Magnesium 27 Sulfur 22 Source: International Soil Fertility Manual, 1995, Potash & Phosphate Institute, Norcross, GA. With permission.

3.2.6 NUTRIENT ELEMENT SUFFICIENCY

3.2.7 COMPOSITION OF SEED Nutrient Element Utilization (lb/acre) by 40- and 60-Bu/Acre Soybean Crops Nutrient

Element Nitrogen Phosphorus Potassium Magnesium Sulfur 40 bu/A 224 53 97 18 17 60 bu/A 324 64 142 27 25 TABLE 3.22 Soybean Nutrient Element Sufficiency Ranges a Major Elements Sufficiency Range % Nitrogen 4.00–5.50 Phosphorus 0.25–0.50 Potassium 1.70–2.50 Calcium 0.35–2.00 Magnesium 0.25–1.00 Sulfur 0.20–0.40 Micronutrients ppm Boron 20–55 Copper 10–30 Iron 50–350 Manganese 20–100 Molybdenum 1.0–5.0 Zinc 20–50 a Sampling procedure: 25 mature leaves from new growth prior to pod set. Source: Plant Analysis Handbook II: A Practical Sampling, Preparation, Analysis, and Interpretation Guide, 1996, MicroMacro Publishing, Athens, GA. With permission. TABLE 3.23 Nutritive Values of Whole Soybean Seed Component Value Calories/100 g 403 Protein, % 34.1 Fat, % 17.7 Total calcium, mg/lb 226 Total phosphorus, mg/lb 554 Total potassium, mg/lb 1,677 Carbohydrates, % 33.5

3.2.8 NUTRIENT ELEMENT DEFICIENCIES 2

3.2.8.1 Boron (B)

3.2.8.1.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Boron-deficient crops show poor growth, lack vigor, and yield poorly.

Affected plants are very stunted and have stout stems and dark green leaves. If the deficiency

persists and becomes severe, plants may die before setting pods. Mild deficiencies reduce branching

and plant size and interfere with pollination and seed set, resulting in reduced grain yields. Severely

deficient plants may either fail to branch or develop only a few flowers and pods, thereby producing

little or no grain. Interveinal chlorosis and necrosis of young leaves: Because B is not transferred from old to

young leaves, symptoms develop first and are more severe on young leaves and are most severe

on leaves that are still growing. Young leaves turn pale green and develop pale yellow interveinal

chlorosis. Dark brown necrotic lesions appear in the chlorotic tissues. Old leaves remain dark green and appear healthy. Deformed younger leaves: On severely affected plants, leaflets on the young leaves become

deformed. The tips and sometimes the margins of the leaflets curl down and under. Shortened internodes and deaths of buds: Boron deficiency greatly affects the growth of

internodes and the development of apical and axillary buds. The upper internodes of the stems

of affected plants are shortened, giving mildly deficient plants a rosette appearance. On severely

deficient plants, the apical and axillary buds die and the young, undeveloped leaves or flowers

turn pale brown.

3.2.8.1.2 Problem Soils

Boron deficiency is likely to occur in: • Soils derived from parent material low in B, such as acid igneous rocks or fresh water sediments • Sandy soils from which B has been leached by heavy rainfall • Alkaline soils, especially those containing free lime • Soils low in organic matter • Acid peat and muck soils

3.2.8.1.3 Correcting Deficiency

Deficiencies can be corrected by applying soil dressings or foliar sprays of B fertilizers. Soil

dressings are more effective if broadcast and mixed into the soil some months before sowing.

Borax, boric acid, and chelated B compounds are suitable for soil application. Boric acid and

chelated B compounds are suitable for foliar sprays and should be applied 5 to 6 weeks after Composition of Soybean Seed Substance % Protein 34.1 Carbohydrate 33.5 Fat 17.7 Water 10.0 Ash 4.7 Tests can estimate the amount of available B in a soil and predict whether fertilizer is needed.

The best prediction can be obtained by seeking advice on fertilizer practices used on similar soils

in the district.

3.2.8.2 Calcium (Ca)

3.2.8.2.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Calcium deficiency causes poor crop growth and can kill plants when

severe. Affected plants are stunted and have short internodes, stout stems, and dark green, often

distorted, leaves. If the deficiency occurs in old plants, the young leaves may develop yellow

discolorations. Branching is reduced or even prevented if the deficiency is severe. Pod set may be

severely reduced even by mild deficiencies. As a result, grain yields can be much lower than usual. Deaths of young buds: Because Ca is not transferred from old to young tissues, symptoms are

more severe on the youngest leaves that are still developing from buds. When a deficiency is severe,

the youngest leaves and bud meristems die and turn brown. Distorted young leaves: In young plants, the first leaves are distorted. Their tips fail to expand

and become chlorotic, then develop pale brown necrosis. Tissue between the veins continues to

expand, causing the margins to be cupped upward or downward. The bud meristems usually die

quickly if the deficiency persists. Chlorosis and necrosis of veins: When severe deficiencies develop in old plants, the bud

meristems die and turn brown. The larger veins on young leaflets then become necrotic and turn

brown. Yellow chlorosis develops in tissue adjacent to necrotic veins.

3.2.8.2.2 Problem Soils

Calcium deficiency is likely to occur in: • Acid sandy soils from which Ca has been leached by heavy rainfall • Strongly acid peat and muck soils that have low total Ca •

Alkaline or sodic soils in which exchangeable Na and pH are high and depress plant uptake of Ca • Soil with high levels of soluble Al and low levels of exchangeable Ca

3.2.8.2.3 Correcting Deficiency

Calcium deficiency can be corrected by broadcasting a suitable fertilizer and mixing it into the

soil some months before sowing. Where the problem is strictly a lack of Ca, suitable fertilizers

are gypsum (calcium sulfate) and calcium nitrate or chloride. However, if the soil pH is low,

lime, limestone (calcium carbonate), and dolomite (a mixture of calcium and magnesium car

bonates) are more suitable. A soil test can determine the lime or Ca requirements of a soil. However, since the correct rate

of application depends on soil type and the crop to be grown, advice should be sought on fertilizer

practices used on similar soils in the district. The excessive use of lime may induce deficiencies

of K, Mg, Fe, Mn, Zn, and Cu so care should be taken to prevent overliming.

3.2.8.3 Iron (Fe)

3.2.8.3.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Soybeans seem to be relatively sensitive to Fe deficiency and affected

crops are unthrifty and lack vigor. The plants are stunted and have thin, spindly stems, yellow

young leaves, and dark green old leaves. Mild Fe deficiencies may not seriously reduce branching, Interveinal chlorosis on younger leaves: Because Fe is not readily transferred from old to young

leaves, symptoms develop first and are more severe on leaflets of young leaves. The youngest, still

expanding leaves are often the most severely affected if a deficiency persists. In mild deficiencies,

pale yellow chlorosis develops in the interveinal areas of young leaflets. The veins remain green

and easily seen. As the deficiency worsens, the veins fade and the chlorosis expands over entire

leaflets. Old leaves remain dark green and appear healthy. Necrotic lesions on veins of younger leaves: On severely affected plants, dark brown lesions

develop on the veins of young leaflets. The lesions are more prominent on the undersurface of the

leaflet and usually appear after the veins have turned yellow. The interveinal areas of affected

leaflets may be puckered and the tips and margins of the leaflets curl down under the lamina. Necrotic lesions on petioles and laminae of younger leaves: As symptoms develop, pale brown

necrotic lesions appear on the petioles and margins of leaflets of younger leaves. These symptoms

develop only after the whole leaves turn yellow and they can be used to distinguish between Fe

and S deficiencies.

3.2.8.3.2 Problem Soils

Iron deficiency is likely to occur in: • Alkaline soils in which levels of soluble Fe are low • Waterlogged soils • Acid soils with excessively high levels of soluble Mn, Zn, Cu, and Ni that depress Fe uptake • Sandy soils low in total Fe • Peat and muck soils whose organic matter ties up Fe

3.2.8.2.3 Correcting Deficiency

While dressings of inorganic Fe salts such as sulfates or chlorides have corrected deficiencies in

some soils, the applied Fe quickly becomes insoluble and less available to plants. Iron salts of

organic chelates are more promising as soil dressings because the chelate has the property of keeping Fe in solution. For acid soils, FeEDTA is the most effective chelate. FeHEDTA and FeDTPA

are best on neutral soils and FeEDDHA is best for alkaline soils. However, large amounts of chelates

may be required and this may prove too costly. An equally effective remedy is to apply solutions of inorganic salts or chelates to the foliage

(1% solutions or 1 kg salt per 100 L water per ha). Because Fe is so immobile in plants, sprays

may need to be applied every 10 to 15 days to provide Fe to new leaves. Advice on fertilizer

practices used on similar soils in the district should be sought to obtain the best remedy for the

affected crop under local conditions.

3.2.8.4 Magnesium (Mg)

3.2.8.4.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Magnesium-deficient crops lack vigor and are pale green. Affected

plants are slightly shorter than usual with thin, spindly stems and pale green to yellow leaves.

Although branching is not reduced initially, deficient plants set fewer pods. The pods contain fewer

seeds than usual and thereby reduce grain yields. Interveinal chlorosis of older leaves: Symptoms begin as pale yellow, interveinal mottling on

leaflets of middle leaves and spread rapidly to older leaflets. If the deficiency persists, these

symptoms advance up the stems to younger leaflets.

the margins. The veins remain green and tissue near the veins may appear puckered.

3.2.8.4.2 Problem Soils

Magnesium deficiency is likely to occur in: • Acid sandy soils from which Mg has been leached • Strongly acid peat and muck soils that have low total Mg • Soils that have been over-fertilized with Ca (for example, lime) or K, thus inhibiting Mg uptake

3.2.8.4.3 Correcting Deficiency

Magnesium deficiency on acid soils is corrected by broadcasting dolomite (a mixture of calcium

and magnesium carbonates) and mixing it into the soil some months before sowing. When the

problem is only a deficiency of Mg, band applications of magnesium sulfate or chloride can be

made at or before planting. Tests can estimate the amounts of soluble and exchangeable Mg in the soil, and predict the

amount of fertilizer needed. The best prediction can be obtained by seeking advice on fertilizer

practices used on similar soils in the district. Magnesium deficiency in existing crops can be corrected by applying soluble salts, such as

magnesium sulfate, chloride, or nitrate, with irrigation water. Foliar sprays of similar salts are

usually not recommended because of the large number of applications needed to meet crop require

ments.

3.2.8.5 Manganese (Mn)

3.2.8.5.1 Deficiency Symptoms

Patchy, low-yielding crops: Soybeans are sensitive to Mn deficiency and affected crops often

appear patchy. Plants in Mn-poor areas are stunted and have short, thin stems and pale green to

yellow foliage. Affected plants produce less grain because branching is reduced and fewer pods

are developed. Mottled, interveinal chlorosis on younger leaves: Leaflets on the youngest leaves turn pale green and pale yellow mottling develops in interveinal areas. The veins remain green. Old

leaves remain green and appear. This pattern of development occurs because manganese is not

transferred from old to young leaves, and symptoms develop first and are more severe on

younger leaves. Brown necrotic lesions on younger leaves: As symptoms develop, small, brown lesions appear

between the veins and the leaflets often curl downward. Leaf fall of younger leaves: If a deficiency persists and becomes very severe, the affected young

leaflets readily fall off, leaving bare stems and petioles on the upper parts of the plants. Mildly

affected and healthy green leaves remain on the lower parts.

3.2.8.5.2 Problem Soils

Manganese deficiency is likely to occur in: • Strongly alkaline soils in which Mn is less available to plants • Poorly drained soils with high organic matter content in which Mn is tied up in forms less available to plants • Strongly acid sandy soils from which soluble Mn has been leached by heavy rain • Soils formed from rocks low in Mn

Soil dressings are more effective when broadcast and mixed into the soil some weeks before

sowing. However, foliar applications have generally been more successful. One or more foliar

sprays of 0.5 to 1% solutions of soluble Mn salts (for example, 0.5 to 1 kg manganese sulfate

per 100 L water per ha) usually correct the deficiency, the first to be applied 5 to 6 weeks after

seedling emergence. If the symptoms reappear, sprays should be repeated immediately. While

soil dressings usually last 5 to 6 years before fresh applications are needed, foliar sprays must

be reapplied to every crop. Tests can estimate the amount of available Mn in a soil and predict whether fertilizer is needed.

The best prediction can be obtained by seeking advice on fertilizer practices used on similar soils

in the district.

3.2.8.6 Nitrogen (N)

3.2.8.6.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Rhizobium bacteria normally live in symbiosis with soybeans in the

nodules attached to roots. The bacteria can fix atmospheric N_2 and supply all or most N requirements

of the plant so N deficiencies are rare. However, they can occur if a crop is sown in N-deficient

soil and the proper bacteria are not present naturally in the soil or not supplied at sowing, or if soil

conditions prevent the bacteria from fixing N_2 . Affected plants are stunted and have thin, spindly

stems and small, pale green to yellow leaves. Deficient plants branch less profusely and set fewer

pods that contain fewer seeds, resulting in low grain yields. Pale yellow older leaves: Because N is readily transferred from old to young leaves, symptoms

appear first and are more severe on old leaves, working up the plants to younger leaves if the

deficiency persists. Young leaves remain pale green while old leaves fade from pale green through

pale yellow to almost white. Eventually, the leaflets on affected leaves die, turn pale brown, and

fall readily from the petioles. Downward pointing leaflets: On healthy plants, the leaflets are carried in a horizontal plane,

but on deficient plants, leaflets are often held with tips pointed toward the ground.

3.2.8.6.2 Problem Soils

Nitrogen deficiency is likely to occur in: • Sandy soils that have been leached by heavy rainfall or excessive irrigation • Soils low in organic matter • Soils with a long history of cropping, whose N supplies have been exhausted Even fertile soils may suffer temporary N deficiency when double-cropped, heavily leached,

or waterlogged.

3.2.8.6.3 Correcting Deficiency

When soybeans are grown for the first time in a particular field, it is essential to treat the seeds

before planting with a culture of the specified N_2 -fixing bacteria. In some soils it may be advisable

or even necessary to innoculate subsequent crops to ensure effective nodulation. If, for any

reason, nodulation fails, N deficiency in existing crops can be corrected by applying soluble salts

such as urea with irrigation water or as a foliar spray. Spray applications usually result in a rapid,

short-lived response, and additional sprays 10 to 14 days apart may be necessary to meet crop

N requirements.

3.2.8.7.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Soybeans demand high levels of P and young plants develop easily

recognizable symptoms. Affected crops lack vigor. The plants are stunted and have thin, spindly stems

and small, bluish-green leaves. Phosphorus deficiency delays maturity and reduces branching, the

number of pods produced, and the number of seeds per pod. As a result, grain yields can be severely

reduced. Brown necrotic lesions on older leaves: Symptoms are clearly recognizable even when a

deficiency is mild. All leaves are dull bluish-green, and the leaflets are smaller than usual. Small,

dark brown necrotic lesions appear in interveinal areas on leaflets of old leaves. As the symptoms

develop, the lesions become surrounded by dark yellow chlorosis. The symptoms appear first and

are more severe on old leaves, working up the plants to young leaves if the deficiency continues. Dark yellow older leaves: In severe deficiencies, leaflets of old leaves turn dark yellow and the

interveinal tissue is covered by small, dark brown necrotic lesions. As the leaflets die, they turn

dark orange then brown and fall readily, leaving the petioles attached to the stems. Eventually, the

petioles are shed. Downward pointing leaflets: Older leaflets on healthy plants are carried in a horizontal plane.

On deficient plants the tips of affected leaflets point toward the ground.

3.2.8.7.2 Problem Soils

Phosphorus deficiency is likely to occur in: • Soils low in organic matter • Soils with a long history of cropping and exhausted P supplies • Highly weathered, Fe-rich soils whose phosphate is fixed in less available forms • Soils whose topsoil has been lost through erosion • Alkaline soils whose P may be tied up in insolube phosphates that are less available to plants

3.2.8.7.3 Correcting Deficiency

Phosphorus deficiency can be corrected by applying phosphatic fertilizers to the soil at or before

sowing. Suitable fertilizers are single or triple superphosphates and ammonium phosphates. Growth

depends on the amounts of water-soluble phosphates and the rates of exchange between soluble

and insoluble forms of P in the soil. Tests can estimate the amount of available phosphate in a soil and predict the amount of fertilizer needed. The best prediction can be obtained by seeking advice on fertilizer practices used on similar

soils in the district. Phosphorus deficiency in existing crops can be corrected by applying soluble salts such as

ammonium phosphates with irrigation water. Spray applications of similar salts are usually not

recommended because of the large number needed to supply crop requirements.

3.2.8.8 Potassium (K)

3.2.8.8.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Like other legumes, soybeans have a great need for K. Deficient

crops lack vigor and mature more slowly than usual. Affected plants are short and have thin stems

and pale green older leaves. Potassium deficiency delays branching and reduces the number of pods

set and the number of seeds per pod. Severely deficient plants may produce deformed seeds. Marginal necrosis on older leaves: Symptoms appear first and are more severe on old leaves

because K is readily transferred from old to young leaves when a deficiency occurs. While the

the tips of the leaflets. As more K is withdrawn, the lesions join and advance along the margins

toward the bases of the leaflets. If the deficiency persists, the symptoms move up the plants to

younger leaves. Dark yellow older leaves: When a deficiency is very severe, leaflets on old leaves develop

general, dark yellow chlorosis before dying, turning dark brown, and falling from the plants. Red veins on older leaves: When a sudden, severe deficiency occurs, leaflets on middle and

older leaves may become distorted and develop red lesions on the main veins before other symptoms appear. Reddening of the veins is more noticeable on the undersides. The interveinal tissue becomes

puckered and the tips of the leaflets curl downward. Necrotic lesions on petioles of older leaves: On severely deficient plants, dark brown necrotic

lesions develop on the petioles, which then collapse. The leaves hang down around the stems before

the leaflets die and fall from the plants.

3.2.8.8.2 Problem Soils

Potassium deficiency is likely to occur in: • Soils low in organic matter after many years of cropping • Sandy soils formed from parent material low in K • Light-textured soils from which K has been leached by heavy rainfall

3.2.8.8.3 Correcting Deficiency

Potassium deficiency is corrected by applying potassium nitrate, sulfate, or chloride to the soil

at or before sowing. Crop yield depends on the amounts of water-soluble and exchangeable K

in the soil. Tests can measure the amount of available K and predict the amount of fertilizer

needed. The best prediction can be obtained by seeking advice on fertilizer practices used on

similar soils in the region. Potassium deficiency in existing crops can be corrected by applying soluble K salts, such as

potassium sulfate, chloride, or nitrate, with irrigation water. The foliar application of similar salts

is usually not recommended because of the large number needed to supply crop requirements.

3.2.8.9 Sulfur (S)

3.2.8.9.1 Deficiency Symptoms

Unthrifty, low-yielding crops: Sulfur deficiency causes unthriftiness, lack of vigor and delayed maturity. Whole plants in young crops may be pale green, but in more mature crops, plants

are stunted and have thin stems. Only young leaves are pale green to yellow. Affected plants

produce fewer branches that set fewer pods containing fewer seeds than usual. As a result,

grain yields are reduced. Pale yellow younger leaves: Because S is not readily transferred from old to young leaves,

symptoms appear first and are more severe on young leaves. Old leaves remain green and appear

healthy. In young crops, whole plants may appear pale green and the youngest leaves will be

yellowest. As the crop matures, leaflets on young leaves turn pale yellow while those on old leaves

remain green.

3.2.8.9.2 Problem Soils

Sulfur deficiency is likely to occur in: • Acid, sandy soils from which sulfates have been leached

3.2.8.9.3 Correcting Deficiency

Soil dressings of any S fertilizer will correct deficiencies. Elemental S (flowers of sulfur) may be

broadcast and thoroughly mixed into soil about 4 months before sowing in alkaline soils. Gypsum

(calcium sulfate) is a useful source of S in neutral and acidic soils. Tests can measure the amount of available sulfate in the soil before sowing and predict the

amount of fertilizer required. The best prediction can be obtained by seeking advice on fertilizer

practices used on similar soils in the district. Sulfur deficiency in existing crops can be corrected by applying soluble salts, such as magne

sium, ammonium, or potassium sulfate, in irrigation water.

Foliar sprays of similar salts are usually

not recommended because of the large number of applications needed to supply crop requirements.

3.2.8.10 Zinc (Zn)

3.2.8.10.1 Deficiency Symptoms

Patchy, low-yielding crops: Soybeans are relatively sensitive to Zn deficiency. Affected crops grow

poorly, lack vigor, and mature slowly. The plants are very stunted and have thin, short stems and

pale green, bronzed foliage. Zinc-deficient plants develop fewer pods than normal, resulting in

reduced grain yields. Yellow mottling on older leaves: The earliest symptom is pale yellow mottling in interveinal

areas on leaflets of middle leaves. The yellow mottling then appears in older leaves until they are

all pale yellow; young leaves remain green and appear healthy. If the deficiency persists, these

symptoms move up the plants to younger leaves. Bronze necrosis on older leaves: When a deficiency is very severe, small, bronze necrotic

lesions develop in the chlorotic interveinal areas of old leaflets. The veins remain green but the

leaf edges cup downward and the leaflets point toward the ground. Eventually, the leaflets die, turn

pale brown, and fall readily from the petioles.

3.2.8.10.2 Problem Soils

Zinc deficiency is likely to occur in: • Strongly alkaline soils where the availability of Zn is depressed • Leached sandy soils whose total Zn is low • Leveled soils whose Zn-deficient subsoils may be exposed on the surface • Soils in which heavy applications of phosphatic fertilizers may have reduced the use of Zn by crops

3.2.8.10.3 Correcting Deficiency

Foliar and soil applications of Zn salts have been used to correct deficiencies. Soil dressings of

zinc chelates, sulfates, or oxides should be broadcast and mixed into the soil 2 to 3 months before

sowing. Soil-applied Zn has a residual effect for 6 to 8 years before fresh applications are needed.

Foliar sprays have no residual effects and fresh applications must be made to each crop. Best results

are obtained when a 0.5 to 1% solution of a soluble Zn salt (for example, 0.5 to 1 kg zinc sulfate

heptahydrate per 100 L water per ha) is applied 2 to 3 weeks after seedling emergence. Additional

sprays should be applied as soon as symptoms reappear.

in the district.

3.2.9 MANGANESE AND SODIUM CHLORIDE TOXICITY 2

3.2.9.1 Manganese (Mn) Toxicity

3.2.9.1.1 Symptoms of Toxicity

Unthrifty, low-yielding crops: Soybeans appear to be more tolerant of high levels of Mn than many

other crops. Affected crops lack vigor and show poor growth. Plants are stunted and have short,

stout stems and dark green leaves. If the toxicity persists and becomes severe, branching is reduced

and plants set fewer pods that contain fewer seeds than usual. Necrotic lesions on older leaves: Excess Mn is carried in transpiration streams and accumulates

in older tissues. Symptoms develop first and are more severe on old leaves, working up the stems

to young leaves if the toxicity persists. Leaflets on old leaves remain dark green and develop

pinpoint, red-brown necrotic lesions on their upper surfaces. The lesions tend to concentrate in tissues adjacent to the larger veins. Red-brown lesions: All veins develop red-brown lesions on veins of older leaves when a

deficiency is severe. Although the lesions are more prominent on the undersides, they are easily

seen on the upper surfaces. Yellow mottling on youngest leaves: The leaflets on the youngest leaves are smaller than usual

and develop pale yellow, interveinal mottling. As the leaflets mature, the mottling disappears and

is replaced by red-brown necrotic lesions.

3.2.9.1.2 Problem Soils

Manganese toxicity is likely to occur in: • Strongly acid soils that show increased solubility of Mn • Waterlogged soils in which poor aeration reduces unavailable manganic (Mn^{3+}) ions to manganous (Mn^{2+}) ions that can be taken up by plants

3.2.9.1.3 Correcting Toxicity

Manganese toxicity is usually corrected by management practices that reduce levels of soluble Mn

in soil. If soils are strongly acid, liming to an alkaline reaction will reduce excess levels of soluble

Mn. Drainage of waterlogged soils prevents anaerobic conditions that produce soluble Mn^{2+} ions.

If soils are over-treated with Mn^{2+} fertilizers, heavy leaching with low-Mn irrigation waters or

mulching with organic materials removes soluble Mn.

3.2.9.2 Sodium Chloride (NaCl) Toxicity

3.2.9.2.1 Symptoms of Toxicity

Unthrifty, low-yielding crops: Soybeans are more sensitive to excess NaCl than many other summer

crops. Affected crops show poor growth, lack vigor, and appear harsh and droughty. Plants may appear wilted and have short, thin stems and small, pale green and grey foliage. The number of

pods set and the number of seeds per pod are both reduced and grain yields are low. Droughty, limp appearance: When high soil concentrations of NaCl occur, plants have difficulty

obtaining sufficient water for normal growth. Affected plants often have harsh, droughty appearance

and wilt readily on hot days even when ample water is available. Wilted plants may recover overnight

but eventually permanently wilted.

plants to young leaves if the toxicity persists. Leaflets on older leaves wilt and grey necrosis develops

on the margins near the tips. The necrosis advances rapidly into interveinal areas until only the veins

remain green. If the toxicity persists, the leaflets or entire plants die and turn pale brown.

3.2.9.2.2 Problem Soils

Sodium chloride toxicity is more likely to occur in: • Saline soils formed from salt water sediments • Previously fertile soils that have been flooded or heavily irrigated with water containing high concentrations of NaCl

3.2.9.2.3 Correcting Toxicity

Leaching with good quality irrigation water is the most effective means of removing excess Na

and Cl from soil. The water table may have to be lowered. Permeable soils such as well structured

sandy soils are often easily reclaimed, but the problem is more difficult in less permeable soils (for

example, poorly structured heavy clays). If exchangeable Na in the soil is high, reclamation involves replacement of the adsorbed Na

with Ca by applying gypsum (calcium sulfate) and then leaching the dissolved Na and Cl beyond the rooting depths of the plants. If irrigation water is to be used to leach the Na, its quality should

be checked before use to ensure it is not saline. Where excess NaCl cannot be wholly corrected

by soil leaching, a more tolerant species may have to be grown.

3.2.10 WEIGHTS AND MEASURES

One bushel of soybean grain has an approximate net weight of 20 lb or 27.2 kg. One gallon of

soybean oil has an approximate net weight of 7.7 lb or 3.5 kg.

TABLE 3.25 Weight and Standard Yield of Level Full Bushel of Soybean Grain

Weight of 1 measured bu (lb)	Multiplication factor to yield standard bu
64	1.07
62	1.03
60	1.00
58	0.97
56	0.93
54	0.90
52	0.87
50	0.83
48	0.80
46	0.77
44	0.73
42	0.70
40	0.67

4 Chapter 4. Cotton (spp.) Fiber

1. Smith, C.W., Crop Production: Evolution, History, and Technology, 1995, John Wiley & Sons, New York.

2. Grundon, N.J., Hungry Crops: A Guide to Nutrient Deficiencies in Field Crops, 1987, Queensland Department of Primary Industries, Brisbane, Australia.

TABLE 4.12 Cotton Seeds/lb, Weight/bu, and Germination Time Seeds/lb (1,000) Seeds/g (no.) Weight/bu (lb) Germination Time (days) 4 8 — 12 TABLE 4.13 Cotton Weights and Measures Approximate Net Weight Commodity Unit lb kg Cotton bale, gross 500 227 bale, net 480 218 Cottonseed bushel 32 14.5 Cottonseed oil gallon 7.7 3.5 Source: U.S. Department of Agriculture, Agricultural Statistics, 2001, U.S. Government Printing Office, Washington, D.C.

7 Chapter 7. Physical, Chemical, and Biological Properties of Soils

1. Glossary of Soil Science Terms, 1987, Soil Science Society of America, Madison, WI.

2. Grundon, N.J., Hungry Crops: A Guide to Nutrient Deficiencies in Field Crops, 1987, Queensland Department of Primary Industries, Brisbane, Australia.

8 Chapter 8. Soil pH, Liming, and Liming Materials

TABLE 8.21

Cumulative Relative Frequencies (%) for Soil Test Water pH in North America by Region

Region	Water pH (1:1) 5.0	5.1–5.5	5.6–6.0	6.1–6.5	6.6–7.0	7.1–7.5	7.6–8.0	8.1–8.5	>8.5
North Central (994,652 Samples)	2	8	27	56	80	92	98	100	100
Northeast (45,327 Samples)	5	16	42	73	93	99	100	100	100
Northern Great Plains (124,057 Samples)	0	2	8	18	33	52	82	98	100
Southeast (848,258 Samples)	7	20	48	72	88	97	99	100	100
Southern Great Plains (221,718 Samples)	4	15	31	48	62	75	90	99	100
West (91,249 Samples)	2	7	12	20	31	46	71	96	100

Notes: Regional category averages are means of state or province percentages and are not weighted by number of samples.

North Central: Missouri, Ohio, Kentucky, Illinois, Indiana, Iowa, Michigan, Wisconsin, Minnesota.

Northeast: Prince Edward Island, New Brunswick, Maine, Massachusetts, Delaware, Quebec, New Hampshire, Maryland,

Connecticut, New Jersey, Nova Scotia, Pennsylvania, New York, Vermont.

Northern Great Plains: Alberta, Manitoba, South Dakota, Saskatchewan, North Dakota, Montana.

Southeast: North Carolina, South Carolina, Alabama, Florida, Mississippi, Louisiana, Georgia, Tennessee, Virginia, Arkansas.

Southeast: Oklahoma, Nebraska, Texas, Kansas.

West: Oregon, Washington, Califonia, Colorado, Nevada, New Mexico, Idaho, Utah, Arizona, Wyoming.

Source: Soil Test Levels in North America: Summary Update, PPI/PPIC/FAR Technical Bulletin 2001-1, Potash &

Phosphate Institute, Norcross, GA. With permission.

10 Chapter 10. Plant Mineral Nutrition

1. Arnon, A.I. and Stout, P.R., 1939, The essentiality of certain elements in minute quantity for plants with special reference to copper, Plant Physiol., 14, 371.

2. Best Managment Practices Begin with the Diagnostic Approach, 1991, Potash & Phosphate Institute, Norcross, GA.

11 Chapter 11. Soil Analysis

1. Nelson, W.L. et al., 1951, Soil Testing in the United States, National Soil and Fertilizer Research Committee, U.S. Government Printing Office, Washington, D.C.

2. Bray, R.H., 1954, A nutrient mobility concept of soil-plant relationships, Soil Sci., 78, 9.

3. Scarsbrook, C.E., 1965, Nitrogen availability, in Soil Nitrogen, Bartholomew, W.V. and Clark, F.E., Eds., Soil Science Society of America, Madison, WI, p. 486.

4. Brady, N.C., 1974, The Nature and Properties of Soils, Macmillan, New York.

5. Barber, S.A., 1984, Soil Nutrient Bioavailability: A Mechanistic Approach, John Wiley & Sons, New York.

6. Dahnke, W.C. and Johnson, G.V., 1990, Testing soils for available nitrogen, in Soil Testing and Plant Analysis, 3rd ed., Westerman, R.L., Ed., Soil Science Society of America, Madison, WI, p. 128.

7. Peck, T.R. and Soltanpour, P.N., 1990, Principles of soil testing, in Soil Testing and Plant Analysis, 3rd ed., Westerman, R.L., Ed., Soil Science Society of America, Madison, WI, p. 1.

8. Troeh, F.R. and Thompson, L.M., 1993, Soils and Soil Fertility, 5th ed., Oxford University Press, New York.

9. Black, C.A., 1993, Soil Fertility: Evaulation and Control, Lewis Publishers, Boca Raton, FL.

10. Bundy, L.G. and Meisinger, J.J., 1994, Nitrogen availability indices, in Methods of Soil Analysis, Part 2, Microbiological and Biochemical Properties, Weaver, R.W., Ed., Soil Science Society of America, Madison, WI, p. 951.

11. Glossary of Soil Science Terms, 1987, Soil Science Society of America, Madison,WI.