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91 Chapter 5 Sources of plant nutrients and soil amendments A large number of diverse materials can serve as sources of plant nutrients. These can be natural, synthetic, recycled wastes or a range of biological products including microbial inoculants. Except for microbial inoculants (biofertilizers), all of these contain one, two or several plant nutrients in readily or potentially available forms. A certain supply of mineral and organic nutrient sources is present in soils, but these often have to be supplemented with external applications for better plant growth.

In practical farming, a vast variety of sources can find use in spite of large differences in their nature, nutrient contents, forms, physicochemical properties and rate of nutrient release. These are not mutually exclusive but can be used together as components of INM. Nutrient sources are generally classified as organic, mineral or biological. Organic nutrient sources are often described as manures, bulky organic manures or Organic fertilizers. Most organic nutrient sources, including waste materials, have widely varying composition and often only a low concentration of nutrients, which differ in their availability.

Some of these, such as cereal straw, release nutrients only slowly (owing to a wide C: N ratio) while others such as the N-rich leguminous green manures or oilcakes decompose rapidly and release nutrients quickly. Residues from processed products of plant or animal origin are increasingly important as nutrient sources and lead to nutrient saving by recycling. In addition, a very wide range of products obtained from the recycling of crop, animal, human and industrial wastes can and do serve as sources of plant nutrient.

A significant amount of N is made available through BNF by a number of micro-organisms in soils either independently or in symbiosis with certain plants. The inocula of such micro-organisms are commonly referred to as biofertilizers, which are used to enhance the N supply for crops. The majority of nutrient input to agriculture comes from commercial mineral fertilizers. Organic manures are considered to play a significant but lesser role in nutrient contribution, leaving aside their beneficial effects on soil physico-chemical and biological properties.

Such a conclusion could be due in part to inadequate data on the production and consumption of organic sources as compared with mineral fertilizers. Appreciable amounts of nutrients can also be brought in with rain (e. g. atmospheric deposition of nitrate and sulphate) and with irrigation water. This chapter describes common sources of plant nutrients. The last section deals with various soil amendments. Chapters 7 and 8 provide guidelines for the application of various nutrients through different sources. 92 Plant nutrition forfoodsecurity MINERAL SOURCES OF NUTRIENTS (FERTILIZERS)

Definition, classification and general aspects Definition The term fertilizer is derived from the Latin word fertilis, which means fruit bearing. Fertilizer can be defined as a mined, refined or manufactured product containing one or more essential plant nutrients in available or potentially available forms and in commercially valuable amounts without carrying any harmful substance above permissible limits. Many prefixes such as synthetic, mineral, inorganic, artificial or chemical are often used to describe fertilizers and these are used interchangeably.

Although organic fertilizers are also being prepared and used, they are not yet covered by the term fertilizers, largely owing to tradition and their generally much lower nutrient content. Strictly speaking, the most common mineral fertilizer, urea, is an organic compound that releases plant available N after transformation in the soil. In this section, the term fertilizer is used in a more narrow sense and widest acceptability. Fertilizer grade is an expression used in extension and the fertilizer trade referring to the legal guarantee of the available plant nutrients expressed as a percentage by weight in a fertilizer, e. . a 12–32–16 grade of NPK complex fertilizer indicates the presence of 12 percent nitrogen (N), 32 percent phosphorous pentoxide (P2O5) and 16 percent potash (K2O) in it. On a fertilizer bag, the NPK content is always written in the sequence N, P2O5 and K2O. Synthetic fertilizers are sometimes referred to as being artificial or chemical fertilizers, implying that these are inferior to those termed natural (mainly organic) products. However, fertilizers are neither unnatural nor inferior products. Many fertilizers are finished products derived from natural deposits, either made more useful for plants (e. . phosphate fertilizer) or separated from useless or even harmful components (e. g. K fertilizer). Although most N fertilizers are indeed produced artificially, i. e. synthesized in chemical factories, their N is derived from atmospheric air and their components such as nitrate, ammonia or urea are identical with the substances normally occurring in soils and plants. The primary source of all P in fertilizers is PR, a natural mineral that has to be mined, refined and solubilized in order to be useful. Classification

Fertilizers have been traditionally classified as follows: ? Straight fertilizers: These contain one of the three major nutrients N, P or K. This is a traditional term referring to fertilizers that contain and are used for one major nutrient as opposed to multinutrient fertilizers. For secondary nutrients, these include products containing elemental S, magnesium sulphate, calcium oxide, etc. In the case of micronutrients, borax, Zn and Fe chelates and sulphate salts of micronutrients are straight fertilizers. However, the term is not often used for micronutrient carriers.

This is not a very accurate term because many straight fertilizers also contain other essential plant nutrients, such as S in ammonium sulphate. These can also be termed single-nutrient Chapter 5 – Sources of plant nutrients and soil amendments 93 fertilizers. The term focuses on the most important nutrient for which a product was traditionally used disregarding other valuable constituents. In a strict sense, the term is justified only for products such as urea, ammonium nitrate (AN), and elemental S. ? Complex/compound fertilizers: These contain at least two out of the three major nutrients.

They are produced by a chemical reaction between the raw materials containing the desired nutrients and they are generally solid granulated products. These include both two-nutrient (NP) and threenutrient (NPK) fertilizers. These are also referred to as multinutrient fertilizers, but do not include fertilizer mixture or bulk blends as no chemical reaction is involved. The term is rarely used for multimicronutrient fertilizers or fortified fertilizers containing both macronutrients and micronutrients or for liquid fertilizers.

The term multinutrient fertilizers is more appropriate as it includes both major nutrients and micronutrients. Moreover, it does not restrict itself to a particular production process. Multinutrient fertilizers can be further classified into: (i) complex/compound fertilizers; (ii) mixtures and bulk blends; (iii) multimicronutrient carriers; and (iv) fortified fertilizers. A brief historical overview The use of fertilizers started in the early nineteenth century when saltpetre and guano where shipped from Chile and Peru to the United Kingdom and Western Europe, respectively.

The first " artificial fertilizer", namely SSP, was produced in 1843 in the United Kingdom, to be followed by many SSP factories throughout Europe. Production of potash fertilizers started in 1860 in Germany and of that N fertilizers from ammonia (derived from coal) in about 1890. A significant advance in the productiontechnologyof N fertilizers came with the production of synthetic ammonia by the Haber-Bosch process in Germany in 1913. Production and use of urea as a fertilizer started from 1921. Since then, a large variety of solid and liquid fertilizers containing one, two or several plant nutrients have been produced and used.

The fertilizer scene is dominated by products containing N, P and K in many chemical and physical forms and their combinations in order to meet the need for their application under different conditions throughout the world. General aspects In most countries, the effectiveness and safe use of substances to be registered as fertilizers is ensured by law. Recently, in developed countries, there has been a trend towards regulating some aspects of fertilizer application inrespectofpollution. The nutrient concentration of fertilizers is traditionally expressed in terms of N, P2O5, K2O, etc.

For example, an NPK fertilizer 15–15–15 contains 15 percent each of N, P2O5 and K2O, or 45 percent total nutrients. The percentage composition of a fertilizer refers mostly to the total concentration of a nutrient, but sometimes only to its available portion. For solid fertilizers, the percentage generally refers to the weight basis, e. g. 20 percent N means 20 kg of N in 100 kg of product. For 94 Plant nutrition for food security liquid fertilizers, both weight and volume percentages are used, e. g. 20 percent by weight of N of a solution with the specific weight of 1. 3 corresponds to 26 percent by volume (260 g N/litre).

In scientific literature, the nutrients are expressed mostly in elemental form whereas the industry, trade and extension services continue to express P and K in their oxide forms. The fact is that neither N nor P exists in soils, plants or fertilizers in elemental form. In any case, owing to the mismatch between the forms in which plant nutrients are expressed in research, extension and trade literature, care is needed when converting research data into practical values. Where the optimal application rate is reported as 26 kg P/ha in a research document, this translates into 60 kg P2O5/ha.

From small beginnings in the nineteenth century, the use of fertilizers has grown dramatically. The total consumption of NPK through fertilizers is now almost 142 million tonnes at an average rate of 100 kg of nutrients (N + P2O5 + K2O) per hectare of arable area (Table 15). Five countries (China, the United States of America, India, Brazil and France) account for 61 percent of the total fertilizer consumption, while more than half of total consumption takes place in China, the United States of America and India. The nutrient consumption rate in different countries varies from very high to extremely low (Figure 2).

Even more than 150 years after the beginning of fertilizer use, there are still large areas of the world where no or very little fertilizer is used. Fertilizers containing nitrogen Origin All N in fertilizers originates from the nitrogen gas (N2) in the atmosphere, which contains 79 percent N by volume. Above every hectare of land at sea level, there are 78 000 tonnes of N2. This is the N that is converted into ammonia in the fertilizer factories, and this is also the N that is fixed biologically into ammonium by various micro-organisms. Thus, there are abundant supplies of N for the production of nitrogenous fertilizers.

Only a small amount of fertilizer N is still obtained from natural deposits such as Chile saltpetre and guano. As the nutrient TABLE 15 Five leading countries in terms of the consumption of mineral fertilizers, 2002–03 Country Consumption N P2O5 K2O Total kg/ha of arable area (million tonnes) China 25. 200 9. 854 4. 162 39. 216 275. 0 United States of America 10. 878 3. 875 4. 545 19. 298 109. 6 India 10. 474 4. 019 1. 602 16. 095 99. 7 Brazil 1. 816 2. 807 3. 059 7. 682 130. 2 France 2. 279 0. 729 0. 960 3. 968 215. 1 World 84. 746 33. 552 23. 273 141. 571 100. 8 Source: FAOSTAT, 2005.

Chapter 5 – Sources of plant nutrients and soil amendments 95 N is captured from the air, N fertilizer production is primarily a matter of available energy, which is mainly derived from oil or natural gas reserves. Production of N fertilizers The main features of the production of N fertilizers are: ? Ammonia: It is the starting point and basic intermediate for the production of

N fertilizers. It is synthesized by the Haber-Bosch reaction which combines the very stable molecule of atmospheric N_2 with hydrogen, e. g. from natural gas, under a pressure of 200 atmospheres at 550 °C: ir + natural gas + water A ammonia + carbon dioxide O_2 + N_2 + CH_4 + H_2O A NH_3 + CO_2 ? Nitrate fertilizers: In this case, nitric acid (HNO_3) is produced by the oxidation of ammonia and then neutralized with materials such as calcium carbonate ($CaCO_3$) to produce calcium nitrate $Ca(NO_3)_2$. Nitrate fertilizers may also be derived from other sources such as Chile saltpetre. ? Ammonium nitrate (AN) fertilizers: These are produced by neutralizing nitric acid (derived from the oxidation of ammonia) with ammonia.

The solid granulated fertilizer is obtained by spraying the highly concentrated solution in cooling towers. HNO_3 + NH_3 A NH_4NO_3 nitric acid + ammonia A ammonium nitrate (solution) ? AN with lime: It is produced: (i) by mixing AN with calcium carbonate to obtain calcium ammonium nitrate (CAN); and (ii) by the reaction of calcium nitrate with ammonia and CO_2. ? Urea: It is produced by the reaction of NH_3 and CO_2 at 170 atmospheric pressure and a temperature of 150 °C.

Care is needed during drying to ensure that the biuret formed is minimum and within the permissible limits set out in fertilizer-quality standards. Consumption of N fertilizers The annual consumption of N through fertilizers is almost 85 million tonnes of N (2002–03 data). Out of this total, more than 50 million tonnes of N is consumed in five countries (China, United States of America, India, France and Brazil). China, India and the United States of America each consume more than 10 million tonnes of N through fertilizers annually. The number of N-containing fertilizers is large.

Straight N fertilizers are listed in Table 16 and the major ones are described below. Multinutrient fertilizers containing N are discussed in a later section. Anhydrous ammonia Gaseous ammonia can be used directly as a fertilizer. It has a pungent odour and is toxic to plants and humans when concentrated but harmless in dilute form. When liquefied under pressure for transportation, it is referred to as liquid or anhydrous ammonia (containing 82 percent N). It is injected as a gas by special equipment into the soil, where it reacts rapidly with water to form ammonium hydroxide. 6 Plant nutrition for food security Because of its low price, and in spite of its high application cost, it accounts for a large part of N consumption in some countries, e. g. the United States of America. Special safety precautions are needed during its transportation, handling and application. It is also the major intermediate for the production of other N fertilizers, both straight and complex. Aqua ammonia Aqueous ammonia is a solution containing water and ammonia in any proportion, usually qualified by a reference to ammonia vapour pressure. For example, aqua ammonia has a pressure of less than 0. 7 kg/cm2 Commercial grades commonly contain 20–25 percent N. It is used either for direct application to the soil or in the preparation of ammoniated superphosphate. It is easier to handle than anhydrous ammonia, but because of its low N concentration, it involves higher freight costs per unit of nutrient. Ammonium sulphate (AS) AS is the oldest synthetic N fertilizer. It contains about 21 percent N (all as ammonium) and 23–24 percent S (all as sulphate). It is an acid-forming fertilizer and is highly soluble in water. It can be produced through various processes and used directly or as an ingredient of fertilizer mixtures.

It is used as part of the basal dressing or as top-dressing to provide both N and S. In S-deficient soils, it works as an N + S fertilizer. AS should not be mixed with PR or urea. Ammonium nitrate (AN) AN is produced by neutralizing nitric acid with ammonia. Fertilizer-grade AN has 33–34. 5 percent N, of which 50 percent is present as ammonium and 50 percent as nitrate. It is usually in a granular or prilled form and coated with a suitable material to prevent absorption of moisture and caking in storage. It is a valuable N fertilizer, but also a dangerous explosive, hence, its trade and use as fertilizer is forbidden in many countries.

It can be rendered harmless by mixing it with calcium carbonate to produce CAN. It is also used to produce liquid fertilizers. AN leaves behind an acidic effect in the soil. TABLE 16 Common straight N fertilizers Fertilizer Percent N Ammonium fertilizers Anhydrous ammonia NH3 Aqua ammonia NH4OH Ammonium sulphate (NH4)2 SO4 Ammonium bicarbonate NH4HCO3 Ammonium chloride NH4Cl 82 26 21(also 24% S) 17 25 Nitrate fertilizers Calcium nitrate Ca(NO3)2 Sodium nitrate (Chile saltpetre) NaNO3 16 (also 20% Ca) 16 Ammonium + nitrate fertilizers Ammonium nitrate NH4NO3 Calcium ammonium nitrate NH4NO3 + CaCO3

Ammonium nitrate sulphate NH4NO3 + (NH4)2 SO4 35 27 26 (also 15% S) Amide fertilizers Urea CO(NH2)2 Calcium cyanamide CaCN2 46 22 Urea ammonium nitrate fertilizers Urea ammonium nitrate solution 28 Slow-release N fertilizers Several products, e. g. CDU, S-coated urea, polymer-coated products, oxamide, IBDU VariableChapter 5 – Sources of plant nutrients and soil amendments 97 Calcium ammonium nitrate (CAN) CAN is a mixture of AN and finely pulverized limestone or dolomite, granulated together. It contains 21–26 percent N, half in the form of ammonium and the rest in the form of nitrate.

Its use does not make the soil acid by virtue of the carbonate in it. Sodium nitrate Also known as Chilean nitrate of soda or Chile saltpetre, it was the first mineral N fertilizer to be used. It is obtained by refining the crude nitrate deposits called Caliche found in Chile. It contains about 16 percent N, all as nitrate. Natural saltpetre from Chile is still used as a fertilizer. The product also contains 0. 05 percent B, which makes it particularly suitable for fertilizing sugar beets. Urea Urea is the most important and widely used N fertilizer in the world today.

It is a white, crystalline, non-protein, organic N compound made synthetically from ammonia and CO2. Urea contains 46 percent N, all in amide (NH2) form and it is readily water soluble. It is the most concentrated solid N fertilizer that is produced as prills or granules of varying sizes. It is hydrolysed in the soil by the enzyme urease to furnish ammonium and then nitrate ions. During the manufacture of urea, a small amount of biuret (NH2-CO-NH-CO-NH2) is also produced. Urea should not contain more than 1. 2 percent of the toxic biuret for soil application and ot more than 0. 3 percent where sprayed on leaves. It is used as a solid N fertilizer for soils, for foliar application, as an ingredient of liquid fertilizers and in NP/NPK complexes. Urea leaves behind an acidic effect in soils. However, this is much smaller than the acidic effect of AS. Others N is also provided through a number of liquid fertilizers or fertilizer solutions. One example is the aqueous ammonia discussed above. Another is urea ammonium nitrate solution, which contains 28–33 percent N. Liquid N fertilizers can be highpressure solutions or low-pressure solutions.

Slow-release fertilizers are of particular importance for special applications and they increase the efficiency of N. These have been developed to better adapt the rate of N release to the N demands of plants, reduce the number of splits required, improve nitrogen-use efficiency and reduce N losses. There are a large number of slow-release fertilizers and their mixtures, with N-release rates extending from short to long periods. Some examples of slowrelease fertilizers are crotonylidene urea (CDU), isobutylidene diurea (IBDU), combinations of formaldehyde and urea, and oxamide (diamide of oxalic acid).

Polymer-coated urea has been shown to be an effective N source. However, like the other slow-release products, the cost is high. Different degrees of release can be distinguished by analytical methods with fractions soluble in hot water acting more slowly than those soluble in cold water, and fractions insoluble in hot water 98 Plant nutrition for food security acting extremely slowly. Soil microbes gradually liberate the N in these slowrelease fertilizers with the decomposition rate depending largely on temperature. They are expensive in terms of per unit of N and are, therefore, restricted mainly to commercial and special applications.

Fertilizers containing phosphorus Phosphatic fertilizers contain P, mostly in the form of calcium, ammonium or potassium phosphates. The phosphate in fertilizers is either fully water soluble or partly water soluble and partly citrate soluble, both being considered as plant available. Citrate-soluble P dissolves slowly and is relatively more effective in acid soils. The concentration of P (usually indicated as percent P2O5) refers either to the available or the total portion of phosphate. Origin and reserves The primary source of phosphate in fertilizers is the mineral apatite, which is primarily tricalcium phosphate [Ca3(PO4)2].

It is the major constituent of PR, the basic raw material for the production of phosphatic fertilizers. These phosphatecontaining rocks are found in special geological deposits and some phosphatecontaining iron ores or other P compounds. PRs consist of various types of apatites. Depending upon the dominance of F, Cl or OH in the apatite crystal structure, it is known as fluorapatite, chlorapatite or hydroxyapatite. Weathering processes over long periods of time resulted in the accumulation of primary apatites or apatite-containing bones, teeth, etc. of animals of earlier geological periods.

Many such deposits occur near the earth’s surface, from where they are obtained by opencast mining and utilized either directly or after beneficiation for fertilizer production. Large deposits of PR exist in several parts of the world, for example: ? North Africa (Morocco, Algeria, Tunisia, etc.) in the form of organogenic phosphorite, either as more or less hard rocks or as soft earth phosphate; ? the United States of America, e. g. Florida apatite, which is in the form of moderately hard pebbles and the teeth and bones of sea animals. ? Russian Federation, in the form of hard earth, coarsely crystalline apatite, e. . magmatic Kola apatite. It is not always realized that phosphate is a scarce raw material, probably the most critical one. Global reserves (actual and probable) with more than 20 percent P2O5 content seem to be in the range of 30–40 000 million tonnes, amounting to about 10 000 million tonnes P2O5. With a future annual consumption of 40–50 million tonnes P2O5, these reserves would last less than 200 years, or may be 100 years assuming an increased rate of consumption. In the past 100 years, phosphate has been discovered at a rate that exceeds the rate of P consumption (Sheldon, 1987). One source of uture phosphate production is offshore deposits, which occur on many continents. None of these deposits is currently being mined because ample reserves exist onshore. Chapter 5 – Sources of plant nutrients and soil amendments 99 Production of P fertilizers Superphosphate, or rather SSP, was the first mineral fertilizer to be produced in factories in the 1840s in the United Kingdom. There are two principal ways of producing P fertilizers from PRs: ? Chemical solubilization of PR into fully or partially water-soluble form by: • Sulphuric acid resulting in SSP: Ca3(PO4)2 + H2SO4 A Ca(H2PO4)2 + CaSO4 ricalcium phosphate + sulphuric acid A [monocalcium phosphate + gypsum] = SSP • Phosphoric acid resulting in triple superphosphate (TSP) as follows: Ca3(PO4)2 + H3PO4 A Ca(H2PO4)2 tricalcium phosphate + phosphoric acid A [monocalcium phosphate] = (TSP) • Partial solubilization of PR with lesser amounts of sulphuric acid to produce what are known as partially acidulated phosphate rocks (PAPRs). ? Mechanical fine grinding of reactive PR for direct application as fertilizer. ? For the commercial evaluation of PRs, their total P content is determined using strong mineral acids.

Most P fertilizers are evaluated by the “ reactive” or “ available” portion of their total phosphate content. This is based on chemical solubility, which is supposed to correspond to plant availability. Several solvents are employed for the extraction of the “ available” portion of P fertilizers: ? Water: for SSP, TSP, etc. ; extraction of water-soluble phosphate. ? Neutral ammonium citrate for SSP, PR, etc. is used in some countries to determine quick-acting phosphate. In some cases, the first extract is discarded and the second extract taken for evaluation of PR.

High solubility in citrate (> 17 percent) indicates high reactivity. ? Citric acid (2 percent) for nitrophosphates and Thomas phosphate. ? Formic acid (2 percent) for PR in some countries. High solubility (> 55 percent) indicates high effectiveness. Consumption of P fertilizers The world consumption of phosphate fertilizers is 33. 6 million tonnes P2O5, accounting for 24 percent of total nutrient usage (Table 15). Almost 63 percent of the global P2O5 consumption in 2002–03 occurred in China, India, the United States of America, Brazil and France.

China alone accounts for almost 10 million tonnes P2O5 consumption through fertilizers. The consumption in terms of arable area ranges from negligible in several countries to 109 kg P2O5/ha in Japan, with a world average of 24 kg P2O5/ha. The nutrient composition of major phosphate fertilizers is summarized in Table 17. This is followed by a brief description of common P fertilizers. Ammonium phosphates are discussed under complex fertilizers. 100 Plant nutrition for food security Superphosphates Single superphosphate (SSP) is the oldest commercially produced synthetic fertilizer and the most ommon among the group of superphosphates. The prefix “ super” probably refers to its superiority over crushed animal bones when it was first produced in the 1840s. SSP is a mixture of monocalcium phosphate [Ca(H2PO4)2] and calcium sulphate or gypsum (CaSO4 . 2H2O). It contains 16 percent water-soluble P2O5, 12 percent S in sulphate form and 21 percent Ca. As is clear from its composition, it is known as a straight or singlenutrient (P) fertilizer only for historical and traditional reasons. Its bulk density is 96. 1 kg/m3 , critical relative humidity is 93. 7 percent at 30 °C and angle of repose is 26°.

It is commonly used as part of basal dressing either as such or as part of fertilizer mixtures. Its S component comes from the sulphuric acid used during its manufacture. The Ca component of SSP is particularly valuable for crops such as groundnut during pod formation. SSP should not be mixed with CAN or urea unless the mixture is applied immediately and not stored. TSP is obtained by treating PR with phosphoric acid. It contains about 46 percent P2O5, mainly in water-soluble form. Unlike SSP, it contains very little S. Basic slag Basic slag is a by-product of the steel industry.

It is considered to be a double silicate and phosphate of lime [(CaO)5P2O5SiO2]. It contains 10–18 percent P2O5 (part of which is citrate soluble), 35 percent CaO, 2–10 percent MgO and 10 percent Fe. Basic slag can be used as a fertilizer-cum-soil conditioner because it contains lime and citric-acid-soluble P. The steel slags are very hard – their use in agriculture is possible only where they are ground to a fine powder. Thomas phosphate, a type of basic slag, is a by-product of the open-hearth process of making steel from pig iron. It may contain 3–18 percent P2O5 depending on the P content of the iron ore.

Thomas phosphate (14–18 percent P2O5) was a popular phosphate fertilizer in Europe. It is a dark powder and its slow action is well-suited to maintaining soil P levels. The standard specification of Thomas slag is that 70–80 percent of the material should pass through 100 mesh. It has some liming effect. The availability of this fertilizer is decreasing and it is unimportant in much of the world. TABLE 17 Some common phosphate fertilizers Fertilizer P2O5 P (%)

Single superphosphate (SSP): Ca(H2PO4)2 + CaSO4 . 2H2O 16–18 7–8 Enriched superphosphate (ESP) is a special form of SSP 27 12

Triple superphosphate (TSP): Ca(H2PO4)2 + CaHPO4 46–50 20–22 Partly acidulated phosphate rock (PAPR). About 40% water soluble + 30% citric acid soluble P, giving 70 percent “ available” portion, contains 20% gypsum 23 10 Basic slag (Thomas phosphate): citric-acid-soluble concentration contains Ca phosphate silicate (75 percent), CaO (5 percent), some Fe, Mn, etc. 10–15 4–7 Phosphate rocks, finely ground (< 0. 16 mm): evaluated according to solubility in citrate or formic acid 23–40 10–17Chapter 5 – Sources of plant nutrients and soil amendments 101 Phosphate rock (PR) PR can also be used directly as a fertilizer.

It contains 15–35 percent P2O5. The quality of PR as a fertilizer depends on its age, particle size, degree of substitution in the crystal structure and solubility in acids. PR also contains several micronutrients. Their average contents are 42 mg/kg Cu, 90 mg/kg Mn, 7 mg/kg Mo, 32 mg/kg Ni and 300 mg/kg Zn. Their Cd content varies from 1 to 87 mg/kg of PR. In PRs for direct application, the Cd content should preferably not exceed 90 mg Cd/kg P2O5 (27 mg/kg of PR). Reactive PRs can also be used directly as P fertilizer in acid soils with or without any pre-treatment.

Such PRs can be used in acid soils and for long-duration crops. Their suitability depends on the reactivity of the rock, its particle size, soil pH and type of crop. Their suitability for direct application can be estimated by dissolving the PR in certain extracting solutions. The most common solutions are neutral ammonium citrate, 2-percent citric acid and the preferred 2-percent formic acid. The effectiveness of PRs is not only related to the reactive “ available” portion but it also depends on the P-mobilization capacity of the soil, which is related to pH, moisture status and biological activity.

This means that the final evaluation of PR must be based on field experiments. Several aspects of PR for direct application have been dealt with in detail in publication produced by FAO (2004b). Partially acidulated phosphate rock (PAPR) PAPR is obtained by the partial acidulation of PR to convert only a part of its P into water-soluble form, as compared with complete acidulation, where fertilizers such as SSP or TSP are produced. The degree of acidulation is usually referred to in terms of the percentage of acid required for complete acidulation, e. g. to produce SSP.

Where only 30 percent of the acid needed to make SSP is used for preparing PAPR, it is referred to as PAPR 30 percent H2SO4. It is an intermediate kind of product between SSP and PR. It can serve as an effective phosphate fertilizer in neutral to alkaline soils that are not highly deficient in P and where long-duration crops are grown. These are widely used in Europe and South America (FAO, 2004a, 2004b). Others Dicalcium phosphate (CaHPO4) is a slow-acting product used as a component of multinutrient fertilizers but it is rarely used as a fertilizer by itself in present times.

Other P fertilizers are polyphosphates and diluted phosphoric acid (H3PO4), which can be used in hydroponics or for preparing liquid fertilizers. The problem of low P-utilization efficiency and the desire to obtain products suitable for fertilizer solutions and fertigation has led to a range of new P fertilizers, such as condensed phosphates (polyphosphates, metaphosphates and ultraphosphates), all with high P concentrations. They are partly water soluble and rapidly hydrolyse in the soil, i. e. convert into the plant available orthophosphate form.

Phosphates coupled with sugars (glycido-phosphates) have been found to be useful for fertigation. 102 Plant nutrition for food security There are also liquid fertilizers based on phosphoric acid that may have several other nutrients such as N and micronutrients along with P. Phosphate fertilizers can also be derived from the processing of municipal wastewaters, namely iron and aluminium phosphates. Where practically free of toxic impurities, these are valuable although slow acting and are likely to gain greater importance in the future. Fertilizers containing potassium Potash fertilizers are predominantly water-soluble salts.

For historical reasons, their K concentration is generally still expressed as percent K2O, particularly by the industry, trade and extension. As such, the nutrient K does not exist as K2O in soils, plants or in fertilizers. It is present as the potassium ion K+ in soils or plants and as a chemical compound (KCl, K2SO4) in fertilizers. Origin and reserves Large deposits of crude K salts were first found in Germany in the mid-1850s. In recent times, deposits in several countries, especially in Canada, have been mined and utilized for the production of potash fertilizers.

Canada and the countries of the former Soviet Union have 90 percent of the known potash reserves (IFA, 1986). These deposits were formed millions of years ago during the process of drying up of seawater in former ocean basins. Layers of common salt (NaCl) were overlain by smaller layers of K minerals, which hardened to rock under pressure. Crude K salts are thus natural seawater minerals, which are now mined from great depths. World K reserves are large and more are expected to be discovered. Production and consumption The first potash fertilizers were ground crude K salts containing 13 percent K2O.

These are still used to some extent for fertilization of grassland in order to supply K and Na. They are also accepted in biofarming as a natural fertilizer. The main K fertilizers used at present are purified salts. The production of potassium chloride (KCl) or MOP involves grinding of the salt rocks, which consist of minerals such as kainite (19 percent K2O) and carnallite (17 percent K2O). The unwanted components such as Na, Mg and Cl are then separated, which involves heating (dissolution of salts) followed by crystallization of KCl upon cooling. In the newer flotation process, KCl rystals are coupled with organic agents, floated to the surface and removed. Electrostatic methods separate solid crystals of KCl from other compounds. Potassium sulphate is produced by the chemical reactions of different crude salts as also by the reaction of KCl with sulphuric acid. Besides the salt deposits, there are K-containing industrial waste products, e. g. dust from cement production, that can serve as a K fertilizer. World consumption of K through fertilizers was 23. 3 million tonnes K2O in 2002–03. This amounted to about 16 percent of the total nutrient consumption through fertilizers.

Almost 62 percent of total potash consumption takes place in Chapter 5 – Sources of plant nutrients and soil amendments 103 five countries (the United States of America, China, Brazil, India and France) with the United States of America, China and Brazil accounting for 50 percent of the total potash consumption. Unlike most countries, potash consumption exceeds phosphate consumption in large-consuming countries such as the United

States of America, Brazil and France while it is well below phosphate consumption in India and China.

At the global level, potash consumption ranges from negligible in many areas to 107 kg K2O/ha of arable area in the Republic of Korea, with a world average of 16. 6 kg K2O/ha. Potassium chloride (MOP) Potassium chloride (KCl), also called muriate of potash (MOP), is the most common K fertilizer. It is readily soluble in water and is an effective and cheap source of K for most agricultural crops. Grades of MOP vary from 40 to 60 percent K2O. Fertilizer containing 60 percent K2O is almost pure KCl containing about 48 percent Cl.

MOP comes as powders or crystals of varying colours and hues from white to pink but these differences have no agronomic significance. Its critical relative humidity is 84 percent at 30 °C and it has a higher salt index than potassium sulphate. It is used either directly as a fertilizer or as an ingredient of common NPK complexes. Potassium sulphate (SOP) SOP is actually a two-nutrient fertilizer containing 50 percent K2O and 18 percent S, both in readily plant available form. It is costlier than MOP but is particularly suitable for crops that are sensitive to chloride in place of KCl.

It has a very low salt index (46. 1) as compared with 116. 3 in case of MOP on material basis. It also stores well under damp conditions. SOP should not be mixed with CAN or urea. Others Other important sources of potash such as potassium magnesium sulphate and potassium nitrate are discussed under multinutrient fertilizers in a later section. As there may be some salinity damage with high K applications, particularly as MOP (especially in gardening), slow-acting K fertilizers such as less soluble double salts, fritted K containing glass and soluble-coated K salts have been developed.

Special rock powder, e. g. from potassium feldspar, is an extremely slow-acting K fertilizer, even after fine grinding. Fertilizers containing sulphur Most S-containing fertilizers are in fact sulphate salts of compounds that also contain other major nutrients or micronutrients. S-containing fertilizers such as AS, SSP and SOP have been discussed above under the respective sections on fertilizers containing N, P or K. Multinutrient fertilizers including NP/NPK complexes containing S as also liquid fertilizers (e. g. ammonium thiosulphates) are discussed in a later section.

The only truly single-nutrient S fertilizers are the elemental S products. 104 Plant nutrition for food security Some sources of S and their approximate S content are: ? ammonium sulphate (NH4)2 SO4: contains 24 percent S; ? ammonium sulphate nitrate (NH4) 2SO4. NH4NO3: contains 12 percent S; ? SSP: contains 12 percent S; ? ammonium phosphate sulphate: contains 15 percent S; ? potassium sulphate (K2SO4): contains 18 percent S; ? potassium magnesium sulphate (K2SO4. 2MgSO4): contains 22 percent S; ? magnesium sulphate monohydrate (MgSO4. H2O): contains 22 percent S; ? magnesium sulphate heptahydrate (MgSO4. H2O): contains 13 percent S; ? gypsum/phosphogypsum (CaSO4. 2H2O): contains 13–17 percent S; ? elemental S products: contain 85–100 percent S; ? sulphur bentonite: contains 90 percent S; ? pyrites (FeS2): contains 18–22 percent S; ? sulphate salt of micronutrients: contain variable amounts of S. Formulations containing S in elemental form are increasingly finding use as S fertilizers (Messick, de Brey and Fan, 2002). Elemental S products are the most concentrated source of S. The elemental S in them has first to be oxidized to sulphate in the soil by bacteria (Thiobacillus thiooxidans) before it can be absorbed by plant roots.

The rate of S oxidation depends on the particle size of the fertilizer, temperature, moisture, degree of contact with the soil, and level of aeration. To facilitate oxidation from S to SO4 2- , elemental S sources are usually surface applied a few weeks ahead of planting. Fertilizers containing calcium Raw materials for Ca fertilizers are abundant as whole mountains consist of calcium carbonate ($CaCO_3$) and there is no shortage of gypsum ($CaSO_4$. $2H_2O$) either as a mineral or as a by-product (phosphogypsum) of the wet-process phosphoric acid production. Common Ca fertilizers are: ? calcium oxide (CaO): contains 50–68 percent Ca (Ca ? 1. = CaO); ? slaked lime [$Ca(OH)_2$]: contains 43–50 percent Ca; ? agricultural limestone ($CaCO_3$): contains 30–38 percent Ca; ? dolomite ($CaCO_3$. $MgCO_3$): contains 24–32 percent Ca, ? CAN: contains 7–14 percent Ca; ? calcium nitrate [$Ca(NO_3)_2$]: contains 20 percent Ca; ? calcium chloride ($CaCl_2$. $6H_2O$): 15–18 percent Ca; ? SSP: contains 18–21 percent Ca; ? gypsum ($CaSO_4$. $2H_2O$): contains 23 percent Ca; ? calcium chelates: variable. Calcium nitrate contains about 15 percent N and 28 percent CaO. It is a good source of nitrate N and water-soluble Ca and is particularly used for fertilizing horticultural crops and for fertigation. Calcium nitrate is uitable only where N application may also be required. Water-soluble Ca fertilizers such as calcium chloride or calcium nitrate may be applied as foliar sprays. A component of several Chapter 5 – Sources of plant nutrients and soil amendments 105 commercial leaf sprays, calcium chloride solutions with 10 percent Ca are used for spraying fruits such as apples. Gypsum, with its moderate water solubility, is a very useful

Ca fertilizer for soil application, but few soils need it to increase Ca supply. The main role of mineral gypsum is on alkali (sodic) soils for the removal of toxic amounts of Na and to supply S in deficient situations.

The same is true of phosphogypsum, where it is not contaminated with heavy metals such as Cd. Fertilizers containing magnesium Natural reserves of Mg are very large, both in salt deposits ($MgCl_2$, $MgCO_3$, etc.) and in mountains consisting of dolomite limestone ($CaCO_3$. $MgCO_3$). There are several commercially available materials of acceptable quality that can be used to provide Mg to soils and plants. There are two major groups of Mg fertilizers, namely, water soluble and water insoluble. Among the soluble fertilizers are magnesium sulphates, with varying degree of hydration, and the magnesium chelates.

The sulphates can be used both for soil and foliar application whereas the chelates, such as magnesium ethylenediamine tetraacetic acid (Mg-EDTA), are used mainly for foliar spray. Some sources of Mg are: ? magnesium oxide (MgO): contains 42 percent Mg (Mg ? 1. 66 = MgO); ? magnesite ($MgCO_3$): contains 24–27 percent Mg; ? dolomitic limestone ($MgSO_4$. $CaSO_4$): contains 3–12 percent Mg; ? magnesium sulphate anhydrous ($MgSO_4$): contains 20 percent Mg; ? magnesium sulphate monohydrate ($MgSO_4$. H_2O): contains 16 percent Mg; ? magnesium sulphate heptahydrate ($MgSO_4$. $7H_2O$): contains 10 percent Mg; ? magnesium chloride ($MgCl_2$. H_2O): contains 12 percent Mg; ? potassium magnesium sulphate (K_2SO_4. $2MgSO_4$): contains 11 percent Mg. Magnesium sulphate is the most common Mg fertilizer. In anhydrous form, it contains 20 percent Mg. As a hydrated form, $MgSO_4$. $7H_2O$ (Epsom salt), it contains 10 percent Mg. It is readily soluble in water, has a bulk density of 1 g/cm3 and an angle of repose of 33°. It can be used for soil application and for foliar application. Kieserite is the monohydrate form of magnesium sulphate ($MgSO_4 \cdot H_2O$). It contains 16 percent Mg and is sparingly soluble in cold water but readily soluble in hot water.

Its bulk density is 1. 4 g/cm3 and its angle of repose is 34°. It is used as a fertilizer for soil or foliar application to provide Mg as well as S. Among the insoluble or partially water-soluble sources are magnesium oxide, magnesium carbonate and magnesium silicates. The insoluble or partially soluble materials are used more often as liming materials. However, in acid soils, they can also be used as Mg fertilizers. Magnesium carbonate, the major component of the mineral magnesite, is also used as a raw material for the production of magnesium sulphate. Fertilizers containing nitrogen and phosphorus (NP)

These are not only the starting materials for the production of NPK fertilizers but they are also used for the simultaneous supply of two major nutrients (N and P) 106 Plant nutrition for food security required in many cropping systems. They are produced by different processes and their nutrient concentration is indicated in percent N + P_2O_5. The main solid types of NP fertilizers are mono-ammonium phosphate (MAP), di-ammonium phosphate (DAP), nitrophosphates, urea ammonium phosphates and ammonium phosphate sulphates. NP solutions consist of ammonium phosphate and polyphosphates with a specific gravity of about 1. and nutrient concentrations about 10 percent N + 34 percent P_2O_5. Special-purpose NP types are ultrahigh concentration fertilizers that are not phosphates but phosphonitriles or metaphosphate with a composition of 43 percent N + 74 percent P2O5 as an example (sum of nutrients > 100 percent if based on P2O5), but actually 43 percent N + 33 percent P. Mono-ammonium phosphate (MAP) MAP (NH4H2PO4) is produced by reacting phosphoric acid with ammonia. It contains 11 percent N and 55 percent P2O5. It can be used directly as an NP fertilizer for soil application or as a constituent of bulk blends.

It can also be fortified with S to make it more effective on S-deficient soils. Di-ammonium phosphate (DAP) DAP [(NH4)2HPO4] is an important finished fertilizer as well as an intermediate in the production of complex fertilizers and bulk blends. It is produced by treating ammonia with phosphoric acid. It typically contains 18 percent N + 46 percent P2O. About 90 percent of the total P is water soluble and the rest is citrate soluble. In some countries, efforts are underway to fortify DAP with the needed micronutrients. Ammonium nitrate phosphate (ANP) ANP is produced by reacting PR with nitric acid.

Several grades are produced and a typical grade contains 20 percent N and 20 percent P2O5. Also known as nitric phosphates or nitrophosphates, all of them contain 50 percent of the total N in nitrate form and 50 percent as ammonium. Part of the total phosphate (30–85 percent) is water soluble, the rest being citrate soluble. Products with less water-soluble P are more efficient in acid soils or soils that are at least of medium P fertility, particularly for long-duration crops. In neutral to alkaline soils, particularly for short-duration crops, 60 percent or higher levels of water-soluble P2O5 content are generally preferred.

Ammonium phosphate sulphate (APS) These are in reality three-nutrient fertilizers containing N, P and S, all in watersoluble, plant available forms. APS can be seen as a complex of AS and ammonium phosphate. Both the common grades (16–20–0) and 20–20–0) also contain 15 percent S, which comes from the AS portion. Chapter 5 – Sources of plant nutrients and soil amendments 107 Urea ammonium phosphates (UAPs) UAPs are produced by reacting ammonia with phosphoric acid to which urea is also added in order to increase the N content in the product.

The most common example of this type of NP complex is 28–28–0 (the first UAP to be commercially produced in the world). As the name suggests, it contains part (68 percent) of its N in the amide (urea) form and the rest (32 percent) in ammonium form. All its nutrients are readily soluble in water and in available form, amide N being available after conversion into ammonium. Fertilizers containing nitrogen and potassium (NK) Of the fertilizers containing N and K, potassium nitrate is perhaps the most important. It typically contains 13 percent N and 44 percent K2O (37 percent K).

It is a good source of K and N for crops that are sensitive to chloride. It finds greatest use for intensively grown crops, such as tomatoes, potatoes, tobacco, leafy vegetables and fruits, and in greenhouses. It has a moderate salt index (between that of MOP and SOP) and is also less hygroscopic. It is useful for normal application and also for fertigation. Fertilizers containing nitrogen and sulphur (NS) Fertilizers containing N and S have already been mentioned under nitrogenous fertilizers. Common types are AS, ammonium sulphate nitrate and combinations of urea with ammonium sulphate. S-coated urea is a slow-release fertilizer.

Fertilizers such as AS are ideal for top-dressing a growing crop where S deficiency has been detected and an N application is also required. They combine two important nutrients for crops with high S demand. Ammonium thiosulphate is a liquid NS fertilizer containing 12 percent N and 26 percent S (thio refers to sulphur). Fifty percent of its S is in the sulphate form and the rest is in elemental form. It can be used directly or mixed with neutral to slightly acid P-containing solutions or aqueous ammonia or N solutions to prepare a variety of NPK + S and NPKS + micronutrient formulations.

It can also be applied through irrigation, particularly through drip and sprinkler irrigation systems. Fertilizers containing nitrogen, phosphorus and potassium (NPK) Theoretically, with 6 major nutrients, there are 20 possible combinations of three nutrient fertilizers. The most prominent ones of these are NPK fertilizers. These can be complex/compound fertilizers, mixtures or bulk blends. In fact, even some so-called single-nutrient or straight fertilizers such as superphosphate can belong to this group as they contain P, Ca and S. There are a large number of standard-type NPK fertilizers with different nutrient ratios.

Their nutrient concentrations are indicated as percentage of N + P2O5 + K2O, the individual nutrient concentrations ranging from about 5 percent to more than 20 percent. While a different fertilizer for every crop and field may 108 Plant nutrition for food security appeal to sophisticated farmers, the majority of growers use a limited number of standard types. Most NPK types are produced by the acid decomposition of PR with incorporation of ammonia, thus producing an NP fertilizer to which a K salt, usually MOP or SOP, is added. These can be solid or liquid fertilizers. Solid NPK fertilizers

More than 50 types are available on the market, with the N and P components being present in one or several forms. Thus, even in NPK fertilizers with the same grade or nutrient ratio, a given nutrient can be present in several chemical forms (Table 18). In most NPK complexes, the K component is often derived from MOP, but some types contain K through SOP, which makes them suitable for many chloride sensitive plants and horticultural crops. Some NPK fertilizers contain Mg as an additional component. This is often through magnesium sulphate, which makes them suitable for crops with high Mg requirements.

This actually results 1Water soluble; 2 Citrate soluble. Source: Tandon, 2004. TABLE 18 Forms of nitrogen and phosphate in various NP/NPK fertilizers Percent N as Percent P2O5 as Fertilizer (grade) NH4 NO3 NH2 WS 1 CS 2 Di-ammonium phosphate (18–46–0) 18. 0 0 0 41. 0 46. 0 Ammonium phosphate sulphate (16–20–0) 16. 0 0 0 19. 5 20. 0 Ammonium phosphate sulphate (20–20–0) 20. 0 0 0 17. 0 20. 0 Ammonium nitrate phosphate (20–20–0) 10. 0 10. 0 0 12. 0 20. 0 Ammonium nitrate phosphate (23–23–0) 11. 5 11. 5 0 18. 5 23. 0 Ammonium nitrate phosphate (23–23–0) 13. 0 10. 0 0 20. 5 23. Urea ammonium phosphate (28–28–0) 9. 0 0 19. 0 25. 2 28. 0 Urea ammonium phosphate (24–24–0) 7. 5 0 16. 5 20. 4 24. 0 Mono-ammonium phosphate (11–52–0) 11. 0 0 0 44. 2 52. 0 Ammonium polyphosphate (10–34–0) (liquid) 10. 0 0 0 22. 1 34. 0 Nitrophosphate with K (15–15–15) 7. 5 7. 5 0 4. 0 15. 0 NPK complex (15–15–15) 12. 0 0 3. 0 12. 0 15. 0 NPK complex (17–17–17) 5. 0 0 12. 0 14. 5 17. 0 NPK complex (17–17–17) 8. 5 8. 5 0 13. 6 17. 0 NPK complex 18–18–18 (100 % ws 1) 8. 2 9. 8 0 18. 0 18. 0 NPK complex (19–19–19) 5. 6 0 13. 4 16. 2 19. 0 NPK complex 19–19–19 (100 % ws 1) 4. 4. 0 10.

5 19. 0 19. 0 NPK complex 20–20–20 (100 % ws 1) 3. 0 4. 9 12. 1 20. 0 20. 0 NPK complex (10–26–26) 7. 0 0 3. 0 22. 1 26. 0 NPK complex (12–32–16) 9. 0 0 3. 0 27. 2 32. 0 NPK complex (22–22–11) 7. 0 0 15. 0 18. 7 22. 0 NPK complex (14–35–14) 14. 0 0 0 29. 0 35. 0 NPK complex (14–28–14) 8. 0 0 6. 0 23. 8 28. 0 NPK complex (20–10–10) 3. 9 0 17. 1 8. 5 10. 0 NPK complex 13–5–26 (100 % ws 1) 6. 0 7. 0 0 5. 0 5. 0 NPK complex 6–12–36 (100 % ws 1) 1. 5 4. 5 0 12. 0 12. 0 Calcium nitrate (15. 5 % N, 18. 8 % Ca) 1. 1 14. 4 0 0 0 Mono-ammonium phosphate (12–61–0) (100 % ws) 12. 0 0 0 61. 0 61. 0 Monopotassium phosphate (0–52–34) (100 % ws 1) 0 0 0 52. 0 52. 0 Potassium nitrate (13–0–45) 0 13. 0 0 0 0Chapter 5 – Sources of plant nutrients and soil amendments 109 into a fertilizer containing four major nutrients. NPK fertilizers are granulated for uniform distribution. Their colour is often greyish but, in order to be better recognized by farmers, some fertilizers are specially coloured in some countries, e. g. red may indicate a composition of 13–13–21, yellow of 15–15–15, and blue of 12–12–20 with K as sulphate. Liquid NPK fertilizers

For more accurate and convenient application of fertilizers on large farms, liquid fertilizers offer certain advantages. Farmers do not need to carry fertilizer bags, they simply rely on pumping. Spraying machines used for crop protection can be used but suspensions require special nozzles. There are two different types of liquid fertilizers: ? Fertilizer solutions: These are clear liquid fertilizers of low to medium nutrient content. In most of these, the sum of nutrients adds up to 30 percent and they have a specific gravity range of 1. 2–1. 3.

Their common components are urea, ammonium, nitrate, ammonium phosphate and a K salt. ? Suspensions: These are saturated solutions with fine crystals in a stabilized condition in which the sum of nutrients can be up to 50 percent. Their specific gravity is about 1. 5. Their components are urea, ammonium, nitrate, polyphosphates and other phosphates, and a K salt. For both types, the nutrient ratios vary in a wide range from 5: 8: 15 up to 25: 6: 20 (N: P2O5: K2O). The optimal nutrient ratio in NPK fertilizers On the question of optimal nutrient ratios in NPK fertilizers, theoretical onsiderations and the actual trend are not in agreement. Strictly speaking, nutrient ratios should be fine tuned to every cropped field. However, in practice, this is neither possible nor necessary. Farmers want to handle as few fertilizers as possible. A practical approach to the optimal nutrient ratio is derived from nutrient removal data. Decades ago in Western Europe, average rotations removed nutrient from the fields in an N: P2O5: K2O ratio of 1: 0. 5: 1. 2. This figure was corrected for the different utilization ratios, which resulted in a final ratio of 1: 1: 1. 6.

This was the basis for the common NPK fertilizer of 13: 13: 21. In recent decades, the ratio has become increasingly dominated by N with a tendency towards 1: 0. 5: 0. 5. This is partly explained by greater the buildup of P and K in the soils over the years and the consumers’ emphasis on N supply. In India, which is the world’s third-largest user of fertilizers, on a macrolevel, balanced nutrient application is represented by the ratio 1: 0. 5: 0. 25. This historical ratio has represented the trend of importance given to fertilizer nutrients and the extent to which these are qualitatively deficient in Indian soils.

This ratio bears no relationship to the ratio in which plant nutrients are absorbed by crops or the ratio in which these are removed with the harvest. The overall ratio in which nutrients are removed by crops in India is 1: 0. 45: 1. 75. Although a large number of NPK complexes with a wide range of nutrient ratios are produced and used in India, 110 Plant nutrition for food security there is no such thing as an ideal ratio that can be applied over large areas. Even within a given region, the optimal nutrient ratio can never be the same for diverse crops (grains, fodders, fruits, sugar cane, tea, etc. . At present, the nutrient ratio of global fertilizer consumption is about 1: 0. 4: 0. 3. Differences in ratios among countries are as large as between regions within the same country. The search for a single optimal ratio or a few ratios is thus futile for large countries with diverse soils and cropping systems. With increasing emphasis on precision farming and site-specific nutrient management (SSNM), it is best that the optimal ratio be determined by the soil, the crop and the growth conditions. Fertilizers containing other combinations of major nutrients Fertilizers containing N nd Mg are suitable for supplying these two nutrients in the growing season. They contain AS or AN combined with magnesium sulphate or magnesium carbonate (as dolomite). Micronutrients may be added, such as 0. 2 percent Cu for grassland. Potassium magnesium sulphate is a unique threenutrient fertilizer without N. It typically contains 11 percent Mg, 22 percent K2O and 22 percent S. Potassium magnesium sulphate is used where the application of S and K is also required. It contains less than 1. 5 percent Cl. It has a neutral effect on soil reaction but should not be mixed with urea or CAN.

Micronutrient fertilizers The importance of fertilizers containing micronutrients has been increasing over the years for several reasons. Decades ago, at medium yield levels, fertilization with micronutrients was restricted to the recovery of acute visible deficiencies that occurred in some areas of sandy, metal-fixing, overlimed or just poor soils. However, on most soils, the natural soil supply of micronutrients was adequate, so that micronutrients were not a large component of fertilization programmes. With intensive cropping and high yields, the situation has changed considerably (Chapters 4, 6 and 7).

For several micronutrients, there are now increasing reports of insufficient soil supplies to meet increased crop requirements. This is affecting both crop yields and produce quality. Increasingly, micronutrients have become yield-limiting factors and are partly responsible for a decreasing efficiency of NPK fertilizers. Therefore, standard NPK-based fertilization must often be supplemented by the deficient micronutrients. Of the six practically relevant micronutrients, deficiencies of Fe, Mn and Zn tend to occur more on neutral to alkaline soils and under arid and semi-arid conditions.

A deficiency of B and Cu is more likely to occur on acid soils in humid climates although large-scale B deficiencies have been reported from many neutral to alkaline soils in east India. Common micronutrient fertilizers are briefly described here. Chapters 7 and 8 provide their application guidelines. Boron fertilizers Historically, Chile saltpetre was the first B fertilizer used. Its excellent effect on crops such as sugar beets was not only due to the N but also to the B contributed Chapter 5 – Sources of plant nutrients and soil amendments 111 by the small amount of borax present in it.

This B contribution was not recognized during the first 70 years of its use. Common B fertilizers are sodium tetraborate or borax ($Na_2B_4O_7$. $10H_2O$) (10. 5 percent B), boric acid (H_3BO_3) (17 percent B), Solubor $Na_2B_4O_7$. $5H_2O$ + $Na_2B_{10}O_{16}$. $10H_2O$ (19 percent B), and boron frits. Borax, or sodium tetraborate, is the standard B fertilizer. It is a white gritty salt suitable both for soil and foliar application. Boric acid is more soluble but relatively toxic to plants where applied as a foliar spray. The best fertilizers for spraying on leaves are polyborates.

For soil application, borax involves the risk of B toxicity to sensitive plants. However, there are slow-acting B fertilizers, such as colemanite or fritted boron silicates (fine glass powder containing B), that are safe. However, they lack a rapid initial supply. On B-deficient soils, about 1–2 kg B/ha may be needed for high yields. As the actual fertilizer amounts applied are small and difficult to distribute evenly, B is usually supplied together with special combined fertilizers (N or P or NPK with B).

Chlorine fertilizers The nutrient Cl is often present in the soil in adequate amounts or is incidentally added through chloride-containing fertilizers and in some cases through irrigation water or seaspray in coastal areas. Chloride deficiency is not common. It has been encountered in palms cultivated away from coastal areas. Common fertilizers containing Cl are KCl (47 percent Cl), NP/NPK complexes in which KCl is an input, sodium chloride(60 percent Cl) and ammonium chloride (66 percent Cl). Copper fertilizers

Cu fertilizers were first used for the treatment of Cu deficiency in boggy soils to correct the “ heath-bog disease” of oats or for the “ lick disease” of cattle raised on Cu-deficient grassland because humic substances tend to fix Cu in unavailable forms. Some common Cu fertilizers are: copper sulphate $CuSO_4 . 5H_2O$ (24 percent Cu), $CuSO_4 . H_2O$ (35 percent Cu); and copper chelate Na_2Cu-EDTA (12–13 percent Cu). Copper sulphate ($CuSO_4 . 5H_2O$) is the oldest and best-known fertilizer. It is a blue salt containing 24 percent Cu or 35–36 percent Cu with less water in its structure.

It comes in particle sizes varying from fine powder to granular and is used either in solid form for soil application or as a dilute solution for foliar spraying, which is more effective than soil application. For foliar spraying, copper oxychloride and copper chelate are preferable to the sulphate salts. Cu fertilizers based on metallic oxide and silicate forms can also be used to treat Cu-deficient soils. These substances must first be solubilized in the soils, i. e. converted into Cu^{2+} ions. These are more suitable for long-term Cu supply, in contrast to copper sulphate, which is more suitable for immediate effect.

Some fertilizers for grasslands contain both Cu and Zn and even Co. 112 Plant nutrition for food security Iron fertilizers The majority of Fe fertilizers are water-soluble substances, being either salts or organic complexes (chelates). Common Fe fertilizers are ferrous sulphate $FeSO_4 . 7H_2O$ (19 percent Fe) and ferrous ammonium sulphate $(NH_4)_2SO_4 . FeSO_4 . 6H_2O$ (16 perce