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Content

Chapter 4 Factors affecting the availability of nutrients to plants

The concept of availability

Plants can absorb and use nutrients only if they are in simple forms, usually ionic. Soil minerals such as micas, feldspars, hornblende and augite are complex silicates containing among them potassium, sodium, calcium and magnesium but these elements are of no immediate value to the plant and are said to be 'unavailable'. They become 'available' by conversion through weathering of the rock mineral to ionic forms (K^+, Ca^{2+}, Mg^{2+}, Na^+) which enter the soil solution. All ions in the soil solution are available to the plant, provided they can reach an active root or it can reach them. The concentration of ions in the soil solution at any given moment is, however, usually low, except immediately after the application of water-soluble fertilizers.

Most nutrients are taken up by the plant in the form of cations which are positively charged. Available cations either in the soil solution or held against leaching by negatively-charged clay or humus particles are easily taken up by the plant.

Other plant nutrients, notably phosphorus, boron and molybdenum, are taken up by the plant as anions which are negatively charged. The concentration of anions in the soil solution is usually low because they become converted to new, less soluble chemical forms. Phosphate ions, for example, may be converted to insoluble iron or aluminium phosphates which are less taken up by to the plant.

Nutrients contained in soil organic matter are also available in varying degrees to the plant. The organic matter is derived from plant residues, manures and dead or alive soil animals including a vast population of micro-organisms. Substantial proportions of nutrients contained in organic matter are in complex forms unavailable to the plant. They include the nitrogen, phosphorus and sulphur contained in the persistent organic materials. Other organic matter, particularly from recent crop residues or manures,

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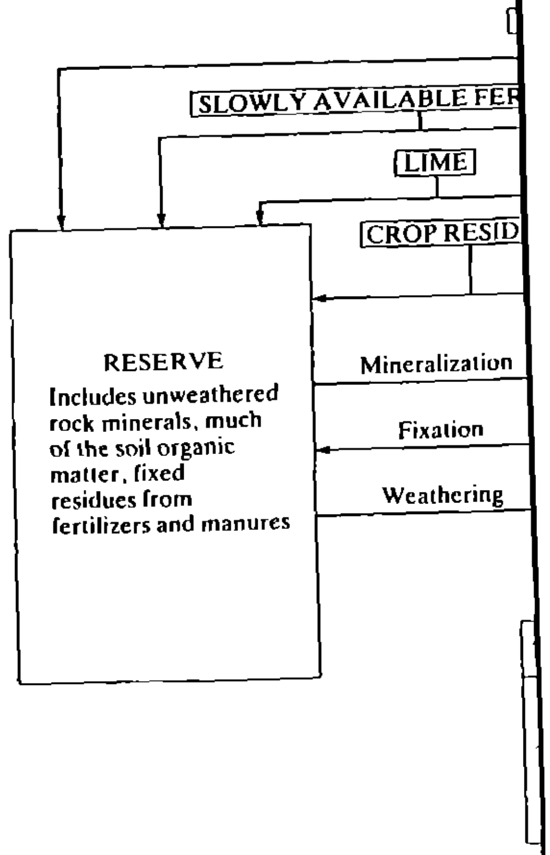
Figure 4.1 The availability cycle of nutrients.



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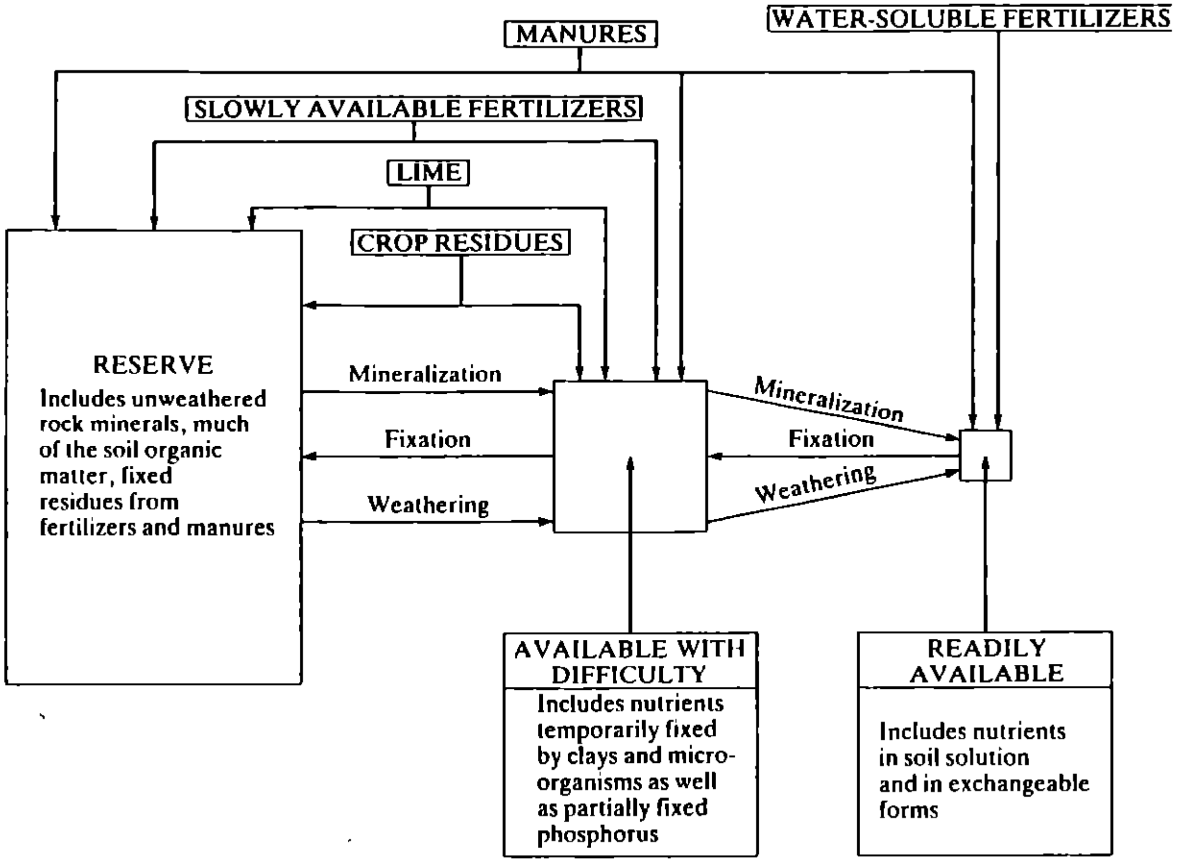
can be decomposed quickly by bacteria and thus 'mineralized'. Their carbon is released to the atmosphere as carbon dioxide and the nutrient elements become available to the plant as ammonium, nitrate, phosphate, sulphate and other ions.

In both inorganic and organic fractions of the soil the amount of a particular nutrient in forms chemically available to the plant varies from day to day and even from minute to minute if a vigorous crop is absorbing it. The system is in a continuous state of flux.

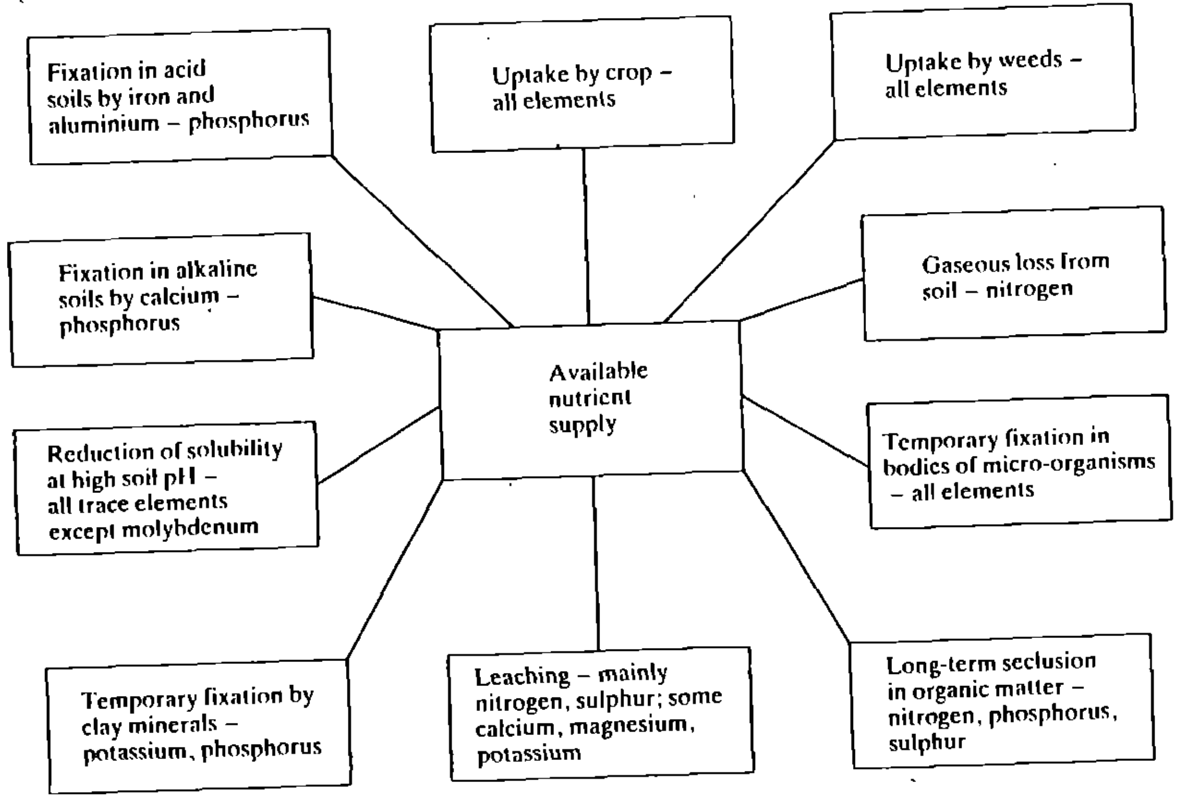
Figure 4.1 The availability cycle of nutrients.



The ever-changing pattern is broadly represented in Fig. 4.1. The sizes of the 'boxes' indicate very roughly the proportions of a nutrient in three empirical fractions: 'reserve', 'available with difficulty' and 'readily available'. Taking potassium as an example the 'reserve' would include potassium locked up in rock minerals such as potash feldspars. 'Available with difficulty' would include potassium trapped temporarily in clay lattices and 'readily available' would include potassium ions in the soil solution or held on the clay and humus as 'exchangeable' potassium.

However much 'readily available' nutrient a soil may contain, various physical features of the soil may make it impossible for the plant roots to absorb it. It then becomes 'positionally unavailable'. These features include pans and other forms of poor soil structure, waterlogged or

Figure 4.2 Competition for nutrients in the soil.



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Factors restricting availability

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Table 4.1 Factors restricting the availability of nutrients to th

Restricting factor	Effects on specific nutrients
Chemical:	
Alkalinity (high soil pH)	*Phosphorus* – fixed as tri-calcium phosphate in calcareous soils. *Manganese, iron, zinc, boron, cop cobalt* – compounds are converted soluble forms. *Nitrogen* – some loss of ammonia b volatilization, especially after ap cations of urea or ammonium fe *Potassium, magnesium* – availabili reduced by antagonism of excess calcium.

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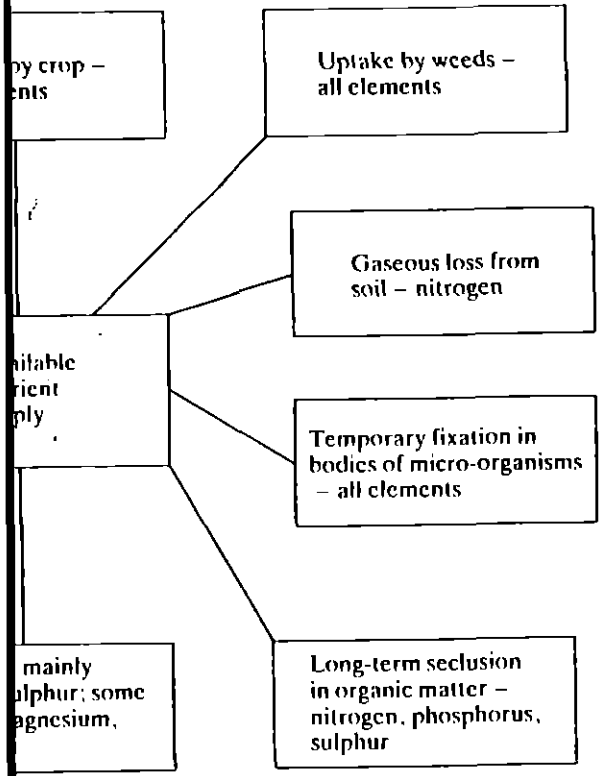

excessively dry horizons. Thus a soil might contain large amounts of available phosphorus within clods which roots cannot penetrate and from which the phosphorus can diffuse only very slowly. In such cases the so-called 'availability' of the nutrient becomes meaningless.

Competition for nutrients

Figure 4.2 illustrates the competition that a crop plant must overcome from inorganic components of the soil and from organic matter, living or dead.

Because of the many competing factors the proportion of the total plant nutrients in the soil taken up annually by the crop is very small, in some cases much less than 1 per cent. Even newly applied water-soluble nutrients from fertilizers are subject to leaching, uptake by weed species or other soil organisms, and fixation in forms less available to the plant. The result is, commonly, that only some 15–25 per cent of fertilizer phosphorus is taken up by the first crop and very much less by subsequent crops. The uptake of fertilizer nitrogen, especially by vigorously growing grass crops, can be much greater – in rare cases as much as 80–90 per cent of the amount applied.

In general, however, the crop plant is a poor competitor for nutrients from soil, manure or fertilizer.

Factors restricting availability

Table 4.1 summarizes the many factors which restrict nutrient availability and gives examples of the elements mainly affected. The right-hand column indicates the likely effectiveness of fertilizers or manures used to alleviate resultant deficiencies. The factors are presented in four groups – chemical, physical, biological and climatic – although there are considerable overlaps between the groups.

Table 4.1 Factors restricting the availability of nutrients to the plant.

Restricting factor	Effects on specific nutrients	Crop responses to supplements from manures or fertilizers
Chemical:		
Alkalinity (high soil pH)	*Phosphorus* – fixed as tri-calcium phosphate in calcareous soils. *Manganese, iron, zinc, boron, copper, cobalt* – compounds are converted to less soluble forms. *Nitrogen* – some loss of ammonia by volatilization, especially after applications of urea or ammonium fertilizers. *Potassium, magnesium* – availability reduced by antagonism of excess calcium.	Good short-term responses but added nutrients will be subject to the same adverse influences as nutrients already in the soil and will rapidly decline in availability. For trace elements, sprays applied to foliage are commonly more effective than applications to the soil.

Table 4.1 (*Cont*)

Restricting factor	Effects on specific nutrients	Crop responses to supplements from manures or fertilizers
Chemical: Acidity (low soil pH)	*Phosphorus* – fixed as iron and aluminium phosphates. *Nitrogen* – poor nitrification, poor nitrogen assimilation by soil bacteria; clovers, peas and beans (most legumes) cannot tolerate low pH. *Calcium, magnesium, potassium, copper, zinc* – strongly leached in acidic soils of high rainfall areas. *Molybdenum* – converted to unavailable forms. [NB Manganese and aluminium become more soluble and may become toxic to the plant, restricting the uptake of other nutrients.]	Response restricted in very acid soils because of damage to root systems, especially in sensitive crops such as barley and sugar beet. Liming essential to ensure more efficient uptake by the plant of both indigenous and added nutrients.
Antagonism of a gross excess of another element	Any nutrient cation may be affected. The most common examples are *magnesium* deficiency induced by excess potassium – usually derived from fertilizers or cattle slurry, and *potassium* or *magnesium* deficiency induced by excessive liming with calciferous limes.	Good short-term responses. The antagonisms can be greatly reduced by sensible policies for use of lime, fertilizers and manures – avoiding excessive applications.
Low cation-exchange capacity (sandy soils containing little humus)	All cations subject to leaching. Appreciable losses of *calcium, magnesium* and *potassium*. Copper and zinc may become deficient.	Good responses, but added nutrients are also subject to rapid leaching, especially if water soluble.
Absolute deficiency	*Calcium* – in acid soils. *Potassium* – in many sandy soils and deep peats. *Phosphorus* – some peats. *Copper* – in some reclaimed peats or podzols and in some calcareous soils.	Immediate and vigorous responses unless there is some severe restricting factor such as extreme acidity.
Fixation by clays	*Potassium* – temporarily trapped in clay particles. *Phosphorus* – held on positively-charged zones on the surface of clays.	Not well defined

Table 4.1 (*Cont*).

Restricting factor	Effects on specific nutrients
Physical: Pans (compacted layers)	*All nutrients*, but immobile nu *phosphorus* are affected most because roots cannot penet and phosphates in or below diffuse upwards very slowly
Large clods or natural soil-structure units which roots cannot penetrate	*All nutrients*, but immobile nu *phosphorus* are affected most
Biological: Competition from living soil organisms (weeds, soil animals, micro-organisms)	*All nutrients*, but especially *ni* micro-organisms compete v available nitrogen, especial organic matter with a high c nitrogen ratio such as straw recently incorporated.
Lack of earthworms	*All nutrients*. Earthworms pla in improving soil structure a ability of roots to seek out n
Immobilization in organic matter	*Nitrogen, phosphorus and sul* affected by seclusion in poo acidic organic matter such a mor humus in podzols and i which have not been draine
Pests and diseases	*All nutrients* but *nitrogen* defici symptoms are the most com Uptake is restricted becausc the efficiency of the plant. T effects are from pests or dise attack roots (e.g. nematode at ground level.

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Table 4.1 (*Cont*).

Restricting factor	Effects on specific nutrients	Crop responses to supplements from manures or fertilizers
Physical:		
Pans (compacted layers)	*All nutrients*, but immobile nutrients such as *phosphorus* are affected most seriously because roots cannot penetrate the pan and phosphates in or below the pan diffuse upwards very slowly.	Some response to water-soluble fertilizers because of increased concentration of nutrients above the pan. Response is usually restricted, e.g. by waterlogging or limited root development. Top dressing of nitrogenous fertilizer gives some benefit by stimulating a root system in the surface soil but the pan *must* be broken for long-term benefits.
Large clods or natural soil-structure units which roots cannot penetrate	*All nutrients*, but immobile nutrients such as *phosphorus* are affected most seriously.	Nitrogenous fertilizers give limited short-term benefit by encouraging root penetration. Long-term benefits from large, repeated applications of farmyard manure.
Biological:		
Competition from living soil organisms (weeds, soil animals, micro-organisms)	*All nutrients*, but especially *nitrogen*. Soil micro-organisms compete with plants for available nitrogen, especially if fresh organic matter with a high carbon/nitrogen ratio such as straw has been recently incorporated.	Good response.
Lack of earthworms	*All nutrients*. Earthworms play a vital part in improving soil structure and hence the ability of roots to seek out nutrients.	Any addition of manures will help to maintain or increase the earthworm population.
Immobilization in organic matter	*Nitrogen, phosphorus and sulphur* mainly affected by seclusion in poor quality acidic organic matter such as hill peat or mor humus in podzols and in other peats which have not been drained.	Vigorous response to liming and, in some peats, to drainage. After these operations crops will respond better to fertilizers or manures.
Pests and diseases	*All nutrients* but *nitrogen* deficiency symptoms are the most common result. Uptake is restricted because of effects on the efficiency of the plant. The worst effects are from pests or diseases which attack roots (e.g. nematodes) or stems at ground level.	Limited responses, in the case of root nematodes or fungi, to nitrogenous top dressings but these are no substitute for dealing with the pest or disease.

Table 4.1 (*Cont*).

Restricting factor	Effects on specific nutrients	Crop responses to supplements from manures or fertilizers
Climatic:		
Leaching resulting from excess rainfall	*All nutrients* are leached to some extent, especially in areas of high rainfall with freely-drained acidic soils. Least affected is *phosphorus*. Most affected is *nitrate-nitrogen* because the soil has no mechanism for retaining it. *Sulphate-sulphur* is also readily leached.	Good responses, but added nutrients, especially if water-soluble, are also subject to leaching.
Physical:		
Waterlogging, resulting from poor drainage or from excess rainfall	*Nitrogen* – through denitrification, lack of mineralization, poor nitrogen fixation. The chemical availability of some elements (e.g. *phosphorus, manganese*) is actually increased by waterlogging but this is usually counteracted by the restriction of root systems.	Little response unless waterlogging ceases. Top dressing of nitrogenous fertilizer gives some benefit except in prolonged surface waterlogging.
Drought	*All nutrients*.	Little response unless the drought breaks or irrigation can be used.
Low soil temperature	Mainly *nitrogen, phosphorus and sulphur*. Release of these nutrients from organic matter by mineralization is most rapid in moist, warm summers. Other nutrient elements are released only slowly from rock minerals at low temperatures. Root systems do not elongate and ramify and thus uptake of all nutrients is restricted.	Little response unless soil becomes warmer.

Processes affecting availability

Weathering of rock minerals

Weathering brings about the decomposition and transformation of rock minerals under the influence of rain, frost, sun, wind, plants and animals. During weathering many complex minerals, especially silicates, are converted to more soluble forms. Particles are reduced in size, giving increased surface areas for plant roots to contact. Some silicates are converted to clays which are capable of retaining cations, in exchangeable forms, available to the plant.

Weathering is thus a slow process which releases available nutrients from rock minerals and may also increase the capacity of the soil for retaining nutrients in available forms.

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Cation exchange

Both clays and humus are negatively charged and therefore attract cations, which are positively charged, including several important nutrient ions (K^+, Mg^{2+}, Ca^{2+}, NH_4^+ and trace elements). The amount of cations which can be adsorbed by a clay or a type of humus (measured in milli-equivalents per 100 g) is described as the *cation-exchange capacity*. This varies considerably from one type of clay to another and from one type of humus to another. Well-decomposed humus has the highest cation-exchange capacity, two to three times as great as the 'best' clay (montmorillonite). Other types of clay, more common in the British soils (illites, kaolinite) have much lower cation-exchange capacities.

Thus the cation-exchange capacity of British agricultural soils depends largely on the humus content in light soils and on clay content in heavier soils.

Table 4.2 gives some examples of the cation-exchange capacities of soils in the British Isles.

Table 4.2 Cation-exchange capacities of soils.

Soil	Cation-exchange capacity in milli-equivalents/100 g soil
Coarse sand	2–4
Coarse sandy loam	4–7
Sandy loam	6–18
Loam	10–22
Silty loam	13–28
Clay loam	16–40
Clay	25–50
Well-decomposed low-moor peat	180–220
Mor humus	20–50
High-moor peat	30–80

Source: Data from several sources.

Nutrients are held on the cation-exchange complex sufficiently strongly to resist leaching but are available for uptake by the plant either directly or by transfer to the soil solution by exchanging with other ions in the solution.

The process of *cation exchange* is involved in several aspects of nutrient availability. Cation exchange is very rapid and follows the normal laws of chemical reaction. A divalent cation such as calcium (Ca^{2+}) will exchange with *two* monovalent cations such as hydrogen (H^+) thus:

$$\mathrm{Ca\,(clay)} + 2\mathrm{H}^+ = {}^{\mathrm{H}}_{\mathrm{H}}\mathrm{(clay)} + \mathrm{Ca}^{2+}$$

This equation represents the replacement of calcium adsorbed on the cation-exchange complex by hydrogen ions from the soil solution. The Ca^{2+} released into the soil can then be leached, taken up by the plant or readsorbed on the cation-exchange complex.

Leaching, soil acidification and antagonistic effects among nutrient cations are all dependent upon the cation-exchange capacities of soils and the process of cation exchange.

Leaching

Leaching is the removal in solution or suspension of substances from the soil to drains and watercourses. Leaching of cations is greatest in areas of high rainfall, low temperature and from soils with a low cation-exchange capacity (gravels, sands, sandy loams with small humus content, see Table 4.2). In soils of very low cation-exchange capacity indigenous cations, cations from water-soluble fertilizers (NH_4^+, K^+) or from the water-soluble fractions of manures are easily leached. In most other British soils such leaching is slight and in high-humus clays very little removal of cations will occur, provided that the soil is not allowed to become strongly acidic.

Some nutrient *anions*, particularly nitrate and to a lesser extent sulphate, are very susceptible to leaching. The soil has no mechanism for retention of nitrate (NO_3^-) and unless taken up by the plant it will, in the event of heavy rain, move rapidly downward through the soil. This is particularly important when considering the choice and time of application of nitrogenous fertilizers.

The rate of leaching is increased by the application of some water-soluble fertilizers; directly because of their solubility and indirectly because of their acidifying effects.

Leaching will inevitably result in soil acidification except in strongly calcareous soils such as those derived from chalk.

Acidification

Soil acidification is caused by carbonic acid received in rainfall and mineral and organic acids produced during microbial decomposition of organic matter or mineral weathering. It is enhanced by atmospheric pollutants such as nitric acid and sulphurous and sulphuric acids. The use of nitrogenous fertilizers containing ammonium ions (NH_4^+) or urea ($CO(NH_2)_2$) also causes considerable acidification because hydrogen ions are produced during nitrification – conversion to nitrates.

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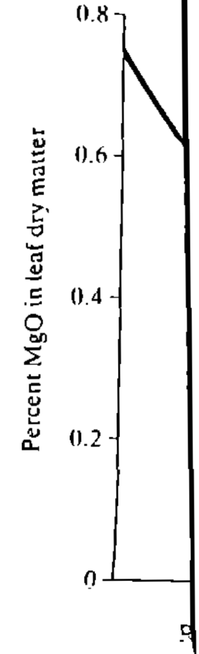

$^{+} = {}^{H}_{H}(\text{clay}) + Ca^{2+}$

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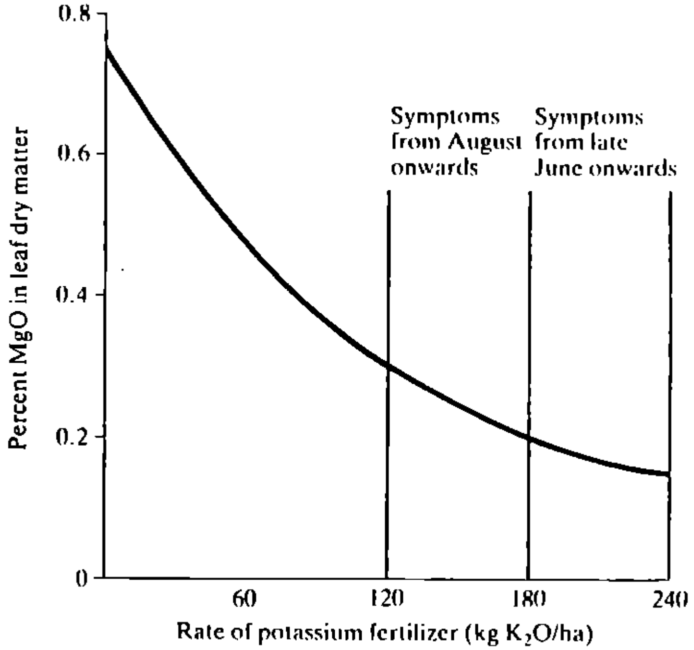
Acidification is most rapid in areas of high rainfall in soils of low cation-exchange capacity. Hydrogen ions dominate the soil solution and, by cation exchange, progressively dominate the cation-exchange complex along with aluminium ions in very acid soils. As a result basic cations (Ca^{++}, Mg^{++}, K^+) are displaced into the soil solution and are leached. Consequently the soil pH falls.

The effects of soil acidification on nutrient availability are very great. In addition to intensified leaching, mineralization of organically bound nutrients is retarded and phosphorus is fixed in forms unavailable to the plant. Also manganese and aluminium become more soluble and become toxic to the plant.

Antagonism

If one or more elements are available in excess this can adversely affect both the uptake and the efficiency of other nutrients. Such *antagonism* usually occurs among cations and may be at least partly explained in terms of cation-exchange reactions. One of the

Figure 4.3 *Effect of increasing potassium fertilizer rate on the magnesium content of potato leaves. Unpublished data from a field experiment, Edinburgh School of Agriculture.*



best known examples of antagonism is that of potassium for magnesium. Crops such as potatoes and tomatoes are known to require much potassium. However, large amounts of potassium fertilizer may induce magnesium deficiency in the crop. This may be diagnosed from leaf symptoms – green leaf margins, yellow or brown areas between major veins which also remain green.

There are two reasons for this. Within the soil, potassium and magnesium will compete for sites on the cation-exchange complex. An excess of potassium will cause leaching of magnesium and there will then be less available magnesium in the soil. Also, within the actively growing plant the *total* concentration of cations is fairly constant. The bulk of the cations present consists of potassium, magnesium, calcium and sodium, with potassium dominant in most plant leaves. Potassium is much more readily taken up by the crop than the other elements and is very mobile within the plant. The resultant luxury uptake of potassium will inevitably depress the proportion of magnesium, calcium and sodium in the leaves and it is the less mobile magnesium that becomes deficient. Figure 4.3 gives an example of potassium/magnesium antagonism in potatoes. As the potassium supply to the plant was supplemented by increasing the rate of potassium fertilizer, the concentration of magnesium in the leaf declined. At levels lower than 0.30 per cent MgO in the dry matter the leaves showed magnesium deficiency symptoms with large yellow or brown areas between the major veins.

Other examples of antagonism include calcium-induced potassium deficiency in plants grown on calcareous soils and deficiencies of calcium, magnesium or potassium caused by an excess of hydrogen and aluminium ions in acid soils.

There are even some soils so naturally rich in magnesium (ultrabasic soils) that calcium and potassium deficiency may be induced. Apart from these rare cases and the much more common effects of excess calcium (calcareous soils), almost all deficiencies induced through antagonism are caused by excessive use of lime, neglect of liming, or misuse of fertilizers.

Synergism When two nutrient elements each reinforce the influence of the other on plant growth they are said to be *synergetic*. Figure 4.4 illustrates a synergetic interaction in which a nitrogenous fertilizer, applied alone to a potato crop growing on a phosphorus-deficient soil, had virtually no effect on yield. When phosphorus fertilizers were also applied, the crop was able to use the available nitrogen,

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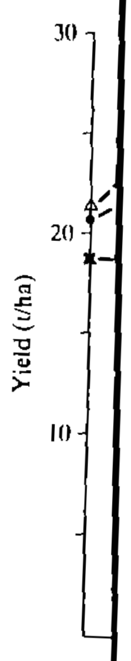

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gonism in potatoes. As the potassium supply to
pplemented by increasing the rate of potassium
ncentration of magnesium in the leaf declined. At
n 0.30 per cent MgO in the dry matter the leaves
ium deficiency symptoms with large yellow or
ween the major veins.

ples of antagonism include calcium-induced
ency in plants grown on calcareous soils and de-
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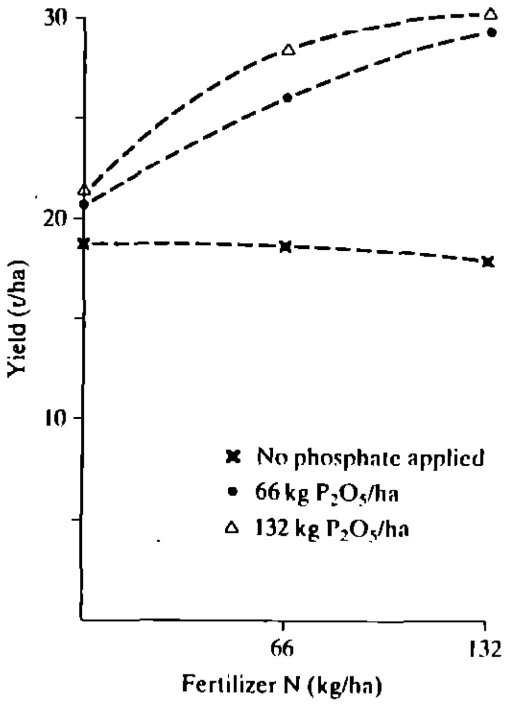
n some soils so naturally rich in magnesium (ultra-
calcium and potassium deficiency may be induced.
e rare cases and the much more common effects of
(calcareous soils), almost all deficiencies induced
ism are caused by excessive use of lime, neglect of
e of fertilizers.

ient elements each reinforce the influence of the
growth they are said to be *synergetic*. Figure 4.4
rgetic interaction in which a nitrogenous fertilizer,
a potato crop growing on a phosphorus-deficient
ly no effect on yield. When phosphorus fertilizers
d, the crop was able to use the available nitrogen,

Figure 4.4 *Interaction of nitrogen and phosphorus fertilizers on the yield of potatoes. Adapted from the data of K. Simpson,* Soil Science, **20**, *1.*



resulting in an appreciable yield increase. Typically, synergetic effects do not improve further once a certain nutrient supply is reached. Thus in Fig. 4.4, doubling the rate of phosphate fertilizer improved the effect of the nitrogenous fertilizer on yield only very slightly.

Figure 4.4 represents the simplest form of synergism. Much more complex interactions occur involving three or more elements. For example, a shortage of potassium can, in some crops, cause iron deficiency in plant leaves. This is probably the result of the failure of enzyme systems involving not only iron and potassium but also phosphorus. Because of this breakdown, iron can enter the plant but gets no further than the roots or stems, thus becoming deficient in the leaves.

Synergism between plants and micro-organisms The most important synergetic effect in crop production involves the harmonious and beneficial living together of plants and bacteria, *Rhizobia*, which inhabit nodules on the roots. This type of synergism is quite different from those which occur between nutrient elements as it involves living organisms. The plants involved are mostly leguminous: clover, peas, beans, lucerne, lupins. Some non-legumes have similar root nodules but the species are not important in agriculture.

In return for some sustenance supplied by the plant the *Rhizobia* take nitrogen from the atmosphere of the soil and convert it into forms available to the plant. The quantities of nitrogen converted can be great. In a vigorous grass/clover sward as much as 150–200 kg/ha of nitrogen can be involved annually. Leguminous arable crops take so much nitrogen from the atmosphere in this way that they seldom require any further nitrogen from manures or fertilizers.

The available nitrogen produced in this way can frequently carry over to reduce the requirement of the following crops for nitrogenous fertilizer. The legume/*Rhizobia* synergism is very complex and involves several nutrient elements, including calcium, phosphorus and the trace element cobalt which is not essential for other species but is essential to legumes because the *Rhizobia* require it in order to survive and multiply.

Synergism between plants and nutrient elements Some plant species are capable of absorbing more nutrients from a soil than others. In some cases this can be explained simply in terms of the vigour and intensity of the root system which enables some species to tap much greater volumes of soil than others. Surface- rooting species such as potatoes and brassica crops are able to colonize much smaller volumes of soil than the deep-rooting lucerne (alfalfa) and cereal crops. Also the intimately ramified root systems of long-established grassland ensure a much more satisfactory assimilation of available nutrients than those of newly sown arable row-crops.

Other differences in uptake of nutrients between species grown on the same soil are the result of substances exuded from the roots (root exudates) into the soil which dissolve nutrients and render them available to the plant. These exudates are usually organic and acidic. An example is found in the ability of the rape crop (*Brassica napus*) to absorb considerably more phosphorus from a given soil, especially if available phosphorus is low, than other species.

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unavailable of nutrients to the plant, either temporarily or permanently, by reaction with soil constituents or living organisms.

It includes, therefore, such diverse actions as temporary immobilization in the bodies of soil animals, fungi and bacteria, the conversion of ions to chemical forms of low solubility and the temporary trapping of ions between the plate-like layers of clay minerals.

Fixation by organisms Temporary fixation in the bodies of soil organisms may affect all nutrients. They are released again when the organism dies and decays. It has been estimated that some 10–30 per cent of fertilizer nutrients are temporarily 'fixed' in this way. Even more fertilizer nitrogen may be immobilized for some months if organic materials such as straw have been recently incorporated in the soil.

Potassium fixation Another example of temporary fixation is the trapping of potassium ions between the plate-like units of some clays, mainly illitic. The fixation tends to occur as the soil dries in the summer and some of the potassium is released after the soil becomes wet in the autumn followed by freezing and thawing during the winter.

Phosphorus fixation Much more serious and permanent fixation of phosphorus occurs in strongly acid soils (pH <5.5) and in calcareous soils (pH >7.0). The processes involved are very complex and have attracted vast amounts of research but the basic position can be summarized quite briefly.

Water-soluble phosphate added to soil in fertilizers, such as superphosphate, mono- and di-ammonium phosphates, is rendered insoluble in the course of days, sometimes hours. It does, however, remain in reasonably available forms for some weeks or months with its availability gradually declining.

The rate of fixation depends very much on soil conditions and particularly on pH. The most serious fixation occurs in very acidic soils (pH <5.0) in which there are large quantities of soluble iron and aluminium hydroxides. These combine with phosphate ions to give iron and aluminium phosphates which have very low solubility, particularly after they have 'aged' in the soil and have become crystalline. This is a gross over-simplification of phosphate fixation in acid soil but does give the essence of it. This type of fixation declines as the pH increases because of the smaller amounts of iron and aluminium hydroxides in solution.

In the middle range of soil pH, 5.5–6.5, fixation is at a minimum but as the pH rises above 6.5 under the influence of excessive liming or naturally calcareous parent material a different type of fixation occurs. This results from the reaction of soluble phosphates with calcium to give insoluble phosphates such as tricalcium phosphate ($Ca_3(PO_4)_2$). This type of fixation is most serious in soil derived from chalk or soft limestones such as oolite.

Phosphates may also be fixed by silicate clay minerals such as illite or montmorillonite. Some of this phosphate as well as that fixed directly by iron and aluminium can again become available to the plant by a process known as anion exchange by which an anion such as hydroxyl (OH^-) or fluoride (F^-) replaces the phosphate on the clay and thus releases it.

Fixation of trace elements The chemical forms of trace elements in soil are very strongly influenced by pH and by the availability of oxygen. In general the higher the soil pH and the drier the soil, the less available are the trace elements. There is one exception, molybdenum, which is converted into less available forms at low soil pH, i.e. in acidic soil. Copper, manganese, iron, boron, zinc and cobalt all become less available at high pH in aerobic soil conditions, because they are converted to less soluble forms. The conversion may be purely chemical but, certainly in the cases of iron and manganese, bacterial oxidation can occur. Certain bacteria oxidize ferrous iron (Fe^{2+}) to the ferric form (Fe^{3+}), which is less soluble. The bacteria involved operate best at high soil pH. Similarly manganous manganese (Mn^{2+}) may be oxidized by specific bacteria to the less soluble manganic form (Mn^{3+})

Mineralization

Mineralization is the conversion of nutrients contained in complex forms in soil organic matter to simple ionic forms available to the plant. The main elements involved are nitrogen, phosphorus and sulphur. It is important that the release of nutrients occurs through the action of soil micro-organisms and will *not* occur if their action is restricted by high carbon/nitrogen ratios, by soil acidity or by poor aeration.

Mineralization is most rapid in moist soils of moderate–high

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pH (5.5–7.5) immediately after the incorporation of green manures or farmyard manure already partially rotted. Release of nitrogen, phosphorus and sulphur from the easily decomposable low C/N ratio organic material is rapid.

Much slower mineralization of more resistant organic matter reserves varies from season to season. It is greatest in warm, moist summers. Obviously, in a season when mineralization is vigorous, less nitrogen, phosphorus and sulphur need to be added in fertilizers but unfortunately the *amount* likely to be released is very difficult to predict.

Nutrient balance

The term 'nutrient balance' has been sadly overused. It conveys the impression of knife-edged precision in the requirements of plants for a balanced supply of nutrients. In fact, most plant species can grow efficiently under a wide range of ratios and quantities of nutrients available to them. In this range the synergetic interactions of essential elements proceed satisfactorily and antagonistic interactions do not reduce the concentration of any element in the plant to a critical deficiency level. It is generally only gross excesses of particular elements which vitiate the synergetic actions and bring about nutrient deficiences through antagonism, causing serious crop problems. Such excesses can be caused by natural soil properties such as calcareous parent material. Unfortunately, however, the most common sources of gross excesses are ill-planned liming programmes and fertilizer treatments concentrated largely on the excessive use of nitrogen, phosphorus and potassium and neglecting other essential elements.

d strip grazing by sheep during autumn and early spring ploughing. A rich mixture of ues is lightly trodden in by the grazing sheep xidative losses are at a minimum. There are s on heavy soils in wet winters but otherwise way of recycling nutrients.

Chapter 9 Fertilizers

Fertilizers are substances which contain appreciable quantities of one or more essential plant nutrients. They are mostly inorganic. The raw materials from which they are made are atmospheric nitrogen, rock phosphates derived from large deposits in North Africa and elsewhere, mineral deposits or ores containing salts of potassium, sodium, magnesium, sulphur and trace elements.

Some of the raw materials, such as rock phosphates and limestones, may be used directly as fertilizers after being ground to a fine powder. More commonly the raw materials must be processed in some way. The obvious case is atmospheric nitrogen which is inert and useless as a fertilizer until it has been combined with carbon, hydrogen and/or oxygen to form ammonia, nitric acid, ammonium nitrate or urea. Other raw materials such as mineral deposits rich in potassium, sodium and magnesium could be, and in fact were, used directly as fertilizers but are hygroscopic and difficult to handle. This has been overcome by refining them and using conditioners to improve their physical condition.

Most modern fertilizers are designed to supply easily available nutrients in water-soluble forms for the crop grown in the year of application. There are often residual effects on crops grown in subsequent years.

Other fertilizers such as ground mineral phosphate and ground limestone are virtually insoluble in water and, when added to soil, release their nutrients gradually over a period of some years.

There are a few organic substances which, because of their high concentration of one or more nutrient elements, may be classed as fertilizers instead of manures. With the exception of urea, which is now produced synthetically on a large scale, they are usually much more expensive than comparable inorganic fertilizers and as a result are not widely used in agriculture. There is no magic about them, as is sometimes claimed and at normal rates of application their contribution towards increasing the organic matter content of soil is negligible. They include bone meal, steamed bone flour, dried blood, hoof-and-horn, guano obtained from vast deposits of bird excreta found in South America and various products from fish and meat wastes.

The purpose of fertilizer use

Fertilizers are used to supplement the nutrients which the plant can obtain from the soil in order to increase crop yields without detriment to quality. This is needed in most types of agriculture and especially in intensive systems from which high yields are sought and where the unsupplemented soil cannot supply nutrients quickly enough or in sufficient quantities to meet the requirements of crops.

Kinds of fertilizer

The farmer is offered a bewildering range of fertilizers. They may be solid and in granular form as are most fertilizers sold in the British Isles at present. They may be liquid, consisting of solutions or suspensions of fertilizer salts, usually in water. Liquid or fluid fertilizers take only a small part of the British market (about 6 per cent in 1983) but are more widely used in other countries including the USA. Gaseous ammonia is also used as a fertilizer by injecting it beneath the surface of the soil from cylinders. Again, although not widely used in the British Isles, this material takes about 50 per cent of the market for simple nitrogenous fertilizers in the USA.

In addition to variations in physical state fertilizers also vary greatly in chemical composition.

Simple or straight fertilizers are designed to supply only one nutrient element. Ammonium nitrate in the form of 'Nitram', containing 34.5 per cent of nitrogen, is a good example. Some simple fertilizers essentially used to supply one element may fortuitously provide another. For example ground mineral phosphate, essentially a phosphorus source, also contains some calcium. Similarly, ammonium sulphate, although designed to provide available nitrogen, contains rather more sulphur than nitrogen. Examples of simple fertilizers are given in Table 9.1.

Compound and blended fertilizers although made in different ways are designed to supply two or more elements. At present the great majority of these fertilizers supply only N, P and K or any combination of two of them.

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Table 9.1 Some simple fertilizers and materials commonly used in compound fertilizers.

Simple fertilizers:	
Nitrogen	% N
Urea	45
Ammonium sulphate	21
Prilled ammonium nitrate	34
Ammonium nitrate/calcium carbonate	21–26
Anhydrous ammonia	81
Liquid fertilizers containing ammonium nitrate, ammonia and urea	20–40
Phosphorus	% P_2O_5
Superphosphate	18–21
Triple superphosphate	45–47
Ground mineral phosphate	29–33
Basic slag	8–22
Potassium	% K_2O
Potassium chloride (muriate of potash)	60
Potassium sulphate	50
Compound fertilizers:	
Nitrogen sources	
Ammonium nitrate, urea, ammonium sulphate, ammonia (in liquids only)	
Nitrogen plus phosphorus sources	
Mono-ammonium phosphate (12% N, 61% P_2O_5) Di-ammonium phosphate (21% N, 53% P_2O_5)	
Phosphorus sources	
Triple superphosphate	
Potassium sources	
Potassium chloride, potassium sulphate	

Solid fertilizers

Solid fertilizers have dominated the British market for more than a century and continue to do so. They include several widely used simple fertilizers (Table 9.1) but a large proportion are sold as 'compounds'.

Compound solid fertilizers Some modern compound fertilizers consist of granulated mixtures of substances such as ammonium nitrate (35 per cent N), triple superphosphate (45 per cent P_2O_5) and potassium chloride (60 per cent K_2O), all of which may be used as simple fertilizers. Thus a compound fertilizer consisting of these substances alone mixed in the ratio of 2 parts ammonium nitrate : one part triple superphosphate: 1 part potassium chloride would have the percentage composition in terms of N : P_2O_5 : K_2O of 17.5 : 11.25 : 15.0. These figures are obtained by dividing the percentages of N, P_2O_5 and K_2O in the constituent substances by 2, 4 and 4 respectively. (One half of the final product is ammonium nitrate with a quarter each of triple superphosphate and potassium chloride.)

The original compounds were made by mixing 'simples' together in powdered or crystalline form. They gave rise to problems of segregation of particles of different density during transport and spreading resulting in erratic distribution – one part of a field receiving much more than its share of N or P or K. The great technical achievement of granulation has solved this problem. In modern technology the final components of the fertilizer are synthesized, mixed and granulated in continuous processes giving water-soluble granules of uniform size, composition and density.

Although designed to supply N, P and K, compound fertilizers during the first half of this century also contained appreciable amounts of the other major elements – sulphur, calcium and magnesium.

Since 1945, however, there has been an increasing tendency to concentrate on N, P and K at the expense of Ca, Mg and S. This has been done by:

- Virtually eliminating magnesium from the raw potassium salts originally used in fertilizers.
- Replacing ammonium sulphate ($(NH_4)_2SO_4$), which contains 24 per cent of sulphur, as the main nitrogenous fertilizer by ammonium nitrate, (NH_4NO_3) or urea ($CO(NH_2)_2$), neither of which contains sulphur.
- Replacing superphosphate, which consists of a mixture of monocalcium phosphate ($Ca(H_2PO_4)_2$) and gypsum ($CaSO_4.2H_2O$) by ammonium phosphates, ($NH_4H_2PO_4$) and ($(NH_4)_2HPO_4$), which contain neither calcium nor sulphur.

The net result of these changes in the composition of fertilizers has been the production of a range of high-technology compound fertilizers rich in NPK. They are granular, easy to spread with

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modern equipment and have lost the tiresome property of absorbing water which was a serious drawback in earlier fertilizers. They also store well without coalescing in the bag.

Anyone who in the 1930s and 1940s had to cope with liquidized fertilizer running out under the door of the fertilizer store or, worse, to take a hammer to a bag of solidified fertilizer (fortunately *not* ammonium nitrate!) will appreciate much more than the younger generation the technical near perfection of the modern granular fertilizer. But it must be appreciated above all that these fertilizers supply, with few exceptions, N, P and K and completely neglect calcium, sulphur, magnesium and the trace elements.

Table 9.2 Composition of typical compound fertilizers (1940–80).

Period	% N	% P_2O_5	% K_2O	Sum
1940–1950	7	7	7	21
1950–1960	9	9	16	34
1960–1970	12	12	18	42
1970–1980	16	16	21	53

Some idea of the changes in NPK concentration over the last forty years can be gained by a comparison of typical compound fertilizers of the four decades (see Table 9.2). Thus, present-day compounds are about three times as concentrated in terms of NPK as their counterparts in 1940–50. This represents a very large saving in the cost of transporting and spreading a given amount of nutrients.

Blended solid fertilizers In some countries, particularly the USA, 'blended' fertilizers are widely used. They consist of granules of simple fertilizers, containing N or P or K, bulk-blended to ordered ratios by mixing them, either on the farm or at a local depot. The idea is very attractive because *any* ratio of N : P : K may be formulated on the spot.

In modern blends the single components are carefully matched in terms of granule size and density in order to avoid segregation during mixing or transport. This problem does not arise with compound fertilizers.

We are unlikely to see widespread use of bulk blends in Britain during the next 20–30 years because of the commitment of vast capital investment to compound fertilizer production by the major manufacturers.

Liquid or fluid fertilizers

Most liquid fertilizers are solutions in water of the same substances that are used in water-soluble solid fertilizers. Recent advances in technology have introduced stable suspensions to which the term 'fluid' may be applied. Some materials rarely used in solid fertilizers are used in 'liquids'. They include ammonia because of its high nitrogen content (81 per cent N) and its solubility in water as well as polyphosphates, some of which are very rich in phosphorus and are soluble in water.

Liquid fertilizers are generally sprayed on to soils or 'dribbled' on to standing crops to minimize leaf scorch. Much of this work is done in Great Britain by contractors who take all risks of storage and machinery corrosion.

Liquid fertilizers were first introduced in areas such as the southern states of the USA where ambient temperatures are high and there are few problems of dissolved substances crystallizing out or precipitating. In cooler climates, including that of the British Isles, the risk is much greater, especially in winter storage.

Unfortunately once crystallization has occurred the crystals settle out, forming a discrete layer, and it is very difficult to re-dissolve them, needing both a considerable rise in temperature and vigorous stirring of the liquid over a long period. Thus storage in tanks on farms in the climates of northern Europe is difficult and it is preferable to take delivery of liquid fertilizers in bulk tankers when they are needed for spreading.

At present liquid fertilizers make up a much smaller part of the market in Britain and northern Europe (5–8 per cent) than in the USA (30–35 per cent). Most 'liquids' used in Britain are simple nitrogenous fertilizers which are much more easily handled than solutions containing N, P and K.

Farmers considering the use of liquid fertilizers should take very careful account of the advantages and disadvantages compared with solid fertilizers, especially before setting up on-farm storage.

Advantages claimed for liquid fertilizers over solids, which although small are real enough, are:

- More uniform distribution.
- Immediate absorption into soil even in dry periods.
- The possibility of incorporating some pesticide and fungicide materials.
- Lower manual labour because the liquids are handled by pumping.

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- The convenience of 'deliver and spread' services.

Against these advantages must be set several possible disadvantages:

- On-farm storage problems, including corrosion of tanks and crystallization of dissolved substances.
- Risk of foliage scorch if applied to standing crops.
- The need for corrosion-resistant machinery.
- Physical damage to soil by large tanker-spreaders.
- Generally lower concentration.

It is difficult to give a fair comparison of the costs of using liquid and solid fertilizers as so much depends on the bargain struck between farmer and contractor. When comparing costs the value of immediate delivery of liquids compared with on-farm storage of solids must be taken into account.

Simple liquid fertilizers Simple liquid fertilizers are almost entirely nitrogenous. They consist of solutions of urea, ammonium nitrate and ammonia in various proportions. These simple solutions are much easier to prepare and store than compound liquid fertilizers containing phosphates and potassium salts. If ammonia is dissolved under slight pressure it is possible to attain a concentration of 30–40 per cent nitrogen in the solution.

Compound liquid fertilizers The main problem in formulating NPK liquid fertilizers is the solubility of the substances used, especially phosphates and potassium salts. In recent years progress has been made in the use of fertilizer materials suspended in the liquids with the aid of 'gelling clays' and with the introduction of polyphosphates rich in phosphorus. These developments have made it possible to increase concentrations but solid fertilizers can still be made with greater NPK concentrations than liquids. Only 3–4 per cent of the British market is taken by compound liquid fertilizers.

Gaseous fertilizers

The only commercially-used gaseous fertilizer at present is anhydrous ammonia (NH_3) (81 per cent nitrogen). It is transported as a liquid under pressure in cylinders and must be injected beneath the surface of moist soil, when it is immediately converted to ammonium hydroxide (NH_4OH).

Although not done at present it would be feasible to inject sulphur dioxide (SO_2)(50 per cent S) into the soil using similar machinery. The sulphur dioxide would be converted to sulphurous acid (H_2SO_3) then to sulphuric acid and sulphates which would supply available sulphur to the crop.

There are no gaseous potassium fertilizers and it is unlikely that any gaseous phosphorus fertilizer will be used commercially. Phosphine (PH_3) has been used experimentally. The only advantage of phosphine is its very high concentration. It contains 91 per cent of phosphorous which in our present absurd system of quoting fertilizer concentration is equivalent to 208 per cent P_2O_5. It is, however, very hazardous to use, being a deadly poison and decomposing explosively on contact with air!

Fertilizers containing nutrients other than NPK

Because of the exclusion of other nutrients from NPK fertilizers, sulphur, calcium, magnesium and the trace elements must usually be supplied separately. Some soils are sufficiently rich in these elements to need no supplementation but more and more problems are arising from magnesium, sulphur and trace element deficiencies. Fertilizers other than those supplying N, P and K are described in Chapter 12.

Fertilizer information

When considering using a fertilizer it is helpful to have information on:

- Which nutrient elements it will supply.
- How much of each nutrient it contains in percentage terms and hence the ratios of nutrients.
- The proportion of each nutrient soluble in water or, in the case of the phosphorus components, certain other solvents.
- As much information as possible on the chemical form of the nutrients.

This information will help in the selection of a type of fertilizer of a particular nutrient ratio and to calculate the amount needed to meet the requirements of a crop as decided by methods described in Chapter 14.

It is useful to have detailed information about the chemical nature of the components of a fertilizer. For example, nitrate nitrogen is easily leached from soil but ammonium or urea nitrogen is much less so. Thus a farmer working with freely drained soils, especially in wetter areas, would be well advised to use a fertilizer which contains a high proportion of ammonium or urea nitrogen.

Information on the type and solubility of phosphate in fertilizers will give a good idea of the speed of action of the material in soil. It is

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Fertilizer regulations

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with ratios of 1 : 1 : 1.4, 1 : 1 : 1.5 and
e is no effective difference between them.

Chapter 10 The main N, P and K fertilizers

The most commonly used fertilizers vary from country to country. Urea is very widely used in India and Italy whereas ammonium nitrate is the most common nitrogenous fertilizer in the United Kingdom and the Federal Republic of Germany. Dicalcium phosphate is little used in Britain but is used much more in other EEC countries. None the less there are several fertilizer materials that are of major importance. Other materials, widely used in the past, have been largely superseded. The prime example of this is superphosphate which dominated the British market for more than a century between 1850 and 1960 and is now difficult to obtain.

Table 9.1 (p. 111) gives a list of the most commonly used N, P and K simple fertilizers and the materials most used in compound fertilizers.

Nitrogenous fertilizers

Ammonium nitrate

In the British Isles a concentrated form of ammonium nitrate is manufactured and sold in the form of prilled granules guaranteed to contain 34.5 per cent nitrogen. The prilling process consists essentially of coating the granules to protect them to some extent against absorbing moisture in humid conditions and greatly to reduce the risk of fire or explosion when handling the dry material. None the less, when the prills are added to soil the ammonium nitrate dissolves quickly and becomes available within hours unless conditions are excessively dry.

Reasonable care is required in handling and storing this fertilizer. Warnings are printed on the bag that it is an oxidizing agent and 'assists fire'. It is safe if stored away from sources of heat or fire, in tough polythene bags, avoiding such foolish acts as walking over the stacks in hobnailed boots. It is *imperative* not to store it loose or in burst bags where it might come into contact with wood shavings, sawdust, straw or other combustible materials. Once spread on the soil there is no risk of conflagration.

Because of its tendency to absorb water, even in the prilled state this fertilizer should not be left in the distributor longer than is necessary to spread it.

In common with other fertilizers containing ammonium compounds, concentrated ammonium nitrate will acidify the soil and extra lime will be required to neutralize this acidity except in naturally calcareous soils.

Both ammonium and nitrate ions are available to plants. Because of this and the solubility of ammonium nitrate in water it is readily absorbed by plant roots. Unfortunately the nitrate component, half of the total nitrogen, is easily leached. There are cases of the loss of *all* nitrate from the top 25 cm of soil during short periods of heavy rain and in wet springs substantial losses will occur. For this reason the time of application of this fertilizer is critical and applications to bare ground should be delayed as long as possible. The ammonium ion acts as an exchangeable cation and is retained by the cation-exchange complex until converted to nitrate by bacteria.

Ammonium nitrate is ideal for top-dressing a growing crop, especially grass, because the established root system can catch the nitrate as it is leached downwards. There is some risk of loss of nitrogen by volatilization of ammonia if it is applied to the surface of naturally calcareous or newly limed soils. In acidic soils the risk is negligible.

Ammonium nitrate-calcium carbonate mixtures

These mixtures are now classified in the EEC Regulations as 'calcium ammonium nitrate', a misnomer. This type of fertilizer was first produced by ICI more than half a century ago under the trade name 'Nitro-chalk'. The admixture of finely divided calcium carbonate serves a similar purpose to prilling – reducing absorption of water in humid conditions and cutting down the fire risk in dry conditions. Ammonium nitrate-calcium carbonate mixtures contain much less nitrogen than the prilled form resulting in higher transport and spreading costs, but they are also less acidifying because of the built-in neutralizing effect of the calcium carbonate component.

Table 10.1 Composition of ammonium nitrate/calcium carbonate fertilizers.

N (%)	Ammonium nitrate (%)	Calcium carbonate (%)
15	42.8	57.2
21	60.0	40.0
26	74.3	25.7
34.5	98.5	Nil

Urea

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34.5	98.5	Nil

Table 10.1 compares the proportions of ammonium nitrate and calcium carbonate in the various solid ammonium nitrate fertilizers.

The original 'Nitro-chalk' contained only 15 per cent nitrogen and had little or no acidifying effect. Its successors contain more ammonium nitrate and hence less calcium carbonate and cause some acidification, but not so much as the prilled concentrated form. The more recent formulations are as effective per unit of nitrogen as the original form but should be regarded as mildly acidifying – some 25–35 per cent as acidifying as pure ammonium nitrate.

Urea

Urea is an organic fertilizer, being present in the urine of mammals as the chief form of nitrogenous waste material from the body. It has now been produced synthetically for many years and it is this material that is used as a fertilizer. It is cheap to produce, especially where there is ample electric power, and in many countries is used more extensively than in the British Isles. Urea is the most concentrated nitrogenous fertilizer available as a solid and is easily soluble in water. Its formula is $CO(NH_2)_2$ and, if pure, it contains 46.6 per cent of nitrogen. Pure urea is hygroscopic and difficult to use but fertilizer technology has overcome this by prilling with a small amount of conditioner to give a commercial product containing 45 per cent nitrogen.

When applied to moist soil, urea dissolves and is rapidly converted to ammonium carbonate which is alkaline. Thus, if applied as a top dressing urea can raise the pH of the surface centimetre or so of the soil for a period of a few days. This temporary alkalinity gives rise to some risk of loss of ammonia by volatilization but the risk is even greater on chalk or limestone soils which are naturally alkaline.

There is evidence that large dressings of urea in the vicinity of germinating seeds or young seedlings as in combine drilling can damage them and also reduce or delay emergence. It was originally thought that the cause was an impurity in synthetic urea called biuret which is toxic to plants but although the amount of this substance in commercial urea is strictly controlled by EEC regulations to very low levels the ill effects have continued. They may be caused by release of ammonia within the soil. Whatever the cause, it is wise to cultivate newly applied urea well into the top 10–15 cm of surface soil.

Following the brief period of alkalinity caused by its conversion to ammonium carbonate or ammonia, urea nitrogen acts in essentially the same way as any ammonium compound. It is absorbed as an exchangeable cation and is therefore not easily leached. After conversion to ammonium, urea has a strong acidifying effect on the soil which can be greater than that of ammonium nitrate, and this necessitates the use of extra lime.

There have been many experimental comparisons of the effects of ammonium nitrate and urea on crop yields. Some results favour one, some the other, with perhaps a slight overall advantage to ammonium nitrate. Urea tends to be inferior as a top dressing in dry areas of calcareous soil, but should be safe to use as a top dressing in wetter areas of acidic soils. Urea may be superior for arable crops in wetter areas of non-calcareous soils especially if the fertilizers are well incorporated. This is almost certainly due to preferential leaching of the nitrate fraction of ammonium nitrate.

Ammonia

Liquefied anhydrous ammonia (NH_3)(82 per cent N) is widely used as a fertilizer in the USA but not so extensively in Europe. Ammonia is a very toxic gas. It can be produced practically free from impurities and as such it is the most concentrated nitrogenous fertilizer. Its gaseous nature and poisonous properties, however, present difficulties.

It was pioneered as a fertilizer in the vast areas of uniform stone-free silty wind-borne soils of the USA. Injection is made 10 cm or more below the surface of the soil in a slit made by a coulter. The surface of the slit must be closed immediately afterwards. This is easily done in such soils and, for example, in the stone-free silts and peats of the East Anglian fen. Unfortunately many other British soils, particularly in northerly glaciated areas, are stony and variable in texture and structure. As a result major problems are found in using the material.

Liquefied anhydrous ammonia is a remarkable example of the difficulties of transferring a technique developed successfully in one set of conditions to an entirely different set of conditions. The problems are worthy of detailed consideration.

In stony or poorly structured soils the closing of the slit after injection is virtually impossible and serious losses of ammonia can occur.

Because of the draught required to pull the coulters through heavy soils the space between slits needs to be about 50 cm. In

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soils with a high cation-exchange capacity ammonia not lost immediately by volatilization is absorbed as the ammonium cation and does not diffuse adequately into the zones between the slits. The results of this can be best seen after application to grassland. There is a good yield response around the slits and poor in between, giving a 'wavy' appearance.

Immediately after application the strongly alkaline ammonia increases the pH of the soil near the slits well above the normal soil range. Also, in that zone the concentration of ammonia can be so high that the soil is virtually sterilised – young plant roots, worms and other soil organisms being killed.

Injection of large dressings, up to 300 kg N/ha into grassland in springtime, has been recommended by some operators on the grounds that one application will then be sufficient for the season. It is tempting to follow this recommendation, especially as the unit price of liquefied anhydrous ammonia can fall dramatically at high application rates. The reason for this is that the price includes the cost of application by a skilled operator. The ammonia itself is cheap and it is as easy to inject a large amount as a small amount. Experimentation has shown, however, that large applications (200–300 kg N/ha) are either taken up early in the season and thus, in a cutting system, removed in early cuts of grass, or lost from the soil. As a result the effects of such applications do not last beyond midsummer.

It has also been claimed that injections can be made in autumn or early winter for arable crops to be grown in the following season. This may well be so in the Corn Belt of the USA where soils are frozen during the winter and leaching losses small. There would, however, inevitably be leaching losses in British conditions, especially in mild wet autumns and winters during which some of the ammonia would be converted to nitrate. If used for arable crops in the British Isles, injection should be made in early spring.

In common with urea, following its transient effect in raising soil pH, anhydrous ammonia acidifies the soil and extra lime will be needed to combat this.

Because of its extreme toxicity to human beings, the storage, transport and application of liquefied anhydrous ammonia should be in the hands of experienced operators, with all the necessary safety precautions. Storage of cylinders of liquefied anhydrous ammonia on the farm should be avoided. Although normally perfectly safe, tampering with them could lead to tragedy.

Liquid nitrogenous fertilizers

Like liquefied anhydrous ammonia, these fertilizers have been included as a 'main' fertilizer because of their widespread use in the USA.

Aqueous ammonia solutions are made by simply dissolving gaseous ammonia in water. If dissolved under slight pressure, solutions containing 20–30 per cent nitrogen can be made. Although they should be placed below the surface of the soil to avoid ammonia loss they are easier to handle than liquefied anhydrous ammonia, there being less risk to operators and less loss of ammonia in difficult soils.

Other nitrogenous solutions are made using urea or ammonium nitrate or mixtures of the two. Solutions containing 20–30 per cent N can be made, transported to the farm in tankers and spread directly. The nitrogen content of such solutions may be increased to 30–40 per cent N by dissolving, under slight pressure, some gaseous ammonia, thus creating a concentrated liquid fertilizer to compete with solids of similar concentration.

All such solutions may be applied by spraying on to bare soils and incorporating immediately a day or two before sowing arable crops. This has the advantage of giving very even distribution. Problems of losses by volatilization of ammonia will be similar to those for solid fertilizers.

If sprayed on to growing crops there is a considerable risk of scorching the leaves. Crops are said to recover quickly from such scorch but some loss of crop is inevitable. Damage can be reduced in grassland and more so in row crops by the use of large droplet sprays which do not adhere easily to the leaves or by replacing the sprayer with a boom with pipes spaced at 12–18 cm pointing downwards and ending in plastic tubes which reach the soil surface. Only vegetation immediately below the tubes is at risk from scorch. This method does not give the even distribution achieved by spraying.

Phosphorus fertilizers

Most of the phosphorus, almost 90 per cent, applied in UK fertilizers is incorporated in compound fertilizers. There are two main simple phosphate fertilizers: triple superphosphate and ground mineral phosphate. Almost all modern phosphorus fertilizers are derived directly or indirectly from mineral phosphates found in North Africa, Florida, USSR and many other parts of the world. Phosphate rocks vary in composition from

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source to source but invariably the phosphate is in the form of tricalcium phosphate ($Ca_3(PO_4)_2$), usually in combination with calcium fluoride or carbonate. These forms are collectively known as apatite. The P_2O_5 content of a good quality rock phosphate will be around 30 per cent.

Ground mineral phosphate (GMP)

This fertilizer is made, as its name suggests, by simply grinding the rock to a fine powder so that about 90 per cent of it passes through a 100 mesh sieve (apertures approximately 0.015 mm). GMP is most effective in acid soils of pH less than 6.0 in the wetter, northerly and westerly parts of the British Isles. It is insoluble in water and becomes available to the plant only through the action of soil acids and organisms and is fundamentally a long-term fertilizer. The fine grinding provides a large surface area in order to assist this action. Some producers have marketed an ultra-fine flour-like material, much of which passes a 300 mesh sieve, but this is generally little more effective than ordinary GMP in increasing phosphorus uptake by plants.

Softness is an important property of mineral phosphates. GMP from hard rocks acts much more slowly and less effectively than that from soft rocks. Most of the GMP used in the British Isles is made from soft North African rock. The softness and effectiveness of various samples of GMP can be compared by treating with 2 per cent formic acid which will dissolve a greater proportion of the phosphate from soft materials than from hard ones. In the EEC regulations a ground mineral phosphate must have 55 per cent of its total P_2O_5 content soluble in 2 per cent formic acid in order to be described as 'soft'.

Many comparisons have been made in field experiments of the effects of GMP with those of water-soluble phosphates on the yield and phosphorus uptake of crops. Early field experiments, especially on arable crops, were based on a uniform time of application, immediately before sowing the crop. This put the more slowly available GMP at a strong disadvantage. More recently work by ADAS has shown that a soft GMP applied in the previous autumn can be equivalent unit for unit with water-soluble phosphates applied in the following spring. Most of this work was done on acidic soils in high rainfall areas.

Mineral phosphates are least effective in near neutral or alkaline soils (pH greater than 6.5) and should certainly not be used on the dry soils in south-east England derived from chalk or limestone.

They are best used in wetter areas (rainfall more than 900 mm per year) and are most suitable for upland or marginal grassland or for crops such as kale, rape or swede turnips.

Ground mineral phosphates are not pleasant to handle because of their powdery nature. Because of this a GMP has been produced in the form of granules which disintegrate rapidly in the soil.

Triple superphosphate

This water-soluble fertilizer is essentially mono-calcium phosphate ($Ca(H_2PO_4)_2$) approximately 45 per cent P_2O_5. It is made by treating rock phosphate with sulphuric acid to give orthophosphoric acid (H_3PO_4) and then reacting this with more rock phosphate. Because of its water solubility the phosphorus in triple superphosphate is easily available to crops for several weeks after application. It is progressively subject to fixation as the season goes on and supplies only small amounts of residual phosphorus for subsequent crops.

Potassium fertilizers

Only very small amounts of simple potassium fertilizers are used in the British Isles. More than 95 per cent of the total amount used is included in compound fertilizers. In the USA, however, more than half of a very large annual tonnage is applied 'straight'. There are two main potassium fertilizers, potassium chloride and potassium sulphate.

Potassium chloride

Potassium chloride, KCl, is usually sold as muriate of potash containing 60 per cent K_2O, all of which is soluble in water. The term muriate is archaic, dating from the time when hydrochloric acid was called muriatic acid. It is the commonest potassium fertilizer in most countries, made from raw potash salts first extracted from mineral deposits at Stassfurt in Germany. Deposits are now exploited in north-east England, Israel, USSR and many other countries.

It is now marketed both as a dry free-running powder and in the form of granules.

Potassium sulphate

Potassium sulphate (K_2SO_4) 50 per cent water-soluble K_2O, 18 per cent S, is used to a limited extent as a potassium fertilizer for potatoes, vegetables and fruit crops in which it enhances the

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quality as compared with potassium chloride. It is more expensive than the chloride form but can be used to advantage in, for example, seed potato production, increasing the proportion of seed-sized tubers in the crop and resulting in higher dry matter in tubers and better keeping quality. Claims are also made that potassium sulphate, applied at equivalent rates to the chloride, gives better flavoured fruit and vegetable crops.

Potassium sulphate is used specially in countries with saline soils because the chloride form would add to the salinity problem.

It is a useful source of available sulphur.

The main constituents of NPK fertilizers

Because of modern methods of manufacture in which some components of compound fertilizers are synthesized and simultaneously mixed with others it is not always possible to identify precisely some individual substances, particularly phosphates, in the final product. The manufacturer is not required to specify the actual phosphates contained in water soluble form but simply the percentage of water-soluble P_2O_5.

Table 9.1 gives a list of the main components of compound fertilizers. The only ones not previously described are mono- and di-ammonium phosphate.

Mono-ammonium phosphate ($NH_4H_2PO_4$) 12 per cent N, 61 per cent P_2O_5 and *di-ammonium phosphate*, ($(NH_4)_2HPO_4$) 21 per cent N, 53 per cent P_2O_5 are made by reacting ammonia with phosphoric acid. They are usually synthesized during the manufacture of compound fertilizers. They are both water soluble and because of their high P_2O_5 and smaller N contents they are very useful to the manufacturer of concentrated compound fertilizers. Their phosphorus component is similar in action to triple superphosphate and their ammonium component behaves similarly to that in ammonium nitrate.

Chapter 11 Other NPK fertilizers

Those fertilizers described in Chapter 10 make up a very large proportion of the present-day market. There are many other less widely used N, P or K fertilizers. Some were once widely used and have been superseded. Others have not yet found favour because of problems of manufacture, price or scarcity.

Nitrogenous fertilizers

Ammonium sulphate ($(NH_4)_2SO_4$) 21 per cent N, 24 per cent S, known in commerce as sulphate of ammonia, dominated the market as a water-soluble nitrogenous fertilizer in the first half of this century. It has gradually been replaced during the last twenty years by ammonium nitrate and urea. In its day it was the spearhead, along with superphosphate, of the great yield increases produced by fertilizers between 1900 and 1950.

It is water soluble, not easily leached because its nitrogen is in the ammonium form, but acidifies the soil very strongly. It is a very useful source of available sulphur.

Calcium nitrate (so-called), approximately 15 per cent N, is actually a complex double salt of calcium and ammonium nitrates. It is sold in prilled form, is readily available to the plant but easily leached. It is little used in the British Isles.

Calcium cyanamide ($CaCN_2$) 21 per cent N, was originally used in Britain as a combined weedkiller and nitrogen fertilizer before the Second World War. It is now used mainly in Germany and Japan.

Because of its immediate herbicidal effect it should never be applied to a standing crop or immediately before sowing. To get maximum weed killing and minimum crop damage it should be applied 2–3 weeks before sowing a crop, during which time it is converted in the soil first to urea and then to ammonium carbonate.

Sodium nitrate ($NaNO_3$) 16 per cent N, is a fast-acting, easily leached material which was one of the first nitrogenous fertilizers

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aNO$_3$) 16 per cent N, is a fast-acting, easily
which was one of the first nitrogenous fertilizers

used. It was imported in large quantities from Chile in the nineteenth century but is expensive and is now little used in the British Isles.

Slow-release nitrogenous fertilizers

In order to reduce leaching losses and in an attempt to release available nitrogen into the soil when it is most needed by crops, a range of slow-release fertilizers is developing. They are at present very expensive and are not widely used in agriculture. If they could be made cheaply and designed to release available nitrogen to order, they might become important in the future.

Phosphorus fertilizers

Superphosphate is a mixture of mono-calcium phosphate ($Ca(H_2PO_4)_2$) and gypsum ($CaSO_4.2H_2O$), usually containing 18–21 per cent P_2O_5, mainly water soluble, and 10–12 per cent sulphur. This fertilizer was the outcome of the first successful attempt to convert insoluble bone or mineral phosphates to water-soluble form. This was done by treating with sulphuric acid. Superphosphate, a superb fertilizer, dominated both the simple and compound phosphate fertilizer market for 100 years between 1850 and 1950. It has now been superseded by more concentrated water-soluble phosphates and is little used in the British Isles.

Basic slag is, or was, a by-product of steel manufacturing processes now largely superseded. It contains both lime and phosphates. Like GMP it is ground to a very fine powder before use. It is a very dense material and is objectionable to spread in its powdered form. Because of this 'mini-granules' have been produced which are much less dirty and offensive. In the heyday of the British steel industry basic slag was the outstanding 'simple' phosphorus fertilizer and was very widely used on grassland. There is now little or no home-produced basic slag although some is imported from the USSR and the continent of Europe.

Basic slag is very variable in composition. The total P_2O_5 content can vary from 7 per cent to more than 20 per cent, the lime content from 50 to more than 70 per cent $CaCO_3$. There are also useful impurities including magnesium as well as trace elements such as manganese and iron.

Quotations are required by the EEC of the percentage of the total P_2O_5 content which is soluble in 2 per cent citric acid. This is related to the effectiveness of the slag in increasing phosphorus uptake by the plant.

The best approach to purchasing basic slag is to seek a slag with as high a P_2O_5 content as possible, at least 80 per cent of which is soluble in 2 per cent citric acid. It is best used on hill or marginal grassland but may also be used for arable crops on both acidic and neutral soils. Like GMP it is fundamentally a long-term fertilizer.

Ammoniated superphosphate is the product of treating superphosphate with ammonia. This introduces some available nitrogen and reduces the proportion of water-soluble phosphate by conversion to di-calcium phosphate. The theory behind this is to supply a mixture of immediate-acting and long-term phosphorus sources.

Di-calcium phosphate ($Ca_2(HPO_4)_2$) 40 per cent P_2O_5, is chemically intermediate between the water-soluble mono-calcium phosphate in triple superphosphate and the insoluble tri-calcium phosphate which occurs in rock phosphates. It is only slightly soluble in water but is tested under EEC regulations by its solubility in alkaline ammonium citrate. Although it is an effective simple phosphate fertilizer it has never become popular in the British market. One reason for this is its powdered form which makes it difficult to apply. Another is that despite its effectiveness it is not water-soluble. Until recent years substantial government subsidies were given to water-soluble phosphates and this established a tradition of using such materials preferentially.

Nitrophosphates are made by treating rock phosphates with nitric acid instead of the sulphuric acid used in the production of most water-soluble phosphates. By adjusting the amounts of nitric acid used the proportion of water-soluble to insoluble phosphate can be varied. Imported nitrophosphates are on sale in the British Isles. When considering purchase it is necessary to take account of the proportion of the total P_2O_5 which is water soluble and to compare in terms of unit costs with other phosphate sources.

Condensed phosphates are a wide range of phosphates which have not yet found a significant place in fertilizers. This they may well do in the future, because of their high P_2O_5 content (55–75 per cent). Some of them are soluble in water and have been used in liquid compound fertilizers. They seem to be easily available to crops.

Potassium fertilizers

Potassium nitrate (KNO_3) 13 per cent N, 44 per cent K_2O, takes only a small share of the market. It is very soluble, rapidly available but easily leached. *Chilean potash nitrate* is a cruder product containing only 10–15 per cent K_2O and 9–18 per cent of sodium.

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Sulphate of potash magnesium, 28 per cent K_2O, 11 per cent MgO, is a water-soluble double salt used in parts of Europe.

Rock potash is produced by grinding rocks containing potassium-rich silicate minerals, mainly micas. It is used to increase the reserves of weatherable potassium in the soil. It has been used in Scandinavia but not yet in Britain. There are potential sources in schistose rocks in Scotland.

Chapter 12 Fertilizers other than NPK

Because of the concentration of compound fertilizers on N, P and K the other major elements, calcium, sulphur and magnesium, as well as the trace elements need to be supplied separately. At present this is often neglected but as the stress on these available nutrients from the soil has been accentuated by many modern farming practices the need for supplementation has become steadily greater.

A list of fertilizers supplying nutrients other than NPK is given in Table 12.1

Calcium fertilizers

Calcium carbonate ($CaCO_3$) in the form of chalk and limestone is the only regularly used specific calcium fertilizer. Chalk and calciferous limestones contain 35–38 per cent Ca and magnesian limestones contain 20–34 per cent Ca. They are insoluble in water and their calcium is slowly available. Regular liming will ensure that there is no calcium deficiency in field crops. Other fertilizers which supply some calcium are ammonium nitrate-calcium carbonate, 10–16 per cent Ca; basic slag, 25–35 per cent Ca; triple superphosphate, 16–21 per cent Ca; ground mineral phosphate, 35–40 per cent Ca; and gypsum, 23 per cent Ca.

Magnesium fertilizers

Magnesian limestone, 5–20 per cent MgO, consists mainly of calcium carbonate and magnesian carbonate in varying proportions. A good sample would contain about 40 per cent of $MgCO_3$ (20 per cent MgO). It is by far the cheapest source of magnesium and may be used on acidic soils as part of the liming programme. It should not be used on calcareous soils because it would enhance the risk of trace element deficiencies.

Calcined magnesite, 90 per cent MgO, is a useful concentrated but slowly available source of magnesium. Because of its high concentration it could easily be incorporated in compound

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Table 12.1 Some fertilizers supplying nutrients other than NPK.

Calcium	% Ca
Ground calciferous limestone (90% CaCO$_3$)	36
Ground magnesian limestone (50% CaCO$_3$)	20
Basic slag	15–20
Gypsum	23
Magnesium	% MgO
Ground magnesian limestone (40% MgCO$_3$)	16
Calcined magnesite	90–95
Kieserite	29
Epsom salt	16
Sulphur	% S
Ammonium sulphate	24
Gypsum	18
Sulphur	98–100
Potassium sulphate	17
Manganese	% Mn
Manganese sulphate (4H$_2$O)	24
Manganese chelates	8–12
Boron	% B
Borax (10H$_2$O)	11
'Solubor'	20
Copper	% Cu
Copper sulphate (5H$_2$O)	25
Copper oxychloride	58
Copper chelates	8–12
Iron	% Fe
Ferrous sulphate (7H$_2$O)	20
Iron chelates	5–12
Molybdenum	% Mo
Ammonium molybdate	53
Sodium molybdate (2H$_2$O)	38
Zinc	% Zn
Zinc sulphate (H$_2$O)	35
Zinc chelates	10–12
Cobalt	% Co
Cobalt sulphate (7H$_2$O)	20

fertilizers to give 4–8 per cent of magnesium in the final product. Such fertilizers, used on a regular basis, would help to balance the magnesium lost in crops or by leaching from calcareous soils or from acidic soils on which no magnesian limestone is used. Calcined magnesite may also be used as a 'straight' long-term fertilizer. An application of 200–300 kg/ha should help to increase the magnesium content of crops for a period of 3–5 years.

Kieserite ($MgSO_4.H_2O$) 28 per cent MgO and *Epsom salt* ($MgSO_4.7H_2O$) 16 per cent MgO, are water-soluble magnesium fertilizers.

They are more expensive per unit of magnesium than magnesian limestone or calcined magnesite but give more rapid responses where symptoms of magnesium deficiency are found in crops. Kieserite, although more slowly soluble in water, is much cheaper than Epsom salt. An application to the soil of 200–300 kg/ha of kieserite should supply some magnesium to crops for 2–3 years.

Sulphate of potash magnesium, 23 per cent K_2O, 10 per cent MgO and *Kainit*, 10–25 per cent K_2O, 6–20 per cent MgO, supply some magnesium but are used primarily as potassium fertilizers.

Ammonium nitrate with calcium/magnesium carbonate. Ammonium nitrate traditionally mixed with calcium carbonate (Nitro-chalk) may equally well be mixed with dolomite ($CaCO_3.MgCO_3$). A 26 per cent N final product would contain 5 per cent Ca and 3 per cent Mg in the slowly available carbonate form.

Sulphur fertilizers

In the past the fortuitous sulphur content of the then most commonly used nitrogen and phosphorus fertilizers – ammonium sulphate, 24 per cent S, and superphosphate, 11–13 per cent S – along with sulphur reaching the soil from atmospheric pollution, ensured that crops in most areas of the British Isles and other industrial countries received sufficient available sulphur for crops. The clean-air legislation and the switch to ammonium nitrate, urea and ammonium phosphates as the main nitrogen and phosphate fertilizers have radically changed this and it is now necessary to consider using sulphur fertilizers as a routine in the less polluted areas.

Gypsum ($CaSO_4.2H_2O$) 23 per cent Ca, 18 per cent S, is the cheapest form of sulphur fertilizer obtainable in the British Isles. It

e 4–8 per cent of magnesium in the final product.
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$aSO_4.2H_2O$) 23 per cent Ca. 18 per cent S, is the
of sulphur fertilizer obtainable in the British Isles. It

may be applied to the soil after grinding in the same way as limestone. It is extracted from mineral deposits and is also a major by-product in the manufacture of ammonium phosphates and triple superphosphate. Surprisingly the by-product form is little used as a fertilizer at present. As the demand for gypsum increases, easy-to-spread granular forms will undoubtedly be made.

Potassium sulphate, 50 per cent K_2O, 17 per cent S, is water soluble and if included as the standard potassium source in compound fertilizers would help a good deal to alleviate sulphur deficiency problems.

Commercial sulphur, almost 100 per cent S, has been used directly as a sulphur fertilizer in parts of the world where there is severe sulphur deficiency. A threatened world shortage of this material some thirty years ago seems to have been overcome by the recent discoveries of deposits. It has the obvious advantage of having the highest possible sulphur concentration but has varied very much in its effect on crops. In common with all other nutrient elements, elemental sulphur is not directly available to the plant. It must first be oxidized to sulphur dioxide (SO_2) or sulphurous acid (H_2SO_3) and further oxidized to sulphuric acid or sulphates. Although this can occur by simple chemical processes it is very much dependent, in soils, on the specific action of certain sulphur-oxidizing bacteria. These organisms prefer acidic conditions and thrive in sulphur-rich soils. They may be inactive or even absent in alkaline, sulphur-deficient soils and this is probably the main reason for the variable crop responses to commercial sulphur.

Commercial sulphur is a long-established general purpose fungicide. If applied for this purpose in the British climate it is likely to be washed off the leaves quickly. Used at the recommended rate of about 10 kg/ha this would supply some available sulphur through the soil.

Sulphur dioxide (SO_2) 50 per cent S, must be regarded as a fertilizer, although much of it is cost-free! It is the main sulphur pollutant of the atmosphere and is readily converted in the soil to available sulphates. Without it, many of our crops would be suffering from sulphur deficiency. It would, therefore, be reasonable to use the gas, transported under pressure in cylinders, in the same way as ammonia is used as a nitrogen source. The problems involved would be similar to those encountered with liquefied anhydrous ammonia. There would be a risk in poorly structured, stony or heavy clay soils of considerable losses of sulphur dioxide to the atmosphere. It might, therefore, be preferable to use sulphur dioxide dissolved under pressure in water.

Sodium fertilizers

Sodium is not a major element for most crops but it can be used to replace part of the potassium requirement of crops. The general function of potassium in regulating osmotic pressure within the plant can be performed by sodium but some potassium is always needed for specific functions in enzyme actions and carbohydrate transfer.

In practice, sodium fertilizers, although cheap, are little used except for root crops such as sugar beet, mangolds, turnips, red beet and carrots. *Sodium chloride* (NaCl) is sold as Agricultural Salt, 37 per cent sodium. Its prime use is on sugar beet, where it can replace as much as 50 per cent of the potassium requirement.

There is a good deal of evidence that sodium chloride could be used to replace some of the potassium chloride used for other main crop species, including cereals and grasses, but *not* for potatoes because of their sensitivity to chloride.

Sodium chloride is very cheap and reasons for its limited use include problems of incorporation in compound fertilizers, fears of adverse effects of sodium chloride on soil structure (largely unfounded at the rates required) and the long-established tradition of using potassium chloride in compound fertilizers – ably perpetuated by the sellers of potassium salts on the world market.

Despite this, there could well be a significant role for sodium chloride in compound fertilizers as a cheap replacement for a quarter to half of the potassium, depending on the crop.

Trace element fertilizers

Very few traditional fertilizers, whether simple or compound, contain sufficient trace elements to have any appreciable effect on crops. An exception is basic slag which contains variable amounts of manganese and iron which become slowly available to the plant.

Compound fertilizers have been made containing one or more trace elements but they are not extensively used: routine applications of trace elements are still rare. Trace element fertilizers may be used to correct deficiencies indicated by specific visual symptoms, mainly on the leaves of plants. Some are applied to the soil but, in contrast to major element fertilizers, they are commonly sprayed on to the leaves of growing crops and partly absorbed by them.

Foliar sprays

Unorthodox 'fertilizers'

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Commonly used trace element fertilizers are listed in Table 15.8 along with methods and recommended rates of application.

Foliar sprays

Plants can absorb water and nutrients directly through their leaf pores. Because of the intense competition that the plant must face to obtain nutrients from the soil (see Fig. 4.2, p. 30) it is tempting to short-cut the soil by applying nutrients to the leaves. This has been very successful in the treatment of trace element deficiencies where the quantities of nutrients required are small and one spray treatment is commonly sufficient.

It is much more difficult to use major nutrients in this way.

- The quantities required are such that repeated spray treatments are necessary.
- In the early, critical stages of growth the leaf area of the plant is very small and a large proportion of any spray treatment falls on bare soil.
- Almost all substances used as foliar nutrients are salts, similar to those applied to the soil. These salt solutions drying out slowly on leaves will scorch. Urea, not being a salt, will cause less scorch. Unfortunately, rapid drying on the leaves, which reduces scorch risk, also reduces the efficiency of absorption.
- To achieve maximum absorption through the leaf pores, very fine droplets are needed and this encourages scorch.
- In climates like that of the British Isles opportunities for repeated spray applications without serious risk of the spray being washed off the leaves by rain are limited.

For these reasons foliar application of major nutrients is very restricted in the British Isles.

Unorthodox ‘fertilizers’

In addition to fertilizers of proven value the farmer is faced with a range of materials the value of which he does not know. Some are presented with alluring literature making extravagant claims about the product. One such product claimed to increase yield and sugar content of sugar beet, to give a larger proportion of seed-sized tubers in the potato crop and to eradicate every form of insect pest by disrupting their epithelial tissue!

It was a brown fizzy liquid which turned out to be soda water containing dissolved caramelized sugar! This represents the lunatic fringe of the fertilizer world and it sold some fifteen years ago at £5 per litre.

Products range from purely charlatan to respectable but very expensive. Misleading trade names are common among them. Many survive for only two or three seasons in the first of which there is a sales build-up, in the second the big sell and in the third some residual sales, as the true value of the product becomes clear. None of them should be used without prior consultation with a reputable advisory organization.

Chapter 13 F

Adverse effects on growth and yield

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and K may be given in the previous autumn.

The choice of compound fertilizers containing
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ers Compound fertilizers containing any
of magnesium are difficult to obtain.
ıgnesium deficiency symptoms occur, especial-
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salt (4 kg/ha in 200 litres of water). In less
th a soil magnesium index of 0 or 1, 200–400 kg
)$_4$,H$_2$O) per hectare should be applied for de-
h as sugar beet, potatoes, kale, oil-seed rape

dic soils where available soil magnesium is low,
ne should be used as a routine when liming is
d rate of 5 t/ha will be required every 3–4 years,
ly if the soil is intensively cropped.

Figure 15.1 *Transport and storage of fertilizer bags in pallets. Photograph by courtesy of UKF Fertilizers Ltd, Ince, Chester.*

Methods of handling and application

Solid fertilizers

Storage and handling Most solid fertilizers are now sold in granular form in strong polythene bags holding 50 kg. They are easily handled and stored in this form. It is preferable to store them in a dry building but they may be stored outdoors so long as they remain undamaged, if covered by a strong waterproof sheet. If possible, they should be stored in piles five or six high on a raised platform so that when required they do not need to be lifted but may be lowered to the vehicles used to transport or spread the fertilizer. On small farms, using 20–30 tonnes of fertilizer each year, manual handling, though tiring, is probably more efficient than any attempt to mechanize the process.

There are recent developments involving mechanized handling that can be used to advantage on large units.

Pallets (Fig. 15.1) can be used for delivering and handling fertilizer in standard bags, each pallet holding 20–30 bags (1–1.5 t). The pallets can be transported on the farm by fork-lift trucks or by using a special attachment on a tractor front-end loader. Capital costs of equipment are high but, on large farms, there are great advantages in both time and human energy saved, mostly at receipt and during stocking.

Large bags of fertilizer (Fig. 15.2) can also be obtained, containing 500 kg – 1t. The bags consist of a strong woven-plastic cover inside which the fertilizer is sealed in polythene. They may be disposable or returnable. Large bags must be handled mechanically and are most useful where large amounts of fertilizer need to be spread in a very short space of time at high rates.

They can be stacked, no more than two high, and may be handled by hook or crane attachments to heavy-duty fork-lift trucks or tractor front-end loaders. The non-returnable type of bag is simply lifted directly over a hopper-spreader and emptied into it by slitting the bottom of the bag. Returnable bags are designed with an outlet spout for feeding the fertilizer into a distributor.

Bulk delivery and spreading of unbagged fertilizers is done by some contractors and should be left to them. The equipment used is very heavy and soil damage may occur in wet conditions from wheel tracking.

Bulk storage on the farm of unbagged fertilizers is feasible in countries where humidity is consistently low but should be attempted only for short periods in the British Isles.

Figure 15.2

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Figure 15.2 *The use of 'big bags' of fertilizer. Photograph by courtesy of Norsk Hydro Fertilizers, Ipswich, Suffolk.*

Broadcast spreading Most solid fertilizers are now spread by broadcasting, the aim being to distribute the material as uniformly as possible over the soil surface. The fertilizer should then be incorporated in the soil as soon as possible, by harrowing, to avoid volatilization losses of ammonia and to assist uniform distribution within the surface soil.

Broadcasting spreaders The earliest mechanical spreaders consisted of a long trough from which the fertilizer trickled through regularly spaced spouts on to a series of revolving discs which sprayed out the material. Metering was crude and depended on careful observation and control by a second operator in addition to the driver.

Modern spreaders have accurate metering devices using rollers which can be adjusted to give application rates as low as 100 kg/ha or as high as 1 t/ha irrespective of the forward speed of the machine.

Pneumatic spreaders (Fig. 15.3) are the natural successors to the early machines. The fertilizer is fed from a hopper to a metering device and is then blown by a high-speed flow of air through tubes on to spreading plates placed at intervals along a boom about 10 metres wide. The essential characteristic of pneumatic spreaders is to give uniform distribution of the fertilizer to the exact width of the boom but not beyond this. They are, therefore, particularly useful for crops grown on tramline systems. It is essential with these machines to avoid overlapping, which would give double the intended rate, or gapping, in which no fertilizer at all is given. For this purpose most machines are fitted with bout markers (a bout is a single run across a field) which deposit a line of foam or some coloured material to guide the driver for the next bout (Fig. 15.4).

Oscillating spout and spinning disc spreaders rely on overlapping of fertilizer spread from one bout to the next to get even distribution. Thus mistakes in bout width are not nearly so obvious as with pneumatic spreaders, but they are none the less important. Provided that care is taken over bout widths, adjustment of rate mechanisms and maintenance, these broadcasters give a reasonably uniform distribution over well-tilled soil surfaces. Both types of machine depend upon the metering of the fertilizer from a hopper. This is done by adjusting the size of a hole at the bottom of the hopper according to the type of particle (granule or prill) and the required rate of application. The mechanisms below the hopper are designed to throw the fertilizer behind and to the side of the machine.

Figure 15.3 Broadcasting fertilizer using a
Thirsk, North Yorkshire.

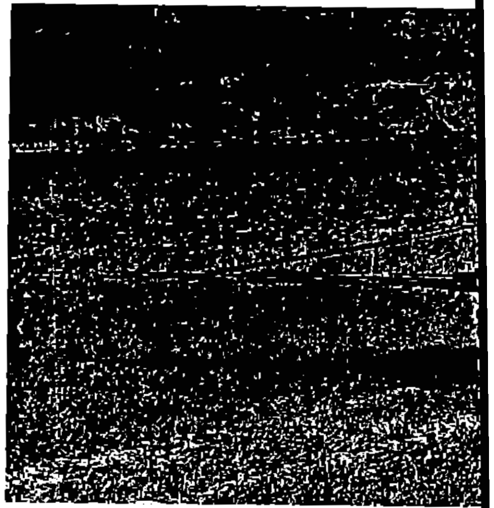

Figure 15.4 A bout
Ltd, Bi

st spreading Most solid fertilizers are now spread by sting, the aim being to distribute the material as uniformly ble over the soil surface. The fertilizer should then be ated in the soil as soon as possible, by harrowing, to avoid ation losses of ammonia and to assist uniform distribution he surface soil.

sting spreaders The earliest mechanical spreaders con- f a long trough from which the fertilizer trickled through y spaced spouts on to a series of revolving discs which out the material. Metering was crude and depended on observation and control by a second operator in addition to er.

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Figure 15.3 Broadcasting fertilizer using a pneumatic spreader. Photograph by courtesy of A. C. Bamlett Ltd, Thirsk, North Yorkshire.

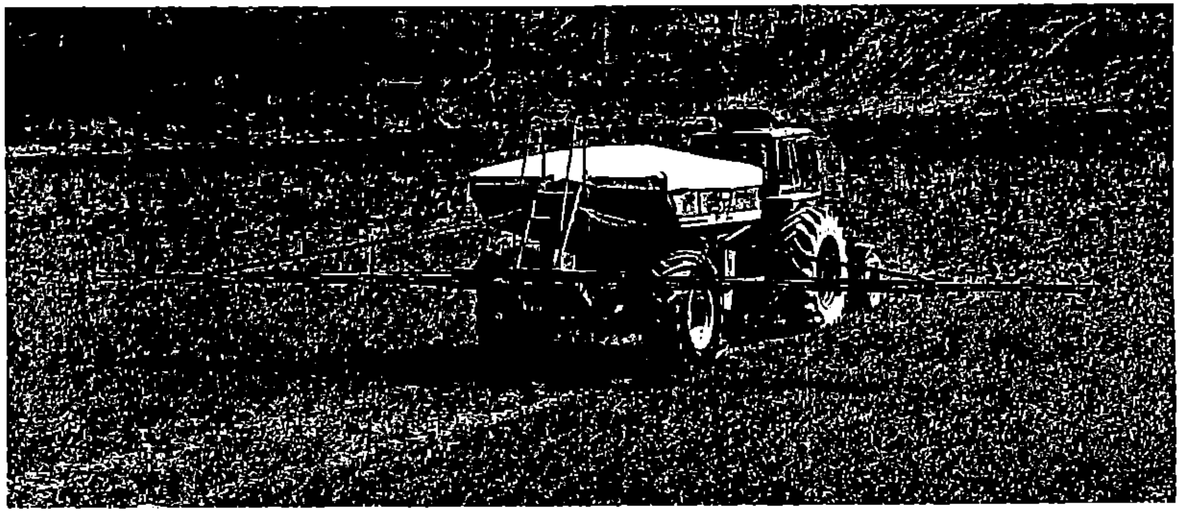
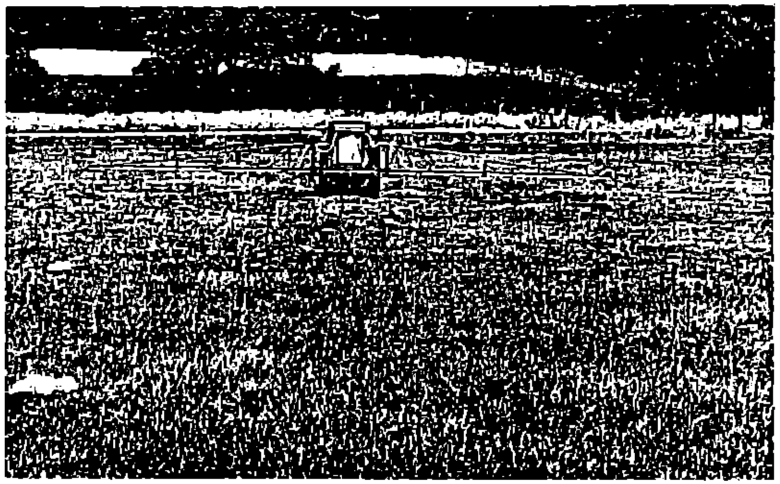


Figure 15.4 A bout marker in action. Photograph by courtesy of Saltney Engineering Ltd, Bishops Stortford, Herts.



The spinning disc machines (Fig 15.5) throw the fertilizer from revolving discs which may be slightly cupped or may have radial vanes. The oscillating spout machines (Fig. 15.6) deliver the fertilizer from a large spout, the speed of oscillation of which can be adjusted to affect the bout width.

Figure 15.5 Broadcasting fertilizer using a spinning disc machine. Photograph by courtesy of Lely Import Ltd, St Neots, Huntingdon, Cambs.

Both machines give a roughly triangular distribution pattern when in motion and bout widths are recommended by the manufacturers to give an overlap of the extreme edges of that pattern. If well managed these machines deliver half as much fertilizer in the overlap as in the main zone behind the machine and the next bout ensures uniform treatment of the area.

Figure 15.6 Broadcasting fertilizer using
Ipswich, Suffolk.

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machines (Fig 15.5) throw the fertilizer from h may be slightly cupped or may have radial ing spout machines (Fig. 15.6) deliver the e spout, the speed of oscillation of which can t the bout width.

hine. Photograph by courtesy of Lely Import Ltd,

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Figure 15.6 Broadcasting fertilizer using an oscillating spout machine. Photograph by courtesy of Vicon Ltd, Ipswich, Suffolk.

Placement As an alternative to broadcasting the fertilizer may be placed, by special machines, in close proximity to the seed at the time of sowing row crops.

Combine drilling of cereal seed and fertilizer is an example of this technique. Contact placement, in which seed and fertilizer are fed down the same spout, should be avoided because of the risk of salt effects and damage to germinating seedlings. The most successful combine drills place the fertilizer slightly below (4–6 cm) and to the side (4–6 cm) of the seed. This reduces the risk of salt damage while concentrating the fertilizer where it is most needed in the early stages of growth.

Placement of fertilizers had major advantages in the British Isles when many soils were deficient in phosphorus and when modest rates of fertilizer application kept the risk of damage to seedlings small. The advantages have diminished and the disadvantages have increased as soils have become more fertile while the concentration of fertilizers and their rate of application has increased.

The following general rules apply:

- Placement is least effective in fertile soils.
- It is most effective for phosphate fertilizers used in phosphate deficient soils.
- It is useful for widely spaced plants with short growing periods.

In these cases rates of application may be reduced if fertilizer is placed instead of being broadcast.

Liquid fertilizers

Storage Liquid fertilizers are usually delivered to the farm in bulk tankers. They may then be applied immediately or stored in bulk tanks on the farm to ensure immediate accessibility. The storage tanks are usually made of mild steel and are subject to corrosion by simple nitrogenous liquid fertilizers. One of the cheapest anti-corrosion measures is to fill new tanks with a liquid compound fertilizer rich in phosphorus. A corrosion-resistant lining will then be formed. Alternatively, plastic coatings may be applied to the inside of the tank before filling.

Storage during spring and summer presents few difficulties but there may be problems in winter because of the reduced solubility of many fertilizer salts at low temperatures. The problems are mitigated to some extent by the time taken for the very large bulk of liquid in the tanks to cool down. None the less, during prolonged periods of very cold weather some precipitation will occur. If precipitates do form they are very difficult to re-dissolve because they settle out in a solid layer. Manufacturers naturally try to avoid formulations that will give precipitates. Among the most difficult formulations to store are those which include potassium salts and ammonium nitrate which react together to form potassium nitrate, sparingly soluble at low temperatures.

Spreaders Liquid fertilizers are best sprayed on to bare soil and immediately harrowed in. The liquid is pumped from a tank through a long boom to a series of spray nozzles (Fig. 15.7).

Figure 15.7 Spreading liquid fer
Doncaster, South Y

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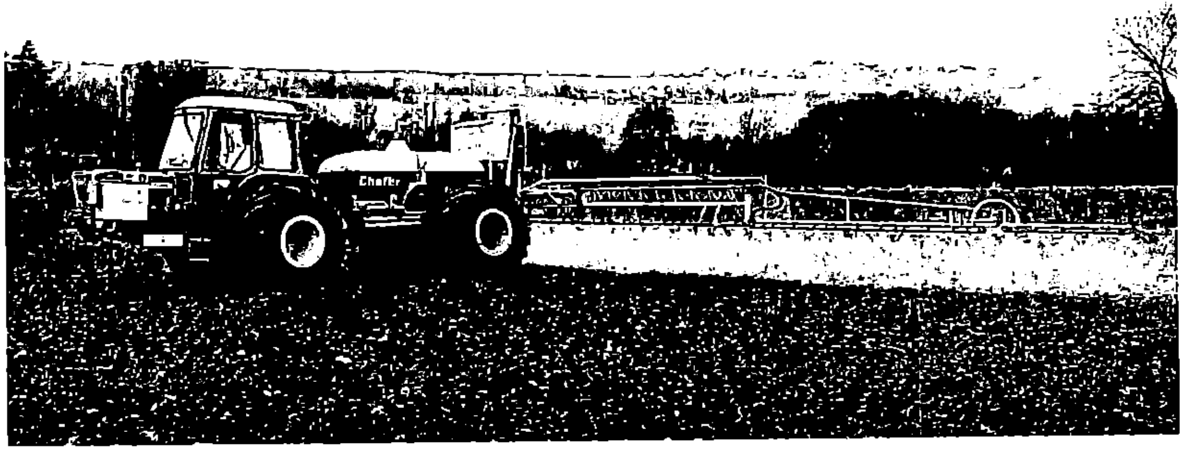
Provided that care is taken to maintain the jets, to use the pressure recommended by the manufacturer and to match the bouts, distribution should be very even. Jet sizes can be adjusted to give different application rates.

Figure 15.7 Spreading liquid fertilizer using a long boom. Photograph by courtesy of J. W. Chafer Ltd, Doncaster, South Yorkshire.



Spray applications to standing crops, especially if the droplets are very small, can cause serious scorching of the leaves. This can be partly overcome by using very large droplet sprays which tend to drop rapidly from vegetation to soil. There is, however, inevitably some collection of liquid, for example between stem and leaf and on some hairy-leaved plants, and this will cause some scorch.

There are also dribble-bar attachments by which the liquid is dribbled through flexible plastic tubes to soil level. The tubes may be spaced to avoid contaminating row crops. Placement of liquid fertilizers may be achieved by using flexible tubes, behind coulters, designed to deposit a stream of liquid under the soil surface.

Injectors for gaseous ammonia This very toxic material requires special handling by trained contractors equipped with protective clothing and safety devices. It is injected from cylinders, under pressure, some 10–15 cm below the surface of the soil through plastic tubes placed behind special coulters. Behind the coulters is a device for closing the injection slit to avoid or reduce the loss of ammonia to the atmosphere. The problems of using liquefied anhydrous ammonia are discussed on page 128.

Urgent fertilizer use

By careful management the need for urgent use of fertilizers to supply phosphorus, potassium, sulphur and magnesium should be avoidable.

Nitrogenous fertilizers

The most commonly needed urgent treatment is that of nitrogenous fertilizer. Any deficiency of nitrogen in a crop shows up very rapidly in the appearance of the plants. They become successively pale green, yellow-green and yellow. Usually older leaves are affected first, turning yellow and dying from the tip. The essential feature is an overall yellowing of the leaf, veins and all, brought about by lack of chlorophyll. These symptoms are fairly reliable indicators of nitrogen deficiency but do not indicate the cause.

Table 15.7 Diagnosis of the causes of nitrogen deficiency in crops.

Diagnostic features* in soil, plant and climate	Cause of deficiency	Likely response to nitrogenous fertilizers or manures
Very wet weather, high annual rainfall, sandy or gravelly soil texture, low soil organic matter.	Leaching.	Vigorous response but nitrates in applied fertilizers subject to rapid leaching.
Very dry weather, soil visibly dry.	Drought.	Response only if drought breaks or irrigation can be used. In either case the nitrogen fertilizers applied earlier become effective.