fertilizers europe

Infinite nutrient stewardship

INFINITE FERTILIZERS

Continuing to feed the world

INFINITE FERTILIZERS
Continuing to feed the world

About this publication

THIS BROCHURE AND ITS SISTER PUBLICATION "INFINITE PRODUCT STEWARDSHIP" ARE INTENDED TO PROVIDE A GENERAL GUIDE TO FERTILIZER PRODUCTION, DISTRIBUTION AND USE IN MEETING THE DEMANDS OF "SUSTAINABLE AGRICULTURE".

The brochure describes the European fertilizer industry's vision of Infinite Fertilizers and the importance of the interaction between all those involved in food production chains in increasing the efficiency of agriculture and in reducing its environmental footprint.

Nutrient stewardship for fertilizers is defined as the promotion of the understanding of the quality and environmental aspects of a fertilizer during its use, application and recycling, taking into account relevant legislation and the best industry and agricultural practice. For mineral fertilizers, this includes knowledge of:

- How plants grow
- Types of fertilizer
- Nutrient management
- Balancing crop and environmental needs
- Food and nutrition
- Nutrient recycling.

Production aspects of the fertilizer life cycle - product development, sourcing of raw materials, fertilizer production, safety, product distribution and storage, marketing and sales - are covered by Fertilizers Europe's product stewardship activities.

Fertilizers Europe
September 2016

INFINITE FERTILIZERS
Continuing to feed the world

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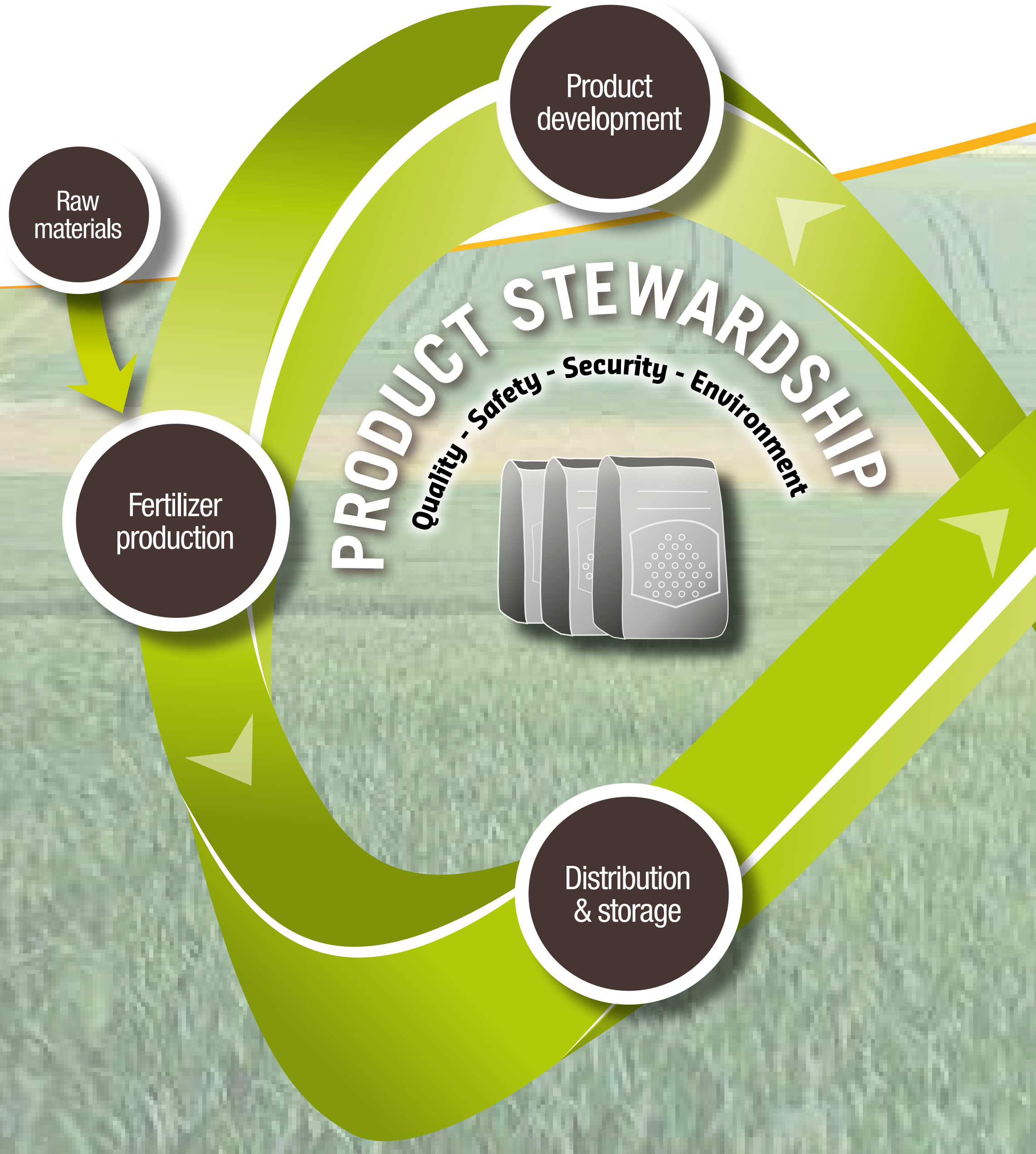
Infinite fertilizers

FERTILIZERS ARE AN INTEGRAL PART OF FOOD PRODUCTION. THE EUROPEAN FERTILIZER INDUSTRY IS COMMITTED TO COLLABORATING WITH ALL THOSE INVOLVED IN FOOD PRODUCTION CHAINS TO INCREASE THE EFFICIENT USE OF NUTRIENTS AND REDUCE THE ENVIRONMENTAL FOOTPRINT OF FOOD PRODUCTION.



INFINITE FERTILIZERS GUIDES THE INDUSTRY'S PRODUCT AND NUTRIENT STEWARDSHIP ACTIVITIES. THESE ENSURE THAT EUROPE'S FARMERS HAVE ACCESS TO A VARIETY OF HIGH QUALITY, LOCALLY PRODUCED PRODUCTS, AS WELL AS INFORMATION ON THEIR CORRECT USE, ENVIRONMENTAL IMPACT AND NUTRIENT RECYCLING OPPORTUNITIES.

INFINITE FERTILIZERS
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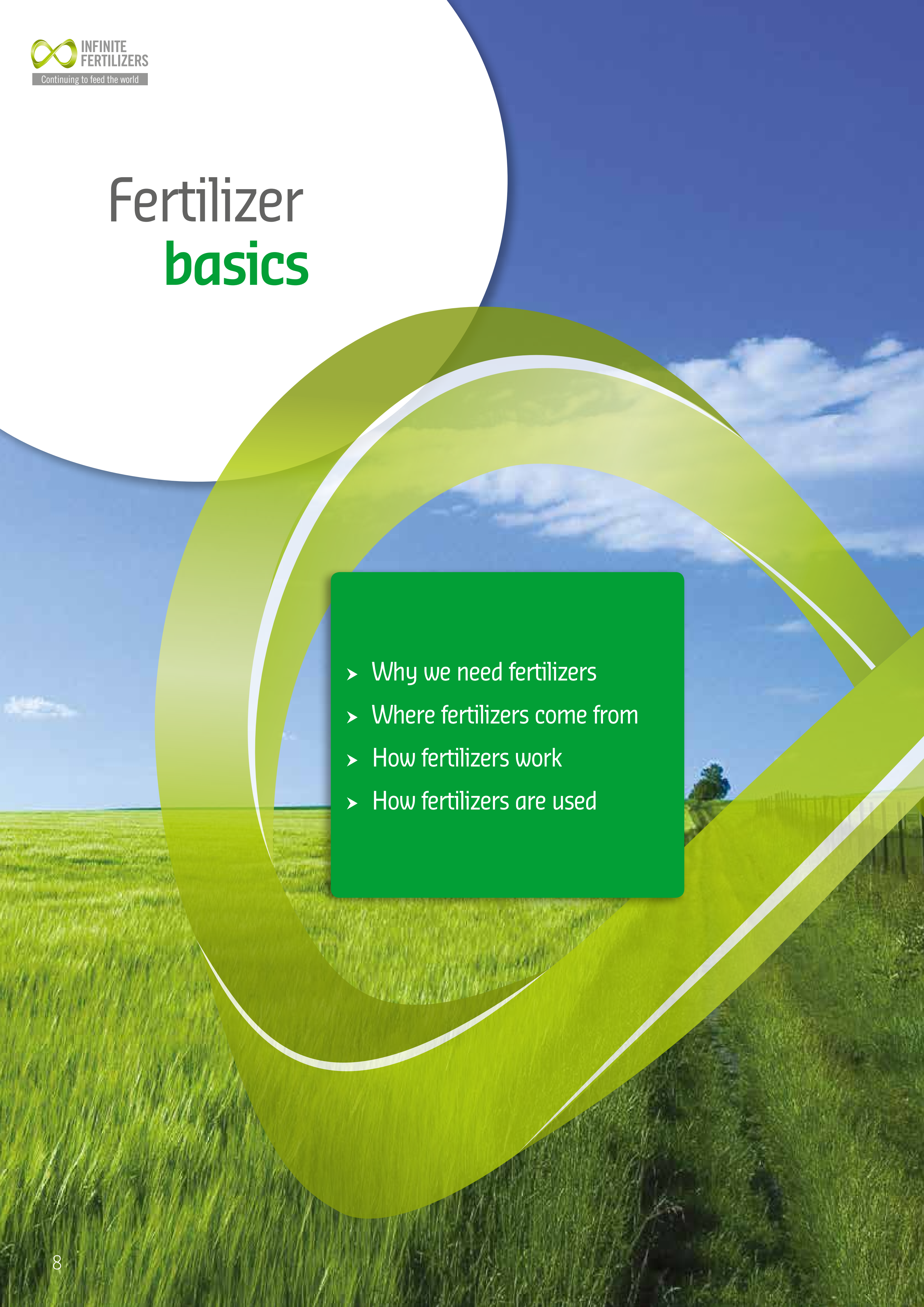


Fertilizer basics

- Why we need fertilizers
- Where fertilizers come from
- How fertilizers work
- How fertilizers are used

Why we need fertilizers

FOOD PRODUCTION MUST INCREASE SIGNIFICANTLY BY 2050 TO ENSURE GLOBAL FOOD SECURITY.

The United Nations' Food and Agriculture Organization (FAO) predicts that the world's population will reach 9.1 billion people by 2050 and that global food production will have to increase by some 60% above 2005/2007 levels to keep pace with demand.

This increase could be achieved by devoting more land to agriculture. However, this land is not readiliy available and the negative impact on the environment and bio-diversity of further converting the planet's natural forests and wild areas is well documented. Today, changes in land use account for some 12% of the greenhouse gas emissions that lead to global warming.

The more sustainable option is to make better use of land currently used for agriculture. This faces challenges of its own, however, in the form of increasing urbanisation, soil erosion and nutrient exhaustion, as well as increasing water scarcity. Since the "green revolution" of the 1960s and 1970s, growth in agricultural productivity has started to slow down in many regions and recent climate change studies predict that this slowdown will continue.

Global food security rests on reversing this trend through better agricultural efficiency, including more effective crop nutrition.

Food security in Europe

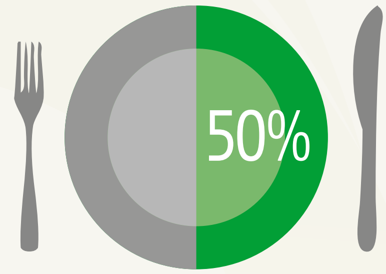
Europe is fortunate in that it has both the climate and enough farmland to be potentially self-sufficient in food production.

Food imports, however, have increased by some 40% over the past 10 years and agricultural land outside the EU the size of Germany is now devoted to producing these. Given the increasing global food demand, this land could be more effectively used to support local food needs.

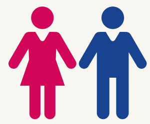
European agricultural policy has a decisive role to play in ensuring that Europe maintains a strong and diverse agricultural sector. It must encourage European farmers to optimize their production at the same time as reducing their environmental impact.

This "sustainable intensification" of European agriculture requires more widespread adoption of the best agricultural practice and soil management and cultivation techniques.

European agriculture must also be economically viable so that Europe's farmers can invest in their operations. Mineral fertilizers have helped European agricultural productivity to become the highest in the world. Every euro invested in a fertilizer in Europe provides, on average, a five-fold return for the farmer, ensuring increased food production and his or her financial security.

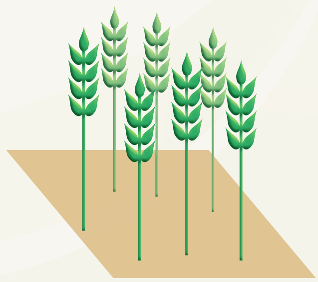


Today, fertilizers* account for
50% of global food production



in 1960
2 people
were fed from 1 hectare of land

in 2025
5 people
will need to be fed from 1 hectare of land



*mineral-based fertilizers

Where fertilizers come from

FERTILIZER PRODUCTION TRANSFORMS NATURALLY OCCURRING RAW MATERIALS INTO PRACTICAL PRODUCTS THAT SUPPORT PLANT GROWTH.

Each year, the European fertilizer industry transforms millions of tonnes of naturally occurring raw materials such as air, natural gas and mined ores into products primarily based on the three essential nutrients nitrogen, phosphorus and potassium, which plants need to grow to their full potential.

For nitrogen-based fertilizers, the largest product group, the process starts by mixing nitrogen from the air with natural gas at high temperature and pressure to create ammonia. Approximately 65% of the natural gas is used as the raw material for sourcing hydrogen, with the remainder employed to power the production process.

The ammonia is then used to make nitric acid, with which it is subsequently mixed to produce nitrate-based fertilizers such as ammonium nitrate. Ammonia may also be mixed with carbon dioxide to create urea fertilizers. Both these fertilizers can also be further mixed with water to form UAN (urea-ammonium nitrate) solution.

Phosphorus and potassium-based fertilizers are both produced from mined ores. Crushed phosphate rock is primarily converted into phosphoric acid, which is then either concentrated or mixed with ammonia to make a range of products. By-products of phosphoric acid production include the fertilizers calcium sulphate or calcium nitrate.

Muriate of potash (potassium chloride) is separated out of crushed potash ore. This potassium fertilizer may then be further treated with nitric or sulphuric acid to produce potassium nitrate or sulphate of potash.

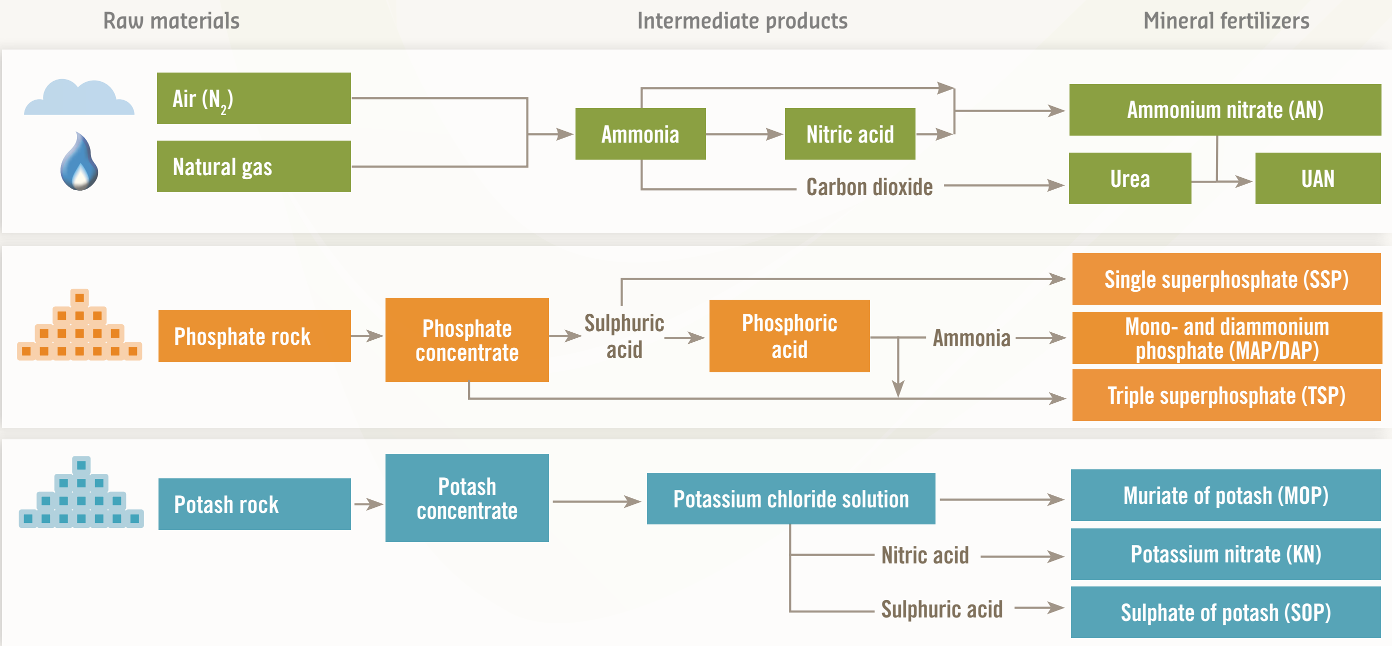
Environmental efficiency

While the basic ammonia synthesis process (Haber-Bosch) has remained unchanged since its invention 100 years ago, process efficiency, control systems and skills have changed dramatically.

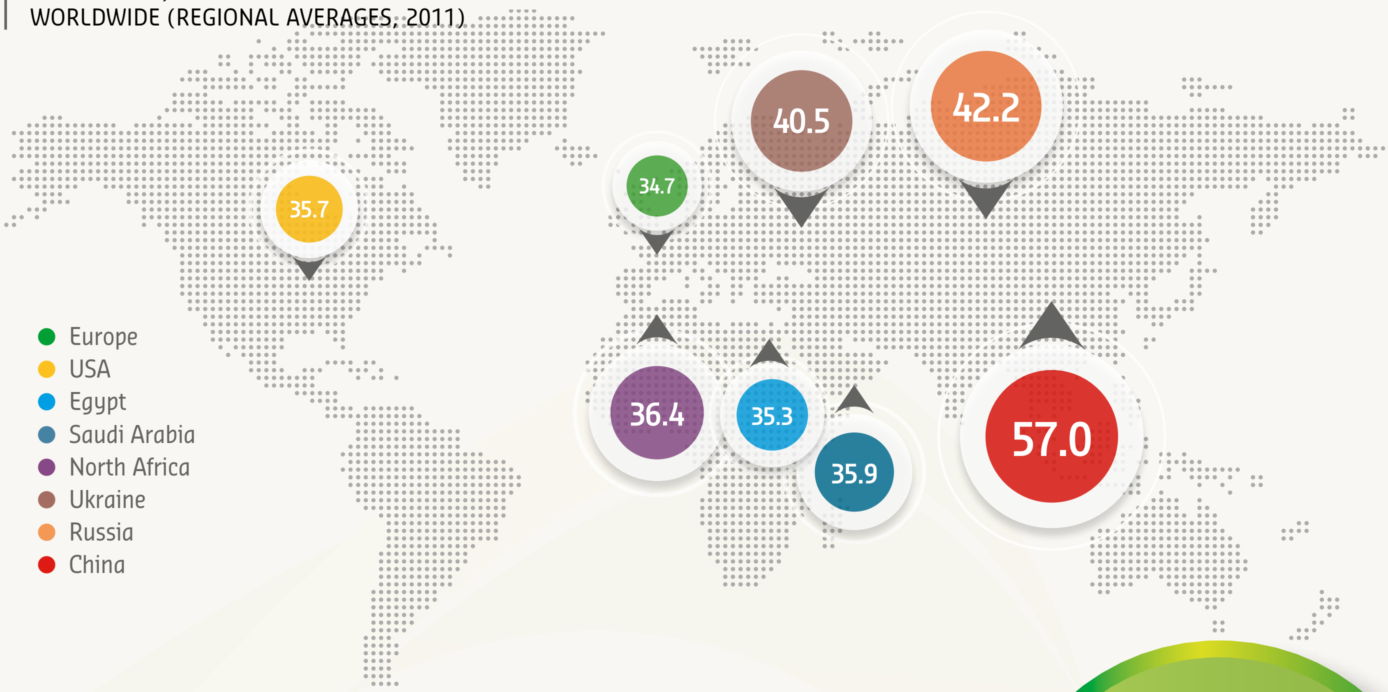
Due to innovative advancements in technology, the European fertilizer industry's ammonia plants are among the most energy efficient worldwide, with the lowest greenhouse gas (GHG) emissions. Its nitric acid plants are also equipped with advanced greenhouse gas emissions reduction technology.

Europe's strict environmental legislation has meant that over the past few years the European industry has invested steadily to increase its efficiency and reduce GHG emissions.

PRODUCTION OF MAIN FERTILIZER PRODUCTS



ENERGY CONSUMPTION (GJ PER TONNE OF PRODUCT) IN AMMONIA PLANTS WORLDWIDE (REGIONAL AVERAGES, 2011)



Competitive energy costs are essential for a vibrant fertilizer industry in Europe.

Industry competitiveness

While deposits of natural gas, phosphate and potash rock are all relatively abundant globally, they can only be found to a limited extent within Europe. The European fertilizer industry is therefore highly dependent on the quality and availability of imported raw materials.

This challenges the industry to be highly efficient in its raw materials use but also makes it vulnerable to the supply and pricing policies of countries outside Europe.

In particular, the high price of gas in Europe makes it very difficult for the industry to remain cost-competitive in a global market. Europe's energy cost-competitiveness is a priority for fertilizer industry profitability, as well as for safeguarding jobs.

Product stewardship

The fertilizer industry's aspirations for efficient, safe and environmentally-friendly fertilizer production has led Fertilizers Europe to develop an industry-wide management system to ensure its advanced production controls are consolidated and maintained.

The Fertilizers Europe Product Stewardship program is compulsory for all members of the association and sets the highest global standards for programmes of this type.

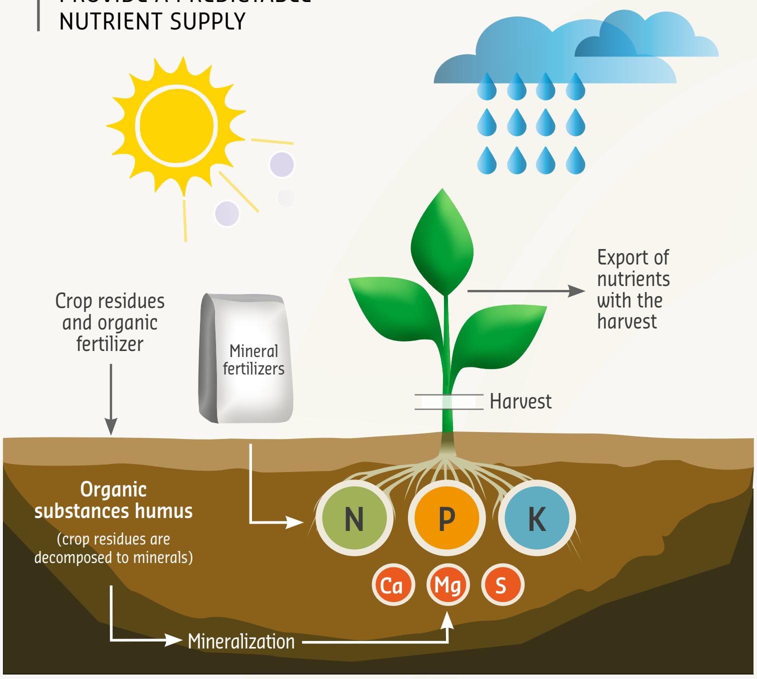
The program (www.productstewardship.eu) also ensures that the industry oversees the transport, distribution and storage of its products, working closely with the supply chain to ensure the secure handling of fertilizers on their way to Europe's farmers.

product stewardship
fertilizers

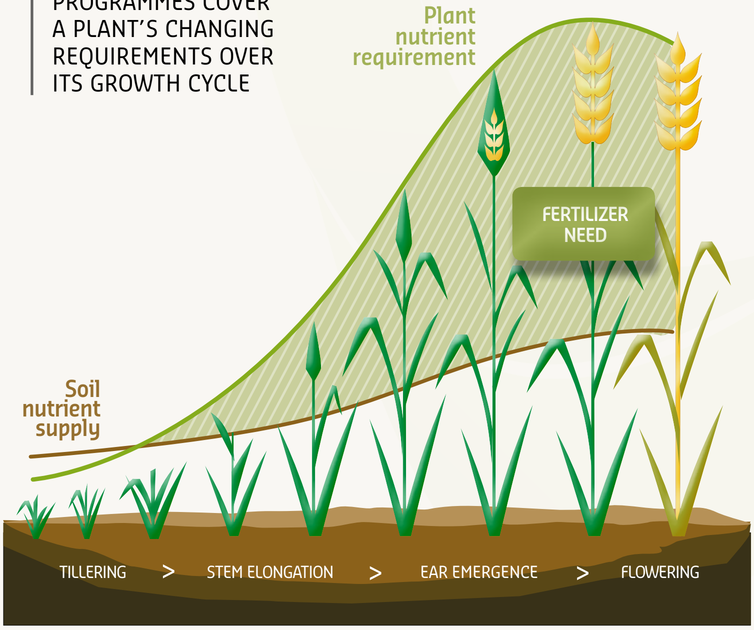
How fertilizers work

EFFECTIVE CROP NUTRITION IS THE KEY TO INCREASING CROP YIELDS AND OPTIMIZING PRODUCTION.

MINERAL FERTILIZERS PROVIDE A PREDICTABLE NUTRIENT SUPPLY



EFFICIENT FERTILIZATION PROGRAMMES COVER A PLANT'S CHANGING REQUIREMENTS OVER ITS GROWTH CYCLE



Crop growth requires sunlight, carbon dioxide (CO_2), water and a balanced supply of the primary nutrients nitrogen, phosphorus and potassium, as well as secondary and micronutrients. These nutrients support a plant's essential metabolic functions.

The water and nutrients are primarily absorbed from the soil via the plant's root system to allow it to develop to its full potential and provide maximum nutritional value. When the plant is harvested, the nutrients it has absorbed are therefore lost from the soil.

Unless the nutrients are replenished, the soil's productive capacity declines with every harvest. Natural processes that break down crop residues and organic material in the soil replace, on average, about half of the required nutrients. The remainder needs to be provided by mineral fertilizers and other organic sources such as manure.

Predictable nutrient supply

The main mineral fertilizers are based on one or more of the essential nutrients, which are delivered in a form that can be readily taken up by the plant.

They enable farmers to offer a specific crop a predictable, balanced supply of the primary nutrients, as well as important secondary elements such as calcium, magnesium and sulphur, and other micro-nutrients. The nutrient content of manures and other organic sources are far less predictable.

Effective fertilization programmes aim to closely balance the composition and availability of the nutrients in the soil with a plant's changing requirements over its growth cycle.

Mineral fertilizers close the gap between the nutrient supply from the soil and organic sources and the the plant's nutrient requirement for optimum development. Targeted application maximizes plant nutrient uptake and ensures healthy and productive growth. It also minimizes nutrient losses from the soil, either to the atmosphere or waterways.

Main fertilizer types

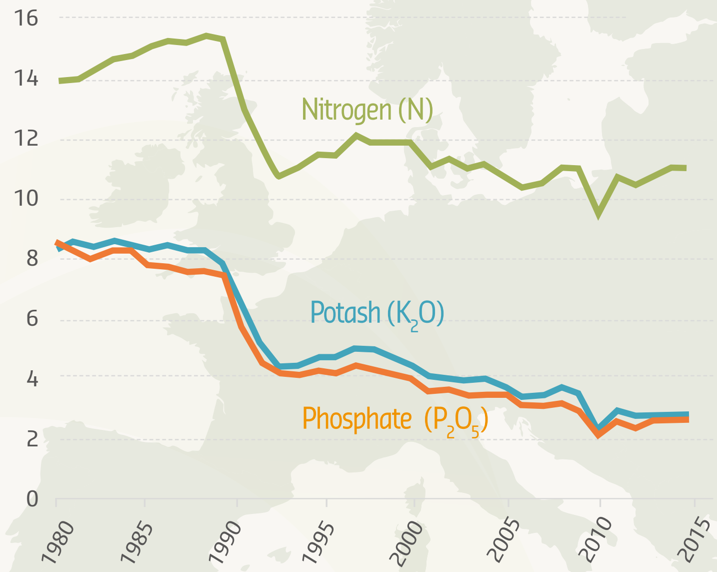
Nitrogen-based fertilizers account for the vast majority of fertilizer use (67% of total consumption in Europe). Phosphate and potash fertilizers account for some 16% and 17% of European fertilizer consumption respectively and can be applied in combination with nitrogen fertilizers.

Most European farmers consider ammonium nitrate (AN) and calcium ammonium nitrate (CAN) to be the most effective sources of crop nitrogen with European climatic conditions. By combining ammonium and nitrate, the two forms of reactive nitrogen that are directly absorbed by the plant roots, they offer the highest nitrogen-use efficiency.

Other nitrogen fertilizers, such as urea and urea-ammonium nitrate solution (UAN), are also available in Europe and are widely used in other parts of the world.

However, unless preventative measures are taken, nitrogen losses to the atmosphere can occur when these latter products are progressively transformed into the nitrate form in the soil. This increases emissions from the field and also reduces their nitrogen-use efficiency.

ANNUAL FERTILIZER USE IN EUROPE (MILLION TONNES)



Source: Fertilizers Europe

Ammonium nitrate and calcium ammonium nitrate are the preferred choice of European farmers.

How fertilizers are used

THE CORRECT USE AND APPLICATION OF FERTILIZERS ARE KEY TO SUSTAINABLE AGRICULTURE AND EUROPE'S FOOD SECURITY.

Sustainable agriculture relies on providing the necessary growing conditions for optimal crop production over the long term. It requires Europe's farmers to adopt the best agricultural practice to optimize crop yields and reduce the environmental impact of agriculture. Fertilizer selection and use are an integral part of this process.

Agricultural experts, legislators and providers of agricultural inputs all have a role to play in ensuring the availability of suitable fertilizers and in promoting good agricultural practice. The European fertilizer industry plays an active role in explaining the specific attributes of its products and in the development of advanced farm management strategies.

Techniques such as crop rotation, minimum tillage and cover crops can help maintain the structure and fertility of the soil, while the basic rule for the correct selection and application of fertilizers is provided by the four principles - the right product, at the right rate, at the right time, at the right place.

Best practice

Modern fertilizer products and application technology are increasingly tailor-made to meet specific crop requirements and cater for different locations and soil types, as well as for the different weather conditions encountered in Europe. Best practice in fertilizer application takes advantage of these characteristics to optimize nutrient-use efficiency.

Modern application machinery is often equipped with new technology such as GPS soil and biomass mapping, which can define nutrient demand down to within a few metres on a particular field. Smart sensors enable highly targeted application patterns, with small coefficients of variation, improving crop productivity and reducing nutrient losses.

While investment in the very latest farm equipment takes time before it becomes mainstream, the fertilizer industry continues to focus on developing practical tools, including GSM-based mobile applications, for improving on-farm nutrient management. Over the years, it has also built up a comprehensive range of information for farmers that addresses the issues of productivity, energy efficiency and the management of emissions.

Reducing environmental emissions

Climate change predictions and the continued focus on the environment mean that reducing atmospheric and water-borne emissions from agriculture remain a priority.

Atmospheric emissions include ammonia and greenhouse gases (GHGs) such as methane, nitrous oxide and carbon dioxide. They primarily result from livestock production, organic sources of nitrogen and the application of certain types of fertilizer.

Ammonia emissions can directly affect human health, as well as cause soil acidification and the eutrophication of waterways. Mitigation measures include a variety of techniques such as low-nitrogen feeds, low-emission housing for livestock, covered slurry storage, and more targeted application of manures and slurries.

Techniques for the reduction of atmospheric emissions resulting from mineral fertilizer use include application measures and the use of inhibitor technology, as well as recommendations for fertilizers outlined in the UN's Gothenburg Protocol and EU Air Quality legislation. With the availability of new fertilizers that limit emissions, the main focus of current GHG mitigation efforts is on the promotion of nitrogen-use efficiency. This has increased by 45% in Europe since 1985, but there is still further scope for improvement.

Fertilizer leaching

Leaching of excess nitrate or run-off of phosphate from the soil can also lead to the eutrophication of waterways and excessive algae growth.This normally occurs when the soil is saturated with water and nitrate is washed beyond the plant root zone or phosphate moves with run-off and soil erosion.

As most losses occur outside the cropping period, good agricultural practice aims to minimize excess nutrient concentrations in the soil after crops have been harvested.

For winter cereals, application of nitrogen fertilizer at the economic optimum rate has been shown to not only maximize nutrient-use efficiency and crop productivity but also to significantly decrease excess nitrate concentrations in the soil after the harvest.

Best practice in fertilizer application takes advantage of product characteristics to optimize nutrient-use efficiency.

Other agricultural practices to limit soil erosion and nutrient run-off include maintaining a porous soil structure, using cover crops to catch residual nitrogen and protect the soil against erosion, and the better synchronization of nutrient availability with crop demand through split fertilizer applications or by using nitrification inhibitors. More appropriate application methods for spreading manure and slurry, such as soil injection, can also have a significant impact.

CARBON FOOTPRINT OF FERTILIZERS

Caculation of the environmental impact of fertilizer application used to be a complicated process. Increasingly, however, European farmers now use electronic applications like the 'Cool Farm Tool' carbon footprint calculator to check the overall environmental impact of their operations. More on this tool can be found later in this publication.

Nutrient use and recycling

Recent attention has focused on "closing the fertilizer loop" through the more effective use of on-farm waste and nutrient recycling. Techniques primarily involve recycling crop waste through composting, anaerobic digestion of manure for energy or fuel generation, and the more efficient use of manure within the overall fertilization strategy.

On an industrial scale, incineration of meat and bone waste and sewage sludge, with the resulting ash being recycled as a raw material for fertilizers, has been successful in several regions. Research continues into other viable nutrient recycling schemes. These contribute to better nutrient-use efficiency, leading to major improvements in resource use.

Product innovation

European fertilizer producers continuously improve their products and processes based on feedback from farmers and explore any possibilities that open up within the food and energy production chain. The focus is on new fertilizer compositions and structures, as well as application technology, to enable more efficient crop nutrition.

Specific fertilizers and application technologies such as fertigation and foliar spraying are increasingly targeted at individual crops to make the most productive use of both nutrients and water.

New fertilizers are increasingly being targeted at specific crops and offer a variety of release profiles.

Infinite Fertilizers

In line with its vision of Infinite Fertilizers, Fertilizers Europe cooperates closely with farmers organizations and other stakeholders within the food chain to develop a coherent approach to Europe's agricultural, environmental and economic challenges and to advancing best agricultural practice within its farming community.

Plant growth

Elements for growth

- Essential nutrients
- Limiting factors
- Balanced nutrition
- Nitrogen, phosphorus, potassium
- Calcium, magnesium, sulphur
- Micronutrients

How plants absorb nutrients

- Nutrient transfer
- Increasing nutrient uptake
- Nutrient reserves
- Nutrient bio-conversion processes
- Transformation of nitrogen fertilizers in the soil

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Elements for growth

PLANTS LIVE, GROW AND REPRODUCE BY TAKING CARBON DIOXIDE FROM THE AIR, ENERGY FROM THE SUN, AND WATER AND MINERAL NUTRIENTS FROM THE SOIL.

Plants create the building blocks needed for human life by transforming energy from the sun into plant energy in the form of carbohydrates and fats and by arranging mineral nutrients into proteins and vitamins.

$$6\,CO_2 + 6\,H_2O \rightarrow C_6H_{12}O_6 + 6\,O_2$$

The photosynthesis process: chlorophyll converts carbon dioxide and water into carbohydrate and oxygen.

In fixing solar energy, the chlorophyll in green plants enables them to transform carbon dioxide and water into carbohydrate molecules (e.g. sugars) via photosynthesis. These sugars are then transported by the plants to their storage organs - the grains of wheat, rice or maize, the potato tuber or the sugar beet root - where they are mostly converted into starch, producing edible forms of energy and protein for animals and humans.

Essential nutrients

Most plants contain almost all the chemical elements known to occur in nature but only 17 are needed for good plant growth. Fourteen are essential and without them, plants will not grow to their full potential.

The three primary nutrients are nitrogen (N), phosphorus (P) and potassium (K), followed by three secondary nutrients: calcium (Ca), magnesium (Mg) and sulphur (S). They are often classified as major or macronutrients because they are required by the plant in relatively large amounts.

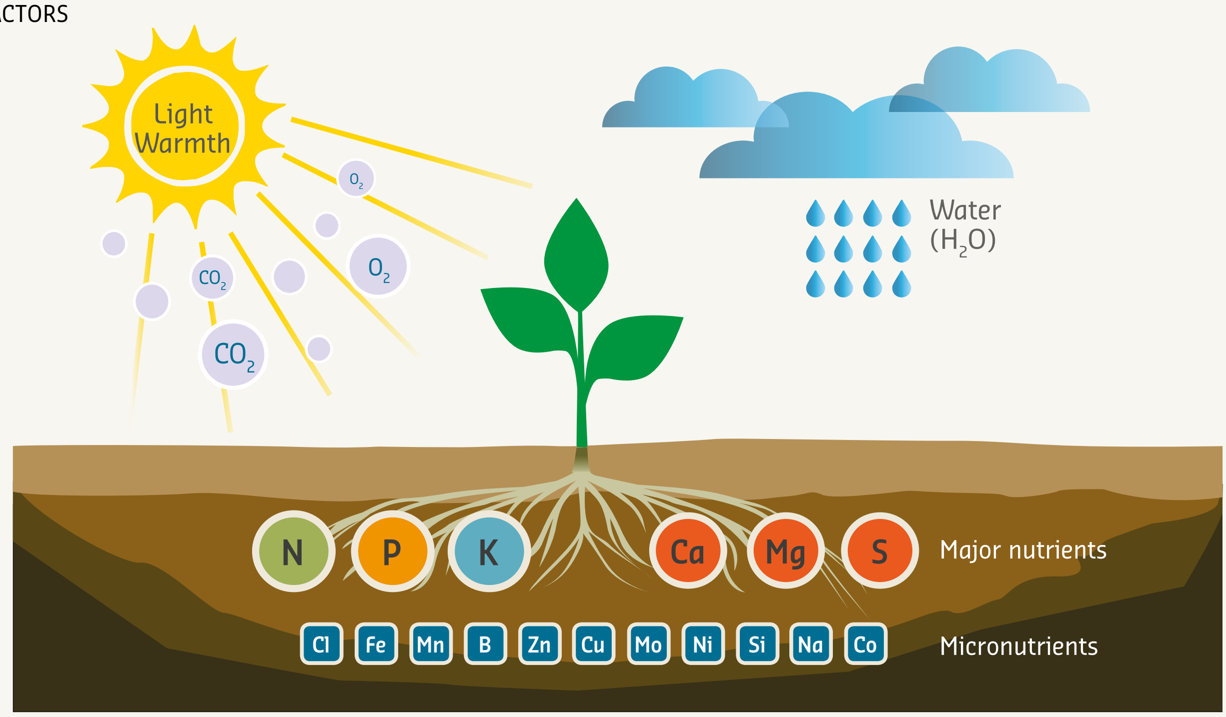
Added to the six macronutrients are eight micronutrients: chlorine (Cl), iron (Fe), manganese (Mn), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo) and nickel (Ni). These are only required by the plant in very small "trace" amounts. Molybdenum and nickel can also be called "ultra micronutrients", because the amounts required by plants differ significantly from the others. In addition, three more elements - silicon (Si), sodium (Na) and cobalt (Co) - are vital for some plant species.

Each of these nutrient has its own distinctive features that enable it to fulfil an essential function within a plant's metabolism.

Limiting factors

In the middle of the 19th century, the German chemist Justus von Liebig discovered that each essential nutrient was equally important to plant growth. Plants require a permanent availability of all of them in proportion to their daily needs. He found that a deficiency in any one nutrient could not be compensated by a surplus of any of the others.

PLANT GROWTH FACTORS



AVERAGE CONTENT OF NUTRIENTS IN PLANT DRY MATTER (DM) NECESSARY FOR ADEQUATE GROWTH		
Element	**Symbol**	**Content** (mg/kg DM)
Macronutrients		
Nitrogen	N	15,000
Potassium	K	10,000
Phosphorus	P	2,000
Calcium	Ca	5,000
Magnesium	Mg	2,000
Sulphur	S	1,000
Micronutrients		
Chlorine	Cl	100
Iron	Fe	100
Manganese	Mn	50
Boron	B	20
Zinc	Zn	20
Copper	Cu	6
Molybdenum	Mo	0.1
Nickel	Ni	< 0.1

Source: based on Marchner, 1995

He therefore formulated his 'law of the minimum' - the level at which the lack of a particular nutrient will limit plant growth.

The classification, therefore, of primary and secondary nutrients, or macro and micronutrients, only refers to the relative amount of each nutrient that a plant needs to grow and the likelihood of any shortfall limiting plant growth. The daily uptake of each nutrient depends on the plant's rate of formation of new tissue and on the type of tissue it is building.

Since many of the nutrients do not exist naturally as pure chemical elements, they are in most cases only available to the plant as a stable chemical compound often combined with oxygen or other elements. For the three primary nutrients, nitrogen, phosphorus and potassium, these are mainly based on the nitrate (NO_3^-), phosphate (PO_4^{---}) and potash (K^+) forms.

Balanced nutrition

The rate and the ratio at which each nutrient is needed by a plant changes over its growth cycle. The objective of balanced fertilization is, therefore, to ensure that the plant has access to an adequate supply of each nutrient at every growth stage in order to avoid any over or under-supply and optimize plant yield.

The nutrients are primarily absorbed from water in the soil, the soil solution, via the plant's root system. A certain proportion are naturally present in the soil as a result of natural microbial processes that break down decaying

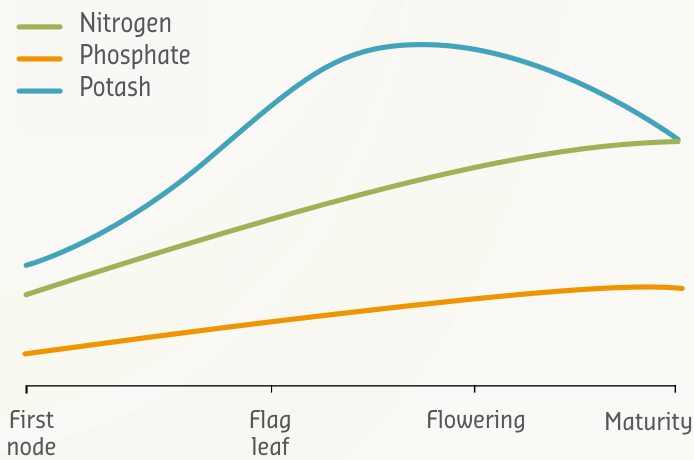
plant and organic matter, but usually these need to be supplemented by nutrients from other organic and mineral sources such as fertilizers to ensure optimal plant growth.

The plant will normally be able obtain all the nutrients it requires from the soil but, if there is not enough of any one, its metabolism will break down at a certain point and healthy growth will not be possible.

When a plant is harvested, the nutrients it has absorbed are lost from the soil and the nutrient supply is depleted. The table on the next page shows examples of the amount of nutrients removed with the harvest by various crops.

Each nutrient has its own distinctive features and fulfils a particular function within a plant's metabolism.

PLANT NUTRIENT UPTAKE



The uptake pattern of nutrients differs over the plant growth cycle. While the amount of potassium in a cereal crop reaches its maximum at the end of vegetative growth, nitrogen and phosphate are accumulated steadily until plant maturity.

NUTRIENTS IN VARIOUS CROPS AT HARVEST				
Crop	Wheat		Potatoes	Sugar Beet
Yield	Grain (8t/ha)	Straw (5t/ha)	Tubers (35t/ha)	Roots (50t/ha)
	Kg/ha			
Nitrogen	150	25	125	85
Phosphate	65	16	50	45
Potash	50	70	210	230
Calcium	5	16	8	25
Magnesium	12	5	15	25
Sulphur	10	9	10	8
	g/ha			
Boron	40	25	55	350
Copper	40	25	40	80
Iron	800	250	310	300
Manganese	320	200	80	230
Molybdenum	5	2	3	6
Zinc	300	95	120	300

Source: Fertilizers Europe

The nutrients above will be removed from the soil when the crops are harvested. Since non-harvested parts of the crop (e.g. roots, stubble and leaves) also contain nutrients, the quantity of nutrients taken up by a plant at peak growth will be far greater than the figures above.

Over time, soils to which additional nutrients have not been added will invariably be unable to supply enough of them to produce optimum crop growth. The organic and mineral fertilizers used by farmers supplement and replace the nutrients lost.

Nitrogen

Nitrogen is more associated with human and plant life than any other chemical element and is an essential constituent of many compounds found in living cells.

All the nitrogen present in animals and humans originally comes from plants and microbes, because only they have the ability to convert mineralized nitrogen into nitrogen in a form that animals and humans can use.

Nitrogen is, therefore, an essential component of the amino acids which make up the proteins in plants, animals and humans. It is also a critical part of chlorophyll which, powered by the sun's energy, carries out the fundamental photosynthesis of carbohydrate from carbon dioxide and water, the first step in the food and energy chain.

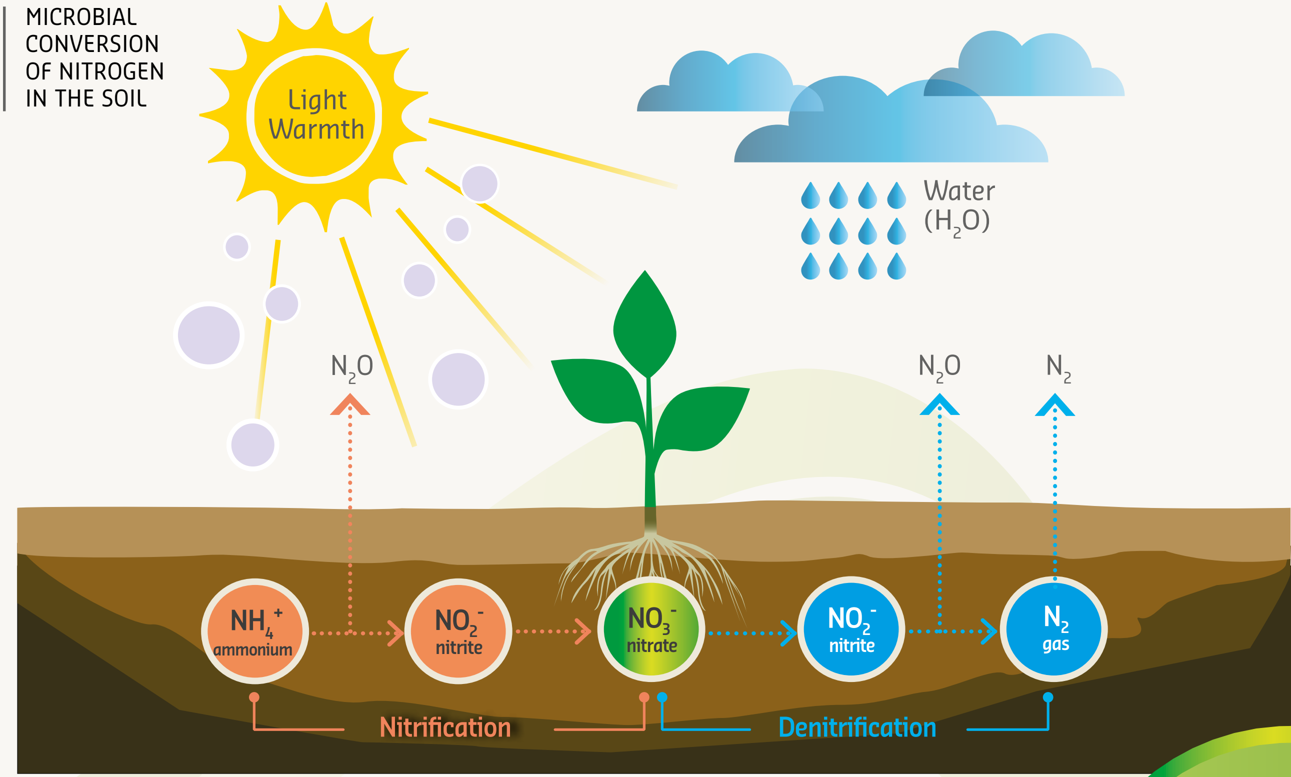
Nitrogen is also a vital element in the energy transfer process and is indispensable in peptides, enzymes, hormones and vitamins and so essential to numerous metabolic functions. Furthermore, it is a constituent of the nucleic acids RNA and DNA that make up the genetic material in all living organisms. It ranks as the fourth most common element in living tissue. Plants primarily take up mineral nitrogen from the soil solution as nitrate (NO_3^-) and ammonium (NH_4^+) and assimilate it into the more complex organic compounds.

Although trials show that plants grow best on a mixture of nitrate and ammonium, most nitrogen is usually taken up in the nitrate form. The microbial conversion of ammonium to nitrate in the soil and nitrate's greater mobility mean that, in practice, plant roots are more exposed to nitrate than ammonium. However in wet or acid ecosystems, this can be different. Crops grown under flood conditions, such as paddy rice, take up most of their nitrogen in the form of ammonium.

Nitrogen taken up by the plant roots is then metabolised and translocated to the upper parts of the plant, usually in the form of amino nitrogen (NH_2). Here most of it is converted into amino acids and then into proteins.

The intensity of nitrogen metabolism and the rate of protein synthesis control the transport of nitrogen to different parts of the plant. Generally it is concentrated in the younger parts with the highest growth rates. However, when the supply of nitrogen from the plant roots is insufficient, nitrogen from the older leaves is mobilized to feed the younger plant organs.

In green plant material, protein-nitrogen is by far the largest fraction of the nitrogen compounds, accounting for 80-85% of the total. Crops such as peas, beans and soya are essentially cultivated to produce this for human or animal consumption.



Nitrous oxide (N_2O) is naturally released during nitrification of ammonium (NH_4^+) to nitrate (NO_3^-) and during the denitrification of nitrate to nitrogen gas (N_2).

Most soils contain too little phosphorus to meet plant demand so fertilizer must be added.

The rate of plant growth and its protein content are directly related to the availability of nitrogen in the soil.

Most plants store their seedling energy as carbohydrate (starch and fat), but leguminous crops like peas, lentils, and beans also accumulate large reserves of protein in their seeds. To prevent the seedling from becoming starved of nitrogen from the soil before it can develop its own symbiotic system for its fixation from the atmosphere, the seed's protein reserves serve as an early nitrogen source.

Phosphorus

Phosphorus is also key element in many physiological and biochemical processes in plants, animals and humans. A component of every cell in all living organisms, it cannot be replaced by any other element.

Phosphorus occurs in complex DNA and RNA structures which hold and translate the genetic information controlling all living processes. It is an essential component of the energy transport system in all cells and also essential to photosynthesis.

The plant roots take up phosphorus in the phosphate (PO_4^{---}) form. However, phosphorus compounds are not very soluble and the amount of plant available phosphorus in the soil solution often tends to be far less than plants require, particularly when they are growing vigorously.

A rapidly growing crop may take up the equivalent of about 2.5 kg of phosphorus per hectare on a daily basis, so fertilizers containing phosphorus must be added to the soil to meet this demand.

A phosphorus deficiency affects not only plant growth and development but also the quality of the plant fruit and the formation of seeds. A deficiency can also delay crop ripening which can set back the harvest, further risking the quality of the crop.

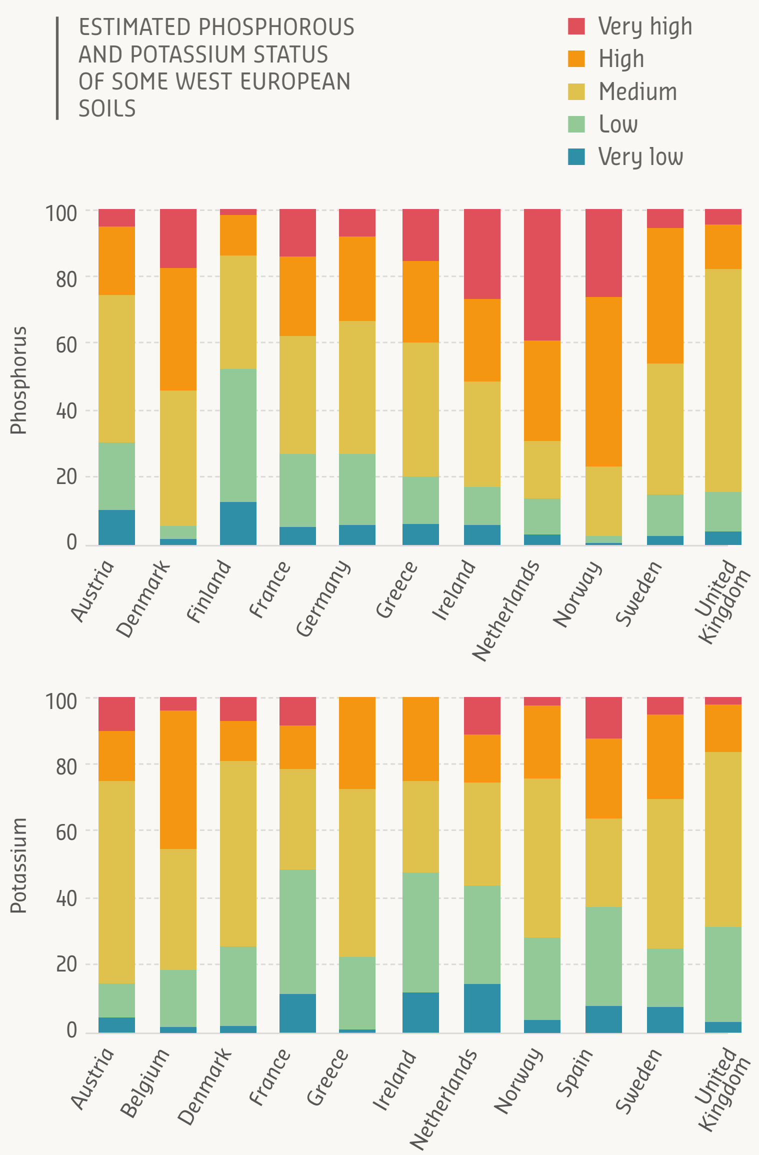
To successfully produce the next generation of plants, seeds and grains must store phosphorus so that the seedling has enough to develop its first roots and shoots. As the root system develops, the growing plant will then be able to take up the phosphorus it requires from the soil, providing there are adequate reserves.

Potassium

Potassium has both biochemical and biophysical roles in the functioning of plant cells. Small amounts are required for the activation of enzymes which are fundamental to a plant's metabolic processes, especially the production of proteins and sugars.

Potassium also maintains the water content and rigidity (turgor) of each plant cell. A large concentration in the cell sap (the liquid inside the cell) creates conditions that cause water to move through the cell wall into the cell by osmosis.

Turgid cells maintain a plant's leaf structure so that photo-synthesis can proceed efficiently. Carbon dioxide (CO_2) from the air enters the plant through tiny openings in the underside of the leaves called stomata, which are surrounded by guard cells. The plant controls the opening and closing of the stomata by regulating the concentration of potassium in the guard cells.



ESTIMATED PHOSPHOROUS AND POTASSIUM STATUS OF SOME WEST EUROPEAN SOILS

Source: Fertilizers Europe surveys

A large concentration ensures turgid cells and open stomata through which CO_2 can pass. When the concentration is reduced, the cells become limp and the stomata close, reducing CO_2 uptake.

A high osmotic potential in plant cells is needed to ensure the transport through the plant of nutrients required for growth and the sugars produced by photosynthesis. By maintaining the salt concentration in the cell sap, potassium helps the plant combat the adverse effects of drought and frost damage, as well as attack by insects and diseases. It also improves fruit quality and the oil content of many oil-producing crops.

Sufficient potassium also ensures that the other inputs required to achieve optimum economic yields are used efficiently. This applies especially to the use of nitrogen where, with an adequate potassium supply, increased yields are accompanied by larger amounts of nitrogen in the crops at harvest and smaller nitrate residues left in the soil.

Plants take up potassium when growing vigorously. A rapidly growing cereal crop will take up as much as 6 kg of potassium per hectare per day and sugar beet up to 8 kg per hectare. To maintain this rate of uptake, the potassium in the soil solution has to be replenished quickly, which is only possible if the soil contains sufficient readily available reserves. These reserves are usually maintained by applying manure and mineral fertilizers.

Calcium, magnesium, sulphur

One of calcium's primary roles is to help maintain the soil's chemical balance, reduce soil salinity and improve soil structure and water penetration. But it is also widely recognized for increasing plant nutrient uptake, in building strong cell walls and increasing plant vitality. It plays a critical metabolic role in carbohydrate removal and in neutralizing cell acids.

Maintaining high levels of plant-available calcium in the soil is essential to achieving adequate levels of plant calcium uptake. However, once fixed, calcium is not mobile within a plant. It is an important constituent of cell walls and can only be supplied from the plant sap. Thus, if a plant's supply of calcium is reduced, it cannot remobilize it from older tissue. If plant transpiration is reduced, the calcium supply to growing tissues will rapidly become inadequate.

A calcium deficiency causes severe plant stress. Visual symptoms include necrosis at the tips and margins of young leaves, bulb and fruit abnormalities, leaf deformation, stunted plant growth and general chlorosis. Although many soils contain high levels of calcium, in most cases this is in the insoluble calcium carbonate form and crops grown in these soils will often show symptoms of a calcium deficiency.

As a component of chlorophyll, magnesium enhances the rate of plant photosynthesis. It also helps a plant form complete proteins, playing an important role in plant respiration and energy metabolism. Plants take up the nutrient as magnesium ions (Mg^{++}) dissolved in the soil solution.

Rocks and clay particles in the soil contain magnesium but it is not plant available. As they break down over time, magnesium is released but the process is very slow. Magnesium is therefore applied to crops as manure, dolomitic limestone and via direct magnesium fertilizers. Low soil pH, high levels of potassium and calcium, low temperatures and dry soil conditions can all contribute to a magnesium deficiency.

Sulphur contributes to plant nutrition directly and indirectly by soil amendment, especially of calcareous and saline soils. It also improves the efficient take up of other essential nutrients, particularly nitrogen and phosphorus. Elemental sulphur must, however, be oxidized to the sulphate form (SO_4^{--}) before it is plant available.

The majority of plants contain as much sulphur as phosphorus, with an average content of approximately 0.25%, but oil crops, legumes, forages, and some vegetables require more sulphur for optimal yield and quality.

Sulphur becomes available in the soil through natural soil mineralization and through the deposition of sulphur dioxide (SO_2) from the atmosphere, historically an important source around industrial areas. However, the more stringent environmental regulations in Europe have substantially reduced atmospheric sulphur deposition over the last 20 years, increasing the need for additional sulphur fertilization. Soil or foliar applied fertilizers containing sulphate rapidly improve the sulphur supply to crops.

Micronutrients

No matter how small the quantity in which they are required, the micronutrients chlorine, iron, manganese, boron, zinc, copper, nickel, and molybdenum are essential to facilitating many critical plant functions. They enhance the translocation of sugars, as well as contribute to plant root strength and a plant's overall immunity to fungal and other diseases. Most act as co-factors in enzymes and the building blocks for proteins and other compounds.

Except for boron, which has a special role as a structural component of cell walls, they are components of enzymes or direct participants in enzymatic reactions. However, the number of enzymes in which individual micronutrients are structural components or that are influenced by them varies. Urease is the only plant enzyme to contain nickel. In contrast, a number of enzymes have iron at their catalytic centre and manganese influences the activities of at least 35.

The specific significance of chlorine lies in its participation in the water-splitting enzymes of photosynthesis. It also has a variety of functions influencing plant osmosis and the regulation of the plant water supply. Iron plays a central physiological role in the biosynthesis of chloroplasts and in the formation of chloroplast proteins. This explains plant leaf chlorosis (turning yellow) when an iron deficiency occurs.

Manganese is the only nutrient with an oxidation potential capable of oxidizing water during photosynthesis, creating oxygen. This makes it fundamental to life on earth.

A rapidly growing crop will take up 6 kg of potassium per hectare per day.

Copper participates in electron transport in photosynthesis and in cell respiration. It also plays a central role in lignin biosynthesis. Boron helps transport carbohydrates through a plant and in forming and filling the fruit. It also sustains microbial life in the soil and is required to help a plant absorb calcium.

A lack of boron in the root area of a plant can lead to a reduction in root growth and to potassium loss from the root cells. Boron is also essential for the pollination process.

Zinc's physiological functions are essentially based on binding with enzymes. It stabilizes tertiary protein structures and the binding of regulatory proteins to DNA and RNA. Nickel is a vital component of the urease enzyme and, as an inlet enzyme for nitrogen assimilation, molybdenum ensures that nitrate can ultimately be converted into amino acids and proteins. This has a special significance for legumes since nitrogenase, an enzyme that reduces atmospheric nitrogen, contains molybdenum.

The significance of micronutrients and the necessity of targeted fertilization in particular cases has increased over the last few years as higher crop yields have led to greater micronutrient depletion.

Application of pure, highly concentrated mineral fertilizers, a decline in livestock farming with reduced availability of farmyard manure, and cultivation measures such as liming, drainage or soil loosening, have also all contributed to a decreased micronutrient supply.

How plants absorb nutrients

FOR EFFECTIVE PLANT NUTRITION, THE MINERAL FORMS OF NUTRIENTS ARE IMPORTANT BECAUSE PLANTS ONLY TAKE UP NUTRIENTS IN THESE FORMS.

As a general rule, the majority of plant nutrients naturally found in the soil are in organic form. Each year, around 2% of these are converted into the mineral form by natural microbial action known as mineralization. This means that, in most cultivated areas, the natural nutrients in the soil need to be supplemented to provide the levels of nutrients required by a productive plant for optimal growth.

Nutrient supplementation can be provided by animal manures and composts, which first need to be broken down over time into their respective mineral forms, and by mineral fertilizers which provide the nutrients in a form that is generally directly available for plant use.

Whatever the source, the nutrients are mineralised into positively or negatively charged ions such as nitrate (NO_3^-), ammonium (NH_4^+), phosphate (PO_4^{---}), potassium (K^+), manganese (Mg^{++}), and sulphate (SO_4^{--}). The ions are dissolved in the soil solution, the small layers of water between the solid particles (e.g. clay or humus) in the soil structure, before being taken up through the plant roots.

Only a small number of nutrients are dissolved in the soil solution at any given time.

Of the two forms of mineral nitrogen, nitrate and ammonium, the positively charged NH_4^+ ion initially fixes itself to negatively charged clay minerals but starts to be converted into the NO_3^- form by microbes in the soil at soil temperatures between 10 to 15° C (the nitrification process). The conversion increases rapidly with the temperature. As a result, the NO_3^- form is usually the predominant type of nitrogen available to plants.

As the concentration of mineral nutrients held in the soil at any time is seldom identical to a plant's actual needs, plants are able to actively absorb selected ions and refuse others.

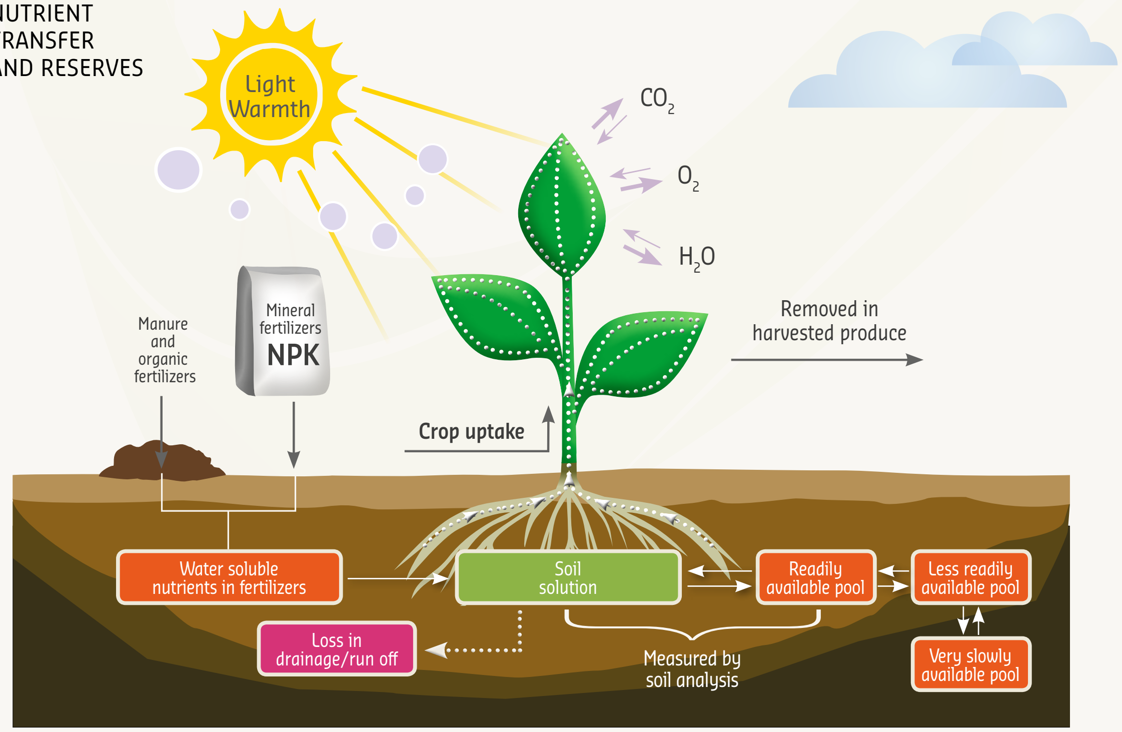
Nutrient transfer

Only a small number of nutrients like nitrogen and sulphur are actually dissolved in the soil solution at any given time. The majority, including phosphorus and potassium, are stored in nutrient pools that are either readily available to a plant or can become available over longer time periods.

The most readily available pools are those where the nutrient ions are adsorbed onto the surface of solid soil particles or bound in easily degradable organic material. Some more slowly available mineral preciptates can also be redissolved relatively easily by organic compounds.

The nutrients available to meet plant needs at any given time can in effect been seen as being held in a series of cupboards. When the plant roots take up a particular ion from the soil solution, the nutrient reserves migrate towards the soil solution from the readily available pool, which itself is then replenished from the slowly available pool.

NUTRIENT TRANSFER AND RESERVES



Conversely, when more nutrient ions are present in the soil solution than are needed by the plant, the ions move in the opposite direction back to the readily available pool and from this reserve to the slowly available pool.

This dynamic back and forth transfer of ions between the soil solution and the nutrient pools is a very important factor in the soil's fertility and its ability to provide sufficient nutrients. Although only a small proportion of a nutrient may be immediately available to a plant in the soil solution, its overall availability also depends on the amounts held in the different nutrient pools.

But even readily available nutrients fixed to soil particles or bound in easily degradable organic matter can experience a considerable time lag before becoming available in the soil solution. As mineralization is a biological process and the activity of the mineralizing microbes depends on soil temperature, humidity and acidity, it is often difficult to predict the exact timing and rate of release of these nutrients.

Increasing nutrient uptake

Some plant species have developed special tools to increase the efficiency of their nutrient uptake. The most obvious is an extensive root zone, and root depth and density differ significantly between species. A wheat crop is very efficient at recovering nutrients, having up to an incredible 30 km of roots per square metre of soil and roots one to two metres deep. Vegetables such as spinach or radish have root systems of only 2 km/m^2 and which are hardly deeper than 15 cm.

Several plant species live in symbiosis with mycorrhizae fungi on their roots. While the fungi feed on organic compounds excreted by the roots, they also supply their host plant with mineralized nutrients beyond the reach of the root hairs. Another example of symbiosis are the nitrogen-fixing bacteria living in specific nodules on the roots of legumes such as beans and peas. In exchange for assimilates, these microbes fix nitrogen from the air and deliver it to the plant's root system.

Such plants use a substantial proportion of the energy fixed during photosynthesis on their symbiotic partners - up to 30% on mycorrhizae and up to 50% on nitrogen fixation.

Nutrient reserves

Depending on the nutrient, different soils have different nutrient storage capacities and processes. Loamy soils with a balanced content of sand, silt and clay, contain about 2-3% organic matter and have a good capacity for holding water and nutrients. Free draining sandy and shallow soils, as well as acidic ones, are less able to retain nutrients. In most alkaline soils, the plant availability of the majority of nutrients is also reduced.

Macronutrients like nitrogen and sulphur exist naturally in the upper soil layer in both organic and mineral forms. In most arable soils, total amounts vary between 3,000 to 10,000 kg/ha of nitrogen and 500 to 2,000 kg/ha of sulphur, with even greater amounts being found in grassland.

NUTRIENT BIOCONVERTION PROCESSES

The main nutrient bioconversion processes in the soil are mineralization and immobilization. Nitrification and denitrification are also important in the nitrogen nutrient cycle.

Mineralization

A wide variety of micro-organisms break down organic material in the soil to access the energy they need to live. During this process, plant nutrients are released. Fresh organic matter such as plant residues are naturally mineralized almost entirely within a few months during summer, while only 10-20% of farmyard manure or compost is mineralized over the year. The soil humus consists of very stable molecules which are only mineralized over long periods.

Immobilization

Micro-organisms feeding on organic soil material incorporate amino acids and mineralized nutrients into their bodies as they grow and multiply. This microbial population can therefore fix mineral nutrients from the soil solution rendering them temporarily unavailable to plants. For example, when easily degradable organic material low in nitrogen, such as straw, is abundant in warm humid weather, up to 100 kg of nitrogen per hectare can be temporarily immobilized.

Nitrification

Some specialised bacteria profit from the energy bound in ammonium (NH_4^+). Nitrobacter bacteria transform NH_4^+ to nitrite (NO_2^-) and nitrosomonas bacteria further convert the NO_2^- to nitrate (NO_3^-) which can be more readily taken up by plants. Under aerobic conditions, almost all of the ammonium available in the soil will be nitrified to nitrate.

Denitrification

When oxygen is limited in flooded or waterlogged soils, some microbes have the ability to use the oxygen from nitrate for their metabolism. This reduces it to the gases nitric oxide (NO), nitrous oxide (N_2O) or nitrogen (N_2), which are lost to the atmosphere. Losses can reach up to 20 to 30 kg of nitrogen per hectare annually.

The rate of microbial activity in the soil depends on several factors such as water content, oxygen supply, soil pH and temperature. Microbes are most active in warm humid soils, the process starting at about 10-15º C. The processes effectively cease at temperatures below 3ºC and in dry soils.

INFINITE FERTILIZERS
Continuing to feed the world

TRANSFORMATION OF NITROGEN FERTILIZERS IN THE SOIL

1 **Application** of nitrogen to the soil in the form of ammonium, nitrate, urea or a mix of these, as well as by organic fertilizers and manures containing complex organic nitrogen compounds.

2 **Uptake** of nitrate is rapid due to its high mobility. Most plants prefer nitrate over ammonium.

3 **Uptake** of ammonium is mostly in the nitrified form as ammonium is generally bound to clay particles in the soil and plant roots have to reach it to take it up in this form.

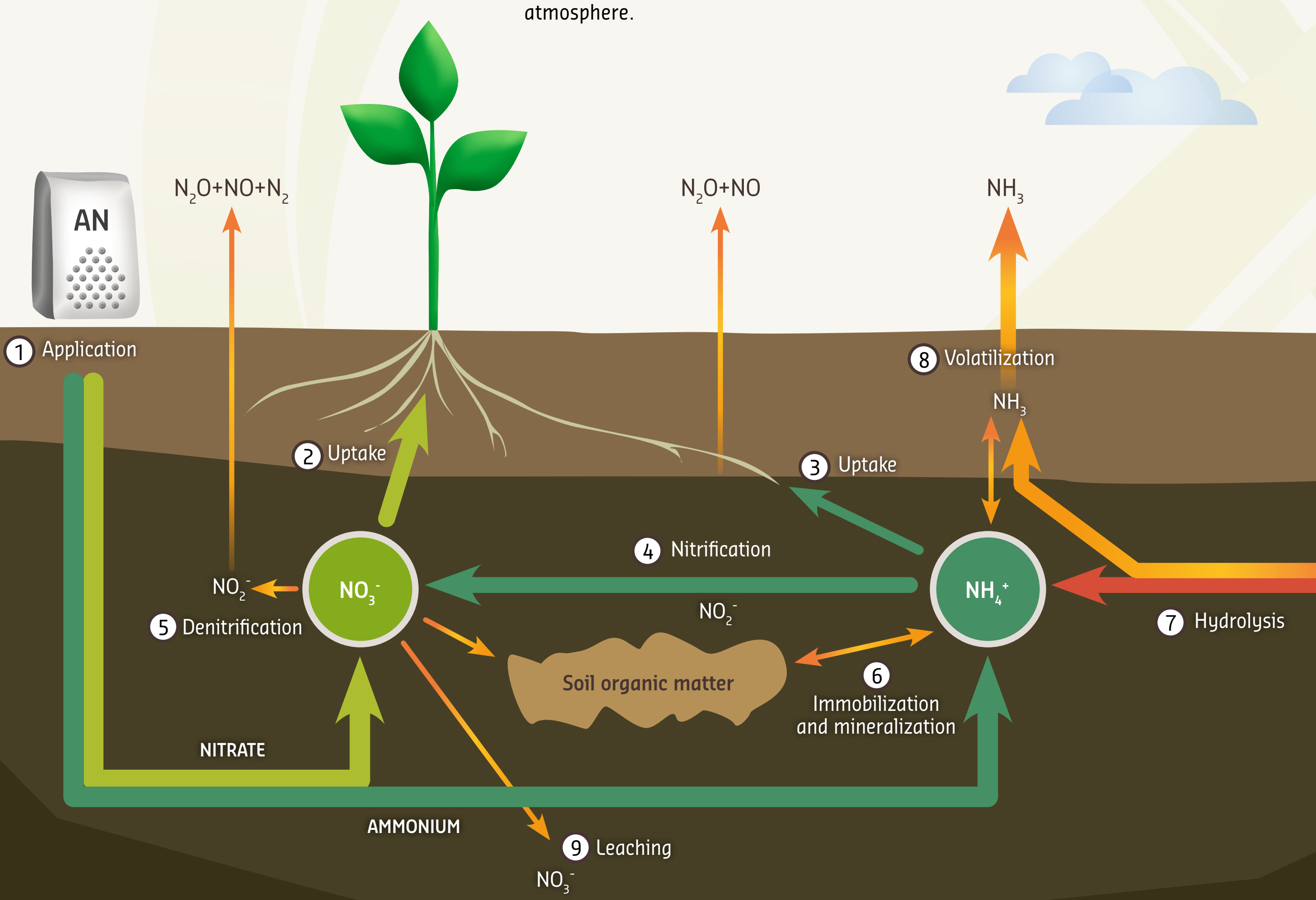
4 **Nitrification** by soil bacteria converts ammonium into nitrate over a period of a few days to a few weeks. Nitrous oxide and nitric oxide gases are lost to the atmosphere during the process.

5 **Denitrification** occurs when the micro-organisms lack oxygen (e.g. in waterlogged or compacted soils). During the process the soil bacteria convert nitrate and nitrite into nitrous oxide, nitric oxide and nitrogen which are also lost to the atmosphere.

6 **Immobilization** fixes mineral nitrogen in soil organic matter. Soil microbe activity is mainly stimulated by ammonium. Immobilized nitrogen is not immediately available for plant uptake, but needs to be mineralized first. Mineralization of soil organic matter (and manure) releases ammonium into the soil.

7 **Hydrolysis** of urea by soil enzymes converts urea into ammonium and CO_2 gas. Depending on the temperature, hydrolysis can take between a day and a week. The pH of the soil around the urea granules increases significantly during the process.

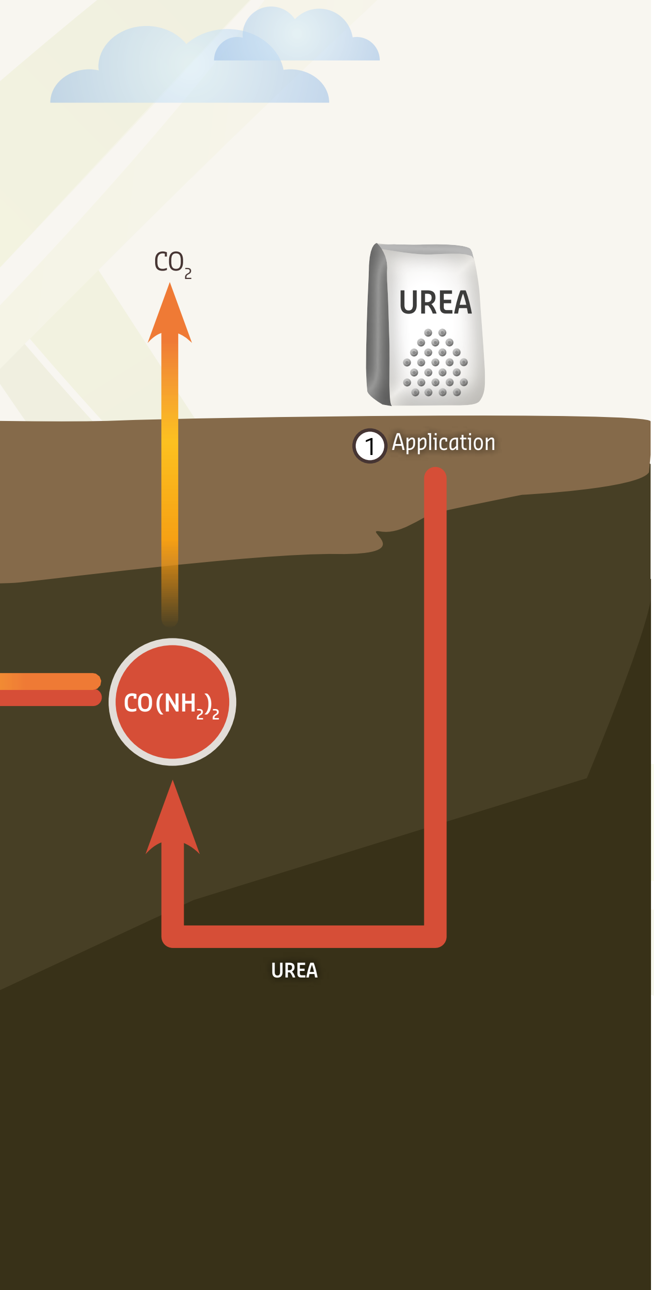
TRANSFORMATION OF AMMONIUM, NITRATE AND UREA IN THE SOIL. UREA SUFFERS THE HIGHEST TRANSFORMATION LOSSES, NITRATE THE LOWEST.



CO_2	carbon dioxide (gas)	NH_4^+	ammonium	NO	nitric oxide (gas)
$CO(NH_2)_2$	urea	NO_3^-	nitrate	N_2O	nitrous oxide (gas)
NH_3	ammonia (gas)	NO_2^-	nitrite	N_2	nitrogen (gas)

8 **Volatization** of ammonium occurs when it is converted to ammonia gas, which is lost to the atmosphere. A high soil pH level favours this conversion. If volatization takes place at the soil surface, losses are highest. These two conditions are met when urea is not immediately incorporated and absorbed after spreading.

9 **Leaching** of nitrate occurs mainly during winter when rainfall washes residual and mineralized nitrate away from the root zone. Accurate fertilization reduces leaching during and after the plant growth period.



The main reserves of nitrogen and sulphur are held in long-term organic matter where they are slowly mineralized to the ammonium (NH_4^+), nitrate (NO_3^-) and sulphate (SO_4^{--}) forms. The negatively charged ions are highly mobile in the soil solution and, if not immediately taken up by a plant, can leach from the soil after rainfall.

Most nutrients which form positive ions (NH_4^+, K^+, Mg^{++}, etc.) are readily adsorbed onto the surface of negatively charged clay and humus particles in the soil and are therefore not particularly mobile and liable to leaching.

Ammonium and nitrate supplied by mineral fertilizers are subject to the same microbial processes. A general rule, if a soil's carbon to nitrogen (C:N) ratio is below 15:1, mineralization dominates. If the ratio is higher than 20:1, immobilization is favoured. Humus, the long-term form of soil organic matter, has a fairly constant C:N ratio of approximately 10:1, so arable soils in most parts of Europe have a C:N ratio of between 8:1 and 15:1 favouring mineralization.

Depending on the nutrient, different soils have different nutrient storage capacities and processes.

Types of fertilizer

A full range of products

- Straight and compound fertilizers
- Handling characteristics
- Nitrogen fertilizers
- Phosphorus fertilizers
- Potassium fertilizers
- Cacium, magnesium and sulphur fertilizers
- Micronutrient fertilizers
- Organic fertilizers

A full range of products

FARMERS IN EUROPE HAVE ACCESS TO A WIDE VARIETY OF MINERAL FERTILIZERS BASED ON THE MAJOR PLANT NUTRIENTS AND SELECTED MICRONUTRIENTS.

Nitrogen-based products make up by far the largest fertilizer group, followed by fertilizers based on phosphorus and potassium.

Production of the large range of fertilizers that are easy to handle and have reliable nutrient release profiles requires the European fertilizer industry to transform millions of tons of naturally occurring raw materials such as air, natural gas and mined ores.

For nitrogen-based fertilizers, the production process first involves mixing nitrogen from the air with hydrogen from natural gas at high temperature and pressure in the Haber-Bosch process to create ammonia, the main building block for nitrogen-based fertilizers.

The ammonia is then either mixed with nitric acid to produce nitrate fertilizers, such as ammonium nitrate (AN), or with liquid carbon dioxide to create urea fertilizers. Both these products can also be further mixed with water to form UAN (urea-ammonium nitrate) liquid solutions.

Both phosphorus and potassium-based fertilizers are produced from mined ores. Phosphate rock is crushed and primarily treated with sulphuric acid to produce phosphoric acid, which is either concentrated or mixed with ammonia to make a range of phosphate (P_2O_5) fertilizers.

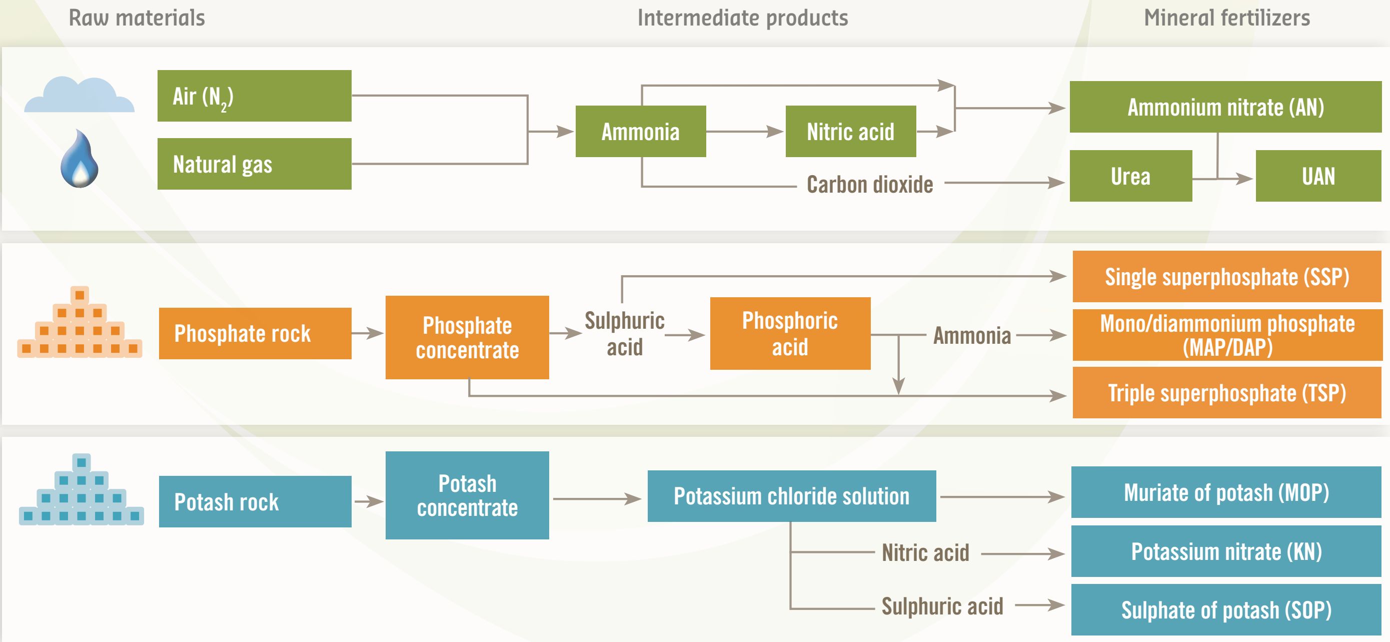
Potash ores are usually rich in both potassium and sodium chloride (KCl and NaCl). Typically, the ore is dissolved in hot water and the NaCl separated out, before the resulting KCl solution is concentrated by evaporation to create muriate of potash (MOP) fertilizer.

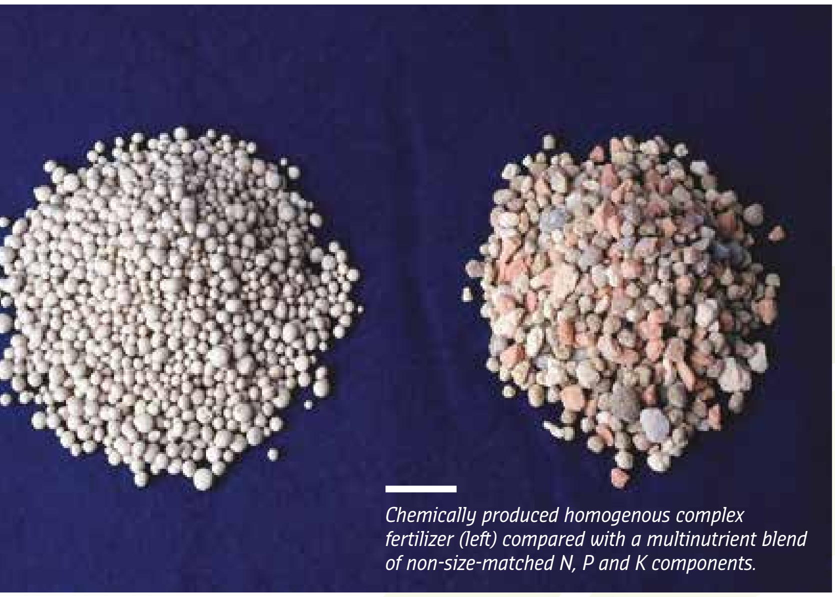
The potassium chloride may then be further treated with nitric or sulphuric acid to produce potassium nitrate (KN) or potassium sulphate (SOP) fertilizers.

Detailed descriptions of the major fertilizer production processes can be found in the Fertilizers Europe Infinite Product Stewardship brochure.

Different fertilizer products have different release profiles and need different spreader settings for efficient application.

PRODUCTION OF MAIN FERTILIZER PRODUCTS





Chemically produced homogenous complex fertilizer (left) compared with a multinutrient blend of non-size-matched N, P and K components.

The type of particle depends on the production process: granular ammonium nitrate, NPK and crystalline calcium nitrate all need different spreader settings..

Fertilizers must be free flowing to assure easy handling and uniform spreading.

Straight & compound fertilizers

Fertilizers are avaialble in straight and compound forms, based on one major nutrient or two or more nutrients respectively.

Straight fertilizers account for the majority (78%) of total fertilizer use in Europe and producers offer a full range of products, often based on meeting the needs of a specific crop. Compound NPK fertilizers account for the remaining consumption and primarily are available in two distinct types: blended and complex fertilizers.

Blended fertilizers are produced by dry mixing two or more intermediate fertilizer materials. In high quality blends, the component granules or particles are precisely matched in size and other physical characteristics so they do not separate (segregate) during handling, which can result in the uneven distribution of nutrients on the field.

Complex fertilizers contain at least two primary nutrients and are usually produced chemically. These have the advantage that each of the components is present in every granule. The granules are of a uniform size range and defined composition, so present no risk of segregation.

The majority of compound fertilizers produced in Europe are complex products and manufacturers supply a range with nutrients in different proportions. For example, a 15:15:15 compound NPK fertilizer will contain 15% N, 15% P_2O_5 and 15% K_2O in each granule.

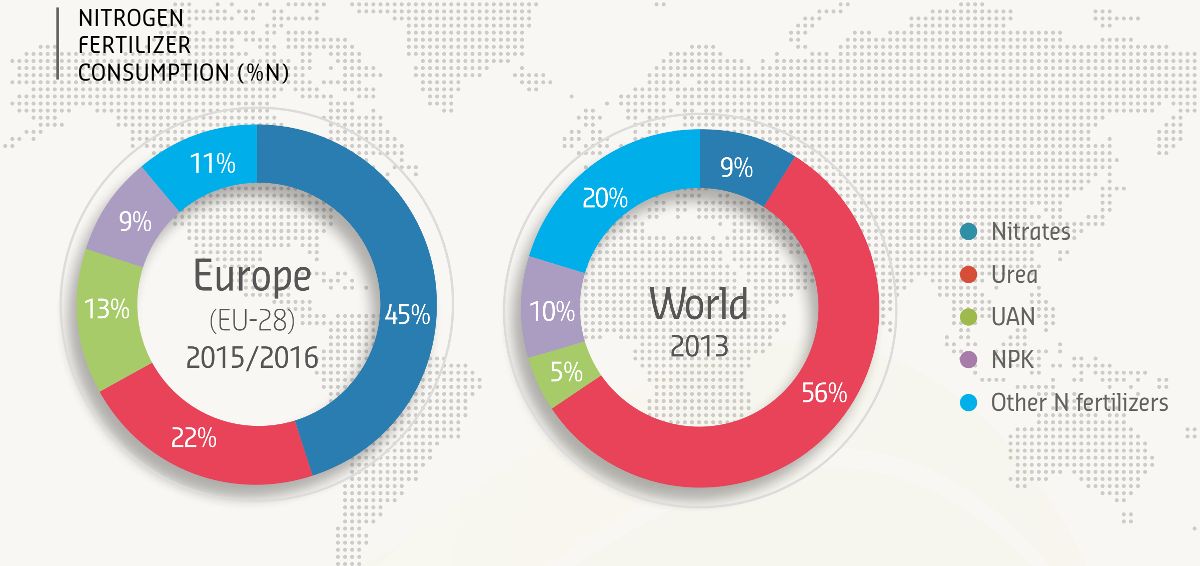
Handling characteristics

Today's highly mechanised fertilizer application equipment requires that solid fertilizers are free flowing to assure easy handling and uniform, accurate spreading patterns.

The industry produces individual fertilizers with particles within a narrow size range and which are sufficiently robust not to disintegrate during transport and spreading. The quality of fertilizer raw materials, intermediates and finished product are extensively checked during the production process.

Nitrogen fertilizers

The majority of nitrogen fertilizers applied In Europe are straight fertilizers. The main products are nitrate-based fertilizers, such as ammonium nitrate (AN) and calcium ammonium nitrate (CAN), which are well suited to most European soils and climatic conditions, and urea and urea ammonium nitrate (UAN) aqueous solution, which are widely used in other parts of the world.



- AN is a mixture of ammonium and nitrate, with a nitrogen concentration ranging from 32% to 34.5%. Half the nitrogen is in the nitrate (NO_3^-) form, which is immediately available to plants, and the other half in the ammonium (NH_3^+) form. AN is the most commonly used straight nitrogen fertilizer in the UK (68%) and France (38%) and accounts for 21% of total nitrogen fertilizer consumption in Europe.

- CAN is a mixture of ammonium nitrate and a minimum of 20% calcium/magnesium carbonate. It is another concentrated source of nitrogen (25% to 28% N) and overall is the most popular straight nitrogen fertilizer in Europe.

- Urea, based on nitrogen in the amide (NH_2) form, is the most concentrated solid nitrogen fertilizer (46% N) accounting for 22% of nitrogen fertilizer use in Europe. However, with urea the availability of plant-available nitrogen is delayed, particularly in cold weather, because it has first to be transformed into ammonium and then into the nitrate form. Since this transformation is dependant on soil temperature, in Europe its use is traditionally strong in areas bordering the Mediterranean.

- Liquid solutions represent 13% of nitrogen consumption in Europe. The most typical, UAN, is made using 50% urea and 50% ammonium nitrate in water (forming a fully dissolved clear liquid fertilizer with 28-32% nitrogen content). UAN offers farmers the advantage of reduced handling but it requires special storage facilities and transport equipment.

Other straight nitrogen fertilizers include ammonium sulphate and ammonium sulphate nitrate, calcium nitrate, sodium nitrate, Chilean nitrate and anhydrous ammonia.

- Ammonium sulphate has a relatively low nitrogen content (21%, all of which is in the ammonium form. But it also contains 24% sulphur, another essential plant nutrient.

  Ammonium sulphate nitrate is a combination of ammonium sulphate and ammonium nitrate. A typical grade contains 26% N (7.5% as NO_3^-; 18.5% as NH_3^+) and 14% sulphur (as S).

- Calcium nitrate contains 14.4% nitrogen in the nitrate form and 19% water-soluble calcium. Due to its quick action, it is a form of nitrogen particularly suited to fast growing vegetable crops as well as fruit trees.

- Sodium nitrate and Chilean nitrate are used in small volumes on specialised crops, while anhydrous ammonia (82% N), which is applied by injection into the soil, represents less than 1% of total nitrogen fertilizer use in Europe.

Nitrate-based fertilizers are the most commonly used straight fertilizers in Europe.

Speciality nitrogen products

Certain weather and soil conditions can lead to nitrogen immobilization, denitrification, volatilization or leaching, all reducing fertilizer efficiency. In response, the industry has developed special types of fertilizers designed to reduce these effects. They include foliar, slow and controlled release fertilizers, as well as fertilizer additives such as urease and nitrification inhibitors.

- In certain situations nitrogen can be very efficiently taken up through the leaves of a plant and foliar fertilizers can be used to avoid the immobilization or leaching of soil-applied nitrogen. However, the quantity of nitrogen which can be applied using foliar sprays is limited and in practice they are primarily used to supplement soil-applied nitrogen.

- Slow and controlled release fertilizers contain nitrogen and sometimes other nutrients in forms that either delay or extend their availability to match crop uptake.

Typically, slow release fertilizers rely on the inherent water insolubility of the material containing the nitrogen, while controlled release products are made through modification of the fertilizer particle through a coating or an encapsulating membrane.

Most controlled release fertilizers release nutrients over 3, 6, 9 or 12 month periods. Slow release fertilizers (based on urea-aldehyde) are designed mainly for professional use on turf and in nurseries and gardens.

Inhibitors

Urease inhibitors are chemical compounds that delay the first step of degradation of urea in the soil, the hydrolysis that can create NH_3 emissions and which may occur before its transformation to ammonium.

Nitrification inhibitors are chemical compounds that delay the nitrification of ammonium by suppressing the activity of nitrosomonas bacteria in the soil. The objective is to preserve the ammonium in its soil-stable form and slow its conversion to nitrate. This temporarily reduces the proportion of nitrate in the soil, and thus the potential for leaching losses or the formation of N_2O gas.

As the cost of controlled-release fertilizers with inhibitors is significantly higher than that of conventional products, their use has largely been restricted to high value crops, specific cultivation systems and non-agricultural, high-value sectors (horticulture, nurseries, greenhouses, etc.) With the introduction of controlled-release urea, however, this is changing fast.

Phosphorus fertilizers

The most common phosphate fertilizers are single superphosphate (SSP), triple superphosphate (TSP), mono-ammonium phosphate (MAP), di-ammonium phosphate (DAP) and ammonium polyphosphate liquid.

All phosphate products are highly water soluble. Ammonium phosphate is also a source of nitrogen. Both MAP and ammonium polyphosphate, either alone or with added potassium, make excellent starter fertilizers because of their high phosphorus-to-nitrogen ratios, water solubility and low production of free ammonia (NH_3), which can harm seeds.

Di-ammonium phosphate is often not recommended as a starter fertilizer because it produces free ammonia. Many starter fertilizers contain DAP, so it is critical that the fertilizer is accurately applied a safe distance (about 5 cm) from the seeds and that high application rates are avoided. Because phosphorus is relatively immobile in the soil, placement of the fertilizer where plant roots will have easy access to it is especially important.

PHOSPHATE (P_2O_5) CONTENT OF COMMON PHOSPHORUS FERTILIZERS (%)

Single superphosphate	18-20
Triple superphosphate	46
Mono-ammonium phosphate	52
Di-ammonium phosphate	46
Ammonium polyphosphate	34

Speciality products, such as slow or controlled-release fertilizers, contain nutrients in a form that either delays or extends their availability in order to more closely match crop uptake.

A number of fertilizer manufacturers produce fertilizers in which the ratio of nutrients is adjusted to meet the specific needs of certain crops or which has certain desirable physical characteristics such as solubility in water.

Soluble fertilizers are increasingly used in fertigation systems with irrigation water or as foliar sprays.

Potassium fertilizers

Potassium is also available in a range of fertilizers which contain potassium only or two or more nutrients.

- Potassium chloride (KCl), known as muriate of potash or MOP, accounts for about 95% of all potassium fertilizers used in agriculture. It is the cheapest per tonne of potassium and the most widely available.

  In the form of fine crystals, muriate of potash can be readily incorporated into granular compound fertilizers or compacted into suitable sized particles to be spread by machine or used in fertilizer blends. Due to the presence of chloride, it is not recommended for use on sensitive crops.

- Potassium sulphate (K_2SO_4) or sulphate of potash (SOP) is more expensive per tonne than MOP as it contains both potassium and sulphur. It tends to be used for high value fruit and vegetable crops and with other crops where it improves crop quality, such as potatoes. As it contains no chloride, it can also be used with crops grown in saline soils, which occur in arid and semi-arid regions.

- Potassium nitrate (KNO_3), known as KN, contains potassium and nitrogen in the nitrate form which is readily available to crops.

Both potassium sulphate and potassium nitrate are also highly suitable for use in foliar sprays or in fertigation systems, where the nutrients are applied together with irrigation water.

THE COMPONENTS OF MAJOR POTASH FERTILIZERS		
Potassium chloride KCl (muriate of potash)	60% K_2O	
Potassium sulphate K_2SO_4 (sulphate of potash)	50% K_2O	45% SO_3
Potassium nitrate KNO_3 (nitrate of potash)	46% K_2O	13% N

Calcium, magnesium and sulphur fertilizers

Calcium (Ca), magnesium (Mg) and sulphur (S) are essential secondary plant nutrients. They are not usually applied as straight fertilizers but in combination with the primary nutrients N, P, and K.

Sulphur is often added to straight N fertilizers such as ammonium nitrate or urea. Other sulphur sources are single superphosphate (SSP), potassium sulphate (SOP) and potassium magnesium sulphate (Kainite), the latter also containing magnesium.

Special fertilizers add important micronutrients such as iron, manganese, boron, zinc and copper.

Kieserite is a magnesium sulphate mineral that is mined and also used as fertilizer in agriculture, mainly to correct magnesium deficiencies. Calcium is mainly applied as calcium nitrate, gypsum (calcium sulphate) or lime/dolomite (calcium carbonate), of which calcium nitrate is the only readily plant available source of calcium.

Micronutrient fertilizers

Today, a large number of special fertilizers are available to supply plants with important micronutrients such as iron, manganese, boron, zinc and copper.

These can be either inorganic or organic compounds, with the inorganic varieties further divided into water-soluble and non-soluble products.

- Ferrous sulphate (20% Fe, 18.8% S) is the most commonly used inorganic source of iron. It is not effective as a soil-applied material but can be used as a foliar spray. One application of a 1-1.5% solution may correct mild iron deficiency. Several applications, one to two weeks apart, may be needed for more severe cases.

- Zinc sulphate (36% Zn; 14% S) is the most commonly used dry zinc material. It is a relatively water-soluble inorganic compound and also effective in granular form. It is often applied to soil areas that are low in zinc or used for foliar application.

- Zinc ammonium sulphate is commonly used in liquid fertilizers. It is effective if properly applied in the soil (band application) and is less costly than organic forms of zinc.

Organic materials are either synthetic chelates, ring-type chemical structures formed around a polyvalent metal, or natural organic complexes. Chelated micronutrients tend to remain soluble longer when applied to the soil, giving more time for the plant to take up the desired nutrient.

Chelating agents are complex chemical structures such as EDTA, DTPA, EDDHA, NTA, and HEDTA and the compound initials are usually attached to the micro-nutrient.

- Fe-DTPA (10% Fe) is the most commonly used iron chelate and can be soil-applied if the soil pH does not exceed 7.5. It is also used as a foliar treatment.

- Zinc chelate (Zn-EDTA) is an effective material. Its main advantage is stability and mobility in the soil. When dry fertilizers are blended and applied as a row band, inclusion a granular zinc chelate is likely to be more effective than granular zinc sulphate.

When liquid fertilizers are used, a zinc chelate does not perform much differently to inorganic sources of zinc and is too expensive to be used at rates needed to increase zinc levels in the soil. The performance of most organic non-chelated zinc is similar to that of zinc sulphate.

Organic fertilizers

Crop residues, animal manures and slurries are the principal organic fertilizers. Although they have varying nutritional values, they are generally present on the farm and the nutrients they contain are recycled.

Animal manures and slurries cover a wide range of nutrient sources with different physical properties and nutrient contents. Furthermore, their nutrient contents vary regionally and depend on the type of livestock and the farm management system. Some typical values of nitrogen content are given below.

As the available nitrogen content of manures and slurries is mostly in the ammonium (NH_4^+) form, it can be susceptible to significant volatilization to ammonia, with a loss of nitrogen to the air. It is also one of the reasons why nitrogen from organic fertilizers is not as efficient as that from mineral sorces, as the organic nitrogen needs to be transformed in the soil over time.

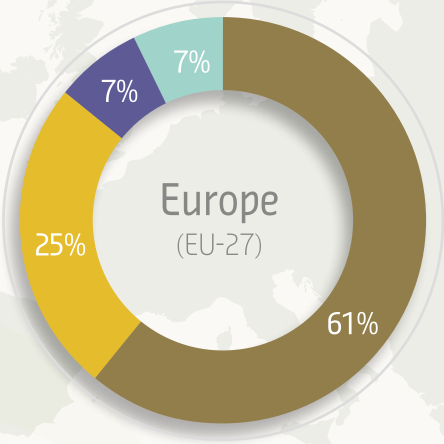
Available quantities on a farm are generally allocated to crops before other nutrient sources are considered. If the organic materials do not satisfy the nutrient needs of the crops, farmers use mineral fertilizers to make up the deficiency. Organic materials contribution to plant nutrition is highest in the year of application but is still measurable over ensuing cropping seasons.

In addition to manure and crop residues available on the farm, other bio-wastes form a further supply of organic materials. These include urban waste (e.g. sewage sludge, biological and waste from gardens and parks) and industrial waste (e.g. food processing waste, paper mill sludge, etc.).

These non-farm sources are known as 'Exogenous Organic Matter' as they are derived outside the agricultural context in which they are often used. The majority of all organic waste materials in the EU are generated and used on farm, with 7% coming from industrial and 7% from urban wastes.

Due to their relatively low nutrient content, the main rationale for the incorporation of sewage sludge and other exogenous wastes is to build up organic matter in the soil and potentially improve its structure.

SOURCES OF ORGANIC MATERIALS



TYPICAL NITROGEN CONTENT OF VARIOUS ORGANIC SOURCES GENERATED ON FARM

Source	Total Nitrogen (N)	Ammonium (NH_4^+)
	g/kg dry matter	% total N
Cattle manure	13 - 29	10
Pig manure	22 - 33	10
Poultry manure	29 - 46	70
Cattle slurries	31 - 47	25 -78
Pig slurries	55 - 103	56 -65
Poultry slurries	28 - 74	21 - 70
Cereal straw	5 - 13	-

Source: Leclerc, 2001

Nutrient management

Following plant needs

- Differing crop requirements
- Plant analysis
- Soil structure
- Soil analysis

Environmental considerations

- Carbon footprint
- Atmospheric emissions
- Emissions to water
- EU emissions ceilings and other international conventions

Following plant needs

EFFECTIVE NUTRIENT MANAGEMENT AIMS TO CLOSELY MATCH THE NUTRIENTS IN THE SOIL WITH A CROP'S NEEDS AT ANY GIVEN TIME.

Nutrients need to be physically available to a crop in sufficient quantities at the different stages of its growth cycle so that they do not limit its optimal development. A balanced nutrient supply is a further prerequisite. For example, a crop's nitrogen-use efficiency can be reduced by an insufficient supply of other nutrients such as phosphorus, potassium or sulphur.

But just as a nutrient deficiency will limit crop growth, an excess of nutrients beyond a crop's needs will result in inefficient nutrient use and possible losses to the environment.

Nutrient requirements vary by crop. A deficiency will limit crop growth but an excess of nutrients beyond the plant's needs will also result in inefficient nutrient use and possible losses to the environment.

Differing crop requirements

Nutrient requirements vary widely by crop species. For example, high-yielding cereal crops with extensive root systems can require up to 300 kg nitrogen (N) per hectare. Conversely, legumes such as peas and beans, which live in symbiosis with nitrate-producing microbes in their root systems, have little need for additional nitrogen. They are often grown and incorporated into the soil to replace the soil's nitrogen reserves.

Lettuce has a shallow root system and can only exploit nutrients in about 20 cm of soil depth, while sugar beet has roots that extend up to two metres or more and can delve far into the subsoil.

Perennial crops, including soft fruit, top fruit and nuts, have relatively large nutrient requirements when they are establishing but a lower requirement in subsequent years. Some of the nutrients taken up by these crops are returned to the soil as their leaves drop off in the autumn. Grass grown between rows of perennial crops further affects nutrient availability.

Recommendations for the nutrient requirements of each crop need to take into account the natural soil nutrient reserves, soil type and potential crop yields. For less mobile nutrients like phosphorus, potassium, calcium and magnesium, the aim is to first establish sufficient nutrient levels in the soil and then to replenish the nutrients that are annually removed by the crops with the harvest.

How much fertilizer is typically applied?

A grower has to first estimate the crop yield for a particular field and then calculate the crop's nutrient demand based on the expected yield. The table gives some examples for north-western Europe for some important crops. Organic and mineral sources of nutrients are equally important in supplying the required crop nutrients and are often applied in combination with each other.

TYPICAL NUTRIENT CONTENT OF DIFFERENT CROPS				RESULTING CROP NUTRIENT DEMAND BASED ON TYPICAL YIELDS IN NORTH-WESTERN EUROPE			
Crop	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Crop yield	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)
	Kg/tonne			Tonne/ha	Kg/ha		
Wheat	20	7.0	6.7	10	200	70	67
Barley	17	6.8	8.7	8	137	55	69
Maize	16	5.9	4.4	12	192	71	53
Oilseed rape	37	21.2	10.0	4	148	85	40
Potatoes	3.3	1.1	5.4	50	165	54	268
Sugar beet	1.9	1.1	1.9	90	172	95	174

The timing of the application of these nutrients, although not as important as for nitrogen, can improve crop response, especially in soils with low natural reserves. For example, spreading 'starter' phosphate fertilizers near seedlings provides additional phosphorus in the early stages of crop development when root systems are limited, with benefits in crop yield and/or crop quality.

Band placement can improve performance of crops with limited root systems, such as potatoes, and split application is sometimes beneficial, especially when fertilization is combined with irrigation in fertigation systems.

Historically, anthropogenic emissions of sulphur used to be sufficient to cover most crop needs. Over the past 50 years, however, annual sulphur deposition in the soil has fallen significantly in Europe and now ranges from approximately 20 kg/ha to less than 4 kg/ha.

Crops like brassica, cereals and grass grown for silage are particularly prone to a sulphur deficiency, especially on light, textured soils. Although livestock manures often contain significant amounts of sulphur, its availability decreases markedly during storage. Consequently, sulphur-based mineral fertilizers are widely used to meet specific requirements.

Soil pH affects the availability of micronutrients. Crops grown on chalky soils often suffer from an induced deficiency of manganese, copper and boron. Conversely, the availability of molybdenum tends to increase with increasing soil pH.

Where the soil naturally contains very little of a particular micronutrient, direct application can be effective. On sandy soils, for example, fertilizers can be supplemented with boron to meet particular crop needs, even though the reserves in the soil will not be built up.

Hand-held N-Tester™ to measure plant chlorophyll content

Where soil conditions induce a deficiency, micronutrients often need to be applied in a protected form or via foliar sprays that can be directly taken up through the plant leaves. A wide range of protected or soluble forms of micronutrient fertilizers has been developed for this purpose.

Grassland presents special issues as far as micronutrient deficiencies are concerned, as the nutrients are needed by both the grass and the animals that graze it. Furthermore, these animals often need micronutrients such as iodine and selenium, which are not required by grass although it usually takes them up, meeting the animals' needs.

Most deficiencies can be corrected by applying micronutrients in supplemented fertilizers or in foliar sprays. It is often more convenient, however, to add the nutrients directly to livestock diets in supplemented concentrates, mineral licks or drinking water.

Plant analysis

Over the past 20 years agronomists and farmers have increasingly focused on direct field analysis to determine optimal crop nutrition. Analysis is based on the principle that the crop itself offers the best indicator of the nutrient supply during the growth period. The current status of the crop is used to guide fertilizer application rates later in the growth cycle.

The simplest techniques include the creation of a fertilizer window (an under-fertilized plot) in part of the field which provides a warning when the nutrient supply becomes limiting. This method, however, offers no information about the optimal amount of nutrients required.

Several tools are available to assess plant nutrient needs and adjust fertilizer application rates based on the colour and vigour of the crop. Farmers can directly measure nitrogen status with simple portable devices that are sufficiently accurate for field use. Such devices are normally based on chemical or optical indicators.

Modern hand-held metering devices to measure nitrogen requirements are based on the measurement of chlorophyll content. Since this is directly related to nitrogen concentration, the resulting readings offer a quick and easy method to obtain information about the crop's nitrogen status and the quantity of additional nitrogen required.

Mechanized equipment (left) for sampling soil to a depth of 90 cm for mineral nitrogen analysis; manual soil sampling (right).

Fertilizer recommendations can be based on a relative approach, using an over-fertilized plot as a reference, or on an absolute figure based on the deviation from a crop-specific value of greenness.

Soil structure

A good soil structure is highly beneficial to good crop development. A well structured soil can absorb substantial amounts of water without significant run-off. A poor soil, however, is dense and has little pore volume. Heavy rainfall often leads to a puddled surface which seals the soil off from the air and inhibits normal soil and root activity.

Depending on the soil type (sandy, clay or loam), climate and natural vegetation, the structure of the soil develops naturally through the activities of the soil flora and fauna (the soil biota). About 35 to 60% of its volume consists of pores of different sizes. These fine capillaries are normally filled with water (the soil solution) whereas air circulates in the larger cavities and supplies oxygen to the soil biota and plant roots.

The soil's organic matter, or humus, plays a central role in its fertility by providing food for the microbes living within it. These microbes break down any added organic material, for example from crop residues or manure, releasing nutrients. The humus stabilises the soil crumbs (mineral particles) and improves the soil structure.

Cropping patterns also have an effect. Crop rotation was originally developed to conserve and maintain nutrients in the soil, with clovers and other leguminous species included in the cycle to add nitrogen. Although the primary reason for crop rotation today is to restrict opportunities for the development of pests and weeds, different crop rotations change nutrient levels in the soil.

Experiments show that long-term use of fertilizers generally leads to increases in soil biomass.

Soil analysis

Regular sampling provides data on the supply of nutrients in the soil in order to guide fertilizer application. It is used to measure the mineral nitrogen content in the crop rooting zone at the start of plant growth. Farmers can draw on a variety of sources to undertake this assessment including specialised soil analysis laboratories, expert advisors and agronomic consultants.

Direct plant and soil analysis are increasingly used to determine optimal nutrition.

The quantity of nitrogen required for a first application is then determined by subtracting the amount of mineral nitrogen available in the upper 60 to 90 cm or so of the soil from that required by the crop at this stage of its growth cycle, based on values calculated from numerous field trials.

During subsequent crop growth, however, the plant-available nitrogen may be exposed to various conversion processes. In addition, although the soil's potential to mineralize nitrogen only changes over long periods, the actual supply of plant-available nitrogen in a particular year may vary considerably (from less than 10 kg/ha to more than 100 kg/ha) due to the weather.

In similar fashion, the crop's nitrogen demand is also influenced by favourable or unfavourable growing conditions. As a result, the optimum fertilizer rate for a particular crop changes from year to year.

Methods based solely on soil analysis, therefore, have limited reliability and flexibility. They can serve to estimate the application of nitrogen at the start of crop development but require further information to support decisions during the growing season.

Environmental considerations

REDUCING ATMOSPHERIC AND WATER-BORNE EMISSIONS FROM AGRICULTURE REMAINS AN ENVIRONMENTAL PRIORITY.

Agriculture is a significant contributor to the production of the greenhouse gases (GHGs) that cause global warming, as well as other atmospheric and water-borne emissions capable of causing health problems, soil acidification and the pollution of waterways.

European agriculture contributes to about 9.2% of its total GHG emissions, compared to 13.5% for agriculture globally. 4.1% of its GHG emissions (EU-27) are due to natural emissions of nitrous oxide (N_2O) from soil and organic sources of nitrogen, 3.9% consist of methane gas (CH_4) mainly from livestock production and 1.2% are emissions of nitrous oxide from the use of mineral fertilizers. To make different GHGs comparable, they are converted into their equivalent impact in the form of the GHG carbon dioxide (CO_2-equivalent).

Carbon footprint

Life-cycle analysis of fertilizers determines their impact on the environment, in terms of resource use and emissions, at every stage of the 'life' of a fertilizer. This includes its overall production, transport and storage, as well as its use on the farm and ultimate disposal.

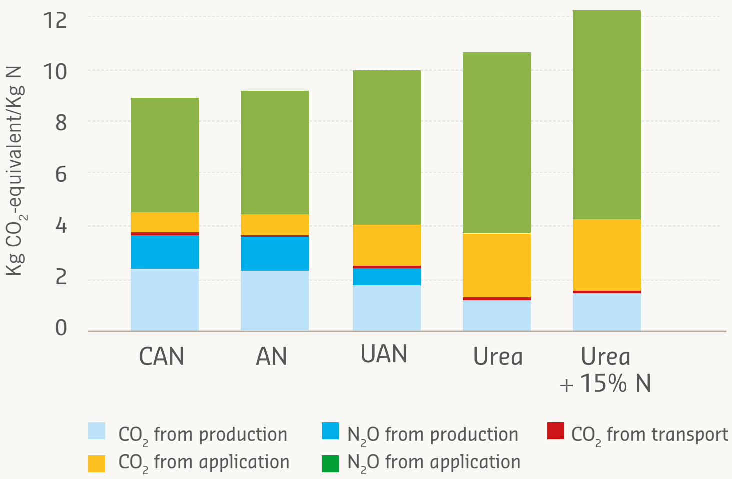
Different classes of fertilizer have different environmental footprints, as well as nutrient-use efficiencies. This is also sometimes the case within the same class. For example, within the nitrogen group, although urea-based fertilizers emit less carbon dioxide during production than nitrate-based products, when applied on the soil urea releases more carbon dioxide and ammonia into the atmosphere, as well as nitrous oxide, during its transformation into the nitrate form used by crops. Over their life cycle, therefore, urea-based fertilizers' environmental footprints are greater.

Furthermore, urea's nitrogen-use efficiency is approximately 15% less than that of nitrate-based fertilizers. When compensated by a correspondingly higher dosage, its environmental impact is further increased, as well as its cost.

Although mineral fertilizers are responsible for significant GHG emissions, the increased crop yields they generate reduce the need for agricultural land and so lessen GHG emissions associated with change in land use.

In fact, the UN's Intergovernmental Panel on Climate Change calculated in 2012 that its Land Use, Land Use Change and Forestry (IPCC LULUCF) category in Europe creates a carbon sink for 304 million tonnes of CO_2-equivalent - not far off the total GHG emissions generated by European agriculture.

CARBON EMISSIONS FROM DIFFERENT FERTILIZER TYPES



Source: Adapted from Bentrup F., 2001.

The life-cycle carbon footprint for ammonium nitrate is lower than for urea and UAN. With a higher dosage of urea to compensate for its lower nitrogen efficiency, the difference is even more marked.

Atmospheric emissions

Measures to reduce atmospheric emissions in Europe are mostly enshrined in EU law through the European Commission's 2013 "Air Quality Package", amending its earlier 2003 Directive on the reduction of national emissions of certain atmospheric pollutants. For agriculture, these principally include ammonia (NH_3) and methane (CH_4). Emissions of the GHGs nitrous oxide (N_2O), carbon dioxide (CO_2) and, again, methane (CH_4) have been regulated since 2009 in the EC's Climate-Change/Energy package.

› Nitrous oxide

All ecosystems emit nitrous oxide, also known as laughing gas. In fact more than 50% of global N_2O emissions come from land with natural vegetation and the oceans.

About 30% of N_2O emissions are estimated to originate from agricultural activity, although this includes the emissions that would have been generated naturally from the soil anyway. According to the IPCC (2001), animal production is responsible for the largest share (54%) of N_2O emissions created by human activity, while use of mineral fertilizers is estimated to account for about 17%.

Two microbial processes: denitrification and, to a lesser extent, nitrification are responsible for natural N_2O emissions from the soil. Different interactions between the soil, the weather and agricultural practice influence the shares of nitrification and denitrification.

Anaerobic conditions are a prerequisite for emissions via denitrification, with the amount of nitrate available in the soil being an important factor affecting the amount of N_2O released. Since denitrifying micro-organisms need organic carbon for energy, the availability of degradable organic matter in the soil is a limiting factor for natural N_2O formation.

In practice, it is very difficult for farmers to avoid or reduce this type of emission as good soil aeration (via ploughing) is important to support crop root growth and to maintain the soil's organic matter content at an appropriate level to stabilize the soil structure.

Small losses of nitrogen occur from mown grassland but in grazed pastures the greatest sources of nitrogen are urine and dung patches, with localised nitrogen rates for cattle equivalent to more than 1,000 kg/ha. These rates are well in excess of plant demand and can lead to significant atmospheric losses, as well as leaching.

On average 3.5% of the nitrogen in urine is lost as N_2O, with another 20% as NH_3. The losses are unavoidable in farms with a high proportion of grazing.

Different fertilizers have different carbon footprints, as well as different nutrient efficiencies.

› Methane

The major agricultural sources of methane emissions in Europe come from enteric fermentation - the digestion of feedstuffs by livestock - and manure. Rice cultivation produces significant quantities of methane in Asia.

Enteric emissions of CH_4 from livestock are difficult to control, although recent research has looked at the effects of different animal feedstuffs and specialized housing systems.

Emissions from animal manures largely depend on their method of storage or management. When stored as a slurry, much of its decomposition is anaerobic and methane is produced in significant quantities. However, manure deposited by animals while grazing, or stored in the form of farmyard manure, tends to decompose aerobically and produce less methane.

Ammonia

Other atmospheric emissions from farming, such as volatized ammonia (NH_3) - ammonia in the gas form - are also part of the natural nitrogen cycle but are relevant from both a human health and an environmental perspective. Ammonia emissions in 2010 in Europe (EU-27) were estimated at 3.5 million tons, with agriculture being responsible for 94% of these.

Volatized ammonia contributes to the formation of micro particles in the air, which can be harmful to human respiratory systems.

The risk of leaching is relatively low during the growing season.

Indirectly, it can also result in emissions of N_2O as well as nitric oxide (NO). The release of ammonia is strictly regulated under European air pollution legislation.

The majority of ammonia emissions from agriculture, almost 80%, derive from organic sources such manure and slurries from livestock production. The remainder comes mainly from the use of fertilizers such as urea and urea-based mixtures. After application, both manures and urea fertilizers emit ammonia into the atmosphere while they are progressively transformed into the nitrate nutrient form taken up by plants.

For urea, initial hydrolysis by soil enzymes converts it into the ammonium form (NH_4^+), some of which is volatized and escapes into the atmosphere as ammonia gas (NH_3). Depending on the soil conditions and the weather, the loss may vary from less than 10% to up to half of the urea applied. The official EMEP European Emission Inventory 2013 assumes an average ammonia emission factor for urea of about 20% on arable land and grassland, compared to an average loss of around 3% for nitrate-based fertilizers.

Emissions to water

Water-borne emissions from agriculture are covered by the EU's 2000 "Water Quality" Directive, which complements its 1991 Nitrates Directive on the protection of waterways against specific pollution caused by nitrates from agricultural sources.

The plant-available forms of nitrogen and sulphur mainly exist in the soil solution in the nitrate (NO_3^-) and sulphate (SO_4^{--}) forms, which are highly mobile and can easily be lost into the groundwater.

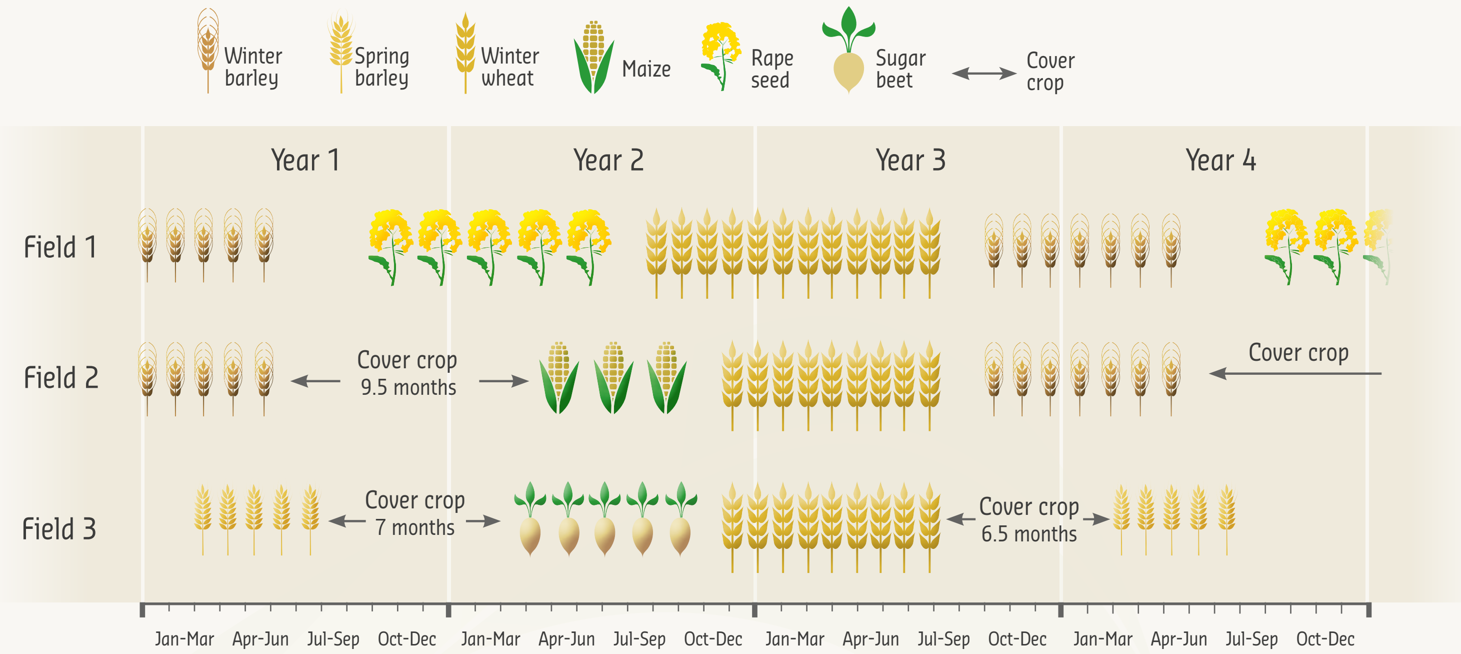
The risk of leaching is relatively low during the growing season because the crops take up most of the nutrients available in the soil solution and any excess water is lost through evaporation or plant transpiration. In Europe, with the exception of occasional extremely wet summers, any leaching tends to start in early winter when the soil can become saturated with water.

Nutrients mineralised naturally from the soil's organic matter outside the growing period can leach downwards through the soil. Research shows that the cropping system influences leaching of nitrate more than fertilization. Leaching is highest on fallow land where there are no plants to take up the water and nutrients, even if the plot is unfertilized.

Farmers are encouraged to avoid the untimely mineralization of the soil's organic matter by ploughing as late in the year as possible or by adopting minimal cultivation. They are also advised to maintain crop cover in the field for as long as possible.

Establishing a crop like winter wheat or winter oilseed rape in the autumn will help to minimize the risk of nutrient loss after the harvest. These crops take up significant quantities of the mineralized nitrogen and other nutrients remaining in the soil after the previous crop has been harvested.

CROP ROTATION AND SOIL COVERAGE



An illustration of the periods during which the land is growing crops over a rotation and the opportunities for the use of 'cover crops' during periods when there is no crop in the field. Growing a catch or cover crop protects the soil from erosion during heavy rainfall and helps to minimize the risk of nitrate leaching and run-off.

Alternatively, a crop rotation that includes 'catch' crops, such as mustard or phacelia (heliotrope), can be sown in the summer to take up any excess of mineral nitrogen. The crop is then ploughed back into the soil in the spring and its nutrient content returned to the soil in organic form.

Late autumn/winter leaching is generally not affected by the amount and type of fertilizer applied during the growing season, provided that its nutrient content is fully used by the crop. The risk only increases when the nutrients applied exceed the crop requirement. For nitrogen, the risk remains consistently low up to the optimum yield, because the crop uses almost all the nitrogen applied. The risk increases significantly, however, when additional nitrogen is no longer transformed into yield.

Major factors influencing nitrate leaching

- Soil texture (water-holding capacity, clay content)
- Water balance (precipitation-irrigation-evaporation-transpiration).
- Rooting depth of the crop
- Nitrogen balance (N input – N output).
- Timing and the amount of nitrogen mineralized from organic fertilizer sources (manure, sewage sludge, crop residues).
- Plant coverage: crop rotation, under-seeding
- Intercropping catch-crops (e.g. mustard, phacelia).
- Crop type (growing period, harvest date, type/quantity of residues.

CROP PHOSPHATE & POTASH REMOVAL			
		Kg/t of fresh material	
		P_2O_5	K_2O
Cereals	Grain only	7.8	5.6
	Grain & straw		
	- winter wheat/barley	8.6*	11.8*
	- spring wheat/barley	8.8*	13.7*
	- winter spring/oats	8.8*	17.3*
Oilseed rape	Seed only	14.0	11.0
	Seed & straw	15.1*	17.5*
Field beans	Seed only	11.0	12.0
Potatoes	Tubers	1.0	5.8
Sugar beet	Roots only	0.8	1.7
	Roots & tops	1.9	7.5
Grass	Fresh grass @ 15-20% DM	1.4	4.8
	Silage @ 30% DM	2.1	7.2
	Hay @ 86% DM	5.9	18.0

* Offtake value is per tonne of grain or seed but includes nutrients in straw.

Source: UK Standard data.

Example of guidelines for calculation of phosphate and potash removal by crops (kilogram of nutrient per tonne of fresh material).

Nutrients such as phosphorus, potassium and magnesium are mainly adsorbed on clay particles or organic matter and so are much less mobile in the soil.

Despite this, cracks and channels within the soil structure can allow them to bypass the soil filter and enter drainage channels. If they are present at excessive levels in the soil or if the climate becomes excessively wet then losses of these nutrients can also occur. As far as phosphorous is concerned, main losses occur via surface run-off.

➤ Eutrophication

One of the signs of nutrient over-enrichment in waterways is eutrophication. Nitrogen and phosphorus are of most concern in relation to eutrophication. However, because phosphorus is the most limiting nutrient in a fresh water environment, it often attracts the most attention.

An early symptom of change in a waterway's ecological structure is the rapid increase in the growth of microscopic algae that are the first link in the aquatic food chain. Rapid algal growth can create an algal bloom, a dense green mass near the water's surface.

During daylight, algae assimilate carbon dioxide and produce oxygen but they require oxygen for respiration when it is dark. When an algal bloom develops rapidly it creates a negative net oxygen balance and a deoxygenation of the water, which can negatively affect its ecological balance. When the algae die and decompose they can also cause toxins to build up in the water, posing a further risk to fish and other aquatic species, as well as to any livestock or other animals drinking it.

EU emissions ceilings and other international standards

In addition to the EU Directives referred to earlier, European ceilings for energy use and emissions have a significant impact on both fertilizer production and use. The mandatory ceilings for 2020 are currently being lowered for 2030 and 2050.

The environmental cross-compliance principle within the EU's Common Agricultural Policy promotes good agricultural practice (GAP) and measures to ensure the environmental sustainability of European agriculture. Other criteria cover restrictions on land use change to protect nature reserves, permanent pastures and non-cultivated forests, as well as to protect the high soil carbon contents of wetlands, peat and continuously forested areas.

Sustainability criteria for biofuels are under development and probably will imply stricter environmental constraints. The minimum acceptable GHG saving compared to equivalent fossil fuels is likely to be set at 35% and increase to up to 50% over the next few years.

Balancing crop and **environmental needs**

> Sustainable crop nutrition

- Fertilizer management
- The 4R principles
- Precision application techniques
- Monitoring tools
- Sustainable management systems

Sustainable crop nutrition

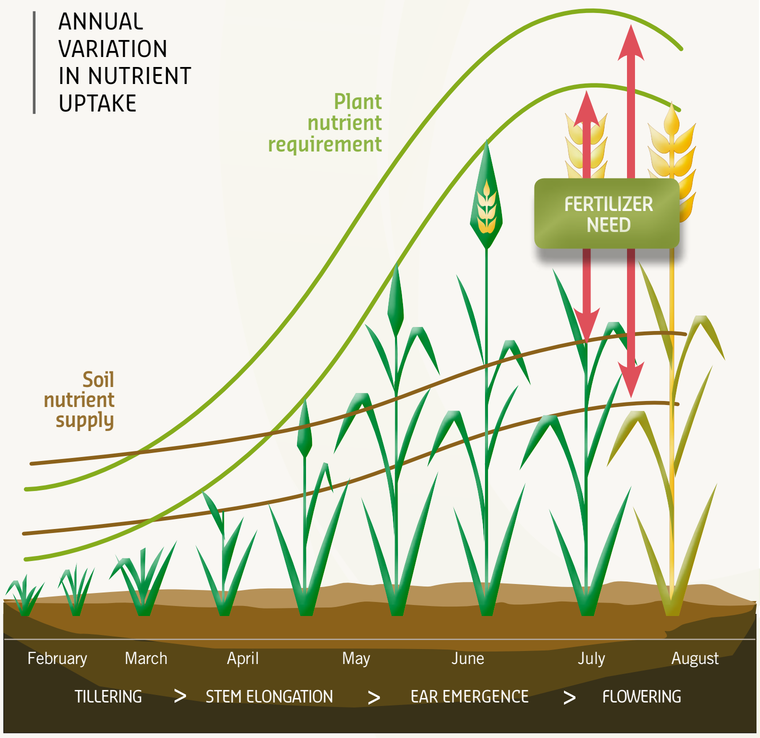
GOOD FERTILIZATION PRACTICE ENSURES THAT FARMERS ARE ENCOURAGED TO OPTMIZE ALL THEIR INPUTS ON THE FARM.

Balanced application of fertilizers requires careful consideration of the amounts of each nutrient, including those supplied by manures and organic material within the soil, needed to achieve optimal crop yield while keeping environmental impact to a minimum.

A planned approach starts with a good understanding of a farm's topography and the characteristics of its soil at field level. Soil type and condition influence crop development and, together with the land's physical features, determine the potential for crop uptake of nutrients or their movement within the soil or across the land surface.

Fertilizer application needs to be planned to accommodate any variability. The main factors to be considered are crop type, anticipated yield, the naturally available nutrients in the soil and the changes in nutrients required by a particular crop over its growing cycle. Calculations are usually based on a combination of scientific research and local experience.

ANNUAL VARIATION IN NUTRIENT UPTAKE



Most crops' nutrient requirements from emergence through vegetative growth, reproduction and maturity follow an S-shaped curve. However, the amount of nutrients taken up by a crop varies between years depending on the growing conditions (shown by the green lines). The mineralization of nutrients in the soil also varies (brown lines). The 'correct' application rate of a fertilizer for the same crop in the same field will therefore be different from year to year (red arrows) and may well need adjustment during the growing season.

A crop's nutrient uptake often varies, both by field and by year. Field variability is primarily due to different soil conditions, while annual variability is often due to changing weather patterns. Application programmes that do not sufficiently account for these variations in uptake can lead to incorrect fertilization.

Since nitrogen is the nutrient that most frequently limits crop growth, it has the highest impact on crop yield and quality. Nitrogen under-fertilization gives less than optimal yields while over-fertilization encourages losses that reduce nitrogen-use efficiency. Both result in economic loss for the farmer.

Fertilizer management

Good fertilizer management involves setting specific budgets for all the nutrients available on the farm and making a fertilizer application plan to ensure their optimal use.

The soil's natural nutrient supply encompasses its mineral content immediately prior to sowing and the predicted soil mineralization during the growing period. Estimates are primarily influenced by soil type, previous crop residues and weather.

Since crops remove different amounts of nutrients at harvest, crop residues have different nutrient contents. Cereal straw, for example, contains a high proportion of carbon which can temporarily immobilize nitrogen, so additional mineral nitrogen may be required to assist in its decomposition. Other residues, such as that from field vegetables, decompose rapidly and can offer an almost immediate source of nutrients.

The fertilizer plan selects the most efficient mix of fertilizer materials, prioritizing use of the farm's natural recycled materials before any supplementation with mineral products. Dosage calculations take into account the content, chemical form and utilization rate of the materials' nutrient components.

Application of highly mobile nutrients such as nitrogen and sulphur need to be precisely targeted to meet a particular stage of a crop's development. Application of less mobile nutrients such phosphorus, potassium and magnesium, however, usually aims to build up reserves in the soil and is often targeted on the most responsive crop in a particular crop rotation.

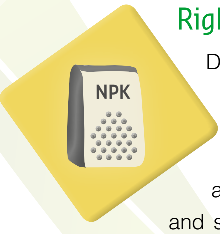
Farmers increasingly have a variety of "on-board" tools to customize the application of fertilizers and avoid waste.

The 4R principles

The basics of good fertilization practice are expressed by the so-called 4R principles: right product, right rate, right time and right place.

The use of products with reliable release profiles and precise application characteristics greatly improves nutrient uptake efficiency and reduces environmental losses. Most fertilizer manufacturers provide information about the physical and agronomic characteristics of their products and how they can be used for maximum nutrient-use efficiency.

Right product



Different crop species have different nutrient requirements and, as shown earlier, there is a wide range of fertilizers with different profiles to meet these. Product selection takes into account the needs of a particular crop, climate and soil properties, economic considerations and method of application.

Crop-specific fertilizers containing a variety of nutrients and designed for efficient application are becoming increasingly common. Granular products remain the largest category, but new water-soluble fertilizers for use in fertigation systems or foliar sprays are increasingly being introduced.

Correct product selection is primarily based on consideration of nutrient availability, the product's physical properties and its interaction with other nutrient sources or associated elements:

- the nutrients are plant-available or can be readily converted to this form in the soil;
- products suit the soil's physical and chemical properties: for example, the use of nitrates on flooded soils and surface application of urea on high pH soils should be avoided;
- interaction with other nutrients: the nutrients provided should complement those supplied by crop residues and farm manures, application of nitrogen increases phosphorus availability, phosphorus interacts with zinc, etc.;
- crop sensitivity to associated elements: the chloride in muriate of potash (MOP) can be detrimental to the quality of some fruit and vegetables;
- effect of non-nutritive elements: natural deposits of phosphate often contain non-nutritive trace metals such as cadmium. The content of these elements needs to be kept within acceptable limits.

Fertilizers with reliable release profiles and precise application characteristics improve plant nutrient uptake.

Right rate

Understanding the nutrient needs of a crop throughout its growth cycle is the first step to calculating a suitable fertilizer application rate. An excess of nutrients will lead to environmental losses, while an insufficiency will limit crop yield. Both reduce economic profitability.

The right application rate for a particular crop primarily involves assessment of five factors:

- the soil nutrient supply: calculated through soil and plant analysis, crop response experiments or reference strips;
- available sources of nutrients: the amounts of nutrients in crop residues, manures, composts, bio solids, irrigation water, atmospheric deposition and fertilizer application;
- crop demand: the amount of nutrients taken up by a crop is largely dependent on its yield, therefore accurate assessment of attainable yield is important;

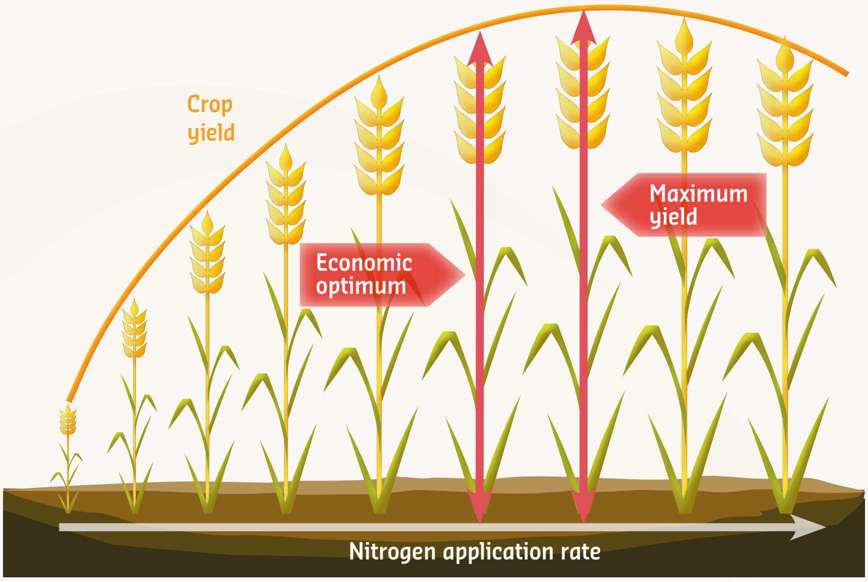
Economic optimum application rate

The economic optimum rate for application of a particular fertilizer provides a farmer with the best financial return based on crop and fertilizer prices.

For example, when different amounts of a nitrogen fertilizer are applied in a particular field, crop yields form a typical response curve. A certain crop yield is achieved without any fertilizer, depending on the natural fertility of the soil. With additional units, the yield initially increases almost linearly but then starts flattening out as the growing conditions or the crop's genetic make-up begin to limit further increases (the law of diminishing returns).

At the time a farmer applies a fertilizer, however, he does not know for certain the growing conditions he will face nor what his final yield will be. By basing his calculations on historic yields over the last three years, excluding any exceptionally high or low years, he can balance the risk of not fully exploiting the yield potential of the field against that of wasting fertilizer, and money, through an oversupply.

TYPICAL CROP YIELD CURVE



- foreseeable losses: some nutrient loss is unavoidable and needs to be compensated for;
- economics: the most economic rate of application is where the last unit of nutrient applied is equal in value to the increase in crop yield it generates, but this also has to be seen in light of environmental losses.

Right time

For optimum yields, sufficient nutrients need to be accessible to a crop as it moves through its various growth stages. But if a nutrient is present in the soil for an extended period prior to crop uptake, it may move outside the root zone or be converted into a less plant-available form.

For example, the plant-available forms of nitrogen and sulphur mainly exist in the soil solution. They are highly mobile and, ideally, need to be used immediately to satisfy crop needs. Less mobile nutrients, which are mainly adsorbed onto clay particles or soil organic matter, are only released as they are used. Regular annual application is generally sufficient for most crops.

Nutrient release is also affected by both the timing and type of soil cultivation. For example, mixing soil and air at soil temperatures above 4°C generally promotes the mineralization of organic nitrogen. Nitrogen mineralised by ploughing after the harvest, therefore, will be at risk of loss over the winter months. In contrast, leaving land dormant and employing minimal cultivation in the spring will tend to conserve nitrogen in the soil.

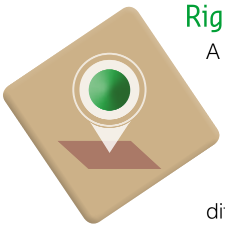
The best timing for fertilizer application is therefore based on consideration of the timing of crop uptake, the dynamics of the soil nutrient supply and the release rates of specific products:

- timing of crop nutrient uptake: primarily based on planting date, plant growth characteristics and sensitivity to deficiencies at particular growth stages;
- the dynamics of the soil's nutrient supply: mineralization of the soil's organic matter can supply a significant amount of certain nutrients, but if a crop's need precedes their release through mineralization, deficiencies can limit productivity.
- nutrient release and availability from fertilizer products: the release rate and the availability of some nutrients are influenced by the weather and soil conditions at application, with potentially significant nutrient and yield losses if not synchronized with the crop's requirements.

Split fertilizer application is commonly used in Europe to divide total dosage into a number of smaller applications that closely match crop demand at specific stages in its growth.

Products with highly predictable release profiles, such as nitrate-based nitrogen fertilizers, are best suited to split application.

The hydrolysis of urea, however, and its volatilization losses depend very much on the weather conditions after spreading, especially rainfall. Studies have shown that losses can vary from 2 to 58% of the nitrogen applied.



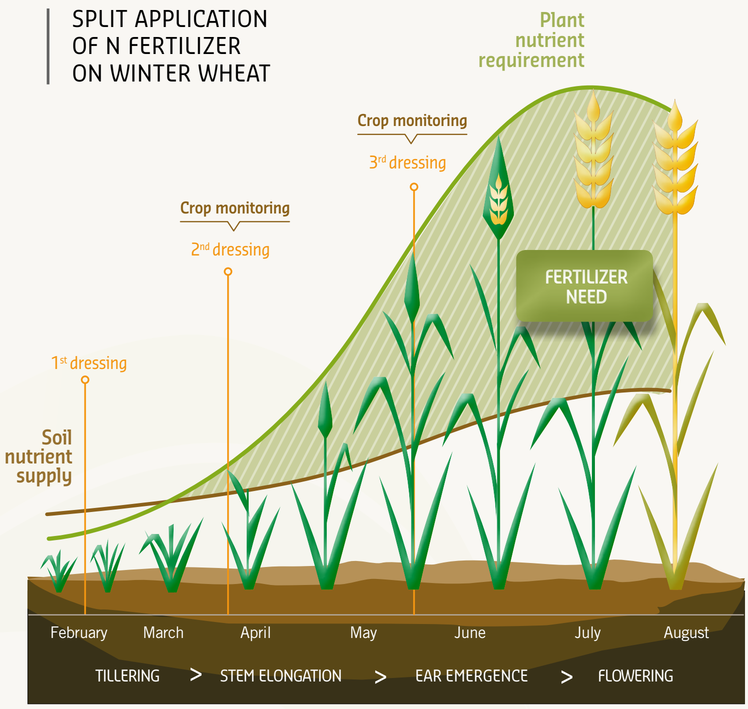
Right place

A plant's full genetic potential is only achieved when the soil structure allows its roots to grow and exploit the maximum soil volume. A good soil structure ensures the right proportion of voids of different sizes for good rooting conditions and improves the roots' ability to locate nutrients. With nutrients in the right location within the soil, crops have the best access to them.

To secure good rooting conditions, farmers typically loosen soil by ploughing, which also incorporates the nutrients in crop residues and organic matter into the soil's upper layer. Ploughing, however, can degrade the structure of light or sandy soils. In such cases, minimal soil cultivation is increasingly being adopted to leave the soil's naturally stable structure undisturbed.

A good understanding of root-soil dynamics is therefore important to ensure that crops can locate nutrients as they need them. Specific application techniques, such as band placement of solid fertilizers or drip-irrigation of soluble products, can be used to position nutrients more directly in relation to the growing roots, ensuring sufficient nutrition of young seedlings and subsequently higher yields.

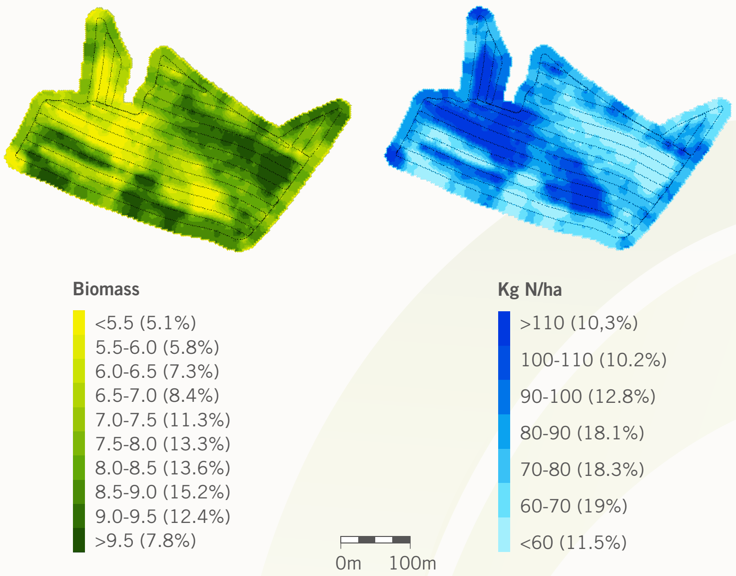
Soil quality often varies across a farm or even within a single field. Crop yield potential varies accordingly, as does the crop's need for nutrients. An experienced farmer should be aware of the variability of his soils and know their particular requirements. The availability of precision farming technology has now made it far easier for farmers to fine-tune nutrient application, varying the rate of application with different crops and locations.



The fertilizer need depends on the soil nitrogen supply and the plant nitrogen requirement. Modern monitoring tools facilitate crop monitoring and help to adjust split applications accurately.

The use of fertilizer distribution systems based on soluble products, such as drip-irrigation or fertigation and foliar spraying, is becoming increasingly popular with specific crops like fruit and vegetables and in areas subject to water scarcity or salinity. These systems also ensure that nutrients are delivered to the crop with minimal loss. In addition, foliar application opens up an additional channel for nutrient

BIOMASS AND NITROGEN MAPPING



Winter wheat, Germany: nitrogen sensors automatically apply optimum nitrogen rates (blue) based on real time mapping of biomass and chlorophyll (green), avoiding both over and under-fertilization.

Source: www.agricon.de

New precision techniques offer greater accuracy in estimating crop nutrient status and optimal fertilization.

absorption other than the plant roots, ensuring that localised peaks in nutrient demand can be met more efficiently.

Precision application techniques

On farms with large, heterogeneous fields and varying soil types, a uniform fertilizer rate is often not effective in meeting overall crop needs and results in local over or under-fertilization. The physical form of the fertilizer, or its lack of homogeneity, and factors such as the wind strength and weather can also degrade spreading patterns.

For example, a study in Germany comparing the spreading loss of CAN (calcium ammonium nitrate) to urea showed that CAN's higher bulk density and lower nitrogen content offered more homogeneous spreading characteristics. Within a spreading width of only 21 metres, a mild breeze of 4 metres per second resulted in a 6% variation with CAN compared to a 26% variation with urea.

Today, new farm machinery is more precisely calibrated and new technology, such as satellite-produced biomass field maps, offers greater precision in estimating crop nutrient status. Furthermore, farmers are generally better aware of the implications of poor spreading practice, particularly in sensitive areas.

Modern equipment has greatly enhanced spreading accuracy. It can offer real-time control over fertilizer application and GPS-based accounting of the nutrient supply.

N-Sensor tractor-based plant nutrient testing.

Sensor-based instruments mounted on the tractor continually measure the crop leaf canopy's reflectance of different light wavelengths, indicating total biomass of the crop and its chlorophyll content. Plant nutrient needs are measured continuously and adjusted throughout the spreading operation, enabling application of the optimum amount of fertilizer to every point in the field.

When used with homogeneous fertilizers, even a relatively low nutrient input can guarantee high yields with minimal losses. Practical experience with new equipment demonstrates significant economic and environmental benefits including increased nutrient-use efficiency, a more uniform crop, better ripening, easier harvesting and higher yields.

Several field trials have compared the use of sensor technology with nitrogen fertilizers to more conventional spreading practices. They have demonstrated increases in plant protein content of 0.2-1.2%, yield increases of up to 7% and a reduction in nitrogen input of some 12%. The new technology allows farmers to improve their resource efficiency.

Monitoring tools

› Nutrient-use efficiency

The overall objective of using fertilizers in agriculture is to increase the performance of a particular cropping system by providing a crop with economically optimum nutrition and minimizing any nutrient losses. The nutrients most commonly limiting plant growth are nitrogen, phosphorus, potassium and sulphur.

Agronomic research, such as that by the EU Nitrogen Expert Panel, has recently focused on crop nutrient-use efficiency (NUE) as an increasingly important tool for the evaluation of different cropping systems. NUE measures how well crops use the nutrients available to them and is expressed in terms of crop yield per unit of nutrient input (fertilizer and nutrient content).

EU Nitrogen Expert Panel

The two main aspects of NUE are crop nutrient uptake and utilization efficiency. Agricultural practice plays an important part, as both can be greatly influenced by fertilizer management as well as by the management of soil and water. Typical NUE benchmarks enable food producers to monitor their performance. These benchmarks are usually set locally within an appropriate cropping system, soil, climate and management context.

The EU Nitrogen Expert Panel was set up to help improve NUE in agriculture and food production and consumption systems and has proposed a practical NUE indicator as

The Cool Farm Tool now enables farmers to quickly assess GHG emissions from their crop production.

a means of setting realistic targets for achieving the UN's Sustainable Development Goals.

The indicator enables differences in NUE to be examined between farms, food production systems, individual countries, and points in time. By identifying the effects of technical progress and/or policy measures, it provides a valuable tool for monitoring sustainable development in relation to food production and the environment. It contributes to improving NUE by considering the limits associated with both the excess and insufficient use of nitrogen.

› Cool Farm Tool

The need to increase understanding of the value of the environment in which European food production takes place has risen in prominence recently. These concerns, however, need to be balanced against the necessity of Europe's farmers to produce adequate amounts of high quality food with sufficient profit in order to be able to invest in their operations.

Until recently neither farmers nor food companies had the possibility to monitor GHG emissions from their production or supply chains. Without the ability to measure these, they were unable to set targets or track their progress in mitigating climate change. Assessment of GHG emissions from farming were either extremely expensive or rough estimates largely based on academic literature.

At the same time, an increasing number of food companies were discovering that emissions from agricultural production generally comprised 50-80% of a food product's environmental impact.

Practical online tools along the lines of the Cool Farm Tool (CFT) are now helping to fill this gap. The tool enables farmers to quickly assess emissions from their crop production, providing instant feed-back on the impact of different farm management options. The tool is simple to use but scientifically robust in dealing with complexities of environmental accounting.

The CFT also allows food companies to evaluate, and so reduce, emissions within their own supply chains. The tool has been tested and adopted by a range of multinational companies who use it to work with their suppliers to measure, manage, and reduce their environmental profile.

Sustainable management systems

In recent years, sustainable crop nutrition systems based on the best agricultural practice and integrated farm management have been developed to enable farmers to produce high quality food profitably, while also conserving the environment in which they operate.

Modern fertilization practice ensures that fertilizer use is directed towards efficient crop uptake and the avoidance of nutrient over or under supply. Possible deficiencies are identified to assess the risk to crop performance and efficient nutrient uptake before symptoms appear in the crop.

Specific environmental issues remain in some areas, however. For example, in managed grassland there can be large releases of nitrogen where long-term fallow land is ploughed for re-seeding or for conversion for arable crops. In arable cropping on some soils, the annual cultivation of the soil to establish the crop can also disturb the structure and nutritional quality of the soil.

Highly integrated farming systems balance profitable food production with crop and animal husbandry, social responsibility and environmental care. They ensure a highly disciplined approach to agricultural production where costs are contained and food produced to the required market specifications.

The principles and procedures employed provide a practical whole farm management approach. The key feature of such systems is that they integrate past experience and new knowledge into a decision-making process under

SUSTAINABLE FARMING

varying situations. This dynamic approach results in farm management decisions which are correct under any particular circumstance.

Successful application largely depends on the local knowledge and experience of all those involved - farm-based, as well as in in supporting roles. The fertilizer industry fully endorses the concept as a valuable contribution to sustainable agriculture.

By putting the emphasis on learning from field experience and farm records, sustainable crop nutrition promotes the implementation of nutrient management policies based on fact. These not only enable farmers to protect the integrity of their businesses and the environment in which they operate but also allow them to assess their performance against their peers and other industry indicators. When needed, they can seek external advice.

Both farmers and equipment operators are increasingly being trained in the adoption of the best fertilization practice. They have a better general awareness of the consequences of using a poor quality fertilizer or an inappropriate application technique.

The integrated approach also covers on-farm fertilizer storage. Storage sites need to be in a safe and secure location with day-to-day storage management meeting industry regulations and accepted operating standards.

A Good Fertilization Practice checklist

General considerations

- Nutrient management plans for all crops
- Management plans for manures and other organic sources
- Up-to-date advice and technical recommendations

Decision-making

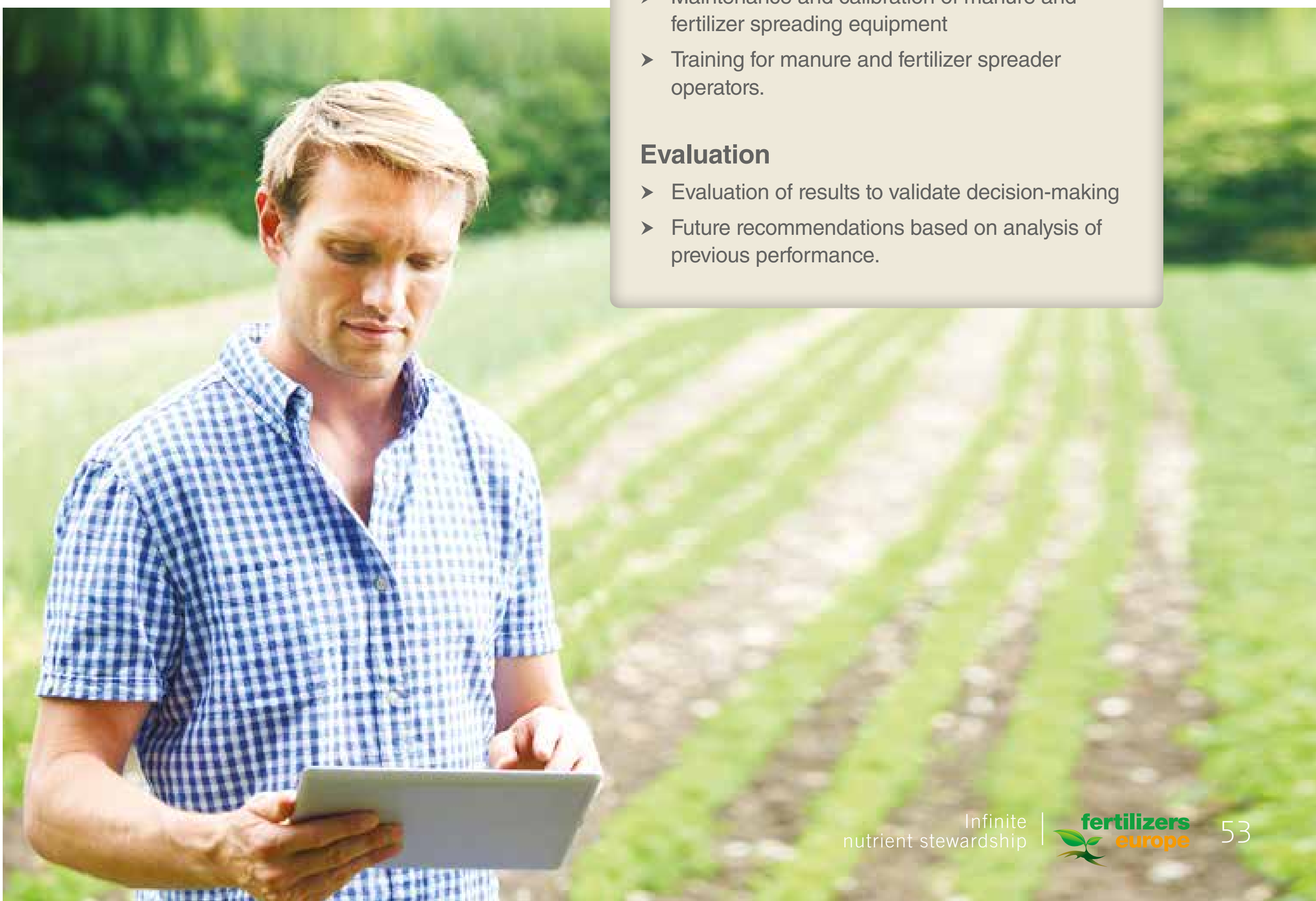
- Calculation of crop nutrient needs and timing
- Estimate of nutrient use efficiency comparing inputs with harvested off-take
- Assessment of nitogen, phosphate and potassium balance from all inputs and crop off-take
- Identification of secondary and micronutrient deficiency potential.

Implementation

- Record of nutrient applications for each field
- Safe storage of manures and other organic fertilizers
- Secure storage of mineral fertilizers to preserve quality and safety
- Record of all organic materials on the farm
- Maintenance and calibration of manure and fertilizer spreading equipment
- Training for manure and fertilizer spreader operators.

Evaluation

- Evaluation of results to validate decision-making
- Future recommendations based on analysis of previous performance.



Food & nutrition

Essential minerals

- Quality criteria
- Human health
- Cereal production
- Potatoes and sugar beet
- Fruit, vegetables and wine
- Livestock feeds
- Feed phosphates

Working with the food chain

Essential minerals

CROPS ARE THE FIRST STEP IN THE FOOD CHAIN. ALL OTHER LIVING ORGANISMS OBTAIN THE ENERGY AND MINERALS THEY NEED FROM THEM.

Crops not only supply edible energy in the form of carbohydrates but are also a primary source of minerals and essential organic compounds for the entire food chain. They provide almost all the nutrients required by humans, whether eaten directly or as meat, milk or eggs from animals. Humans obtain the nitrogen compounds they need for their metabolism, growth and reproduction by eating protein derived from plants and animals.

Proteins are complex organic compounds found in all living cells, where they are intimately connected with all the phases of activity that constitute the life of the cell. Cell walls of animal and human cells are composed almost entirely of lipids and proteins.

Dietary proteins are needed by both humans and animals throughout their life cycle. They are required in relatively large amounts by growing infants, as well as by young and highly productive animals, but their relative needs decline rapidly with maturity. The daily protein requirement for normal adults is around 0.8 grams per kilogram of body weight.

Proteins account for the majority of nitrogen in plants, as well as in humans and animals. Human and animal muscle, skin, hair, feathers, wool and nails consist mainly of protein, which contains an average 16% nitrogen by weight. The human body is made up of around 2.6% nitrogen - a 75kg individual has almost 2 kg.

After calcium, phosphorus is the second most abundant mineral element in the body, accounting for more than 20% of its mineral content. Calcium phosphates, for example, are the major constituent of bones and teeth in both humans and animals, accounting for 85% of the body's total phosphorus. A deficiency not only affects bone structure, but also appetite, growth and fertility.

An adequate supply of potassium is also needed for healthy, normal growth. Most is found within the body cells - approximately 98% of the 120 grams found in an average healthy adult. As in plants, the potassium helps maintain osmotic equilibrium and is used in physical processes such as nerve impulses, muscle activity, heartbeat and in the activation of enzymes in various metabolic processes.

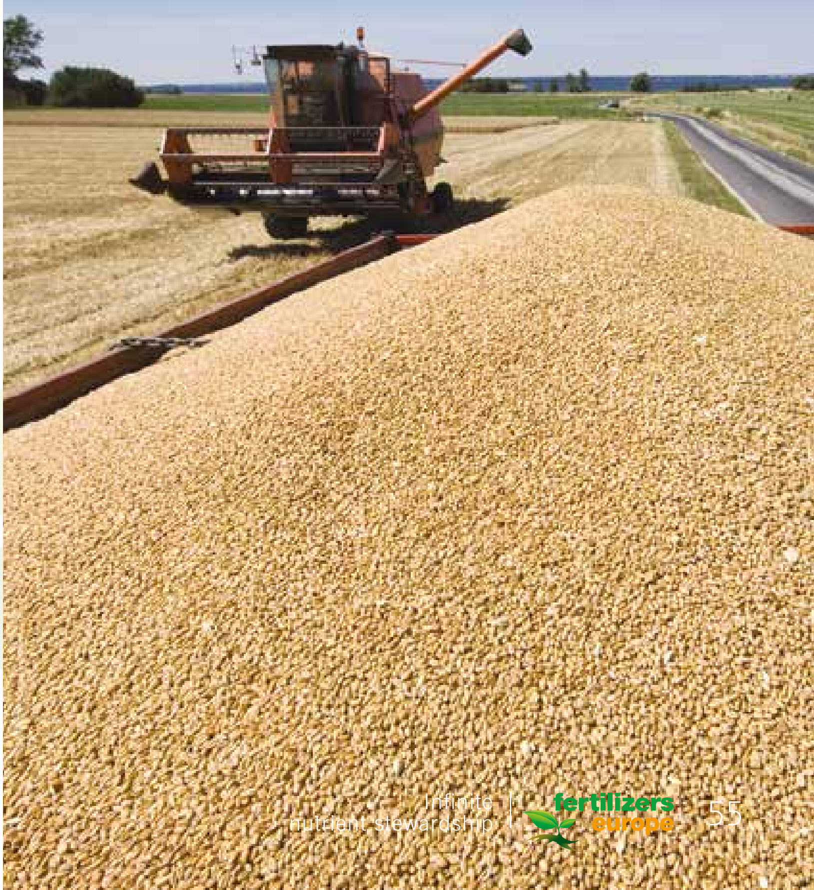
Quality criteria

In addition to their nutritional value, the basic raw materials for food production often have to meet various quality and taste criteria that include processability, palatability, appearance and psychological, cultural or ideological norms. These are all influenced in some way by the fertilization of the crop - the nutrients or balance of nutrients available to it.

Food quality is one of the primary demands of today's consumer and balanced fertilization is an essential pre-requisite for it. As well as ensuring a good protein content in crops, an appropriate supply of available nitrogen and other major nutrients can boost crop health qualities such as vitamin content.

The deficiency of a major crop nutrient can truly affect its physical quality and processability. In Denmark, for instance, due to strict national limits on the use of nitrogen in the 1990's, the baking quality of Danish wheat deteriorated to such an extent that farmers were no longer able to produce sufficient high quality product for the domestic market.

Crops provide almost all the nutrients required by humans, whether eaten directly or used to produce meat, milk or eggs from animals.



Formerly a high quality wheat exporting country, Denmark became a net importer.

Skilful fertilizer use by farmers, both in deciding the quantity of fertilizers to apply and the timing of different applications, are an essential part of growing high quality produce.

Human health

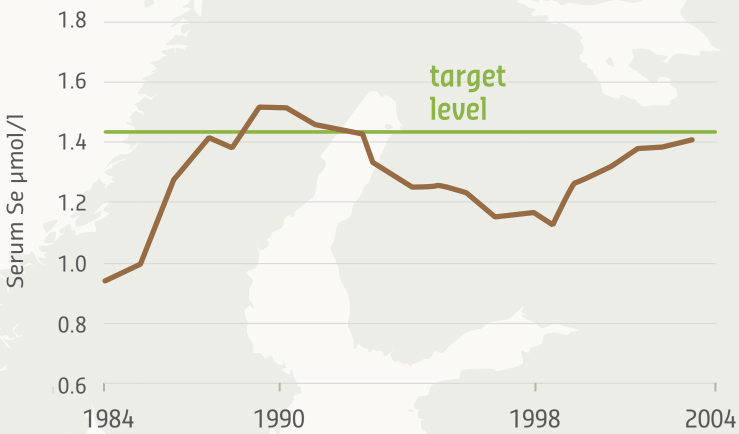
Nutrent deficiencies or lack of a nutrient balance in food can have long term implications for human health. For example, in addition to potassium, the human body require sodium, which it primarily obtains from salt (NaCl) added to food. The ideal ratio of potassium to sodium in a healthy adult should be 2:1. In many processed foods, however, potassium is often lost in the cooking process or canning liquid, while salt is often added.

It is now widely recognized that people in many countries consume too much salt, adversely affecting the potassium to sodium ratio. This influences vascular volume and can often lead to elevated blood pressure. Consuming raw plant-based products rich in potassium like fruit, particularly bananas, and natural fruit juices can redress the dietary balance.

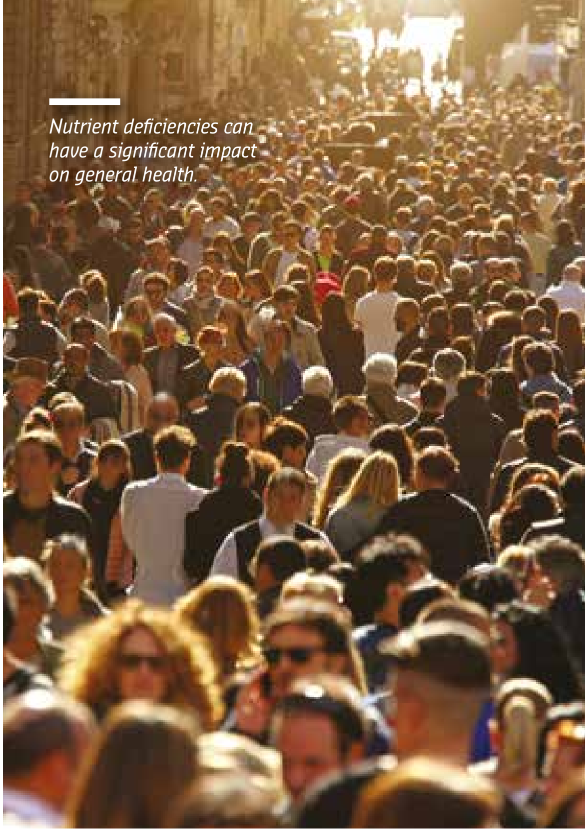
Positive fertilization strategies can influence nutrient deficiencies in food that impact human health.

In fact it is possible to calculate the proportion of the daily potassium intake met by different foods - a normal banana contains about 11% of the recommended daily intake, while a medium-sized potato can supply around 21%.

EFFECT OF FERTILIZATION STRATEGY ON HUMAN HEALTH IN FINLAND



Correlation between Selenium (Se) content in fertilizers and Se in blood samples of the population in Finland: mean annual Se concentration in healthy Finns before and during Se fertilization. Se was added to NPK fertilizers from 1984 onwards with temporary reduced levels from 1992-1998.



Nutrient deficiencies can have a significant impact on general health.

Nutrient deficiencies

Nutrient deficiencies can have a significant impact on the general health of the population unless rectified through positive fertilization strategies. Concerns in Finland, for example, about the low soil content of the micronutrient selenium (Se) on human health caused all NPK fertilizers to be supplemented with it in 1984. The levels were set at 6 g/tonne for fodder crops and hay and 16 g/tonne for food crops.

This substantially increased the Se content of foods such as cereals, milk and meat and the human Se intake by some 20%, bringing blood Se levels up to those recommended for a healthy population.

In 1992, however, the Se supplementation was reduced to 6g/ton for all crops, resulting in an almost immediate drop in blood Se levels throughout the population. In 1998, the supplementation was therefore reinstated, this time to 10g/ha for all crops, with a subsequent return to healthy Se levels across the country.

Nitrate levels

Historical concerns about the effect of levels of nitrate in agricultural products and drinking water on human health have now largely been proved to be unfounded. However, a couple of popular misconceptions about dietary nitrate persist. Ingested nitrate is rapidly excreted from the human body in urine and usually does not accumulate or negatively interfere with the human metabolism.

The main concerns centred around the microbial reduction of nitrate (NO_3^-) to the more active nitrite (NO_2^-) form, which was stigmatised by its chemical relationship to nitrosamines and methaemoglobin.

A specific enzyme keeps the concentration of met-haemoglobin in the adult body below 1-2%, but this enzyme is not fully developed in infants younger than 6-12 months.

An elevated level of ingested nitrate (from water with a high nitrate content) was originally believed to have been the cause of increased methaemoglobin levels in infants (the so called "blue baby" syndrome).

The syndrome was subsequentially shown to have been associated with shallow wells polluted with bacteria, rather than with the ingested nitrate.

Similarly, the theoretical associations of gastric cancer with dietary nitrate have also been shown to be erroneous. More recent work suggests that ingested nitrate actually provides gastro-intestinal protection against food-borne pathogens. These findings are endorsed by the fact that vegetables have consistently been shown to reduce cancer risk, despite being the largest source of ingested nitrate.

Cereal production

The production of cereal crops is the largest arable farming activity in Europe. It supplies a high proportion of all the grain required to produce bread, cakes, pastries, pasta and breakfast cereals, as well as beer and spirits. In addition, it provides large quantities of animal feed.

Cereals play a central role in the European diet - in the UK, the consumption of bread and other cereal products make up about 25% of the average daily protein intake. Carefully planned fertilization of the appropriate varieties of wheat enable European farmers to provide a reliable supply of the increasingly wide range of flours required by its bakeries.

Plant protein content and protein quality are primarily determined genetically, but correct fertilization helps them to use their genetic potential to the full. The quality of gluten, a protein fraction important for baking, deteriorates when wheat is under-supplied with nitrogen or sulphur.

The trend to more healthy diets mean many people are choosing to buy wholemeal bread, where all the grain is incorporated into the loaf. For this type of bread, a high grain protein content of 14% is needed for the dough to be strong enough to allow the bread to rise.

Tin-baked breads need flour with a protein content of about 12.5% to avoid cavities in the loaf, with French bread requiring approximately 11.5% and pitta bread needing a slightly lower level. The great variety of cakes and pastries that are baked in Europe all require their own particular standards of flour, grown precisely with specific use of fertilizers.

The demand for pasta is met by growing Durum wheat, which is a hard wheat with a high protein level. A high proportion of Durum wheat is grown across southern Europe and here again management of fertilizer application can modify the crop's final protein content.

'Malting' barley for brewing and distilling requires quite different fertilizer management, because a high yielding crop is required but with a low grain nitrogen content. As with wheat, specific barley varieties are grown, but the expertise of the farmer in growing the low-nitrogen grain required is essential to the production of high quality malt.

Careful fertilization of the appropriate varieties of wheat enable farmers to provide a wide range of flours for baking.

Potatoes and sugar beet

The wide variety of fresh potatoes now on offer are to a large extent the result of novel growing techniques and fertilizer management. Potatoes grown for storage over winter should have a low availability of soil nitrogen in the final stages of maturity, otherwise they will not store well and may have poor taste or develop black spots during cooking, particularly when potassium is deficient.

Similarly, the efficient production of sugar from sugar beet requires very exact nutrient inputs. Because of its relatively underdeveloped root system, sugar beet require significant amounts of potassium throughout its growing cycle to favour the transfer of sugar and its accumulation in the roots. Several tests have shown that potassium fertilization, whether via the soil or through foliar sprays, increases the yield and sugar content of the crop.

Conversely, although sugar beet has a high nitrogen demand in the third and fourth months after seeding, if its nitrogen content is too high at harvest time this can upset the precipitation of sugar during processing and thus reduce the sugar yield.

Fruit, vegetables and wine

The market for fresh vegetables and salad crops is very quality conscious, and the production of crops in this sector requires the most precise management of all fertilizer inputs.

Highly fertile soils are needed for these short season crops and some, such as onions, often receive small precision applications of fertilizer when they are sown to ensure even establishment and crop uniformity. Other brassica varieties, such as Brussels sprouts, are often supplied with special high nitrogen solution fertilizers which are injected into the soil near the plant roots to ensure a continuing and steady supply of nitrogen, which is required for a high quality harvest.

Few vegetables of the quality the European consumer has now come to expect would be available without the grower's expertise in the use of different fertilizers. For example, many varieties grown with insufficient nutrients tend to be more fibrous and less succulent and appear pale and 'undernourished'.

Although the quantity of fertilizers required for permanent crops such as citrus fruit and grapes is not large, it is significant for high quality production. The seasonal requirement of vines is mainly supplied from nutrient reserves in the roots to support leaf development. Vine leaves need adequate nitrogen for the synthesis of the sugars that are mobilized to the berries. Towards the end of ripening, large quantities of free amino acids are transported to the berries and, by harvest, half of the nitrogen present in the whole plant is located in them.

The advanced ageing of several white wines produced in Germany in the 1990s was subsequently attributed to a shortage of nitrogen in the growing vines. When only about two years old, the taste of these wines had deteriorated to such an extent that they soon became unpalatable.

The wine fermentation process needs a high level of natural sugar in the grapes but it can stall if nitrogen is deficient. The yeasts within the must need nitrogen to grow and wine quality can be spoilt if these have to breakdown natural proteins to find this. If the must is low in nitrogen, a yeast feed is needed. The total nitrogen required is not great but it is essential to allow the fermentation to progress well to produce high quality wines.

Livestock feeds

Animal feeds account for about two-thirds of all cereal production in Europe. In many cases, the forage crops and cereals required for livestock are produced on the same farm where the animals are raised and provide the foundation of their diets. The quality of grass, both when grazed and when preserved as hay or silage for winter feeds, is significantly improved by effective fertilization.

Forage such as grass can supply the majority of the energy and protein requirements of cattle and sheep. Together with cereal crops, other forages, particularly maize and certain brassica, are also major contributors to livestock diets and their nutritional quality largely relies on good fertilizer management.

The production of high quality feedstuffs is also important economically for the farmer. For example, improving the protein content of one hectare of silage from 12% to 15% can save the annual import of half a tonne of protein feed onto the farm. This only requires an extra 40 to 50 kg of nitrogen to be taken up by the crop.

On livestock farms, where there is usually a good and balanced supply of manure, mineral fertilizers are used to supplement this source and ensure the efficient production of much of the energy and protein required by the animals.

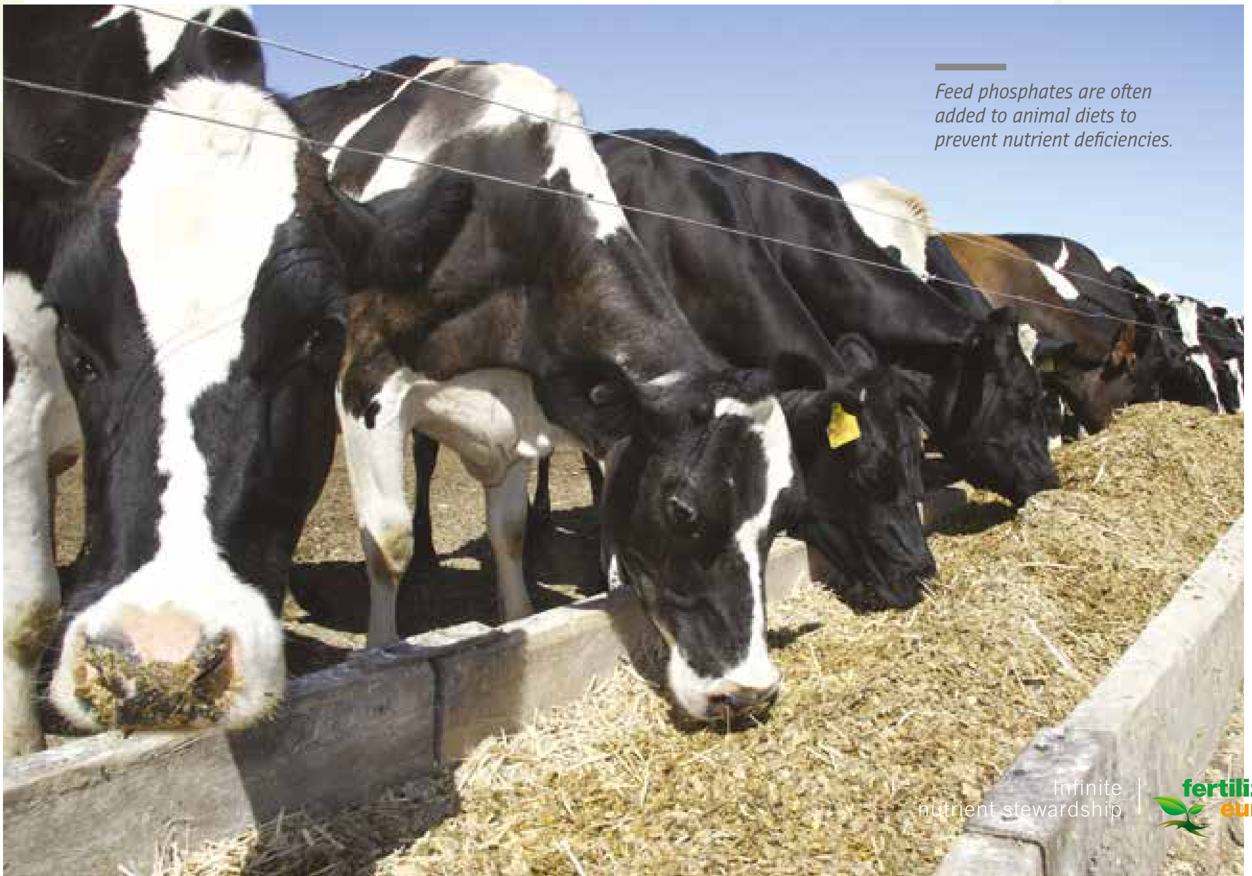
Feed phosphates

Like humans, farm animals need to obtain an adequate supply of phosphorus from their feed. In a similar fashion to plants, a phosphorus deficiency affects many of the essential processes on which their health and fully productive life depends.

Feed phosphates are added to the diet of pigs, poultry and cattle to ensure they do not suffer any deficiency and to prevent health problems, weak bones and impaired fertility.

Often a significant proportion of the phosphorus ingested by animals is excreted in manures, so when properly used these are valuable sources of recycled nutrients.

The nutritional quality of wheat and other forages in livestock diets largely relies on good fertilizer management.



Feed phosphates are often added to animal diets to prevent nutrient deficiencies.

Working with the food chain

TODAY FARMERS, AGRONOMISTS AND FERTILIZER MANUFACTURERS WORK INCREASINGLY TOGETHER WITH FOOD PRODUCERS TO ENSURE THAT THEY DELIVER THE APPROPRIATE RAW MATERIALS FOR HIGH QUALITY FOOD PRODUCTION.

As the direct customers for fertilizers, the European fertilizer industry's relationship with Europe's farming communities is naturally of the utmost importance. The industry works closely with farmers' organizations in holding joint meetings and seminars for farmers on the concept of nutrient stewardship.

These encourage the adoption of sustainable agriculture through promotion of the best agricultural practice and by increasing farmers' knowledge of the correct selection and use of fertilizer products and the adoption of the latest application technology.

The industry produces an increasingly wide variety of scientifically-backed information on agricultural best practice and fertilizer use for Europe's farmers and food producers.

Its advice and statistics are widely drawn upon not only by fertilizer manufacturers wishing to benchmark their activities but also by the European institutions and other international bodies that form agricultural and industrial policy.

The fertilizer industry is also an active contributor to voluntary food industry organisations such The Food Sustainable Consumption and Production Round Table which supports a holistic approach to the European food chain by ensuring a permanent dialogue on a wide variety of issues.

These include subjects such as the sourcing of sustainably produced agricultural products, promoting higher animal welfare standards, helping consumers to make sustainable and healthy lifestyle choices, strengthening nutritional education for children including physical activity, and encouraging more environmentally sustainable food consumption patterns among the general public.

The fertilizer industry is an active contributor to organizations that promote sustainable and healthy food choices.

Nutrient recycling

- On farm recycling
  - Storage facilities
  - Manure management
  - Spreading manure
  - Good agricultural practice
- Industrial recycling
  - Bio-waste
  - Struvite and ash

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On farm recycling

ANIMAL MANURES, ORGANIC WASTES AND CROP RESIDUES CAN PROVIDE FARMERS WITH A USEFUL WAY TO RECYCLE NUTRIENTS.

Livestock manures, crop residues and other organic waste produced on the farm are valuable sources of nutrients which can be taken advantage of when planning fertilizer management.

The nutrients in manures and slurries derive from forage grown on the farm and from imported feeds and it is important they are recycled effectively. This benefits the farmer economically and minimizes nutrient losses to the wider environment. In some regions with intensive livestock production, manures (sometimes processed to reduce bulk) are exported to other mainly arable areas. This helps ensure the best utilization of nutrients by avoiding any excessive application.

For manures and crop residues to be efficiently recycled back into the soil for use by another crop, correct estimation of their nutrient content is needed. Appropriate application timing and spreading techniques are also necessary to minimize any environmental impact.

Efficient recycling of organic material and crop residues requires correct estimation of their nutrient content.

The nitrogen in manure is partly in organic forms that are not immediately available to plants. After application, mineralization enables plant-available nitrogen to be released. The release takes place over an extended period and so is not predictable with the same accuracy as with mineral fertilizers. Some nitrogen will be released at times when crop uptake is low or even zero (for example during autumn and winter before a spring-sown crop) and is then at risk of loss through leaching. This potential for loss has to be taken into account when planning manure applications.

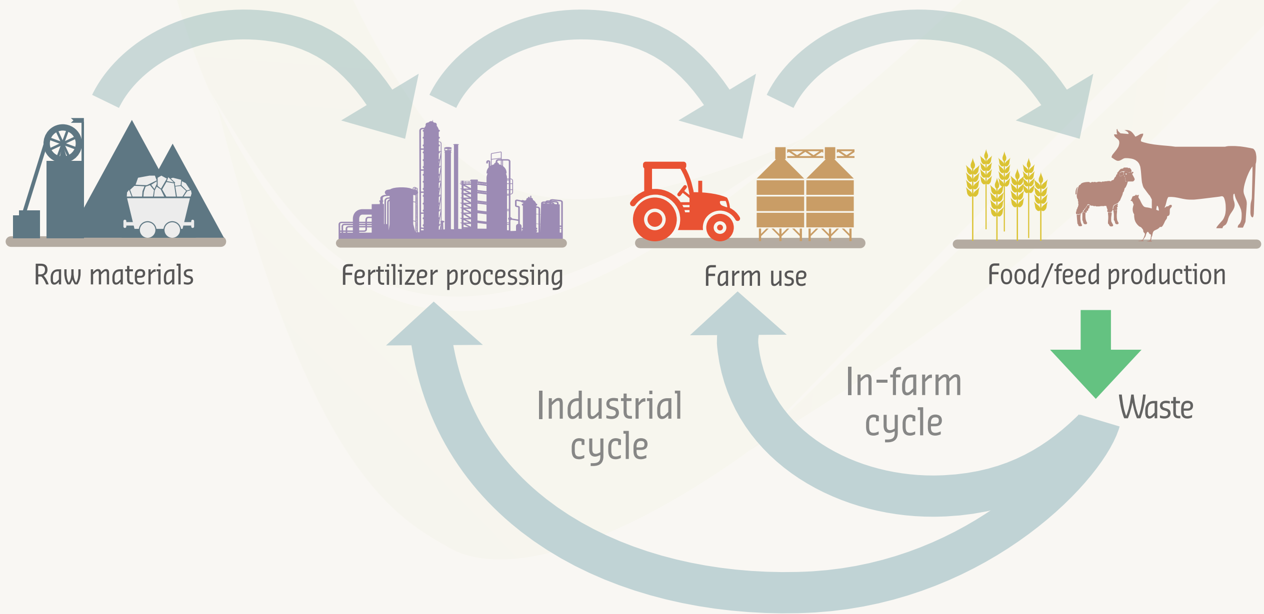
Storage facilities

Because crops use the nutrients from manures only at certain times of the year, effective storage is necessary to preserve their nutrient value. Storage capacity on farm must be calculated according to livestock number, the optimal agronomic period for spreading manures on grass or arable crops, and the crop rotation. In some areas, especially in nitrate vulnerable zones, there are legal requirements for minimum storage capacity.

In temperate areas of northern Europe, the required storage capacity can be up to nine months of production and the period of spreading limited to a few months.

Storage areas for solid manure should have a relatively impermeable base and drainage liquids should be collected into suitable storage containers. For urine and slurry, there is

NUTRIENT RECYCLING OPPORTUNITIES



a particular risk of volatilization of ammonia during storage due to a relatively high pH. To avoid ammonia loss, a tight surface or crust should be established on slurry lagoons and slurry tanks can be covered. The risk of ammonia loss can be further reduced by reducing the pH of slurry by the addition of sulphuric acid.

Manure management

The nutrient content of livestock manures at farm level needs to be calculated annually because it will change with animal age and type, feeding efficiency, and types and amounts of imported feeds.

Web and PC-based software and tables with national or regional data for the nutrient content of animal manures under different feeding and housing conditions are available. However chemical analysis of manures may be appropriate, even if only to compare the situation on a particular farm with the available set of average data.

First the quantity of nutrients in the available manure must be calculated for the number of animals and the type of housing; national or regional references are usually used for this calculation. For example, a Danish farm with 50 Holstein Friesian dairy cows, kept inside all year round and bedded on straw, is calculated to produce a total of about 6,500 kg of nitrogen using the Danish reference values.

The next step is to establish an integrated manure and fertilizer application plan. In the EU, there is a general limit of 170 kg N/ha from organic manures in nitrate vulnerable zones (Directive 91/676 EC). So for the 6,500 kg of nitrogen, a minimum area of 38 hectares is necessary for spreading the available manure.

Straw-based farmyard manure can be ploughed into the soil before sowing, while slurry is preferably incorporated into the soil but can be top-dressed onto grass and will have a faster nutritional effect on the crop.

Of the total nitogen in the manure, only a proportion can be estimated to become available for plant uptake in the season of application. This estimation depends on the type of manure, the timing of application and the type of soil (see Table). In addition, the total input of phosphate (kg P_2O_5/ha) and potash (kg K_2O/ha) must also be taken into account.

Once the nutrient contribution from manures has been estimated, this can be subtracted from crop requirements to determine the quantity of nutrients that must be supplied by mineral fertilizers.

TYPICAL NUTRIENT CONTENT OF ANIMAL MANURES

	Dry matter	Total nutrients		
	%	N	P_2O_5	K_2O
Fresh farmyard manure[1]		Kg/t		
Cattle	25	6.0	3.5	8.0
Pig	25	7.0	7.0	5.0
Poultry Manures		Kg/t		
Layer manure	30	16.0	13.0	9.0
Broiler/turkey litter	60	30.0	25.0	18.0
Slurries[2]		Kg/m³		
Dairy	6	3.0	1.2	3.5
Beef	6	2.3	1.2	2.7
Pig	4	4.0	2.0	2.5

[1] N and K_2O values will be lower if manure is stored in the open or for long periods.
[2] Adjust nutrient content if percentage dry matter is higher or lower.

Source: Potash Development Association

An arable farmer importing any organic manures should know the nutrient content of the manure supplied - i.e. the content of total N, ammonium-N (immediately plant-available N), P_2O_5 and K_2O. In the case of imported organic industrial waste or similar material onto the farm, a certificate showing concentrations of heavy metals should be standard for an integrated farm system.

Application of manures and slurries can have a relatively high potential for nutrient losses to the atmosphere or waterways.

The even application of manures and slurries presents a greater challenge to the farmer than spreading manufactured fertilizer.

Spreading manure

The even application of the nutrients in solid manures presents a greater challenge to the farmer than spreading manufactured fertilizers but, when used correctly, recently developed spreaders can apply reasonably even dressings. Fluid slurry can be more precisely spread using modern equipment, with several techniques being available to suit different situations.

Application of manures and slurries with less sophisticated machinery has a relatively high potential for loss of nitrogen as volatilized ammonia. However, recent advances include the sub-surface injection of slurry into grassland and band application to the soil surface using boom spreaders with flexible trailing pipes, often carried out by contractors. Boom spreaders, with or without trailing pipes, can also be used in early spring on some winter-sown arable crops, notably cereals.

The majority of manures applied to arable land, however, are spread on the soil and incorporated prior to sowing or planting, especially for potatoes. With care and modern machinery, such applications can be made with reasonable accuracy, but precise dressings are difficult and cannot be relied upon at high application rates.

Good agricultural practice

The following points form the basis of good agricultural practice for efficient recycling of livestock manures and other organic materials:

- Determination of annual quantity of manure available (livestock, housing, use of litter, etc.).
- Determination of storage capacity needed by regulation and for optimal timing of application.
- Checking for contamination by heavy metals (e.g. Cu or Zn).
- Assessment of risk of ammonia volatilization (in housing, during transfer of manure and storage) and of ways of reducing such loss.
- Estimation of potential mineral N available in the first year and in subsequent years.
- Timing of applications, considering the immediate crop uptake potential from liquid manures, or the later mineralization and availability from solid manures.
- Keeping a record of quantities of manures applied per field.
- Using nitrification inhibitors.

Industrial recycling

VARIOUS INDUSTRIAL METHODS HAVE BEEN DEVELOPED TO RECYCLE NUTRIENTS FROM MANURE AND OTHER WASTE STREAMS.

The EU's livestock sector produces an estimated 1,400 million tons of liquid and solid manure annually (EU-27). This is practically all applied to agricultural land, the majority in the form of slurry, but also as solid manure or directly deposited by grazing animals. These sources represent up to 86% of the total weight of the organic waste materials spread on the land and 90% of the nitrogen from these materials, with the balance coming from sewage sludge and industrial wastes.

Animal manures are bulky and costly to transport and handle, which is why they are predominantly used within the farm. When they cannot be used on the farm, various industrial methods have been developed to reuse the nutrients they contain. For example, in some areas in the UK, poultry litter is burned to generate electricity, with the ash resulting from the incineration process being sold as a more concentrated source of P and K for crops or horticulture.

Another solution to the transport problem has been to separate slurry into liquid and solid, fibrous fractions. The liquid fraction can then be applied to land as a liquid fertilizer. Slurry is normally separated in large industrial plants but systems which can be used on farm are becoming increasingly common. Slurry can also be used in anaerobic biogas plants to generate methane, again centrally or on farm. The residues from this process can be further used as a nutrient source because they still contain some nutrients.

Various methods for drying and pelletizing manures have also been developed. Removing water greatly reduces its bulk and makes transport more economic, but at a considerable energy cost. Granulated materials are also easier to spread accurately and evenly for a more efficient use of the nutrients.

Bio-waste

The generation of sewage sludge from urban waste water treatment plants can be another source of nutrients. Approximately 40% is now applied to agricultural land, with the remainder mainly sent to landfill (50%) or incinerated (10%) in varying proportions in different EU member states.

In addition, a significant quantity of solid waste is produced by municipalities, of which 30% is potentially biodegradable for compost production. Compost is an organic amendment which can act as a soil improver because of its high content of stabilized organic matter, although it only has modest value as a fertilizer.

The precise use of organic waste materials in the field is not easy. For example, uniform spreading patterns are difficult to achieve and nutrient release difficult to assess. This can have undesirable environmental consequences arising from inappropriate application rates or timing.

Certain low quality bio-wastes may also contain contaminants such as heavy metals (Cu, Zn, Cd and Pb), organic dioxins or furans, certain pathogens (e.g. salmonella, enterobacteriaceae) and pharmaceutical residues.

A substantial part of the organic matter from sewage sludge is mineralized within a few weeks. It should therefore only be spread on land shortly before sowing a crop. This is sometimes difficult to achieve, since it needs to be ploughed in before sowing to avoid direct contact with the growing crop. For reasons of hygiene, sewage sludge may not be applied to several vegetable and food crops, just as its use on grassland is limited in many countries.

Industrial recycling manures and urban waste has been used to generate natural gas, compost and other fertilizers.

Struvite and ash

Substantial research and testing is being carried out to find new ways to recycle nutrients, especially phosphates, from waste streams into high quality mineral fertilizers. One such way is the crystallization of struvite at wastewater treatment plants. Struvite contains phosphate which is soluble in ammonium citrate, but not in water. For technical and quality reasons, struvite cannot fully replace other sources of phosphate in industrial production, but it can act as a secondary source.

Under certain conditions, ash from incinerated sewage sludge can also be used as a secondary source of phosphate. Most promising is the use of ash from incinerated meat and bone meal. This ash is rich in phosphates, is of high quality and can readily replace or be mixed with phosphate rock.

Composting municipal waste.

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Infinite fertilizers

At the forefront of change

- Product Stewardship
- High quality raw materials
- Nutrient Stewardship
- Nutrient-use efficiency
- Life cycle analysis
- Continued dialogue

At the forefront of change

ENSURING THAT EUROPE'S AGRICULTURE SECTOR MEETS INCREASING PRODUCTION AND ENVIRONMENTAL DEMANDS REQUIRES CHANGE. THE EUROPEAN FERTILIZER INDUSTRY IS HELPING TO SPEARHEAD THIS CHANGE.

Global food production needs to increase to keep pace with projected food needs. The "sustainable intensification" of European agriculture will enable Europe's farmers to play their part while, at the same time, reducing their environmental footprint.

The European Fertilizer industry supports sustainable intensification and believes that it can practically be achieved through more widespread adoption of the best agricultural practice, precise crop nutrition, and the latest cultivation and soil management techniques.

As part of this process, the industry has the responsibility not only to provide, safely and efficiently, Europe's farmers with a variety of high quality fertilizers, but also to educate them in their correct selection and use. This belief is exemplified by our vision of Infinite Fertilizers.

Product Stewardship

Mineral fertilizer production is based on large numbers. Each year, the industry transforms millions of tons of air, natural gas and naturally occurring mineral ores into easy-to-use nutrients that support crop growth.

European fertilizer manufacturers increasingly draw on the experience of the entire food production chain when developing their products. Today, these are often targeted at specific crops, with a variety of release profiles that take into account limited resources, such as water, or other environmental factors.

The scale and scope of the industrial processes to produce fertilizers requires us to focus closely on providing a safe and secure environment at our plants and in their neighbouring communities, as well as on safeguarding those beyond the factory gates who store and distribute our products.

Fertilizers Europe has developed a management system within Infinite Fertilizers to ensure that European fertilizer producers live up to this challenge and that their advanced production and distribution controls are consolidated within the industry and updated with the introduction of new technology.

Fertilizers Europe's Product Stewardship Program embodies the industry's aspirations. The program is compulsory for our members and their compliance with it is regularly verified by independent auditors. The program sets the highest global standards for programmes of its type.

High quality raw materials

Our production cycle begins with our raw materials. Apart from the air and natural gas used to produce nitrogen fertilizers, key raw materials are mined deposits of phosphate and potash-bearing rock. While these materials are relatively abundant globally, they can only be found to a limited extent within Europe.

This means that the European industry is highly dependent on imports and the trade, pricing and environmental policies of countries is beyond Europe's control. It challenges us to be highly efficient in the selection and use of our raw materials. Industry quality standards are especially relevant as far as phosphate and potash fertilizers are concerned.

While the basic processes for producing the main types of fertilizer were invented some 100 years ago, the skills, efficiency and control systems we use today have changed beyond all recognition. These enable European nitrogen fertilizer plants to be among the most energy efficient in the world, as well as to have the lowest environmental impact. Investment in our production processes and procedures is continuous.

Beyond the plant gate, we work closely with the fertilizer supply chain to ensure the efficient and secure transportation and storage of our products on their way to Europe's farmers.

Nutrient Stewardship

On the farm, mineral fertilizers offer a predictable, well-balanced supply of nutrients to meet the changing requirements of individual crops over their growth cycle and ensure productive growth. They also help replace the nutrients removed from the soil when the crops are harvested and so help maintain fertile soils.

New technologies such as GPS and sensor-based soil and biomass mapping, which precisely define nutrient demand at field level, enable highly targeted fertilizer application with smaller variation, increasing nutrient-use efficiency and reducing the risk of environmental losses.

The industry's activities promoting the correct selection and use of our products fall under the umbrella of nutrient stewardship. Their main objective is to encourage good agricultural practice by increasing farmers' knowledge of our products and their application.

We focus on developing practical guidelines for sustainable nutrient management on the farm and, over the years, have built up a range of publications that address specific issues such as productivity, energy efficiency, air quality and the management of emissions.

Nutrient-use efficiency

The main thrust of our current efforts is on the promotion of nutrient-use efficiency. To optimise crop yields and minimize environmental impact, our basic rule of thumb is application of the right product, at the right rate, at the right time, at the right place. To help maintain the nutritional quality of the soil, we also encourage the use other agricultural techniques such as crop rotation, minimum tillage and catch crops.

Our campaign explaining the benefits of different types of nitrogen fertilizer was well received by farmers across Europe. The campaign was part of our response to reducing environmental emissions from agriculture, where the application of different types of fertilizer has an impact.

Life cycle analysis

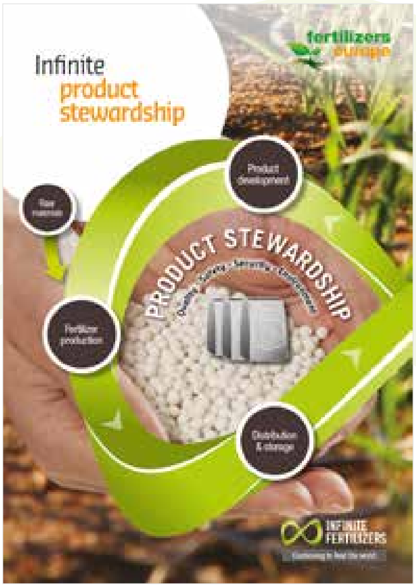
Life cycle analysis of fertilizer products, including their production, transportation and use, is an integral part of assessing agriculture's environmental footprint. Farmers can now use Fertilizer Europe's carbon footprint calculator for fertilizer production in conjunction with applications such as the Cool Farm Tool to check the overall environmental impact of their operations.

The reduction of waste and the recycling of nutrients derived from non-renewable resources are becoming increasingly important globally. To date, the primary focus within European agriculture has been on on-farm measures such as composting crop waste, anaerobic digestion of manures and the more efficient use of organic material in the overall fertilization strategy.

On an industrial scale, several regional projects to capture and concentrate nutrients have been successful. Industry research continues into sourcing viable streams of recycled raw material to close the fertilizer loop.

Continued dialogue

The industry works increasingly closely with all those involved in the food production chain to help create a modern, productive and profitable agricultural sector in Europe. Continued dialogue with policymakers, scientists and other stakeholders ensure the conditions for the European fertilizer industry to continue to develop and innovate.



Product Stewardship

Product Stewardship for fertilizers is defined as the management of the quality, safety, security and environmental aspects of a fertilizer throughout its life-cycle.

This includes product development, sourcing of raw materials, fertilizer production, product distribution and storage, marketing and sales. Product selection, application and recycling are covered by Fertilizers Europe's Nutrient Stewardship activities.

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Fertilizer Europe's Product Stewardship Program sets the highest standards for product quality and the safety, efficiency and environmental impact of fertilizer production and distribution, including the effective use of raw materials. The program is compulsory for all Fertilizers Europe members.

Fertilizer Europe's Carbon Footprint Calculator enables fertilizer producers to better measure and manage the energy use and emissions from the production of major fertilizer products.

Fertilizer Europe's fertilizer family spearheads our activities to encourage the best agricultural practice among Europe's farming community and the correct selection and use of fertilizers. Our DAN campaign promotes nutrient-use efficiency and the benefits of directly available nitrogen fertilizers.

Fertilizers Europe supports and promotes the use of the Cool Farm Tool which enables farmers to simply measure the environmental emissions from their operations and food production companies to evaluate and reduce emissions in their supply chains.

INFINITE FERTILIZERS

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Infinite fertilizers guides the European fertilizer industry's initiatives to ensure that Europe's farmers have access to a variety of safe, high quality, locally produced products, as well as information on their use, environmental impact and nutrient recycling opportunities.

fertilizers europe

Fertilizers Europe represents the majority of fertilizer producers in Europe and is recognized as the dedicated industry source of information on mineral fertilizers. The association communicates with a wide variety of institutions, legislators, stakeholders and members of the public who seek information on fertilizer technology and topics relating to today's agricultural, environmental and economic challenges. The Fertilizers Europe website provides information on subjects of relevance to all those interested in fertilizers contribution to global food security.

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