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Resume 1-4 halaman (tulis tangan, loose-leave, folio bergaris, individu)!

Seafriends - Soil fertility

Farmers have known for a very long time that certain substances, when added to the soil, improve production. These are now called fertilisers. For reasons of cost and ease of use, chemical fertilisers have replaced natural ones. Although plants can't distinguish the difference, artificial fertilisers can easily be over-used, resulting in damage to the soil, rivers and ocean. Learn to know how to produce more, while damaging the soil less.

plant needs	What do plants need? Liebig's law states that the need in shortest supply will be the main factor limiting growth. Often overlooked needs are light and warmth.
watering	A plant's most important need is water. In most places on Earth, water is a problem. There is either too much of it or too little. Water is needed by soil organisms too, so a farmer's most urgent task is to manage the supply of water.
nutrients	Nutrients are found in the rocks. Once weathered into soil, these become available to plants. This supply is not enough, the reason why all terrestrial ecosystems recycle their nutrients with minimal losses. Agricultural soil should recycle its nutrients too, but there are insurmountable problems.
fertilising	Is fertilising necessary and how is it done? How can the fertility of the soil be enhanced and maintained?
trees for grassland	Bringing variety in a monoculture can bring additional fertility. Here the case for trees in grassland is studied.

salt	Because plants do not need salt the way animals and humans do, salt is easily lost from our soils, particularly through modern farming. Produce does not only taste weak, it also contains fewer salts. Salt deficiency in society may arrise from other causes too.

Revised: 20010527,

Plant needs

In the chapter on geology, we've seen that the base rocks from which soil is weathered, ends up quite different in composition from place to place, but in practice all fertile soils on earth follow the rather constant chemical composition of plants, which is similar to animals. This can be understood from the way plants, animals and soil form an ecosystem, cycling the available nutrients many times before they get lost. In the process, unnecessary concentrations of elements (like salt and chlorine) do get lost, resulting in concentrations of available soil elements, closely matching plants' needs, everywhere on Earth. Although their ratios of elements are similar, soils may vary considerably as to their densities, and thus fertility.

Underground, the soil nutrients are not kept in solution but inside the bodies of the living organisms (and some are adsorbed onto clay platelets). No wonder then that the amount of life in good soils is 2 to 10 times more than that above ground. The nutrients become available when some organisms die, which happens frequently because they grow fast. But it does not happen in sudden boosts, as is needed for a monoculture that has been planted all at the same time, like a potato crop. In this respect, natural, productive soil appears to need more fertiliser than it actually does. Modern farming, driven by economic constraints, is forced to use artificial fertilisers, often to the detriment of the soil's natural fertility.

The ecologist *Edward S Deevey Jr* discovered that living matter consists mainly of the six elements hydrogen (H), oxygen (O), carbon (C), nitrogen (N), phosphorus (P) and sulphur (S), in the ratio H:O:C:N:P:S = 2960:1480:1480:16:1.8:1, which is an average for all living organisms on Earth. Of these, the woody plants far outnumber all others, so the formula is biased towards these. The ratio H:O:C:N:P:S = 1600:800:800:9:1:5 is often used for land plants, and 212:106:106:16:1:2 for marine plants and soil humus. From an ecological perspective, it would not be surprising if scientists discover that these ratios for terrestrial life (green matter in plants + animals) are the same as for soil biota (bacteria + fungi + animals). By comparison, the most common component of plants are the carbohydrates (sugars, starches and woody substances), represented by H:O:C = 12:6:6 atoms, or as masses 1:6:8.
With C, O and N having similar atomic masses (12, 16, 14), as a rule of thumb, each unit of nitrogen belongs to 200 units of life (dried) and 100 units of carbon.

What every plant needs for growth is:

- **sunlight**: to obtain the energy for photosynthesis.
- **carbon dioxide**: necessary input for photosynthesis. The atmosphere cycles this effectively.
- **oxygen**: when plants rest at night, they need oxygen, while producing carbon dioxide. In slow-growth areas such as the Boreal forests, respiration during the long winters is almost equal to photosynthesis during the short summers.
- **warmth**: to be able to perform the biochemical processes of life. Plants have adapted to a wide range of temperature, but the warmth of the tropics promotes highest productivity.
- **water**: the biochemical process of photosynthesis requires much water. Water or the lack of it, causes problems in most geographic areas.
- **macronutrients**: the main nutrients N,P,K,S,Ca,Mg and **micronutrients**, the trace elements.

The soil biota have similar requirements, but since they do not photosynthesise, they need neither light nor carbon dioxide. The requirements above are often called 'limiting factors' because each could limit the plant's growth. More accurately, they should be called 'life-determining factors'.

Liebig's Law

The scientist Liebig discovered that all of the above needs need to be satisfied, and that the one in shortest supply will be the main cause of limiting growth. Thus in winter, when it freezes, plants do not need either carbon dioxide or water or nutrients. What they need is warmth first.

Sunlight and warmth

Sunlight and warmth go together, since the only input of energy comes from the sun (see oceanography/radiation). Seasonal cycles affect particularly the temperate areas. But it can be influenced considerably. A glasshouse for instance, traps heat radiation by trapping visible light but preventing infrared radiation from escaping. In cold climates, glasshouses are often heated by burning fossil fuel. Cropland can be sheltered from cold winds, by means of shelter belts. Heat from sunlight can be trapped by stands of vegetation. Evaporation from soil causes enormous loss of warmth, but it can be minimised by mulching or planting a soil-covering crop.

The amount of sunlight in summer may be too much, causing the soil to dry out. Sheltering trees can be planted that lose their leaves in winter. Crops can be spaced properly to prevent them shading each other out.

Carbon dioxide

Carbon dioxide is rather scarce in our atmosphere, where it is found as one molecule in every 30,000. All plants on the planet compete for this resource, since all places on earth connect to the same atmospheric pool of carbon dioxide. The most successful plants, living in warm tropical areas scavenge it more successfully than plants living in cool areas with less light.

Only recently did nature evolve a plant, capable of converting carbon dioxide more efficiently than any other plant, while also using less water. Their photosynthetic conversion requires four biochemical steps, rather than the usual three, a process that saves it both energy and water. These plants, called **C4** plants, include the bamboo-like grasses, and the agricultural crops sugarcane, maize and sorghum. They are about twice as efficient in converting sunlight and need four times less water. C3 plants have maximum sunlight conversion efficiency of 15% and C4 grasses up to 24%. In practice, due to leaf shading, these figures are five times lower. Photosynthesis in C3 plants converts 0.1-0.4 g CO2 with 1 kg water, whereas C4 plants convert 0.4-0.8 gram.

Succulent plants are active at night, taking up CO2 with their stomata (leaf pores) wide open, when other plants close theirs to minimise respiration. During the night, CO2 is absorbed and converted into chemical storage as oxaloacetic acid and then as malate. During the day, these compounds are converted and normal C3 photosynthesis takes place, with the plant's leaf pores closed to prevent unnecessary evaporation. This special form of CO2 fixation is called Crassulean Acid Metabolism (**CAM**). CAM plants are succulents, agaves, lilies, bromeliads, orchids, cacti, euphorbia, geraniums and many more. They use a minimum of water. (For more details and differences between C3, C4 and CAM plants, see the table below)

Differences between C3, C4 and CAM plants

characteristic	**C3**	**C4**	**CAM**
leaf structure	laminar mesophyll, parynchymatic bundle sheaths	mesophyll arranged radially around chlorenchymatic bundle sheaths	laminar mesophyll, large vacuole
chloroplasts	granal	mesophyll granal, bundle-sheath cells granal or agranal.	granal
chlorophyll a/b ratio	~ 3:1	~ 4:1	< 3:1
CO2-compensation concentration at optimal temperature	30-70ppm	<10 ppm	in light: 0-200 ppm in dark: <5 ppm
primary CO2 acceptor	RuBP	PEP	in light: RuBP in dark: PEP
first product of photosynthesis	C3 acids (PGA)	C4 acids (malate, asparate)	in light: PGA in dark: malate
carbon-isotope ratio in photosynthates	-2 to -4 %	-1 to -2 %	-1 to -3.5 %
photosynthesis depression by O2	yes	no	yes
CO2 release in light	yes	no	no
net photosynthetic capacity	slight to high	high to very high	in light: slight in dark: medium
light-saturation of photosynthesis	at intermediate intensities	no saturation at highest intensities	at intermediate to high intensities
redistribution of assimilation products	slow	rapid	variable

dry-matter production	medium	high	low

From W Larcher: Physiological plant ecology, 1980. After Black 1973, Laetsch 1974, Tieszen 1975, etc.

As can be expected, the C3 plants, which are limited in their CO2 uptake, react more vigorously to CO2 increases than the C4 plants. They also still outnumber the C4 plants, which are limited by temperature.

In externally heated glasshouses, carbondioxide from burnt fossil fuel for heating, is often piped into the glasshouse to enhance growth.

Water and **nutrients** will be discussed in their own subchapters below. See also the periodic table of elements for essential nutrient needs and symptoms of deficiency in plants, animals and humans.

Watering

Water is by far the most restrictive of a plant's needs. In spite of the massive size of the water cycle, which causes rain and snowfall, water is in short supply in most areas of the world, at least during one or more seasons. Water is not only necessary for a plant's survival but also for its soil biota, on which it ultimately depends. Likewise, the success of farming, depends mainly on how to keep the underground 'circus' alive, and with it, the above ground vegetation.

Plants need water, a large amount of it when growing. The table below gives an indication of how much water is transpired to produce one kg of dry matter.

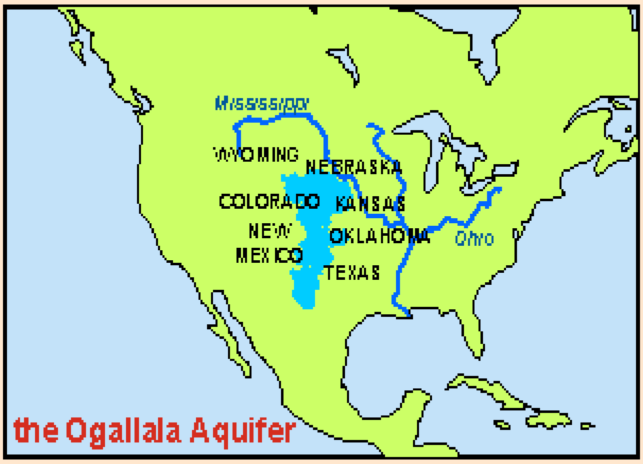
Average transpiration ratios for various plant types
Water amounts in kg per kg dry matter (transpiration ratio).

C3 plant type	water		C4 plant type	water
Grains	500-650		Maize/sorghum in field experiments	260-320
Legumes	700-800		Maize in growth chamber	136
Potatoes and beets	400-650			
Sunflowers (young)	280		**CAM plants**	50-100
Sunflowers (flowering)	670			
Tropical foliage trees & crop plants	600-900			
Temperate foliage trees	200-350			
Conifers	200-300			
Oil palms	~300			

Source: W Larcher: Physiological plant ecology. 1980. Springer Verlag.

A hectare of highly productive grain produces 8 ton of grain and some 10 ton dry matter, requiring some 10 million litres of water during the season (4 months) for photosynthesis alone, or 100,000 litres per day, or 1000mm of rain!
It is common sense therefore, to irrigate crops for higher productivity, and also to increase the cropping area. Particularly as an insurance against the vagaries of weather and climate, farmers all over the world are tapping whatever water resources they can find. The most

common of these are ground water and artificial lakes.



Ground water and aquifers

Although soil and rock are compressed by tremendous forces, there are nonetheless gaps and cracks that have been interconnected by flowing water. One would have expected that water, being three times lighter than rock, is pushed up as sediments and rocks are pushed down by their own weight, so that free water cannot exist at depth. However, as can be observed in limestone Karst systems, water can exist deep down to 300 m and perhaps even deeper. What's more, these underground aquifers are interconnected as if it were a single underground lake, accessible by all who live above it.

Pumping groundwater aquifers is so attractive because the water does not need to be transported. But aquifers replenish slowly. The deeper they are, the longer it takes. Saudi Arabia is estimated to have some 2000 cubic km of 10,000 - 30,000 year old water stored in aquifers to 300m deep.

The Ogallala aquifer in the USA spans eight states, covering some 452,000 square km, and estimated to hold 3700 cubic km of water, a volume equal to the annual flow of more than 200 Colorado rivers, an underground 'lake' of 120m deep. Today, the Ogallala alone, waters 20% of US irrigated land, depleting it by 12 cukm/yr. In several decades of pumping, the 3700 cukm reservoir has been shrunk by 325 cukm, facing extinction 300 years from now. It is the typical tale of all ground water reservoirs in the world.

Bangladesh is sinking into the sea because its groundwater has been pumped so extensively. In other places the lower water table is drying out valuable wetland areas. One may think that it is a stupid idea to pump water from underneath the plant's roots in order to put it on top of the land, where much of it evaporates. Yet this is exactly what has been happening all over the world. Since the groundwater is used by all but owned by none, it follows the 'tragic of the commons' (why should I limit my use, when the other guy is not?), unless rigorously managed by governments.

Groundwater is formed from water penetrating the soil and sinking to deeper levels. As it is pumped, the water table drops, encouraging water to flow more freely and thereby carrying substances that should not be there. The table below gives an idea of the kinds of threats to groundwater systems and how these affect humans. Note that the effects on the environment are not mentioned.

Chemical threats to groundwater

threat	**source**	**effects**	**where**
pesticides	runoff from farms, backyards, golf courses, landfills	organochlorides linked to reproductive and endocrine damage in wildlife; organophosphates and carbamates linked to liver and nervous system damage and cancers.	USA, eastern Europe, China, India
nitrates	fertiliser runoff; manure from livestock operations; septic systems.	restricts amount of oxygen reaching brain, which can cause death in infants (blue baby syndrome).	Mid-Atlantic USA, north China plain, western Europe, northern India.
petro-chemicals	underground petroleum storage tanks	benzene and other petrochemicals can cause cancer, even at low exposure	USA, United Kingdom, parts of former Soviet Union.
chlorinated solvents	metals and plastics degreasing; fabric cleaning; electronics and aircraft manufacturing.	linked to reproductive disorders and some cancers.	western USA, industrial zones in East Asia.
arsenic	naturally occurring	nervous system and liver damage; skin cancers	Bangladesh, eastern India, Nepal, Taiwan.
fluoride	naturally occurring	dental problems; crippling spinal and bone damage.	northern China, northwestern India.

source: World Watch Institute: Vital Signs 2000.

Irrigation from artificial lakes

About 6000 years ago the Sumerians invented irrigation by diverting water from the Euphrates river to their crop lands. It improved yield and living conditions considerably. Today, wherever feasible, rivers are dammed for hydro electricity and irrigation. The high water pressure makes it possible to transport high volumes of water through a system of reticulated pipes. When carefully managed, it allows farmers to extend their cropping season and to increase productivity. One would think that irrigation is just another form of rainfall, but it is not.

The water collecting in a reservoir is the run-off from rain falling on the upper-catchment area. In its journey to the lake, it has dissolved valuable nutrients but also the not so valuable salts that have been discarded by living soil. If this water were applied to soils that experience a good soaking several times per year, the salts would be washed further down the slopes, eventually ending in the sea. But so often it is the irrigated land's main source of water. As water evaporates from the soil, it leaves the salts behind, resulting in gradual salinisation which degrades the land. Much irrigated cropland has been lost this way. As stated before, it is difficult (or risky) to bring dry land into production. Irrigation from lakes can help in some climate situations, mainly to reduce the risk of drought. Hydro lakes do reduce the flow of the river, resulting in less flooding downstream and thus less soil fertility replenishment. The Aswan Dam in Egypt has caused such problems.

The table below shows how much world agriculture depends on irrigation of its crops. Not surprisingly, the driest countries rely on it the most, and it is in these places that irrigation brings its problems. In the table below, padi culture has been included as irrigated land, but this is a sustainable form of water harvesting. The growth of irrigated cropland first kept pace with world population growth, but is now falling behind, mainly because the most suitable land has been used. About 20% of irrigated land is damaged by salinisation.

Irrigated area in the top 20 countries and the world

country	**irrigated area Mha**	**% of crop land**	**aquifer deficit cukm/yr**	**country**	**irrigated area Mha**	**% of crop land**	**aquifer deficit cukm/yr**
India	50.1	29	104	Uzbekistan	4.0	89	
China	49.8	52	30	Spain	3.5	17	
United States	21.4	11	13.6	Iraq	3.5	61	
Pakistan	17.2	80		Egypt	3.3	100	
Iran	7.3	39		Bangladesh	3.2	37	
Mexico	6.1	22		Brazil	3.2	5	
Russia	5.4	4		Romania	3.1	31	
Thailand	5.0	24		Afghanistan	2.8	35	
Indonesia	4.6	15		Italy	2.7	25	
Turkey	4.2	15		Japan	2.7	62	
North Africa			10	Other	52.4	-	
Saudi Arabia			6	World	255.5	17	

Source: UN FAO 1996 Production Yearbook.; various other sources.

Water harvesting

Having a water lake above each farm sounds like a good idea. The stored water can reach lower farmland through the water table or by being piped there. Small lakes or ponds are used in this way to provide for drinking water for grazing stock, but the larger lakes are too much of an engineering challenge.

One sound ecological way is to leave a stand of forest above each farm, crowning the hill tops. Forests can soak up large quantities of water and release these slowly down-slope. Hill tops are difficult to farm because of their low water tables, but they are relatively flat, offering access to tractors, a reason why many have been denuded. But in Japan, steep hillsides and hill tops have been left alone, clad in their native forests.

Water saving

Water can be saved by reducing evaporation direct from the soil. Water evaporates faster in high temperatures and wind. So if wind speed can be reduced at soil level (and above it) while the soil can be kept cool, much water loss can be avoided. Covering the soil with mulch and erecting wind break hedges is one solution. In Spain and around the

Mediterranean Sea, where the climate is too dry in summer, farmers till the soil under their olive trees to prevent weeds drawing water and mulch the soil with tilled, dry soil. However, this method leaves the soil wide open to erosion when sudden rains appear.

Irrigation through open and unpaved channels, and applying it to the land through surface furrows, may lose 50% of the water into the soil where it is not needed and through evaporation. Applying water to crops by means of drip irrigation, although more expensive, can reach up to 95% efficiency in water use. Water savings have been achieved by replacing high pressure sprinklers that make fine droplets, with low pressure sprinklers making large droplets.
In many places in the world, fresh water is now a commodity that can be traded in the freemarket. With the aim of encouraging farmers to conserve water, it has also opened the way to feudal land ownership and water rights being bought by industries and cities, who are in a better position to offer higher bids.

Water horror stories

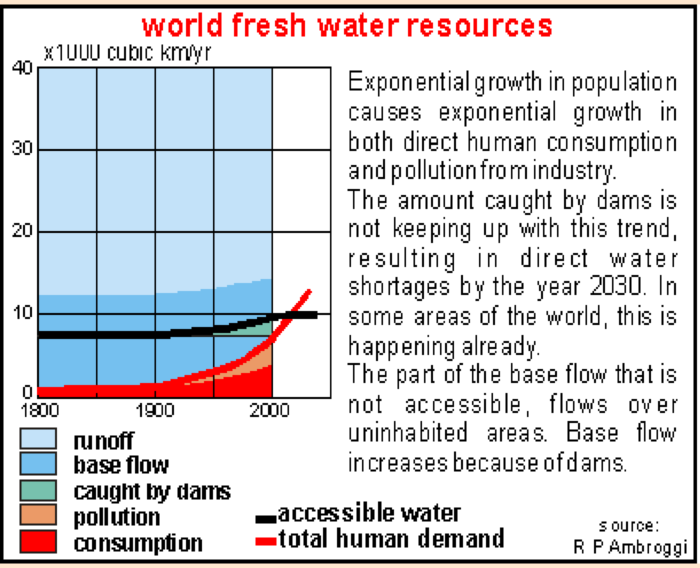
- **United States**: The High Plains Aquifer System (Ogallala) underlies 20% of all US irrigated land and contains some 3700 cukm. Net depletion in 30 years amounts to 325 cukm. More than 65% of this depletion has occurred in the Texas High Plains, where irrigated area dropped by 26% between 1979 and 1989. Current depletion is estimated at 12 cukm/yr.
- **United States, California**: Groundwater overdraft averages 1.6 cukm/yr, amounting to 15% of the state's annual net groundwater use. Two thirds of the depletion occurs in the Central Valley, the country's (and to some extent the world's) fruit and vegetable basket.
- **United States, Southwest**: Overpumping in Arizona alone totals more than 1.2 cukm/yr. East of Phoenix, water tables have dropped more than 120m. Projections for Albuquerque show that, if groundwater withdrawals continue at current rates, water tables will drop an additional 20m by 2020.
- **Mexico City and Valley of Mexico**: Pumping exceeds natural recharge by 50-80%, which has led to falling water tables, aquifer compaction, land subsidence, and damage to surface structures.
- **Arabian Peninsula**: Groundwater use is nearly three times greater than recharge. Saudi Arabia depends on nonrenewable groundwater for roughly 75% of its water, which includes irrigating 2-4 Mt/yr wheat. At this depletion rate, groundwater reserves would last only about 50 years.
- **North Africa**: Net depletion of groundwater in Libya totals nearly 3.8 cukm/yr. For the whole of North Africa, current depletion is estimated at 10 cukm/yr.
- **Israel and Gaza**: Pumping from the coastal plain aquifer bordering the Mediterranean Sea exceeds recharge by some 60%. Salt water has invaded the aquifer.
- **Spain**: One-fifth of total groundwater use, or 1 cukm/yr, is unsustainable.
- **India**: Water tables in the Punjab, India's bread basket, are falling 0.2m annually across two-thirds of the state. In Gularat, groundwater levels declined in 90% of observation wells monitored during the 1980s. Large drops have also occurred in Tamil Nadu.

- **North china**: The water table beneath portions of Beijing has dropped 37m over the last 4 decades. Overdraft is widespread in the north China plain, an important grain-producing region.
- **Southeast Asia**: Significant overdraft has occurred in and around Bangkok, Manila and Jakarta. Overpumping has caused land to subside beneath Bangkok at a rate of 5-10 cm/yr for the past two decades.

It is evident that practically everywhere on Earth, the amount of irrigation water is seriously overdrawn. Prospects for increasing agricultural yield are therefore not optimistic. It is not only land that needs water in large volumes, but also industries and people. As the world's

Nutrients

Whereas H, O and C are copiously available in water and carbon dioxide, the macro nutrients N, P and S are not. In this barchart one can see the relative abundances of the elements for life. Note that the scale extends over 6 decades from 1 to one million ppm. The brown bars represent the elemental concentration in the planet's crust and the green bars those in plants. Not taking notice of H, O, C, Si, Al, Fe which are the abundant elements contributing to soil hard matter, water and carbon dioxide, the remaining ones population grows and becomes urbanised (where else are jobs found?), water may shift to where it is valued more, the industries and cities. In 25 years, India will add some 340 million people to its cities, more than the current population of the USA and Canada combined. Saving water is not just an agricultural problem, but should be achieved in cities as well.


world fresh water resources

Exponential growth in population causes exponential growth in both direct human consumption and pollution from industry. The amount caught by dams is not keeping up with this trend, resulting in direct water shortages by the year 2030. In some areas of the world, this is happening already. The part of the base flow that is not accessible, flows over uninhabited areas. Base flow increases because of dams.

source: R P Ambroggi

This diagram shows how the world's fresh water resources are heading for a climax. Net fresh water falling on the land is about 40,000 cubic km/yr. Most of this runs off in floods and won't penetrate the soil. Some of the flood water is caught in dams (green area), which increases both the base flow and the amount of accessible water. Back in 1950, human consumption was only a fraction of accessible water, but by 1950 it became 50% and by the end of the millennium it stood at 80%. Only rapid building of dams can prevent total human demand from catching up with the amount of accessible water, but this can no longer be achieved. As a result, there will be a world-wide shortage of drinking and industrial water after the year 2020.

are more important to the chemistry of plants and animals. Of these the four macro

nutrients are N, Ca, K, Mg, P, S. Of these six, the ratios vary between 1/3 rd of a division (50%) to nearly 2 divisions (1%). Only nitrogen is less abundant in the crust than in plant matter.

But scientific data is not unanimous on this issue. Below follows a table as published by W Larcher, 1980 :

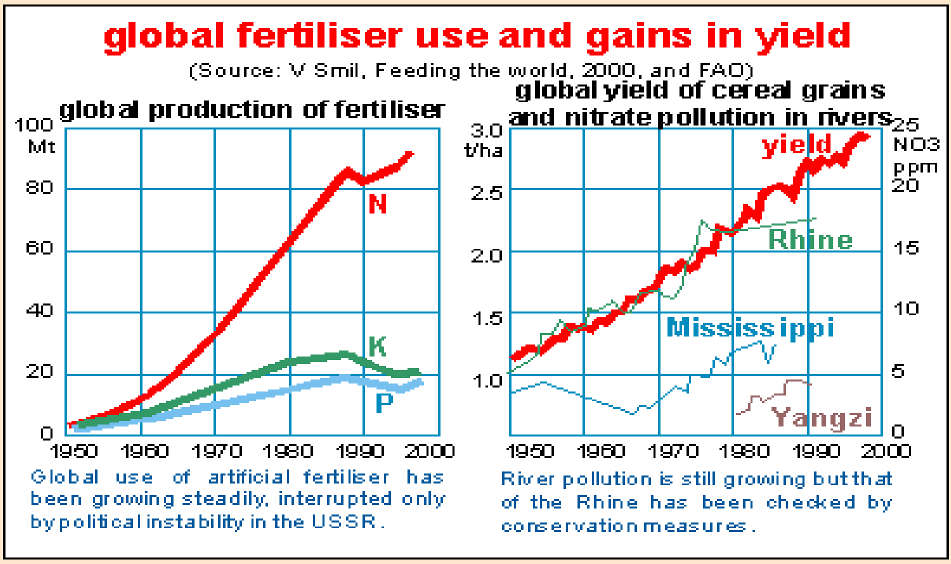
element	stored in soil ppm	land plants dry matter ppm	land plants average ppm	concentration factor

N nitrogen	1,000	10,000-50,000	20,000	20
P phosphorus	700	1,000-8,000	2,000	3
S sulphur	700	500-8,000	1,000	1.5
K potassium	14,000	5,000-50,000	10,000	0.7
Ca lime	14,000	5,000-50,000	10,000	0.7
Mg magnesium	5,000	1,000-10,000	2,000	0.4
Fe iron	38,000	50-1000	100	-
Mn manganes	900	20-300	50	-
Znzinc	50	10-100	20	0.4
Cu copper	20	2-20	6	0.3
Mo molybdenum	2	0.1-1	0.2	0.1
B boron	10	5-100	20	2
Cl chlorine	100	200-1000	100	1
Ni nickel	?	?	?	?
Se selenium	?	?	?	?
Co cobalt				
I iodine				

The table shows soil concentrations and those found in plants and a concentration factor that shows how much plants have to concentrate the element. As one can see, rather large differences between plants exist, and nitrogen is the element in shortest supply. A word of caution on the use of the 'dry matter' weight, which is obtained by driving all water out. Plants and trees have two very different kinds of tissue: the dead woody stems and the living matter consisting of hair roots, bark and leaves. Their 'ash weight', obtained by driving all carbon and oxygen out, differs tenfold in favour of living tissues. Ash contains the elements in the table above.

Depending on which fertiliser formula to use, plants need about eight times more nitrogen than phosphorus and sulphur. In recent history, too much phosphorus was applied to soils because it was believed that it 'disappeared' in the soil's processes. Ratios of N:P = 2:1 were common but nowadays, soils are replenished in ratios N:P = 6:1 (and N:P:K = 100:18:22 is now a world-wide average), which is more in line with what has been harvested from the soil. The soil's ability to 'fix' (bind) phosphorus compounds is problematic in the sense that it is no longer readily available to plants, but a blessing since it won't leach away easily. Alkaline soils release phosphorus reluctantly but soils rich in soil organisms, make this mineral freely available.

These graphs show a number of important facts relating to the use of artificial fertiliser. The world is now using an amount of fertiliser corresponding to 90 million ton of nitrogen per year, equivalent to 90 x 200 = 18 trillion ton (Gt) of vegetable matter or 9 Gt carbon per year. To bring this into perspective, the primary production of the entire world ecosystems is 160 Gt carbon per year, 100 on land and 60 in the sea (Woodwell & Pecan in Carbon and the Biosphere). The total amount of N applied since 1950 is about 2.5Gt (the area under the curve = 0.5 x 50 years x 100 Mt); the mass of the atmosphere is 5,200,000 Gt and the total amount of nitrogen there 4,000,000 Gt, which appears to make human production pale in insignificance (note that one gigaton Gt equals one petagram Pg).



global fertiliser use and gains in yield

(Source: V Smil, Feeding the world, 2000, and FAO)

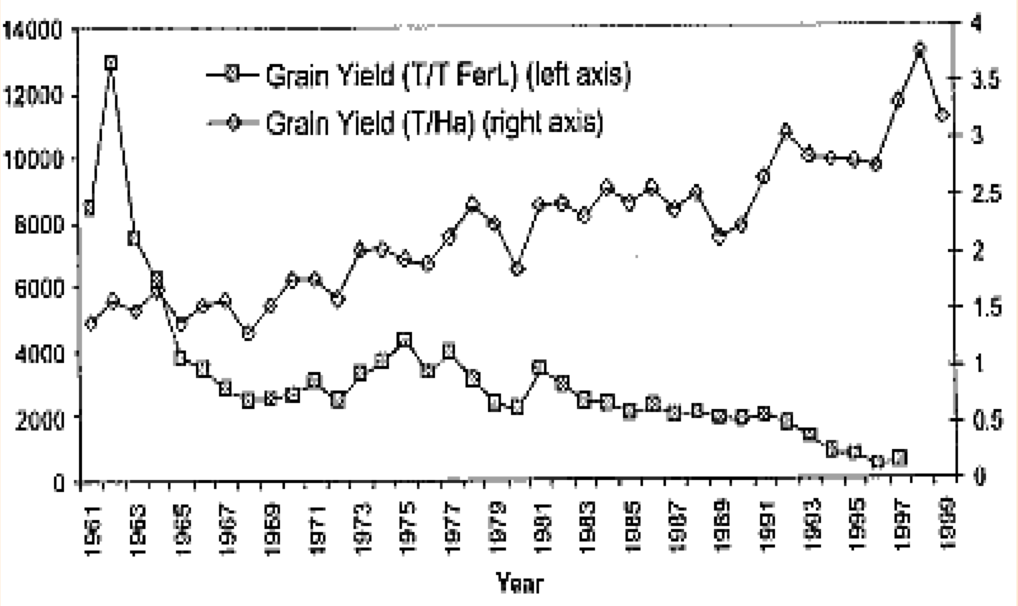
Global use of artificial fertiliser has been growing steadily, interrupted only by political instability in the USSR.

River pollution is still growing but that of the Rhine has been checked by conservation measures.

However, it is estimated (Vaclav Smil, 1997) that around 175 Mt nitrogen flow into the world's croplands every year, and about half this total becomes incorporated into plants. Synthetic fertiliser provides about 40% of all the nitrogen taken up by these crops. Because they furnish - directly as crops and indirectly as animal foods - about 75% of all nitrogen in consumed proteins (the rest comes from fish and from meat and dairy foodstuff produced by grazing), about one third of the protein in humanity's diet depends on synthetic nitrogen fertiliser. Children born today, may grow up with 50% of their bodies' protein made from artificially fixed nitrogen.
Note that most fish is caught in coastal seas where they grew on a supply of plankton originating from the fertiliser in the run-off from the land, and thus 50% artificial fertiliser. Dairy grassland is now heavily fertilised with 'artificial' nitrogen, although most hill country grasslands obtain theirs naturally from clover. It is obvious that much of it goes to waste and that there are ecological limits.

Note also that the elements in artificial fertiliser are in no way distinguishable from those in natural fertiliser. Mankind cannot make new elements. A nitrate anion fixed from nitrogen and oxygen by humans, is exactly the same as one fixed by a bacterium or a thunderstorm.

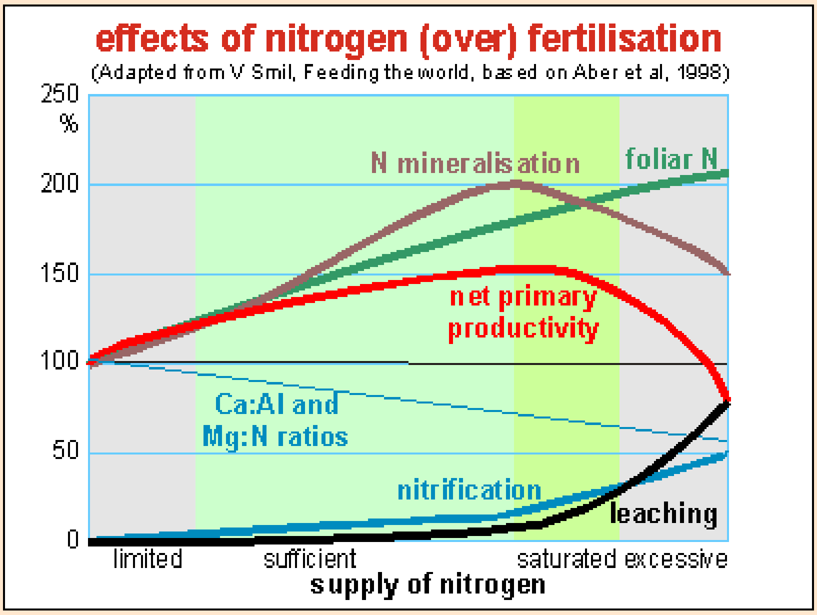
In the right-hand diagram above, one sees the tremendous progress made in the yield of all crops, of which the cereal grains, shown here, are a good example. In the course of fifty years, the use of fertiliser grew ten-fold, in order to double productivity, but fertility expressed as productivity per tonne of fertiliser dropped world-wide, as showh in the diagram on right, for Argentine Pampas cropland. The grain yield expressed as tonnes production per ha, grew twofold, following the world average, but the fertility of the area expressed as production for the amount of fertiliser used, dropped 10 to 20-fold! Such farmland is probably close to the state of ecological collapse, with erosion accelerating. (Source: Hall, A J et al "Field crop systems of the Pampas" in Pearson C J (Ed), Ecosystems of the world: Field crop ecosystems. Elsevier, Amsterdam. 1992).



It must be noted that those gains were not made by artificial fertiliser alone, but also from irrigation, multiple harvests and improved crop varieties. In the top diagram, the amount of nitrate in rivers is shown. Note in this respect that 50ppm is the health limit for drinking water and a marine aquarium is in serious trouble with this concentration. In Holland, the nitrate concentrations in groundwater average 134ppm and 243ppm underneath dairy farms! Pollution control measures in Europe have flattened the Rhine pollution, but elsewhere nitrate concentrations are on the rise. It is interesting to note that the pollution concentration in rivers is less in high rainfall areas (due to water dilution) and more when the catchment area has much crop land (the source of it).

Note at this point that a number of crops do not react well to nitrogen:

- **Leguminous crops** like alfalfa, soy beans and many more, produce nitrogen fertiliser within root nodules or within their tissues, with the help of nitrogen-fixing bacteria. Productivity increases when bean seeds are coated with these bacteria. Their capacity of fixing nitrogen ranges from 15-330 kg/ha, but 100 kg/ha is normal, about 30-70% of their own needs.
- **Rice paddies** are purposely water-logged during the rice growing season, causing an oxygen-deficient soil. Azolla ferns *(Azolla pinnata)* grow in these conditions, fixing the rice plants' required nitrogen with the help of the nitrogen-fixing cyanobacterium *Anabaena azollae*.
- **Sugarcane**, a very efficient C4 photosynthetic plant, has nitrogen fixing bacteria inside its tissues.



Genetic engineers may ultimately succeed in splicing the *Rhizobium* bacterium into the root cells of our most important food plants, endowing them with their own nitrogen factories, but this is no easy task.

The graph here shows how the soil and plants react to nitrogenous fertiliser. It is a conceptual diagram, in the sense that it shows the principles of what is happening, rather than exact data, because each plant species reacts differently. It is an important graph, because it also represents a typical ecosystem response to an artificial addition of a natural component. Horizontally the amount of fertiliser applied, vertically its relative effects. If you wish to tag some figures here, saturation corresponds to 50 kg/ha; sufficiency to 20-30 kg/ha. The coloured bands in the background correspond to the qualitative conditions of being limited, sufficient, saturated and excessive. To bring this into perspective, many places in the world, experience fertiliser-laden rain (acid rain) to the tune of 50-100kg/ha, originating from industrial processes. This unsolicited input has a major influence on forests, dunes, marshes, and croplands.

As fertiliser is applied, its effect is immediately visible in an increase of net primary productivity (NPP at around 10 kg dry matter for 1 kg N), which decreases sharply after saturation is exceeded (perhaps 16 t/ha vegetation with 8 t/ha harvest maximum) and nitrogen gradually becomes poisonous. Ironically, the amount of green foliage increases with further N application, but at a much slower rate, due to reduced NPP. Nitrogen mineralisation represents the amount that is accommodated in the soil and foliage. It drops sharply after exceeding sufficiency. Excessive nitrogen now leaches away with rain water and as the soil rejects excessive nitrogen, bacteria convert more of it into gas (NH_3, N_2 and N_2O). Nitric oxides (N_2O, laughing gas) are very powerful greenhouse gases, about 280 times more potent than carbon dioxide. Their contribution to global warming already amounts to 6%. As the world attempts to squeeze more production out of the dwindling area of cropland, nitric oxide's contribution to global warming will increase sharply.

Estimated global losses of nitrogen amount to 10kg/ha on flat land and 50kg/ha on sloping land (2-4 degrees) in windy areas. Nitrogen loss in the form of ammonia (NH_3, a potent greenhouse gas) escaping into the air, is about 25 kg per head of cattle per year. Phosphorus losses would be ten times less, because phosphorus compounds are less soluble and much less of it is applied.

Nitrogen compounds in the biosphere

	nitrogen gas	ammonia	urea	amino acids	proteins
Formula	N_2	NH_3	$NH_2.CO.NH_2$	$n(CH_2).m(NH_2).COOH$	-
Nitrogen share by weight	100%	82%	47%	8-27%	~16%
Biosphere abundance (Gt)	10,000*	10	0.01	10	1

(*) does not agree with the 4 million Gt at the beginning of this chapter. Treat these values as indications of their magnitude.
Source: V Smil, SciAm July 1997

Reference: V Smil: **Global population and the nitrogen cycle**. SciAm July 1997.

Potassium (K) is important for photosynthesis and in the formation of amino acids and protein from ammonium ions. Potassium deficiency shows as premature death of leaves, and an increased sensitivity to stresses. Potassium, like phosphorus may become fixated in the soil, and thus unavailable to plants, however, this element is much easier leached from soils than phosphorus. Optimum pH for availability is 6-8. The three-layer smectite clays contain potassium in their structure, but the two-layer kaolinitic clays do not, and are usually deficient in potassium.

Calcium (Ca) deficiency in plants causes stunting of roots and leaves. Plants need large quantities of calcium. Lucerne contains nearly 3%. Lime is added to soils to regulate soil acidity, and over-liming (alkaline soil with pH above 7) could reduce the availability of nitrogen, phosphorus and potassium.

Sulphur (S) is not required in large quantities by growing plants, but is nevertheless an important nutrient. Its cycle in nature is similar to that of nitrogen. Small amounts of sulphur are obtained from sulphur dioxide (SO_2) in the atmosphere, produced by volcanoes and the burning of fossil fuel.

Fertilising

From the previous chapters we have seen that farming for the very long term is a delicate balancing act. Fertilisers can help the soil, but they can also cause damage. The natural ecosystems of the world have never needed additional fertilisers, so why do humans need it now?

In very primitive societies, the production of food was motivated by hunger. The search for food stopped when the tummy was full. Overharvesting was unknown. As societies became more sophisticated, the reasons for producing food changed. Agricultural societies started to produce food for others. Today's farmers do it for money. They are able to do so because of world trade, a monetary system, transport, subsidies and means of preservation. Let's be honest: food is not produced because someone somewhere else on the planet is hungry. It is not produced 'to feed the world'. The free market system just happens to distribute it efficiently to those who can afford to pay, making it seem so.

Everywhere in the world and over many thousands of years, farming has been a hit-and-miss affair. Land was cleared and farmed. If it failed, the land reverted back to scrub and forest or was lost altogether, leaving the bones of the land, the naked rock, behind. Today's farming is very much the same, but in the meantime we hope to have learnt from some of our mistakes.

There are three principal reasons for applying fertiliser:

- **balancing the soil**: to bring the composition of nutrients in a soil up to the mix required by crops, or to add nutrients that are in short supply. By analysing the base rocks from which the soil is weathered, and knowing the requirements of the standing crop or mix of crops over a few seasons, the nutrients in shortest supply can be determined and these can be added in the from of artificial fertiliser. In traditional soil testing, a sample of the A horizon is analysed, rather than the C or B horizons. This is done because the composition of the A horizon, the plough and root zone, is of immediate interest for this season's production. By analysing the C or B horizons as well, the original nutrients in shortest supply can be detected and added to improve future soil composition.
- **replacing**: to replace the nutrients that have been harvested. In small-scale primitive societies, human and animal wastes were returned to the cropland where they originated from, but in large-scale agriculture where the produce is sold and consumed very far away, this can no longer be achieved. Artificial fertiliser is then necessary to maintain the soil's natural fertility. See also the note on traditional farming and waste recycling below.
- **rapid response**: quick release fertiliser is applied to meet the sudden need of a fast growing monoculture.
- **optimising**: artificial fertiliser is added to optimise some economic parameter, usually the amount of profit from the operation. Many fertiliser companies define optimal yields without mentioning increased risk of soil and water pollution, and down-slope degradation such as poisonous plankton blooms in the sea.
- **feeding soil organisms**: a most important aspect often overlooked is the use of fertiliser to feed soil organisms from the woody substances in it. In the 19th century, Dutch 'mixed farmers' applied up to 20t/ha of manure. Nitrogen can escape from manure in the form of ammonia NH_3, a highly volatile form of nitrogen.

The table below shows some of the most popular fertilisers in use:

Commonly used fertilisers

type of fertiliser	formula	active element	comments
Ammonium bicarbonate	$NH_4.HCO_3$	N 18%	Highly volatile. Needs sealed bags. Best applied underground. Up to 50% lost after application. Cheap to make.
Ammonium nitrate	$NH_4.NO_3$	N 35%	Very potent fertiliser made by the Haber-Bosch industrial process. Dissolves easily into water and is taken up quickly by plants. Leaches out quickly too.
Urea	$NH_2.CO.NH_2$	N 47%	Slow-release fertiliser that needs to be converted by soil bacteria before ammonia is available to the plant. Urea pellets are easy to pack, handle, store and apply.
Rock phosphate	$Ca_3(PO_4)_2$	P 19% Ca 38%	Adds both phosphorus and calcium. Mined from guano (sea bird excretions) deposits.
Super phosphate	$CaSO_4$ 53% CaP_2O_5 34%	S 12% P 11% Ca 24%	Made from rock phosphate or bones, ground to a powder, then mixed with sulphuric acid. Popular in New Zealand and Australia.
Super phosphate	$Ca(H_2PO_4)_2$	P 26% Ca 17%	The most common form of phosphate fertiliser, highly soluble
Triple super	$CaHPO_4$	P 23% Ca 29%	Widely used, slightly soluble in water.
Lime, calcite	$CaCO_3$	Ca 40%	Adds calcium to the soil and combats acidity.
Potassium oxide	K_2O	K 83%	Adds potassium

Other fertilisers used: liquid ammonia ($NH_4.OH$), ammonium sulphate ($(NH_4)_2.SO_4$), muriate of potash (KCl), potassium carbonate (K_2CO_3), lime (CaO, $Ca(OH)_2$, $CaCO_3$, dolomite ($CaMg(CO_3)_2$), calcium bicarbonate ($Ca(HCO_3)_2$),

Soil tests give soil concentrations in ppm (parts per million). Two different values are obtained for phosphorus, depending on the type of test: Bray or Olsen. Olsen figures are generally 30% lower than those from Bray tests. Soil is considered optimal with P concentrations of 10-20 ppm; deficient with 0-5 ppm. Typical application rates are 50 kg/ha (P_2O_5) for high intensity farming.

Potassium is extracted from soil with ammonium acetate, giving an optimal soil at 90-130 ppm and deficient soil at 0-50 ppm. Typical application rates are 40 kg/ha (K_2O) for high intensity farming. Note that 1000 ppm = 1 kg/ton.

If fertiliser is withheld, highly productive dairy pasture degrades by 5% and hill country by 10-15% per year, to level off at around 30-40% less yield.

In traditional farming systems, there was enough recycling of animal and human wastes to keep up with losses from harvesting. The cropland was cycled between cropping and grazing. Confined meat animals were fed the residues from crops and the feedlot crops that were grown specially for them. Their wastes were recycled onto the land, just in time before the new crop needed its nutrients. Crop diseases were combated by suitable rotations, rather than by chemical means. It is a way of farming that has earned its existence for well over a thousand years, and that is finding much support today by those advocating permaculture.

But modern cropping and meat production have been allowed to proceed independently, the one being located far away from the other, making transport costs too high to justify recycling of wastes. It is a freemarket idea that has no respect for sustainability, but it can be changed by relocating chicken and pork farmers to where their wastes can be recycled.

We have seen from the preceding chapters already, that the soil's natural fertility is contained in the soil organisms and hardly anywhere else. This will be treated more firmly in the chapter on sustainability. In deciding how to treat the soil, be it by ploughing, fertilising or pest control, the sustainability-conscious farmer must first of all think about the soil biota. What do they need? How do they wish to be treated? What to do to get more of them? In this respect, artificial fertiliser is not the same as recycled wastes. Artificial fertiliser contains only the nutrients for plants. Their wastes and roots then feed the soil. By contrast, animal wastes feed the soil and the soil makes the nutrients available for the crops. It is an important difference.

There is also a huge difference between perennial crops such as tea, coffee, rubber, pasture, and seasonal crops such as beans, wheat, potatoes. Perennial crops do not require ploughing, a continuous disruption of the soil, which is very detrimental to soil biota. The longevity of these crops allows the soil to adjust to the new plant community above it and to retain those nutrients that are most needed.

Most human crops differ remarkably from natural ecosystems and their communities in their complexity. Human crops are almost all monocultures, whereas natural communities have the highest possible variety for the given locale of climate and soil type. A high variety of plants means that their average composition of nutrients better matches that of an optimal soil community. In other words, plant variety increases soil fertility. This is explained in more detail in the chapter on sustainability. Although no proof exists (yet), it is to be expected that meadows with a variety of grasses and other plants, maintain a more fertile soil than those with a monoculture of one species of grass.

Minimising risks

Being intimately involved with his farm, knowing its history and having observed how it reacts to varying circumstances and trials, the farmer is the person most suited to judge environmental risks. Here are some general practices to reduce risk to the environment:

- Have soils tested yearly. Take several samples spread over the farm at recurring spots and in the same month each time. Take advice from an agricultural expert. Remember that the tests measure immediately available nutrients, whereas soil organisms release 'unavailable' nutrients slowly. Good soils may have high pools of 'unavailable' nutrients.
- Have plant tissues analysed for actual nutrient takeup.
- Keep a record of soil and tissue tests, fertiliser application and crop yields. Also rainfall.
- Apply fertiliser in calm wind conditions, less than 5km/hr. Spread/apply evenly. Avoid open water.

- Don't fertilise when the soil is saturated with water (is at field capacity). Apply when tile drains are not running.
- Soil temperatures should exced 5ºC. Time applications with the season of fastest growth.
- Apply slow-release fertiliers in preference to fast-release, or a mix of both to meet expected demand.
- Apply smaller quantities more frequently if possible and affordable.
- Be present when contractors fertilise, and check their result.
- Be sure that the land is suitable for your type of use of the land (soil, slope).
- Keep an eye on plant growth in surrounding open waters. Test open water and aquifer water for nutrients.

Using natural rock as fertiliser

Proponents of permaculture and organic farming use pulverised natural 'hard rock' as a means of natural fertiliser. It is spread over the land. Soil organisms then cover it and bring it into the moist and acid environment that promotes weathering at a rate exceeding that of natural weathering of 1 ton/ha. Of course, at the C horizon, the base rock weathers at this rate, bringing new nutrients. Often the hard rock is a metamorphosed sedimentary rock like greywacke or an igneous rock like basalt. The chemical constitution of these two differ, but on average one could expect the following yield in nutrients (see table of abundance of elements):

Estimated composition of rock fertiliser

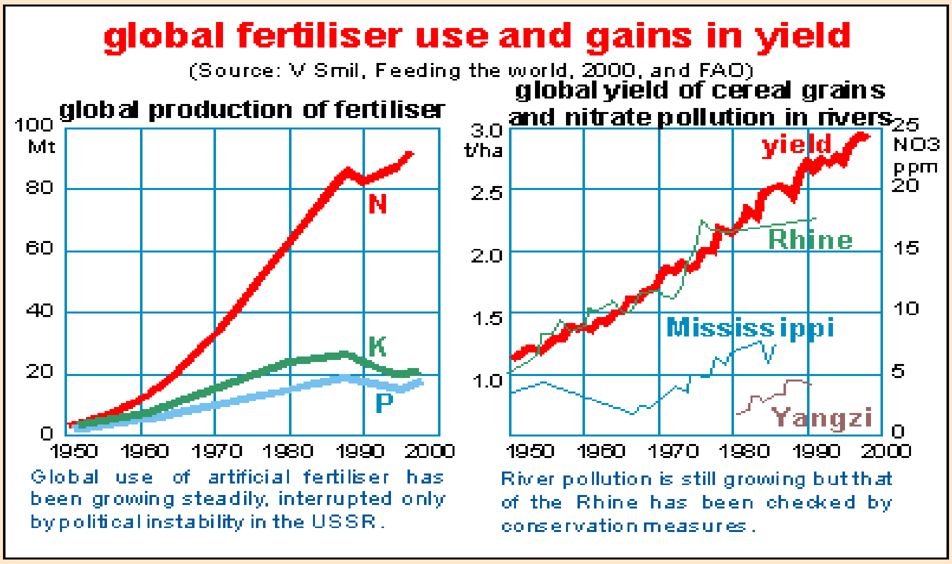
element	rock [1] concentration ppm	rock [1] kg/ton	soil [2] kg/ton
N - nitrogen	100	0.1	1.0
P - phosphorus	700	0.7	0.7
K - potash	1,200	1.2	14
S - sulphur	1,000	1.0	0.7
Ca - lime, calcium	20,000	20	14
Mg - magnesium	20,000	20	5

[1] average concentration of the Earth's crust, for lack of details on greywacke, granite and basalt.

[2] see table above

As one can see, it is a very inefficient way of increasing fertility, when only 50 kg of 1000 kg (5%) rock produces useful fertiliser, compared to about 40-50% in artificial fertilisers, and it does not add nitrogen. The table also illustrates the limits posed to natural soil productivity when produce is taken off the land and not recycled. It roughly corresponds to 10kg fertiliser per ha (N:P:K=8:1:1, excluding N) for forest soils weathering at the rate of 1t/ha, and perhaps 40kg/ha for agricultural land which weathers faster.

Reader please note: these figures are estimates and I'd be interested to obtain actual measurements and data from field experiments. E-mail Floor Anthoni.



global fertiliser use and gains in yield

(Source: V Smil, Feeding the world, 2000, and FAO)

Global use of artificial fertiliser has been growing steadily, interrupted only by political instability in the USSR.

River pollution is still growing but that of the Rhine has been checked by conservation measures.

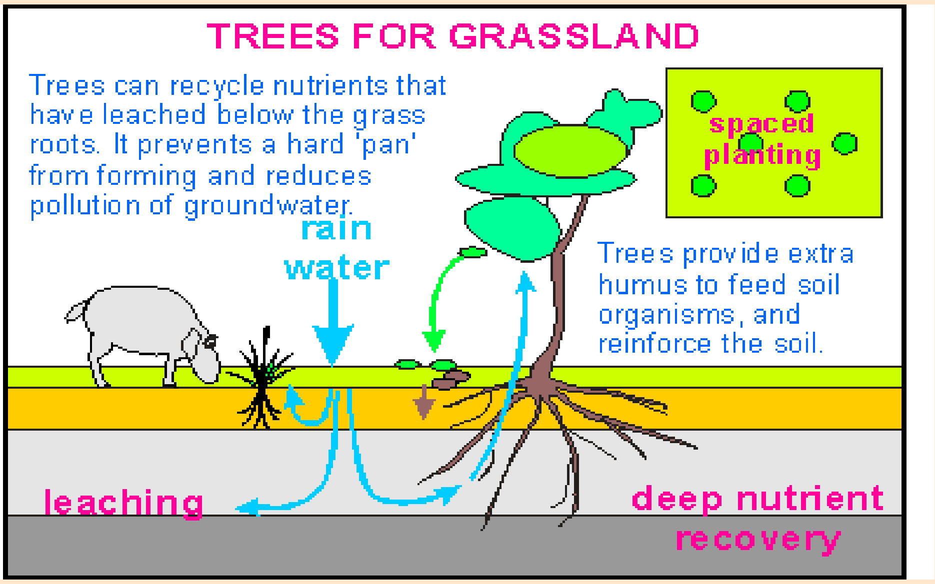
Trees for grassland

This diagram illustrates an ecological idea for extending the fertility of grassland soils while at the same time providing better protection against erosion. The idea is to plant suitable trees in moderately hilly grassland. Their roots reach much deeper down than those of grass, so that they are able to draw nutrients from deeper down, thereby also assisting the weathering process. The leaf and branch fall feeds the soil organisms who return the nutrients to the A horizon. The following benefits are obtained:

- nutrients are drawn from deep down and cycled to the surface.
- leached nutrients are drawn back to the surface, reducing groundwater pollution.
- leaf litter feeds the soil organisms. There is a larger source of humus.
- deep roots prevent soil movement such as creeping, slumping and slipping, thus reducing soil erosion.
- deciduous trees provide shelter in hot and bright summers, but let sunlight through in the winter.
- spaced trees trap more warmth.

The idea is particularly useful for sloping terrain that is unsuitable for cropping and difficult to fertilise. The trees themselves need to satisfy the following requirements:

- **deep roots**: to find deep nutrients and to anchor a large volume of soil.
- **fast growing**: the tree must metabolise fast, not only because grassland has a fast metabolism but also to be effective.
- **deciduous**: by dropping leaves in autumn, a large quantity of leaf litter is produced. In winter or early spring when the grass is limited by light and warmth, the tree lets light through to warm the soil and wind to dry it more quickly. In summer when the grass is limited by drought, the foliage shelters it. A stand of trees lifts the winds, thus protecting the grass from drying out.



- **the right size**: trees must be self-limiting to reduce maintenance. A height of 6-12m is perhaps optimal.
- **easy to plant**: trees must be planted by means of staking poles that reach higher than cattle can graze.
- **optional fodder**: if the grazing animals like the tree's foliage, it can be used in case of drought.
- **soft stems**: stems and branches must decompose easily, minimising their mess.

Some poplar trees may be suitable, but here is certainly a challenge for scientists and the farming community.

A question of salt

Two of the most important elements in the human body are sodium and chlorine, known as salt (NaCl, sodiumchloride). Chlorides play an essential role in the neutrality and pressure of extracellular fluids and in the acid-base balance of the body. Hydrochloric acid is produced in the stomach for the digestion of food. It is also lost in sweat, urine and faeces (92%). The body's supply of chlorine can deplete rapidly through excessive perspiration or loss of acid in the body. It is found in animal products, including dairy products, but little in vegetables.

Sodium is an element that functions with chloride and bicarbonate to maintain the balance of positive and negative ions in body fluids and tissues. Sodium has the property of holding water in body tissues. Excess sodium may result in edema or water retention. Too little of it disturbs the tissue-water and acid-base balance, necessary for good nutritional status. The hormone aldosterone controls the balance of sodium and water in the body. Symptoms of sodium deficiency may include feelings of weakness, apathy, nausea, cramps. Sodium is found in all animal foods and table salt. (See also periodic table/nutrient deficiency)

There is no doubt that salt is an important nutrient for humans, yet a number of recent developments could render society suffering from salt-related deficiencies. What follows in this subchapter, are my own observations, not (yet) verified by scientific method. However, they are important enough to raise awareness. Note, that although we will talk only about salt, it includes a host of other minerals that are not essential to plants but only (or mainly) to animals (boron, magnesium, fluorine, iodine, iron, chromium, manganese, molybdenum, selenium, silicon, vanadium and so on). I am using the word salt as also including the salt balance. Many people ingest an excess of salt from commercial foods like snacks, fast food, bread, cereals, etc., but this is pure table salt, lacking the balance of essential minerals.

Salt loss in soils

Plants do not need salt for their functioning (see also abundance table/soil&plants), but they include salt in their body tissues when absorbing water through their roots. The process by which plants absorb water, is called osmosis. Water is drawn from a weak concentration (the soil), through a 'semi-permeable' membrane, to a higher concentration of salts (the plant). Plants always maintain their body fluids more concentrated than the soil. They do so by evaporating pure water through their leaves. If the soil is dry, plants need higher concentrations than when the soil is moist, reason why desert plants are saltier. When the soil is salty, plants also need higher concentrations, like mangrove trees standing in seawater.

But salt is highly soluble in water, and is lost rapidly from the soil. Plants do not mind this, but the soil organisms do. They need salt just like humans do, and they store it jealously inside their body tissues, cycling it between them and the plants above ground. As modern farming becomes more reliant on artificial fertilisers, rather than the soil's natural fertility, the soil organisms are lost, and with it the pool of underground salt. As a result, modern produce has become tasteless and 'watery', while providing less salt.

Beliefs

A number of beliefs are doing the rounds in society, limiting the amounts or balance of salt in our bodies:

- **salt causes heart problems**: doctors prescribe salt-less diets in the belief that salt causes heart problems like high blood pressure. But there is sufficient medical literature showing either the reverse or no cure after salt-less diets.
- **salt causes ageing**: people believe that they live longer by reducing their salt intake, but suffer from liver failure, kidney problems and indigestion instead. There is no medical evidence to support this belief.
- **salt experiments**: most, if not all scientific experiments relating to salt intake have been conducted with refined salt, rather than sea salt. It is plausible that when salt is deficient, other minerals will also be deficient, and when taking extra salt, other minerals must be taken as well. All ions in the human body act in balance with all others. These are present in unrefined sea salt in concentrations not unlike that of the human body.
- **meat is bad**: although the harmful effects of excessive protein intake on kidneys and liver are sufficiently known, meat has always been an important part of the human diet. In fact, our metabolism has evolved to rely on ten amino acids that our bodies cannot make, but which are found in meat. Meat also provides the salts that plants don't provide. A growing number of people now believe that 'meat is bad' or

'red meat is bad' or 'meat shortens your life'. Many people now have salt- and protein-related deficiencies, for which meat is often blamed.

- **drinking water**: it is widely believed that humans must drink copious amounts of water to 'rinse out toxins' from their bodies. Quantities of one litre a day ore more are touted. People now live with drink bottles on their desks, or can't walk a mile without a sip. But in the hot tropics, native peoples drink much less, giving them a higher sense of wellbeing. Remember that the human body rejects excess, resulting in excessive sweating and urinating, and with every drop of water excreted, precious body salts are lost too. Equally, the human body gets used to a situation of excess, causing discomfort when reducing one's water intake to more natural levels.

Sea salt, rock salt and table salt

The best replenishment of body salts comes from salt, rich in other minerals, such as natural sea salt. But the salt available in shops is table salt, a very refined form of sea salt. Table salt has lost all other minerals, but iodine is added at the end to prevent the iodine-deficiency disease goitre (the swelling of one's thyroid glands in the neck). This fact alone should have warned scientists of the possibility of other, as yet unrecognised, salt-related deficiencies. In any case, pure sea salt gives perhaps the best replenishment of our mineral needs. (See detailed composition of sea water)

The problem is that nearly all salt products on the market have deliberately been mislabelled as 'sea salt' or 'rock salt', their contents being ordinary refined table salt, but with bigger crystals. Pure sea salt is recognisable by the following qualities:

- It is **moist** and unsuitable for salt shakers and many salt grinders, although some grinders work. The mineral magnesium chloride is hygroscopic and attracts moisture.
- It is **not white**, but greyish to pinkish from the remains of plankton organisms.
- It **smells grassy**, like plankton or the smell of the sea.
- It **tastes bitter** from magnesium chloride.
- It **tastes tart**, possibly from zinc or iodine.
- It has a **sharp taste** on the tip of the tongue, possibly from potassium chloride.
- It does not necessarily have large crystals.

Rock salt is the salt found underground as compressed haline rock. It originates from an inland sea or lake having dried up, then covered by sediments. In principle, rock salt has the same composition as today's sea salt, but geological processes such as leaching, may have changed it. In orderto be safe, use sea salt.