DIAGNOSIS OF SOIL RELATED CROP PROBLEMS

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INTRODUCTION

Initially, this manual was written as my farewell document to support students during the practical "Analysis and design of organic farming systems", organized by the Farming Systems Ecology group from the Wageningen University. I have visited many organic farms and low external input farms throughout the world and on many farms physical, chemical and / or biological soil fertility could be improved based on existing knowledge. This manual aims to guide you through the labyrinth of that existing knowledge. It is meant to be a diagnostic tool for junior agronomists to identify soil related problems in crop production and to provide some suggestions to find solutions, that are affordable and acceptable within organic agriculture and low external input agriculture. The basics of soil science are supposed to be known and , if not, I hope that the included basic background information and the links to relevant literature may help you to deepen your understanding of soil properties and soil processes. I have tried to bridge the gap between theoretical and practical knowledge by including some practical aspects of farming, as these aspects are often underexposed at universities.

After a brief introduction in organic agriculture we take the performance of a crop as starting point for our diagnostics. We focus at the level of the individual plant and the soil profile below, that can be studied in a soil pit. Comparing soil profiles and soil properties below better or worse performing plants within a field, farm or region will help you to find causes of different crop performance within a field/farm/region

The second step is to get ideas how to deal with those differences and how the management of a field could be improved (more productive, more sustainable, less polluting).

The third step is to figure out if and (if yes) how the configuration and management of the whole farm should be improved to be able to improve the management of fields (crop rotation, stocking rate, manure and crop residue management, soil tillage). I hope to include this third step later.

The diagnostic key is completed with links and stories. The links give more detailed information or further explanation. I hope the stories will motivate you to put your energy in the analysis of practical problems of farmers. Probably, worldwide application of existing knowledge will more contribute to nourish the growing world population than novel technologies. This manual is only a starting point to find relevant information via discussions, internet and literature. The number of potential relevant links is almost infinite and it will take time to select the better ones.

I am aware that this manual is based on my personal experiences and still a lot of work could be done to improve it. In future I hope to improve and extend its content. Therefore, I would welcome feedback and additional information and experiences (oomen490@planet.nl). Improved versions of this document can be downloaded from: https://irp-cdn.multiscreensite.com/1bce804b/files/uploaded/diagnosis%20of%20soil%20related%20crop%20problems%20%28final%29.pdf or , if it does not work via www.goedbodembeheer.nl , look under " publicaties" , the second document.

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HOW TO USE THIS DOCUMENT

If you have an idea what the problem could be and how it could be solved, you can check if your ideas are supported by what is written in this document. You can find the relevant place in this document via the list of content. If you are already able to read a soil profile, but do not have a clear idea about the cause of a problem, you can start directly with Diagnosis of individual plants . If you are not an experienced reader of soil profiles, you could start with Quick scan of soil properties . Via links within this document and via links to internet sites you can deepen your understanding and check your hypothesis as far as necessary for the problem to be solved. **In a word-document**

you can type a letter just before a link to a place within the document before you follow the link. By " undo typing" or "Ctrl Z" you come back on the place you have left. In a PDF-document, notice on which page you are before you follow a link. You can go from that link back to the page you have left, via " page thumbnails".

ORGANIC AGRICULTURE

Organic agriculture is a social movement of producers, consumers and the people in between them (processers, transporters, marketers etc.). In the beginning the focus was on refraining from the use of agrochemicals and nowadays also attention is given to the realization of wider goals of sustainability (animal welfare, ecology, economy, society, culture , accountability).

Although worth to strive after, these wider goals cannot be claimed by the organic movement for itself, but the movement and individual farmers do guarantee that these goals are reached to a certain extent. In this document we focus on how a high production of food can be attained in a sustainable way without using agrochemicals to control pests, diseases and weeds and without using external inputs to improve soil fertility except some minerals. Ideally, an organic farm or a network of organic farms is self-reliant. That means that the unavoidable losses of nutrients in sold products are compensated not by using nutrients and organic matter from other farms/networks, but by weathering of primary minerals, recycling of unpolluted urban waste like struvite, deposition of sulfur and biological fixation of nitrogen and , if not sufficient, by all mineral fertilisers except artificial nitrogen fertilisers. Primary minerals can be imported of dug up from subsoil, more soluble fertilisers can be purchased. In reality, many organic farms are still using external inputs like feed, bedding material or manure from other farms, from conventional nearby farms (mainly straw and manure) or from organic farms far away (mainly in concentrates). In this way they also import residues from pesticides from conventional farms and enrich their soil at expense of organic farms elsewhere. Artificial nitrogen fertilizers are not used directly, albeit that they may be used indirectly via manure from conventional farms. Some farms are really Nevertheless, the organic movement as a whole is moving towards that ideal of self-reliant networks of farms. On a self-reliant farm high yields are only possible, if loss of nitrogen is minimised by proper management. Moreover, if loss of nitrate (an anion) by leaching is minimised, the loss by leaching of cations as Ca, Mg and K is reduced as well. If loss by denitrification is minimised by taking care of a sufficient aeration of the soil, leaching of bicarbonates of calcium, magnesium and potassium is reduced as well. There are many reasons to refrain from using huge amounts of artificial nitrogen fertilisers (pollution of environment, CO_2 emission during production, weaker plants, less nutritive food because of a lower content of micronutrients, more weeds, less organic matter input in soil via exudates and fine roots, less microbiological activity in soil), but there are not so many reasons to refrain from the use of small amounts of artificial nitrogen fertilisers for fine tuning the supply to the demand of crops. Some organic farmers consider artificial nitrogen fertilisers as a poison. That may be true for huge applications, but it is not so clear for small amounts. There are still two reasons to refrain from its use:1) it is difficult to determine in which situation how much artificial nitrogen fertiliser could be allowed to be used and 2) the capacity to fix nitrogen biologically in a network of farms that corresponds with a healthy consumption pattern suffices to attain sufficiently high yields if nitrogen losses are minimised by proper management. According my global calculations (see N flow diagram) it is possible in Europe and probably also elsewhere. By refraining from artificial nitrogen fertilisers farmers force themselves to minimise losses and to optimise nitrogen use efficiency (N in food/ N input).

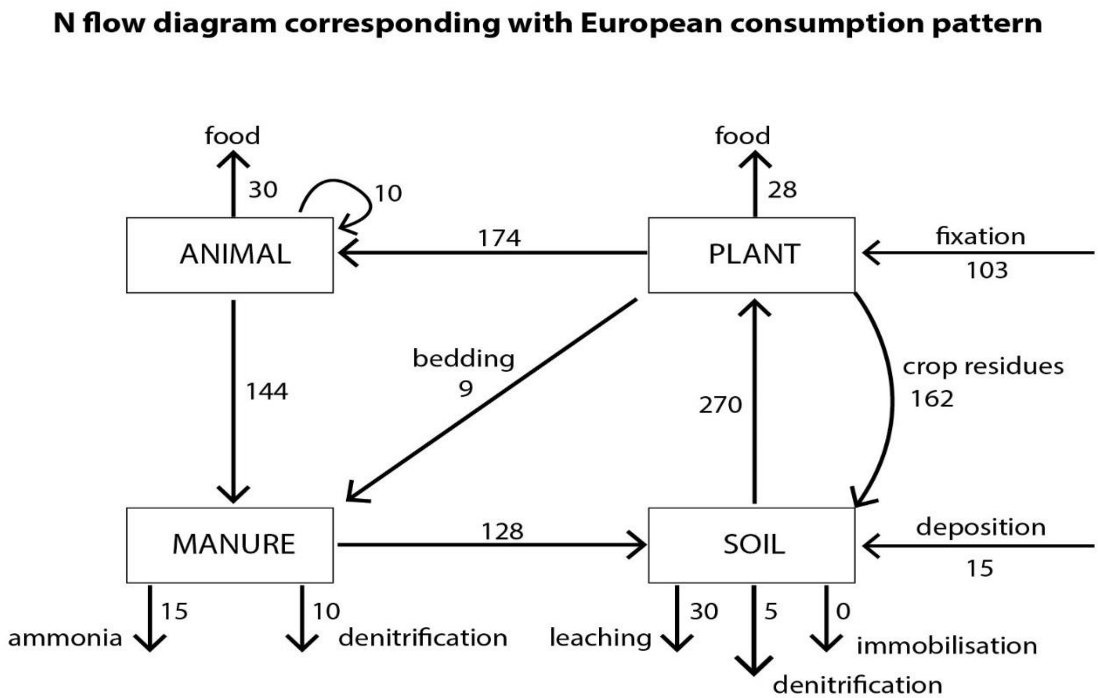


Figure 1: Flow of nitrogen in a farm corresponding to the current European consumption pattern with an achievable fixation of nitrogen and assuming a feasible and acceptable loss of nitrogen by volatilisation, denitrification and leaching

In the flow diagram of figure 1 the yields have been set at a level attained in reality without using pesticides , for instance cereals at 7000 kg/ha and potatoes at 45000 kg/ha (using the new varieties resistant to potato blight). Organic matter content is assumed to be in equilibrium with the farm system. For biological fixed N versus industrial fixed N see: https://moritz.botany.ut.ee/~olli/eutrsem/Crews03.pdf

Such high yields are only sustainable, if organic matter content, soil structure and availability of nutrients are sustained or improved and soil borne diseases are suppressed by the community of crops and micro-organisms.

An attainable yield level does not depend on soil properties only; also climate and plant properties play a role. It is the task of plant breeders, farmers and agronomists to find crop varieties and the proper management of them for a given climate and soil.

DIAGNOSIS OF INDIVIDUAL PLANTS

The first step is recognising that the growth of a crop could have been better. This is only possible if you have an image of what a crop could look like in a certain stage of its development. Such an image can be obtained by comparing performance of a crop within a field or with crops on other fields, within or outside the region with a similar climate.

In Auroville (https://www.auroville.org/) several organic farmers were growing tomatoes with disappointing results (low yield, many diseases, poor taste). One farmer was growing tomatoes on hydroponics under a shade net using tested seed from an international breeding company. He got much better results than his organic fellows. The difference in performance was a reason to figure out what was causing the difference: the variety, the seed quality, the substrate free of soil borne pests and diseases, the nutrition and irrigation and or the shade net.

The second step is unravel the causal clew behind an observed difference.

A low yield of eggplants on Java was caused by a leaf disease and this disease was caused by nematodes that had weakened the root system of the crop. The affected root system was the result of a narrow crop rotation of eggplants and similar crops (pepper, tomatoes). The farmer had grown these crops so often because they were the most profitable crops in his region (as long as enough kilos could be produced).

You can track causes of poor growth and development of a crop by direct observation of soil and crop, by interviewing the farmer and by carrying out simple experiments. Preferably, you start your observations and experiments when plants are young, because at later stages it might be more difficult to distinguish causes from consequences. Otherwise, you have to get information about what was done and had happened before by asking the right questions to the farmers. It helps if you have an idea, a hypothesis about the causes of problems and if you ask for phenomena or practices that fit and do not fit in your hypothesis. Try to verify and falsify your hypothesis and do not forget to ask the farmer for his judgement and explanation.

The third step is to find that solution between possible solutions which is feasible within the social and economic conditions and acceptable for the farmer.

The challenge in the case of the mentioned eggplants was to find a sustainable crop rotation and to get rid of these nematodes without reducing the profitability of that farm during and after the transition. Grafting a susceptible variety on a resistant rootstock or solarisation of soil (http://www.fao.org/3/t0455e/T0455E0f.htm) were acceptable options for the short term, but for the long term new crops had to be found suppressing the soil borne disease and making the crop rotation more profitable (because of higher yields) to widen the crop rotation.

FINDING CAUSES OF POOR PERFORMANCE.

DURING GERMINATION AND EMERGENCE

If emergence is disappointing or seedlings are too weak , go to Too low plant density and too weak seedlings

BETWEEN EMERGENCE AND FLOWERING

During this phase the crop should grow sufficiently without becoming susceptible for pests and diseases and it should develop a strong and extensive root system.

Cereals should develop sufficient tillers and ears with sufficient flowers. After emergence cereal plants form tillers and during the last phase of tillering (just before elongation of stems) the potential number of grains per ear is determined. The number of elongated tillers /plant and grains per ear depend on growing conditions, plant health and genotype. If not enough tillers and grains are formed during this phase, later measures to stimulate the growth will not help to compensate the poor start, because a too low number of grains can only partly be compensated by an increase of 1000-grain weight, which has its limits. .The percentage of tillers that elongate depends on the growing conditions and health of the crop when elongation starts and the percentage of grains that are filled depends on the growing conditions and health of the crop at flowering. It is difficult to indicate what a plant should look like (number of ears/m^2) without knowing the local circumstances and without experience in preceding years. Farmers can try to enhance this vegetative expansion and tillering little by little until they notice that they have passed an optimum (crops become easier affected by pests or diseases, lodging, weeds become a problem, taste decreases, not enough water is left for the filling of the grains/seeds etc.).

There are five primary causes of a poor growth/tillering: a shortage of 1) water and /or 2) nutrients 3) shortage of oxygen, 4) intraspecific (within crop itself) and interspecific competition (with weeds) between plants , 5) pests and diseases , soil borne, seed borne or air borne.

Interactions are possible and it is not always easy to find the main cause.

An excess of water may cause a shortage of oxygen making plants more vulnerable for soil borne diseases. A shortage of water reduces the mineralisation of organic nitrogen and also the transport of nitrogen to the roots and the crop may shows signs of nitrogen deficiency . I remember Faba beans were severely affected by aphids during a dry period.. A heavy rain storm did the aphids disappear.

How to find the main cause?

If weeds dominate over the crop: go to Soil related weed problems .

If pests and diseases are visible : go to Soil related Pests and plagues

When you know previous weather conditions , it is often not difficult to estimate if a shortage of water may have caused a poor vegetative growth : go to Availability of water. However, it is no reason to exclude other causes as soil borne diseases and a low soil fertility or a poor soil structure, as they may make that crops cannot use available water efficiently.

If the growth of a crop free of weeds, pests and diseases is disappointing , when the soil is still moist, the most usual cause is a shortage of nutrients as result of a poor chemical fertility (go to Availability of nutrients) or of a poor soil structure (go to soil structure) .

A shortage of oxygen may play a role if the soil is too wet, too compacted, if soil surface has been sealed and/or if too much of organic matter has been applied and the soil has a greyish colour, sometimes with rust mottles, and a bad odour. Go to Availability of oxygen in soil

You will notice that you will switch between these causes, as they are often entangled.

If you want to know to what extent a shortage of water or a shortage of nutrients play a role simple experiments can help to come to a better diagnose.

1. Keep a square meter free of weeds.
2. Like 1 and keep moisture content of a square meter close to field capacity. Depending weather conditions between 2 and 5 litres water/m^2 per day or14-35 litres/m^2 per week minus rainfall (1 mm = 1 litre/m^2).
3. Like 1 and keep moisture content of another square meter close to field capacity with a complete nutrient solution (available in supermarkets, follow instructions written on the bottle).

After a few weeks the performance and DM-yield of the 3 treatments can be compared. Check again if roots are healthy a few weeks after emergence (Affected root system).

It is important to compare the dry matter yields to avoid an overestimation of an effect of irrigation as result of a higher moisture content of the crop.

DURING FLOWERING AND RIPENING

After flowering has started less can be done to support a crop in its production, except irrigation and some extra fertilisation. Growing conditions during flowering have an influence of the number of seeds that will be filled. A crop like faba beans is flowering during a long period and is very susceptible for drought during flowering. New seeds are no longer formed if water availability becomes too low. After flowering the number of seeds cannot longer be influenced and the formed seeds can only be filled. The longer the filling period lasts the heavier the seeds grow, but there is a maximum weight for seeds.

Crops become weaker and more vulnerable when they start to fill the seeds/grains/tubers. They start to translocate nitrogen, phosphorus and sulfur from leaves and stem to seeds and by doing so they break down their capacity to photosynthesis. As soon as uptake of nitrogen from soil does not suffice the demand for nitrogen for filling the seeds/tubers, that translocation within the plants is accelerated. Roots die back and bacteria that decompose these roots (with a high C to N ratio) compete with the crop for remaining nitrogen. Drought does not only restrict evapo-transpiration of water and absorption of CO_2, but it limits uptake of nitrogen as well.

The main question after flowering and filling of the seeds/tubers/ roots is what could have done previously to keep a crop longer green, healthy and unaffected during that phase of filling the seeds/grains and tubers. The answer can sometimes be found within the field itself. By keeping an eye on emerging differences in a crop within a field during ripening and by observing the whole field from above (with a drone) it is possible to see where a disease breaks out, where weeds dominate, where crops start ripening earlier (and get a more yellowish colour). By comparing soil profiles you get an idea of the cause of the observed differences

Once a farmer showed me a yield map (automatically made during harvest) of a large field winter wheat. Three effects were visible: 1) yield was higher in former ditches (in the meantime levelled out and filled with top soil from elsewhere. These former ditches were visible on the yield map as straight lines), 2) yield was higher where wheat was grown after rape seed instead of after wheat (based on information of the farmer) and 3) yield was lower, where subsoil was sandy instead of clayey or peaty (this became clear after comparing soil profiles)

Patterns in a field are often- but not always- caused by patterns in soil properties and differences in cropping history. Remote sensing techniques help to monitor the reaction of a crop on different growing conditions within a field and to develop a site or field specific management of a crop (spacing, fertilisation, irrigation, in conventional agriculture : weed, pest and disease management) (https://en.wikipedia.org/wiki/Precision_agriculture). In organic agriculture site specific management is still to be developed, but the concept of site specific management fits well in the organic way of thinking.

Some site specific 'management' is even typically for organic agriculture, for instance: a nitrogen fixing green manure crops fix more nitrogen, where growing conditions (except availability of nitrogen) are better, usually on better soils, where the demand of nitrogen by the succeeding crop is higher. Another example is also related to nitrogen: in a pasture white clover stops fixing nitrogen where an animal has excreted its urine.

Many farmers have a global yield map in mind based on experience. They know where yields are lower or higher within a field. They may know if the differences between yields within a field depend on weather conditions. You can ask him to draw such a yield map by distinguishing good, moderate and poor fields within his farm and good, moderate and poor sites within his fields. It is a challenge to ask the right questions to be able to distinguish the effect of differences in soil properties and that of differences in cropping history.

CAUSES OF POOR PERFORMANCE

TOO LOW PLANT DENSITY AND TOO WEAK SEEDLINGS

When plant density is low, intraspecific competition between plants (= of the same crop) is less than at higher densities and individual plants grow taller and produce more. However, if there are not enough plants/m^2 the higher production per plant cannot compensate the production per m^2 in case of more plants/m^2. There is an optimal range of plant densities depending on crop, variety and growing conditions. This range is very wide for some crops

On a Dutch farm 70% of sugar beet plants sown with a precision sowing machine were eaten by insects, nevertheless he got a very high yield (100 ton /ha).

The importance of proper spacing is demonstrated by the results of the SRI-approach for rice (see: http://sri.ciifad.cornell.edu/) However, a low plant density gives more room to weeds and interspecific competition. So, in case of a low plant density mechanical weeding is required to get higher yields.

Farmers know more and less the range for plant density that is suitable for a crop under their conditions and they tend to avoid too low plant densities for cereals, pulses and oilcrops, because then weeds may get a good chance to flourish spot wise and to produce seed. However if growing conditions within a field are homogeneous and if it is possible to control weeds mechanically, it might be wise to go for a lower plant density to avoid a too strong intraspecific competition for water and nutrients between individual plants. It may result in a lower vulnerability for pests and diseases as well. Moreover, harvest index may increase where more soil water is left for the last phase: the filling of the grains. For root crops and vegetables the plant density can be used to give the crop a certain size: many cabbage plants per ha result in small cabbages etc. A wide spacing can compensate a low fertility or a low water retention of the soil.

There is always variation in emergence within a field. Farmers try to minimise this variation by using high quality seed, by preparing a homogeneous seed bed and by using precision sowing machines that put the seeds at a similar depth and distance into the soil. However, although they know the germination rate (under standard conditions), the weight of 1000 grains and therefore the amount of seed per hectare needed to arrive on average at the intended emergence and plant density, emergence may be lower than expected by the farmer, spot wise or over the whole field.

CAUSES NOT RELATED TO SOIL PROPERTIES:

1. Germination rate and vigour of seed were lower than expected and insufficient seeds were sown to compensate it. Germination rate can be tested by counting how much % of 100 – 200 seeds germinate on a moist tissue after a few days. Germination rate and vigour of germination decrease when seed is stored too long and/or stored at too high a temperature and at a too high relative air humidity (>70%). . Also insects like wheat weevils or diseases may have affected germination rate. Traces left behind by them can be seen by using a magnifying glass. Germination rate and vigour also depend on the conditions during ripening: plenty light, cool temperatures and dry conditions are favourable to get vigorous seeds with a high germination rate.

   > In 1982 I introduced seed produced in Europe in Cuntel, a small village at 1300 m altitude on a slope of the Merbabu volcano in Central-Java in Indonesia. The yield of the first generation of peas, carrots and leek was 3 to 4 times higher than that from locally produced seed, mainly because of their better health and in case of carrots and leek also because their higher water content (that made them less tasteful). Farmers reproduced the seed of peas (which was not a hybrid), but the second generation was a failure. It was not possible to maintain the vigour of the seeds under the conditions of the village.

   The bigger seeds (obtained by sieving) have often a higher germination rate and vigour

2. Mice may have eaten or collected seeds before emergence. Mice collect seeds to store them and not all of them are eaten. A part of them emerge in dense clusters. In Indonesia some farmers support and attract owls by placing observation post for them near nurseries for rice plants.
3. After emergence plants may be eaten by snails, slugs and other animals. Damage by snails and slugs can be reduced by keeping the soil bare for a few months (which increases the danger of leaching, erosion and sealing) or by growing a green manure crop that does not stimulate their propagation, for instance white mustard (*Sinapis alba*) and lacy phacelia (*Phacelia tanacetifolia*). There are molluscicides available that do not or hardly affect other life: bran mixed with iron phosphate. Especially crops like sunflowers which are sown in wide spacing may be heavily affected by snails and slugs. Pheasants, crows, and pigeons may thin out a crop. They find the seed under a just emerging plant. Damage can be avoided by sowing the seeds deeper: it makes the seeds less nourishing and less easy to find. On the other hand too deep sowing make plants more vulnerable to soil and seed borne diseases. Weighing the pros and cons is more based on experience than on reasoning. A hunting dog, an inventive

scarecrow, a strong bird repellent laser https://www.youtube.com/watch?v=jyaAv_y7Bog) or gun may help to keep animals away until the crop has developed so far that they cannot longer damage it.

4. Ducks, geese, hares and rabbits may graze a young crop and impede its growth. Also these animals have to scared off by a dog, laser or a gun to keep them away till the crop has developed sufficiently.

CAUSES RELATED TO SOIL PROPERTIES AND WHAT CAN BE DONE

Seedlings may be affected by soil borne diseases or insects, by a shortage of water or oxygen, by a too low temperature, by a too hard top layer or by a combination of them.

1. SOIL ORGANISMS MAY HAVE EATEN SEEDS AND SEEDINGS BEFORE EMERGENCE. Organisms like leatherjackets (larvae from Crane flies (Tipula paludosa) and wireworms: may have eaten seeds and young plants before emergence. Picture soil pests The species concerned can be identified by scrutinizing soil fauna. The population was built up during the preceding period. Grassland is a well-known source of such herbivorous insects. Crane flies seem to prefer clover to lay their eggs under. Also if the soil cover is far from tidy during the period when the insects lay their eggs (in Western-Europe: August-September).

   Growers in the Flevopolders in the Netherlands prefer to grow onions after grass-clover as they have the experience that less weeds emerge then and leatherjackets help them to control weeds between the onions. However, if there are too many leatherjackets they may eat the onions as well.

   Some crops may recover easily (peas for instance) and sometimes the pest is controlled by a predator or a pathogen (e.g. control of the larvae of the pea weevil by *Metarhizium anisopliae* http://en.wikipedia.org/wiki/Metarhizium_anisopliae). Another option is to grow a crop that is not preferred by the pest (for example onion) or to avoid the pest by ploughing out grassland early or by sowing an unattractive green manure crop like white mustard (also unattractive for snails and slugs). All these measures should be tested under local conditions before being applied on large scale.

2. EMERGING PLANTS MAY HAVE BEEN AFFECTED BY SOIL OR SEED BORNE DISEASES. If young plants die or when they do not grow properly, you should check the health of the roots by rinsing the roots in some water. Young plants should have intact white roots without rotten lesions or root knots. (see picture affected root system) If roots are affected, you could try to find out the source of the disease: soil or seed. The soil can be sterilised by cooking the soil “au bain Marie”: put and leave a closed pot filled with soil and a piece of potato in boiling water until the potato has been cooked. If the roots developed in such a soil remain healthy, the disease originates from soil and if not, from the seed. Some soils (usually acid or slightly acid clayey soils) may become toxic for seedlings after being boiled or steamed, because of a temporary excess of manganese. In such a soil the seedlings may grow even worse than in an untreated soil. Seed borne diseases can be reduced by a hot water treatment if seed is produced on the farm itself. Seed from a company should be healthy and if not, the farmer could look for another company.

   Hot water treatment has to be done very carefully and the right technique (temperature and duration of immersion); via internet you can find details). This method is sometimes combined with the use of all kind of extracts. See for example: http://www.growseed.org/seedtreatments.html,

   Soil borne diseases can be avoided by a combination of measures (see Affected root system).

   In Auroville (India) yield of rice increased year after year till it started to decline. Many roots were rotten. I had seen such a phenomenon in a similar soil (calcareous clay loam with a low iron content) in Indonesia, where a low redox potential caused by an almost continuous irrigation had resulted a suffocation of the roots. There a long dry period to “recharge” /oxidise the iron oxides (from ferro to ferri) sufficed to heal the soil. The farmer in Auroville was used to apply huge amounts of organic matter and I supposed that such amounts had caused a low redox potential. It took me much time to realise that this decline was not caused by suffocation, but by a soil borne disease. Usually, flooding is a way to get rid of soil borne diseases. In the case of Auroville erratic rain fall resulted in many dry periods in the rice fields and gave a soil borne disease chance to survive and to infect the roots system. The seedlings were already infected in the propagation beds. After the production system had been changed (propagation of seedlings in fresh soil, after puddling rice fields were kept longer flooded before planting and also during the growth of the rice plants the soil was kept wet) yields increased again.

On Java Amaranthus died immediately after emergence (damping off https://en.wikipedia.org/wiki/Damping_off). A student discovered that she could keep the plants healthy by applying some triple super phosphate just before sowing..

3. SEEDS DID NOT GERMINATE SIMULTANEOUSLY, usually because soil was drying and the top soil was too loose. Some seeds germinated after a rain event and some may have died because their roots could not reach the moist sub soil. If seeds did not emerge simultaneously and a part of them germinate after the soil has been moistened again, the early emerged plants may dominate the later emerged ones. Mechanical weed control becomes more complicated, because all plants need to have a certain size before they can withstand the action of a harrow or hoe. Also timing of harvest may become difficult. In a too loose sandy soil or in loamy or clayey soil that consists of loose clods, water does not flow from moist spots to drier spots, because there is no continuous network of fine pores that allows capillary transport. The fine pores are broken. From a cloddy soil more water is lost to atmosphere as wind has more access to soil. Moreover, in a temperate climate soil warms up in spring and evaporated water does not only diffuse in the direction of the drier surface, but also in the direction of the colder sub soil. If there is a network of continuous small pores, the water that has moved downwards due to the temperature gradient flows back to the top soil due to capillary rise and reduces the drying of the top soil. That water will also concentrate nitrate from lower layers in the very top soil and stimulate the germination of weeds.
   A proper preparation of the seed bed is the key to avoid such problems (After ploughing, disking or ripping the top soil should be slightly compacted by gravity and natural processes like freezing, thawing or drying, and rewetting or by judicious compaction (soil compactor) The finer the seed, the more precise the seed bed should be prepared. The seed should be pressed into a soil layer that remains moist by capillary rise of water from the underlying soil. See also Seed bed preparation:
4. A PART OF THE SEEDS AND EMERGING PLANTS MAY HAVE SUFFOCATED if soil was too wet, the top layer had been slaked and sealed and/or too much fresh organic matter had been applied. Usually, such a soil has a bad smell. Drainage should be improved and sealing should be avoided (How to deal with sealing/ slaking/capping and crusting) or incorporation of organic matter should be reduced.
5. A PART OF THE SEEDS COULD NOT PENETRATE A CRUST formed after the surface was sealed by rain or irrigation and this sealed top layer dried. (see:
   A fine seed bed makes a loamy and loamy sandy soil more vulnerable to slaking, sealing and crusting (http://www.fao.org/docrep/t1696e/t1696e06.htm). Picture:Sealing and crusting: How to deal with sealing/ slaking/capping and crusting
6. THE SEED WAS SOWN TOO DEEP. During their search for light seedlings loose energy and become more vulnerable for soil and seed borne pests and diseases. Some seedlings may die pre-emergence, other may get infected by a disease and die or wither post-emergence.

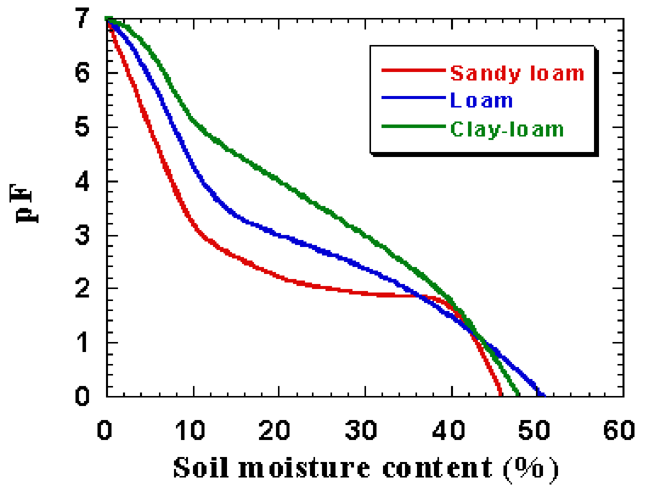
   In 2011 I visited the province Shandong in China. Wheat had been sown row after row by using a simple sowing machine. In some parts of the rows all plants were yellow and their roots appeared to be affected by *Fusarium sp*. After discussing all possible causes we came to the conclusion that only plants that were sown too deep were affected so seriously that they could not recover. About 2% of all plants in that region were affected and they always were growing in straight lines indicating that the soil borne pathogen was everywhere ready to attack weakened plants.

   Seeds may fall too deep in a loose or cloddy seed bed. Preparing a homogeneous seed bed and proper sowing (at the same depth) of homogeneous seed gives all plants a similar start and prevent weaker plants that do not grow well and lower the yield of the whole crop.
7. THE SEED WAS SOWN TOO LATE OR TOO EARLY UNDER COLD AND WET CONDITIONS. Then many young plants are affected by diseases before reaching soil surface and light.

   Some biodynamic farmers in Europe sow a part of their wintercereals “winternah” during the holy nights: between December 25th and January 5th . They do this to make the off spring of the crop stronger. I remember that the emergence of ‘winternah’ sown rye was low, but also that their off spring was clearly stronger than that from rye sown in October. This phenomenon may be the result of a strict selection of seeds: only the very strong seeds survived. Biodynamic farmers assume that also the period itself has an influence.

AVAILABILITY OF WATER

If soil moisture content is at field capacity (https://en.wikipedia.org/wiki/Field_capacity) , crops keep their stomata open, absorption of carbon dioxide is not reduced, uptake of nutrients dissolved in water is not reduced and also diffusion and mass flow of nutrients to root surface is not reduced. When soil becomes drier and soil water suction (pF) increases, uptake of water and nutrients becomes more difficult and plants reduce evapotranspiration by closing their stomata during the most drying hours of the day. The relation of pF and moisture content is described in a pF- curve. Only a part of all retained water is available for plants (moisture at field capacity (pF ≈ 2) minus moisture at wilting point (pF=4.2). In a sandy loam soil most of the water retained at field capacity is available for crop growth and in heavy clay soils only less than 50%) as can be seen from the form of the pF-curves for sandy loam, loamy and clayey soils (see figure).



pF as a function of soil moisture content
$pF = \log_{10}(-P)$, P in cm

On more sandy soils plants tend to waste water in the beginning of a dry period as the increase of soil suction starts flatly and increases more steeply after a substantial part of available water has been used.. This is one of the reasons why crops on sandy soils get earlier stressed by drought than on clay soils. On more loamy and clayey soils plants are earlier stimulated to adapt themselves to drier conditions by reducing evapo-transpiration and by developing roots in the sub soil. So more water remains for the last phase in crop development. In dry top soils less inorganic nitrogen, phosphorus and sulfur are released and also transport of released nitrogen to plant roots is reduced. Also rhizosphere priming (in top soil under pasture and natural vegetation) (http://wwwuser.gwdg.de/~kuzyakov/K-JPNSS2.pdf) does not release nitrogen anymore. So, drought does not only reduce the uptake of water, but also of nutrients. A shortage of water and nutrients may result in a higher concentration of free amino-acids in plant tissue making them more digestible and attractable for insects and fungi.
(https://www.researchgate.net/publication/280009828_The_Role_of_Drought_Stress_in_Provoking_Outbreaks_of_Phytophagous_Insects and https://edis.ifas.ufl.edu/pdffiles/HS/HS118100.pdf)

POSSIBLE CAUSES OF WATER SHORTAGE AND WHAT CAN BE DONE

1. TOP SOIL IS TOO LOOSE AFTER TILLAGE and loses its water too quickly to atmosphere and the sub soil (in a temperate climate by diffusion downwards in spring due to a temperature gradient without returning through capillary rise). When the top soil dries out, mineralisation of organic matter slows down and roots take more water from sub soil as long as possible. Availability of nutrients is usually lower in subsoil and growth is reduced

by a shortage of water and nutrients both. A too loose top soil should be prevented by compacting the soil sufficiently after ploughing.(soil compactor)

2. THE SOIL DOES NOT RETAIN ENOUGH WATER to enable plants to bridge dry periods without suffering too much (low production, pests, diseases, early maturity).
    a. Plants can be planted further apart, so that individual plants disposes of more soil and thus more water. A wider spacing gives weeds more chance to compete with the crop and to use the saved water. Therefore, a wide spacing should be accompanied by good mechanical weed control. Evaporation from soil surface should be reduced by creating a loose top layer of about 2 cm thick to stop capillary rise of water to soil surface.
    A farmer in the sandy area of Northern Germany could grow celeriac (a water and nutrient demanding crop) by using a wide spacing.
    b. In some soils it is possible to deepen the root zone by breaking plough pans, by opening compact subsoils. See also:Hard pan and picture Loosening of subsoil. Such a mechanical opening should be followed by growing deep rooting crops, preferably leguminous crops like alfalfa, honey clover to form a semi-permanent continuous network of wider pores, that can be used by succeeding crops. Ideally, sufficient anecic worms (www.earthwormsoc.org.uk/earthworm-ecology) are already present and they will help to make these wide pores more permanent. The pores are plastered with nutrient-rich material and that will stimulate roots to enter the subsoil. Such worm channels function as 'high ways' to the subsoil If the availability of nutrients like phosphorus and boron is too low in subsoil, leguminous crops will not develop much roots in the opened subsoil. A crop like alfalfa will even stop growing deeper if not sufficient boron is available in subsoil as boron taken up in top soil is hardly transported via phloem to the root tip. The top of the alfalfa crop will show signs of Boron deficiency during dry periods. In such a situation fertilisation with borax may help the alfalfa to explore the deep subsoil (a part of the borax will be leached to the subsoil). Subsoiling is an expensive operation and it is wise to check if fertilisation of the subsoil helps to create that continuous network of semi-permanent pores in the subsoil. A subsoil can also made more fertile and more convenient for roots by mixing a part of the top soil through the subsoil. In the long term mixing top soil through the subsoil will result in an increase of organic matter under the current cropping system (https://www.nature.com/articles/s41598-017-05501-y) ,but in the short term it may result in a lower release of nitrogen and a lower availability of nutrients in topsoil resulting in a lower production. In case of grass clover, clover will fix more nitrogen. If the pan was the result of compaction by heavy machinery, re-compaction should be avoided.
    c. Where perennial trees root deeper than annual crops, they can use water inaccessible for annual crops.
    Near Bobo Dioulasso in Burkina Faso some sandy soils are very deep, much deeper than exploited by annual crops. A tree like *Faidherbia albida* can reach the very deep subsoil via channels made by termites. This tree does not compete for light during the rainy season and takes water (and nutrients) from the deep subsoil during the dry period. If run off is avoided, the excess of rain (about 300 mm) infiltrates , is stored in deep subsoil and will be used by the *Faidherbia albida* trees during the dry season. During the rainy season they shed their leaves and crops can be grown under the (open) canopy. The trees fertilise the soil by dropping leafs, provide feed, honey, wood and shade for animals during the dry season. When number of trees is low, manure is concentrated where animals find shadow during the dry season.

    Some trees and perennial plants like *Meliotus offinalis* bring water from the sub soil to the top soil (https://en.wikipedia.org/wiki/Hydraulic_redistribution#Significance) Around 1920 J.F. van der Meulen found in a rubber plantation on Java Indonesia that the top soil remained moist under a thick cover of *Centrosema pubescens,* even after several months with rain. Without such a cover the soil was hard and dry. His observation was interesting and relevant, but his explanation (absorption of dew) was implausible and no attention was given to what he had observed.. After 60 years the proven process of hydraulic redistribution could explain his finding.
    d. Increasing the organic matter content results in a somewhat higher water retention. The effect of organic matter on available water is limited (between 0.2

mm (clay) and 2.5 mm (sand) per % organic matter in a layer of 10 cm. For instance: if in a layer of 30 cm top soil of a sandy soil organic matter content increases from 2% to 3 % (≈ 42 ton organic matter) only 7.5 mm water (= 75 m^3 /ha) extra is available. https://onlinelibrary.wiley.com/doi/pdf/10.1111/ejss.12475 There are many other reasons to increase organic matter content (stability structure, infiltration rate, release of nutrients, decrease of P fixation). On a self-reliant farm crop rotation has to be changed to increase organic matter content and that might be impossible in the economic context. If possible, it will take much time to increase organic matter content with organic matter produced within a farm. Increasing organic matter content results in an immobilisation of N,P and S and in a temporary decrease of availability of N,P and S. Deeper in soil organic matter decompose more slowly (more protection, no tillage, no high temperatures). Mixing sub soil with top soil , continuously by worms or from time to time mechanically will result in an increase of organic matter content in the whole soil profile. As a consequence crops may root deeper and the amount of available water in the whole profile will increase as result of the deeper rooting. https://www.ncbi.nlm.nih.gov/pubmed/26994321 and https://www.publish.csiro.au/sr/SR17039) See also Soil organic matter

e. Irrigation. There is much information available about irrigation. Here only a few remarks :
    i. Irrigation of infertile soils is not effective.
    ii. Nitrate can be leached from the rooting zone by excessive irrigation (by flooding and sprinkling) and nitrate can move laterally to drier soil, out of reach of roots, in case of drip irrigation and result in salinisation and a loss of nutrients by leaching after start of rains (as I have seen in California :picture).
    iii. Chemical compounds in irrigation water may improve or deteriorate soil: too much salt in combination with too little leaching results in saline soils, plenty calcium bicarbonate may increase soil pH and improve soil structure and availability of most nutrients as long as pH does not exceed 7, sodium salts will deteriorate soil structure and too much bicarbonates will make a soil alkaline .
    iv. Large scale irrigation may raise the groundwater table so much that an increasing capillary rise of (saline) groundwater speeds up salinisation of a region in case of insufficient drainage and removal of salts.
    v. Irrigation has also an influence on the occurrence of pests and diseases. In case of sensitive leafy vegetable crops like lettuce pF of top soil should be kept between 2 and 2.6 to avoid damage by aphids. Regular irrigation may keep soil and plant surface moist and may stimulate diseases like *Sclerotina solani* in lettuce (smet) to develop. In case of less sensitive crops a proper timing of irrigation may prevent pests to explode (for instance black bean aphid /*Aphis fabea* Scopoli /zwarte bonenluis).

3. CAPPILARY RISE IS IMPEDED.

A layer of coarse sand above groundwater level may impede capillary rise of groundwater to higher layers where the roots are and also impede roots passing to deeper soil layers. A layer of heavy clay or a clayey subsoil reduce the amount of water that can move upwards via capillary rise strongly because of its low permeability. Usually, it is very expensive or technically impossible to change texture of a subsoil.

4. **TOO MUCH WATER IS LOST BY RUN OFF**. When the top layer was sealed or compacted , the land is sloping (even slightly sloping) and rainfall is intensive, a part of the water may be lost by run off and may cause erosion. In dry areas such a loss should be minimised by breaking a crust just before the start of the rainy season, by avoiding sealing

or trampling by animals and by some kind of water harvesting in micro-catchment areas (http://www.fao.org/docrep/u3160e/u3160e07.htm) . Run off water can be collected in ditches or basins to infiltrate and to feed the groundwater. See also the "lakescape" or "water retention landscape " of Tamera in Portugal: https://www.tamera.org/water-retention-landscape/

If more water infiltrates than can be retained, nutrients may be leached. Leaching can be reduced by growing crops on ridges or hills. A part of the rain water will flow from the ridge into the furrow and from there to deeper layers without removing the nutrients in the ridge. A part of the water may move back to the ridge via capillary rise.

In Ivory Coast farmers make hills (bûtes) to grow their yams on. A part of the top of hill is covered with mulch. By doing so they concentrate fertile topsoil, allow a part of the rain water to infiltrate and reduce leaching of nutrients from the hills during the rainy season with an excess of rain.

Infiltration of water can be improved by increasing permeability of the top soil by

a. avoiding compaction of soil by machines or trampling animals,
b. avoiding sealing/slaking of the soil surface by leaving soil-protecting crop residues or mulch material from elsewhere and by feeding soil organisms that open soil surface again after a heavy rain storm.
   In Tanzania I met a farmer who was used to collect run off water, but after he started minimum tillage techniques and left residues on top of the soil, he could no longer harvest water because all water was absorbed by soil.

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5. TOO MUCH WATER IS LOST BY UNNECESSARY EVAPO-TRANSPIRATION.

a. From a moist soil exposed to sunlight evaporation is of the same order of magnitude as evapotranspiration by crops. In clayey and loamy soils capillary rise of water to surface may continue for quite some time. In sandy soils a dry layer is formed spontaneously that reduces this capillary rise. A loss of water from the top soil influences availability of nutrients negatively. By mulching with straw (small scale) or by shallow cultivation evaporation from the soil surface can be reduced.(60-70% by about 4000 kg straw mulch / ha).
b. Potassium helps plants to regulate evapotranspiration efficiently. (www.kno3.org/newsletter/html_pna_nl_1_12).
   In case of a shortage of potassium water is wasted.
   On sandy soils in the Netherlands with available water in sub soil grasses keep growing in a former urine spot during a dry spell and such a spot shows a lush growth of grass in contrast to the surrounding area.
c. Water use efficiency is higher in case of fertile soils. Although a lush crop uses more water than a poor crop per day, water use efficiency is higher in case of fertile soils: more dry matter is produced per mm water. In fertile and moderately fertile soils crops tend to develop a deeper root system than in poorer soils as well. Roots are searching for nutrients when they are formed and usually in fertile soils subsoils contain more nutrients including nitrogen leached from top soil. However, in very fertile soils crops do not develop much roots as long as the soil is moist. Moreover, a lush crop may leave less water for the critical period of filling seeds/grains.
d. Evapotranspiration is strongly related to the intensity of radiation . By providing some shade when radiation exceeds the level needed for maximum production water can be saved. In the tropics shade nets are used to protect vegetables and to avoid too much stress . Preferably, these nets are removed when radiation is no longer too intense (about 3 hours before sun set till 3 hours after sun rise). Shade can also be provided by growing shade trees and the degree of shade can be managed by choosing a species that fits and by pruning. Unfortunately, many trees may compete with crops for room, water and nutrients. Nevertheless, growing shade trees may be wise, because they have also other functions: fixation of nitrogen, recycling of nutrients, maintaining soil organic matter content, production of feed, fruit and wood, reduction of wind velocity.

e. Evapotranspiration is also related to wind velocity, especially where relative humidity of air is low . The drying effect of wind is reduced by planting wind breaking hedges perpendicular to the direction of the (main) drying winds. The effect extends about 15 times the height of the hedge. Such hedges need water too and besides they take up room (about 7% of area and water). Hedges have also other functions (prevention of wind erosion, production of wood, feed and fruit, shade for animals, increase of biodiversity, indication of borders, landscape building). Mechanised arable farmers prefer large fields to use their equipment efficiently and many trees and hedges have been removed in Europe.

f. By synchronising critical water demand and water availability.

An example from Western-Europe: by sowing wheat before winter instead of in early spring, wheat will flower earlier and use less water till flowering and more water is left for the period when grains are filled. This will result in a higher yield if there are no other limiting factors and enough grains were developed.

Development of modern varieties is mainly influenced by temperature sum and crops flower earlier if they are earlier sown. More water may be left to fulfill the needs during the last phase. However, early sowing before winter may result in a transfer of diseases , in more weeds that cannot controlled mechanically and may make crops more vulnerable for extremely low temperatures.

6. WATER UPTAKE IS IMPEDED BY AN INFECTION OF THE ROOT SYSTEM. (see: Affected root system)

AVAILABILITY OF OXYGEN IN SOIL

Uptake of water and nutrients is an active process and most plant species need enough oxygen around their roots to generate the necessary energy by oxidising carbohydrates. Also many micro-organisms in soil that decompose organic matter need oxygen. A suffocating root is not only inactive, but also more vulnerable and may be affected by diseases more easily. Earthworms cannot survive if a soil is saturated too long (in cold saturated soils they have a better chance to survive). High temperatures and incorporated fresh organic matter increase O_2 use and CO_2 production and the need for fresh air.

In extreme conditions soil atmosphere oxygen is almost or completely replaced by carbon dioxide and anaerobic bacteria start to dominate and they lower the redox potential (pE) so far that nitrate is reduced to N_2 and N_2O , ferri- and mangani-oxides to ferro- and mangano-oxides and even – in case of very low pE – sulfate (SO_4^{2-}) in sulfite (S^{2-}). H_2S itself is a poison, but it reacts with Fe => FeS. Released CO_2 reacts with water resulting in the weak acid H_2CO_3, that reacts with primary minerals, carbonates, clay and organic matter. Cations, mainly Ca^{++} and Mg^{++}, are exchanged for H^+ and concentration of Ca and Mg in soil solution is increased, so that in case of an excess of rain leaching of cations like Ca, Mg and K increases resulting in an impoverishment and acidification of soil.

In the Netherlands Rhine sediment contains lime and the lime content of the levees (close to the river , less heavy texture, higher in the landscape and better drained) is much higher than that of the backswamps (far from the river, heavy clay, lower in the landscape, impeded drainage during a long period), although the initial lime content of the sediment was higher there.

In well aerated soils CO_2 concentration remains low and O_2 concentration high, uptake of water and nutrients is not impeded and leaching of cations is low (as long as also nitrate, sulfate and chlorite concentrations can be kept low). A well aerated soil is usually a well-drained soil with a good soil structure. In such soils crops develop an extensive root system, that enables them to take up water and nutrients efficiently. See also soil structure .

Rice fields are an exception. These fields are conscientiously inundated and drainage is impeded by creating a nearly impermeable plough pan and by puddling the plough layer. In all soils, acid or alkaline, the pH is changed in the direction of 7 resulting in a higher availability of Phosphorus. Mineralisation of organic nitrogen is speeded up and results in an increase of adsorbed ammonium in soil, that cannot be leached because nitrate is not formed. Only near the soil surface some nitrate is formed, which is partly taken up by algae or the rice crop and partly denitrified after diffusion in the anoxic layer. Rice plants have a (limited) capacity to bring oxygen to their roots and the thin layer of surrounding soil of their roots.

POSSIBLE CAUSES AND WHAT CAN BE DONE

1. SEALING/SLAKING OF SOIL SURFACE may block the exchange of air between soil and atmosphere. The impact of rain drops may ruin the structure of upper 1 – 2 cm of soil. All particles are loosened (dispersed) and the bigger pores are filled with small particles and after a rain event the remaining small pores remain full of water due to capillary forces. After drying a hard crust stays behind. This crust may be too hard for germinating seeds to penetrate. Especially loamy fine sands and silty loams are susceptible for sealing. Clayey soils shrink and crack a bit after drying and sands do not form a hard crust. After emergence a crop protects the soil more and more against rains. On slopes a low permeability of the top layer may result in more run off and erosion. Sealing/slaking and crust formation can be avoided by protecting soil surface and improving stability of structure of top soil. Measures to avoid sealing can be found here: How to deal with sealing/ slaking/capping and crusting
2. COMPACTION OF TOP SOIL by heavy equipment or trampling animals reduces the portion of wider pores in soil, that are important for the distribution of fresh air in soil. In pastures grasses form a dense net of roots that improves the physical carrying capacity. A higher moisture content makes a soil more vulnerable for compaction.. A high moisture content may be the result of a high water table, a poorly permeable subsoil in combination with high rainfall (see below), soil texture (clay>loam>sand) and/or too little patience after a rainy period. A loosened soil is more vulnerable than a untilled well-structured soil . Axle load and tyre pressure determine to what extent a soil is compacted by a machine with a certain weight. (The axle load of a wheeled vehicle is the total weight felt by the soil for all wheels connected to a given axle). See further: How to improve a compact top soil

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3. LOW PERMEABILITY OF SUB SOIL

   Due to a poorly permeable layer in subsoil (a plough pan or impermeable deeper layers) drainage may be impeded. Downwards flow of water stagnates and top soil remains (almost) saturated with water during a long time. Long lasting stagnation of water may result in temporarily anoxic conditions in top soil indicated by rust mottles Picture rust mottles . In the poorly permeable layer itself grey or blue colours dominate. Such poorly permeable layers can have been formed by natural processes in the past: an almost impermeable rock, a pan formed by illuviation of humus or clay (heavier texture/ aggregates covered by a thin skin of clay), a clayey subsoil once deposited by a river, a dense red layer formed by accumulation of iron oxides or a hardpan cemented by silica or lime. They can also be the result of human activities. Ploughing and traffic with heavy equipment may result in a plough pan/ traffic pan, a compacted layer just below where soil is loosened by tillage operations. During ploughing the upwards power to lift soil is compensated by an equal power on underlying soil, that may result in such a compaction. This compaction is counteracted by the loosening effect of burying worms and other organisms and by swelling and shrinking as result of drying and re-wetting. In cold regions frost may play a similar role. If this counteraction does not suffice, soil may get into a vicious circle: compaction=>lower permeability=>longer wet and longer vulnerable for compaction and less worm activity => more compaction et cetera. If you dig a pit to 50 cm depth, such a compacted layer can be recognised. It is more dense, less easy to penetrate with a pin, penetrometer or knife than top soil (both at field capacity), the layer may show some rust mottles and roots bend sideways, where they touch the layer. Read further Plough pan and Compact sub soil below plough pan

4. HIGH WATER TABLE.

A high water table may reduce the air-filled pore space too much. Wet soils are usually used for grazing or rice production..

a. An excess of water can be reduced by a controlled run off. Fields, beds and ditches between can be given such a slight slope that excessive water flows away without causing erosion. The collected water should be discharged safely.

Pastures on heavy clay soils in the Netherlands were often given an undulating shape to promote run off to narrow trenches that drain the excess on ditches. In France some farmers plough their heavy clay soils in such a direction that excessive water can flow downwards through the furrows without causing erosion. In the tropics the very intensive rainstorms make it more difficult to manage the run off water via ditches to grassed waterways without causing erosion.

b. Where water flow stagnates because of a high water table or a deep almost impermeable layer (for instance a rock) drainage can be improved by a regulation of drainage: a system of drain pipes and ditches and a regulation of water level in the ditches. Usually, the design and realisation of such a system is done by specialised companies.

AVAILABILITY OF NUTRIENTS

Nutrients and water should be available in proper proportions and total required amounts depend on crop and its genetic properties. That is the idea behind Liebig's famous low of the minimum. (http://en.wikipedia.org/wiki/Liebig's_law_of_the_minimum). Organic manures from healthy and well fed animals and also green manure crops contain all nutrients more or less in the proper proportions. However, within self-reliant farms export of nutrients in products is not always compensated for by weathering of primary minerals, sulfur deposition and nitrogen fixation. A low availability of a certain nutrient in soil will result in a feed and subsequently in a manure that do not contain enough of that nutrient.

About 40 years ago nearly all young carrot plants were eaten by rabbits on one half of a field, whereas the other half was left unaffected. The boundary between both was a straight line in the middle of the field. About 10 years before these two fields were made to one field and the former different cropping and fertilizing histories had left their traces, which had such an influence on the taste of the carrots plants, that the preference of the rabbits resulted in that straight boundary in the field.

In such farms external inputs are necessary to overcome a deficiency. In Europe and especially in areas where animal production has been concentrated (like in the Netherlands) organic farmers were used to buy concentrates from far away and to apply large amounts of compost and manure (also from conventional farms) resulting in a high availability of most nutrients, but also in an import of residues of pesticides. In the near future farmers or networks of farms have to become more self-reliant for feed, manure and bedding material and are no longer allowed to use manure from conventional farms. Then, some mineral fertilisers will be needed to compensate the yearly loss in products and by leaching, if the natural weathering of minerals in soil does not suffice.

There are three approaches to find out if all nutrients are sufficiently available :

1. By a chemical or biological soil test
2. By a diagnostic field / pot experiment => Diagnostic field experiments
3. analysis of symptoms of deficiency => Symptoms of deficiency

SOIL TESTS

BY A SOIL TEST LABORATORY

A soil test laboratory is well equipped to carry out a reliable chemical or biological analysis of a soil sample. Representative sampling of a field is crucial and it might be obvious that an analysis of a composed sample of 20-40 sub samples from a visually homogeneous field of about 4 ha gives more precise information than one that should represent 100 ha of a heterogeneous field on the same farm.
A test is very useful if little is known about soil and requirements of crops and if you want to check whether improvements based on earlier tests were effective. In case of a well-known fertile clay soil that is fertilised in such a way that export of nutrients and decomposition of organic matter are compensated, it is not useful to test the soil more often than once per 5 - 10 years. In case of sandy soils and of crops with a high gross margin it is wise to test a soil more often.

The laboratory should be able to interpret the test results for conventional farmers. This interpretation can be conversed in an advice for organic farmers. Further reading: (see: http://en.wikipedia.org/wiki/Soil_test)

QUICK FIELD TESTS

SoilCares (http://www.soilcares.com/en) has developed two tools, mainly for agronomists, extension workers or big enterprises: " a scanner and a Lab-in-a-box, that bring the knowledge of their analysts and agronomists into the hands of the farmers in a quick, easy and affordable way. From the moment the soil is scanned with either the Lab-in-a-box or the Scanner, the spectrometry data produced by the spectrometers inside their technologies is started on a journey through several processes and checks until it is returned to the user as a soil status report".

Other, more simple tests can be carried out by an agronomist without support via the world wide web. The idea behind this approach is, that soil samples are taken from several fields with similar physical properties (texture, structure, colour), but dissimilar crop performances. These samples are analysed in a simple way (see: Chemical soil tests, quick, dirty and cheap.) and the comparison of the results with those of the best performing field gives an indication, which nutrients are insufficiently available.

DIAGNOSTIC FIELD EXPERIMENTS/POT EXPERIMENTS

Organic fertilisers contain already all nutrients, but not necessary in the optimal ratios for a certain field. Therefore it may be useful to carry out experiments with mineral fertilisers for diagnostic reasons.

By applying several combinations of nutrients it becomes clear what response combinations of nutrients give . For instance: if the response on treatment NPKS does not differ from that of treatment NPK, no special attention needs to be paid to the improvement of availability of S.

The effect of macro-nutrients (N, P , K, S) can be tested on small plots (1 m^2) within a field fertilised as usual (organically). Preferably, the tests should be carried out in a healthy (check roots) and young crop (with a height of about 10 cm) under favourable weather conditions. Soil should be moist, not wet. Select a strip within a field representative for the field and the condition of all plants within the strip should be similar. Within this strip fertilise small plots of 1 m^2 with

N: 25 g urea (45% N) per m^2

NP: N + 25 g TSP (triple super phosphate, 46 % P_2O_5/m^2)

NPK: NP+ 17 g KCl (muriate of potash, 60% of K_2O) /m^2

NPKS : NP + 20 g of K_2SO_4 (sulfate of potash, 50 % K_2O and 18% of S)

NPSKCa : NPK + 10 g $CaSO4/m^2$

NPSKCaMg: NPSKCa + 10 g $MgCl_2/m^2$

Check after 2 weeks and 10 weeks if you can observe clear differences between the condition of the plants on the plots. Write your observations down in this way: 0< N < NP =NPK< NPKS =NPKSCa=NPKCaMg. Interpretation: Addition of N has a clear effect, but addition of nitrogen plus phosphorus more than addition of nitrogen only. Et cetera.

If crop performance remain poor if all of these nutrients are applied, soil may lack micronutrients, be toxic, saline or soil may fix potassium or phosphorus too strongly. A lack of micronutrients can be tested by spraying 1% solutions on plants. You can make 1% solutions (= 10 g/litre) of the 6 important micronutrients by using Fe EDTA (only in case of alkaline soils), H_3BO_3, or borax, $MnCl_2.4H_2O$, $ZnSO_4.7H_2O$, $CuSO_4.5H_2O$ and $(NH_4)_6Mo_7O_{24}.4H_2O$

You can also take soil from a field and carry out simple pot test elsewhere. The weight of the top soil of 1 m^2= 1m*1m*0,25m* 1400kg/m^3 = 350 kg. So 25 g urea /m2 corresponds with 0.07 g/kg top soil. If you make a stock solution of 25 g urea/liter , you can add 0.07 g urea to 1 kg of soil by adding 2.8 ≈3 ml of the stock solution to 1 kg of soil. You can make the other stock solutions/suspensions (you have to crush TSP to make a suspension) in a similar way and add 3 ml to 1 kg of soil.

Such tests help to find the right direction to a more balanced nutrition of the crop. It does not give precise amounts of fertilisers that should be applied to get the highest yield and /or profit.

VISIBLE SYMPTOMS OF DEFICIENCY

During a field visit it is important to have an open eye for strange phenomena. A deficiency may be visible only in field edges, where the soil has been compacted or may become visible when the soil is drying more and more (for instance a shortage of Boron). In the rest of the field crop growth can be impeded without showing clear sign of deficiency. On internet you can find many descriptions and pictures of deficiency symptoms of crops.

Symptom	Element Deficient
older Leaves Affected	
Effects mostly generalized over whole plant, lower leaves dry up and die	
Plant light green, lower leaves yellow, drying to brown, stalks become short and slender.	**Nitrogen**
Plants dark green, often red or purple colors appear, lower leaves yellow, drying to dark green, stalks become short and slender.	**Phosphorus**
Effects mostly localized, mottling or chlorosis, lower leaves do not dry up but become mottled or chlorotic, leaf margin cupped or tucked	
Leaves mottled or chlorotic, sometimes reddened, necrotic spots, stalks slender.	**Magnesium**
Mottled or chlorotic leaves, necrotic spots small and between veins or near leaf tips and margin, stalks slender.	**Potassium**
Necrotic spots large and general, eventually involving veins, leaves thick, stalks short.	**Zinc**
Young Leaves Affected	
Terminal buds die, distortion and necrosis of young leaves	
Young leaves hooked, then die back at tips and margins.	**Calcium**
Young leaves light green at base, die back from base, leaves twisted.	**Boron**
Terminal buds remain alive but chlorotic or wilted, without necrotic spots	
Young leaves wilted, without chlorosis, stem tip weak	**Copper**
Young leaves not wilted, chlorisis occurs	
Small necrotic spots, veins remain green	**Manganese**
No necrotic spots	
Veins remain green	**Iron**
Veins become chlorotic	**Sulfur**

Source: Davies and Galston. 4th Edition. The Life of the Green Plant.

	N	P	K	Mg	B	Fe	Mn	Cu	Zn	Mo
Oat				x			x	x		
Wheat &barley				x				x		
maize	x	x	x	x		x	x		x	
beets					x		x			
potatoes			x	x			x			
Rape seed	x	x		x						
cabbage			x	x						
Sunflower/celery					x					
Alfalfa/ cauliflower					x					x
flax									x	

Plants that show a signal of a deficiency before other plants show them (from: Bergmann.W., Ernährungsstörungen bei Kulturplanzen, VEB Gustav Fischer Verlag Jena 1983).

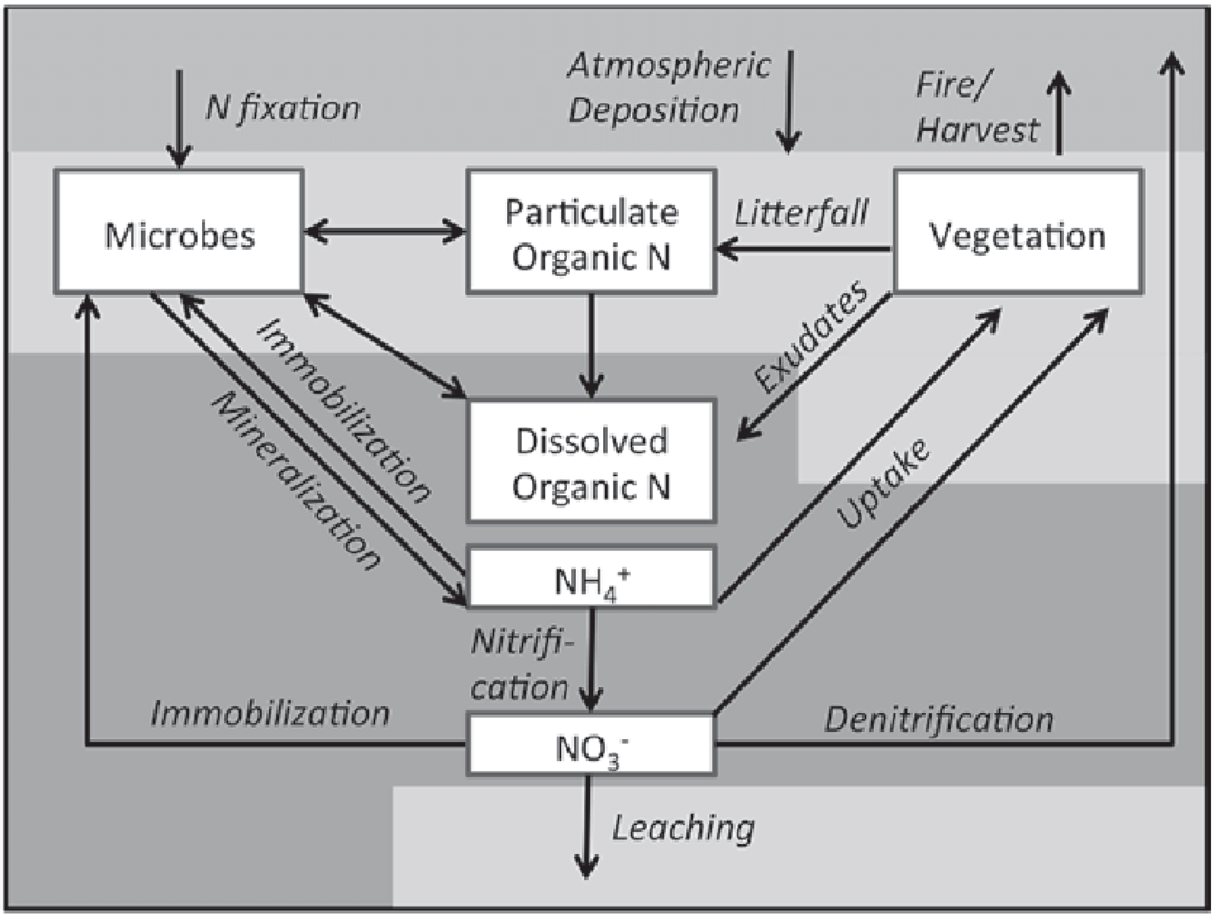
A hypothesis can be tested by painting a leaf or spraying a plant with an 1% solution of a soluble chemical of the nutrient in question.

Once I checked if rice, maize and faba beans had a deficiency of Zn. After spraying a 1% $ZnSO_4$ solution on the leaves , the plants gave a clear reaction. Also a suspected deficiency of Cu in tomato plants was verified after spraying a 1% of copper sulfate solution.

It is not always easy to distinguish deficiency symptoms from disease symptoms and often a weakened plant is affected by some disease or an affected plant may show symptoms of deficiency.

AVAILABILITY OF NITROGEN

The natural cycle of nitrogen (http://en.wikipedia.org/wiki/Nitrogen_cycle) has resulted in an accumulation of organic matter and organic nitrogen in soil. In the diagram below one arrow is missing: plants can take up some dissolved organic nitrogen.



Initially, agriculture was often based on mining these stocks of nitrogen (and of phosphorus and sulfur) built up by the natural vegetation. Organic agriculture aims to organise the cycle of nitrogen on a farm or within a network of farms in such a way that

- productivity is sufficiently high:(75%-100% of a conventional yield on a similar soil type)
- loss to environment is acceptable
- crops and animals remain healthy
- food is tasteful and human health is supported
- without mining the soil
- without using artificial nitrogen fertilisers.

These general aims can be elaborated for a specific farm within its environment. For instance : In the Netherlands by taking 50 ppm nitrate in groundwater as thresshold => leaching should be lower than 33 kg nitrate-N/ha,year to groundwater (as water excess ≈ 300 mm /year) if no denitrification in deeper layers occurs and volatilisation should be lower than 20 kg NH_3-N /ha to atmosphere) . Some farmers have to go a long way to realise all these aims and in many farms about 30% of the applied manure is imported from conventional farms. With this manure residues of all kind of agrochemicals are imported as well and organic farmers have good reasons to organise themselves in self-reliant networks of farms, no longer dependent on conventional farms. Within a self-reliant farm (or self-reliant network of farms) leguminous crops should fix enough nitrogen to fuel the whole farm or network of farms. Sufficient organic nitrogen and organic matter should be returned to the soil to maintain its fertility and in every field all processes in soil should be organised in such a way that losses are minimised and availability of nitrogen for all crops is optimised (sufficiently available at each stage of crop development) . This means an optimal course of inorganic nitrogen content during the year for each crop. Such a course differs from crop to crop. The organisation of all nitrogen flows is a learning process, through which each organic farmer has to go. The use of a computer program like NDICEA (https://www.wur.nl/en/Publication-details.htm?publicationId=publication-way-333438383436) may help a farmers to speed up their learning process and to understand better what is going on within their farms. The program can be dowloaded from (www.ndicea.nl). In the near future an improved version of that program will become available.

In NDICEA most nitrogen related processes are simulated on field level. The basic assumption is that transformation and decomposition of organic matter and release of inorganic nitrogen during decomposition is determined by amount and quality of all kinds of organic matter once added to soil, by timing of application and by environment (the fluctuating temperature, moisture content and pH and clay content). Recent research has made clear that plants may play an active role by stimulating the release or immobilisation of inorganic nitrogen. This process is called "rhizosphere priming effect" (http://wwwuser.gwdg.de/~kuzyakov/K-JPNSS2.pdf_) and it seems to play a role in organically managed grasslands and orchards. In arable land the process does not seem to play an important role. Usually, NDICEA simulates all nitrogen flows sufficiently precise to be used as a tool for a "what if "analyses: what would have changed if a certain measure had been taken at field level.

NDICEA is a tool to estimate nitrogen flows based on historical yields, weather data, soil properties and fertilisation. If calculated inorganic nitrogen contents are close (± 20 kg N/ha) to measured values, the calculated flows of nitrogen are considered to approach real flows of nitrogen. These flows are: release, uptake, leaching, denitrification and volatilisation of inorganic nitrogen and fixation and accumulation of organic nitrogen. By reducing losses and/or increasing fixation and import of nitrogen yields can be improved if the availability of nitrogen was the limiting factor. If the measured value differs too much from the calculated value, some parameters of Ndicea could be calibrated.

WHAT CAN BE DONE

TO INCREASE NITROGEN FIXATION

Leguminous crops can fix a lot of nitrogen, up to 450 kg N per ha and year, if conditions are optimal: sufficient water, a low availability of nitrogen and a high availability of phosphorus, potassium and micro-nutrients and a soil free of soil borne pests and diseases. The major part of leguminous crops are grown to feed domestic animals like cows . The fixed nitrogen by clover is partly (about 65%) recycled via manure (about 35%) and crop residues.(about 30%). Leguminous crops can be grown as green manure as well and in that case about 100% is recycled. How much of the recycled nitrogen can be used by crops, depends on how much is lost from manure by volatilisation and denitrification and from soil by leaching and denitrification. If leguminous crops are grown too frequently, vigour and nitrogen fixation may decrease as result of an infection by soil borne pests and diseases.

- Check pH and availability of all nutrients except N. Most leguminous crops prefer a neutral to slightly acid pH. Although leguminous crops may stimulate weathering of primary minerals and the release of nutrients, a high availability of P, S and K and micronutrients will ensure high yields.

In an Azerbaian field yield of lucerne increased 6 times from 2000 to 12000 kg dm/ha after application of phosphorus, molybdenum and cobalt.

- Check occurrence of soil borne pests and diseases (Affected root system) and if necessary, widen crop rotation.
- Inoculation of seed with Rhizobia sp. Inoculation with soil from a field where the same crop grows very well is also an option, if no effects of soil borne pests or diseases are visible.
- In climates with sufficient rainfall leguminous crops can be grown as a secondary crop with no other goal than improving soil fertility. Such a crop does not replace a food/cash crop, it is just used to fill gaps in between.

  A cover crop should be able to smother weeds. After harvest of cereal crops many weeds may remain, but availability of nitrogen is low. Undersown clover or grass clover is able to smother the weeds, if they were not weakened too much by a too heavy cereal crop and there is no shortage of water. Mowing will help them to dominate over weeds. After a heavy cereal crop leguminous cover crops like faba beans, vetch and peas, that have a quick start are a better option. Usually, a mixture of cover crops (leguminous and non-leguminous) is more able to suppress weeds.

- In areas with a short growing season growing leguminous cover crops for improvement of soil fertility reduces the area food crops. There a combination of growing pulses in combination with cereals and keeping poultry may be a profitable way to stimulate nitrogen fixation without losing an income by missing a cash crop.
- Irrigation of leguminous crops during dry periods.

  1 mm effective irrigation results in about 10 m^3 water/ha * 2.5 kg dm alfalfa (including roots/m^3water = 25 kg dm /ha and 0.04 kg N/kg dm * 25 kg dm = 1 kg fixed N /ha

- In fertile soils, where weeds would compete too much with pulses: grow leguminous crops in combination with cereals that keep availability of nitrogen in soil low. Such a combination will compete better with weeds.

TO REDUCE LEACHING OF NITROGEN BEYOND ROOT ZONE

Leaching of nitrogen beyond root zone is not only a loss, but may also cause pollution of groundwater and surface water. Not everywhere: where the deep saturated subsoil contains organic matter a substantial part of the leached nitrate is denitrified before it reaches surface water or aquifers that are tapped. Nitrogen is leached as nitrate, an anion that is always accompanied by a cation, usually Ca and Mg. Therefore leaching of nitrate beyond reach of roots results in an accelerated acidification of soil. However, a limited leaching of nitrate, namely from top soil into the subsoil till where roots can reach, stimulates crops to develop their roots in the subsoil resulting in a better use of all nutrients and water there. In case of soils that retain a lot of water (available water plus unavailable water) at field capacity, more rain is needed to wash nitrate beyond root zone after a dry period. So, nitrate is more easily leached from a sandy soil than from a clayey soil and more easily from a shallow soil than from a deep soil. Usually, overall leaching is lower in more structured soils (clay soils, channels of worms). In structured soils a part of percolating water flows downwards via wide pores and channels after heavy rains. This preferential flow of water leaves nitrate in the narrow pores in top soil, if water flows quickly to sub soil, but may speed up the leaching through top soil if artificial fertilisers are applied on soil surface. In sub soil the process is a bit different: as long as moisture content of subsoil is not at field capacity, preferential flow may not reach beyond rooting zone and all water in the wider voids and channels is absorbed by surrounding dry soil. As soon as moisture content there is at field capacity, preferential flow results in a faster transport of the nitrate taken up in top soil beyond root zone. Often, the concentration of nitrate is already low then.

1. INCREASE WATER AND NITRATE RETENTION.

a. Deepen the rooting depth. Before you try to deepen the rooting depth, it should become clear why plants and soil organisms themselves fail to deepen rooting depth. See also soil structure
   i. In case of a hard, almost impermeable rock there is no chance to improve rooting depth.
   ii. Sandy sub soils are often compact under the top layer with organic matter. Roots and soil organisms do not go much deeper. By loosening and fertilizing such a subsoil roots start to explore deeper layers and more water and nitrate is available, especially where water table can be managed in such a way that capillary rise of groundwater suffices to provide water to the crops in a dry period. Deepening of rooting depth is less effective on sandy soils where water table sinks so deeply that capillary rise does not play a relevant role in the supply of water.
   iii. By breaking hard pans (hardened by iron oxides, illuviated, tar-like organic matter or illuviated clay) and loosening underlying soil layers these layers can made (more) accessible. Such breaking and loosening should be completed by growing a deep rooting crop like alfalfa to create stable biopores. Often the pH of the hard layers is low and crops like alfalfa do not send their roots in an acid layer. It might be difficult and too costly to increase pH there.
   iv. Toxic sub soils are hardly to improve. If salt content is too high, the salt can be leached. If sub soil is too acid , it might be too costly to increase pH there.
   v. In case of loamy and clayey sub soils growing strong leguminous crops like alfalfa help to deepen the soil bit by bit. These crops keep growing during a dry spell because of their capacity to fix nitrogen and their roots enter the small cracks in sub soil formed when they extract water from subsoil.
   vi. Reduced tillage in combination with leaving enough crop residues may help increase the number deep burrowing anecic worms (nightcrawlers). The channels made by these worms are the highways to the deep sub soil. See also: http://www.sarep.ucdavis.edu/worms/
   vii. Usually, increase of organic matter content is not an option. It is difficult to increase organic matter content on a self-reliant farm, when crop rotation is not changed. Moreover, increasing organic matter content results only in a somewhat higher water retention: (see also: https://www.researchgate.net/publication/222544140_Effect_of_soil_carbon_on_soil_water_retention
      - Clay: about 0.2 mm per 1 % SOM in a layer of 10 cm soil
      - Sand: about 2.5 mm per 1% SOM in a layer of 10 cm soil.

2. SUPPORT PREFERENTIAL FLOW OF WATER by
   a. Avoiding the built up of a plough pan/traffic pan (Plough pan)
   b. Support the formation of deep channels by anecic worms and crops like alfalfa.
3. REDUCE NITRATE CONTENT IN SOIL LOW BY GROWING CATCH CROPS/green manure crops. See also: Growing cover crops
4. AVOID AN OVER-FERTILISATION by designing a proper crop rotation and distribution of fertilisers. All crops have their demands and provide succeeding crops nitrogen via crop residues. Theoretically, each crop can be characterised with its optimal course of available nitrogen in soil. NDICEA is a powerful tool to design a crop rotation, in which the course of nitrogen in soil suffices to realise (realistic) target yields without polluting environment and without mining the stock of organic nitrogen. During this designing it should be borne in mind that in reality nitrogen is not the only factor that determines yield level. Shortage of water, low plant density, weeds or diseases have also an effect on the yield level. Moreover, reality might be more tough then the ideal, for instance: sometimes a farmer has to refrain from growing a catch crop because weeds have to be controlled mechanically or soil might be too dry at the moment it should be sown.

TO REDUCE LOSSES BY VOLATILISATION

Ammonia (NH_3) volatilises during storage and composting of manure , from mulched crop residues (https://www.sciencedirect.com/science/article/pii/S2590162119300310) and from applied fertilisers (most manures) containing ammonium (NH_4^+) or easily decomposable protein (feather meal). A high soil pH (> 7), a high temperature and wind accelerate volatilisation.

1. FROM SOLID MANURE

- By separating urine from faeces as much as possible
- by minimising the time that fresh manure is exposed to the open air,
- by increasing C- to N ratio by adding straw
- by adding soil/clay to manure (1 kg soil/animal/day)
- by storing manure in a compact heap or even in a biogas plant
- by incorporation in soil as quickly as possible
- by application of manures during a rainy period (if soil is dry enough to avoid compaction and moist enough to avoid big clods that do not cover the manure sufficiently).

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2. FROM LIQUID MANURE AND SLURRY

- by adapting the feeding strategy (no excess of crude protein (<15% in dry matter of feed, urea content of milk lower than 20 mg urea/100 g milk).
- by reducing the time the manure is exposed to open air in stable
- by storing it in a tightly closed tank / bio digester
- by incorporation of liquid manure in soil.
- by application of manures during rainy period (if soil is dry enough to avoid compaction and moist enough to absorb the liquid.).
- By diluting liquid manure with water during application (at least 1 : 1, but the more water the better)
- by a controlled nitrification of ammonium by forced aeration of diluted liquid manure/digestate. If the liquid manure is added bit by bit to a tank that is aerated artificially, production of nitrate from added ammonium lowers pH below 6, enough to prevent volatilisation. The very diluted liquid manure could be used to irrigate crops. The liquid manure should contain as little as possible organic matter and the aeration should not be stopped, otherwise nitrate will be lost by denitrification. https://benthamopen.com/contents/pdf/TOWMJ/TOWMJ-3-1.pdf

3. FROM CROP RESIDUES

- by incorporating crop residues in soil. However, it might be difficult to incorporate such materials in standing crops or incorporation may not fit in a no- till strategy to improve soil structure or to preserve soil fauna.
- by choosing a green manure crop for mulching, that has a N content < 2.5% (https://www.sciencedirect.com/science/article/pii/S2590162119300310). Usually, C to N ratio decreases with age of the green manure crop.

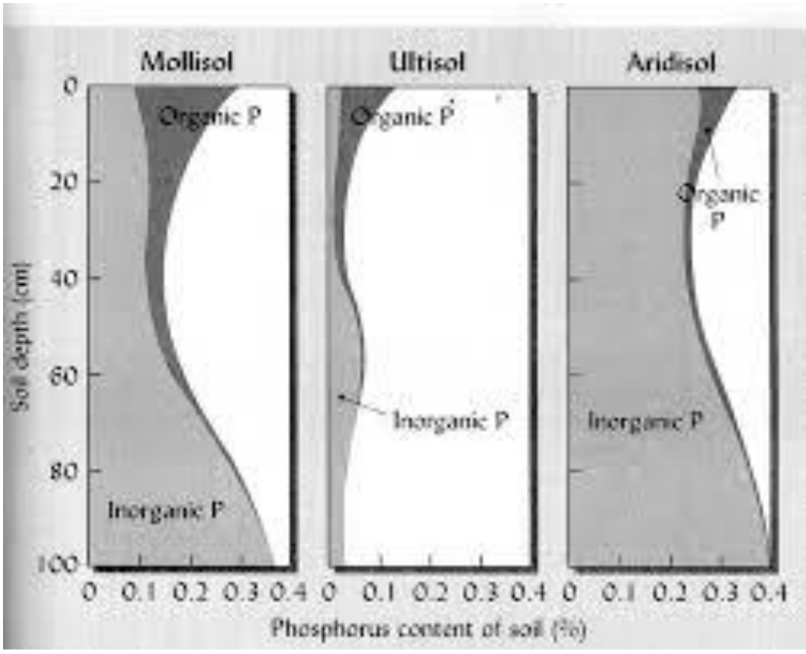
TO REDUCE LOSSES BY DENITRIFICATION

In well aerated arable soils denitrification is of minor importance. Denitrification occurs where inflow of oxygen does not suffice the demand of micro-organisms decomposing organic matter. This may happen in so called hot spots: small spots or layers with a high demand of oxygen like incorporated organic matter or layers with a poor aeration. The speed of the process might be high, especially when soil temperature is high. The process is difficult to simulate.

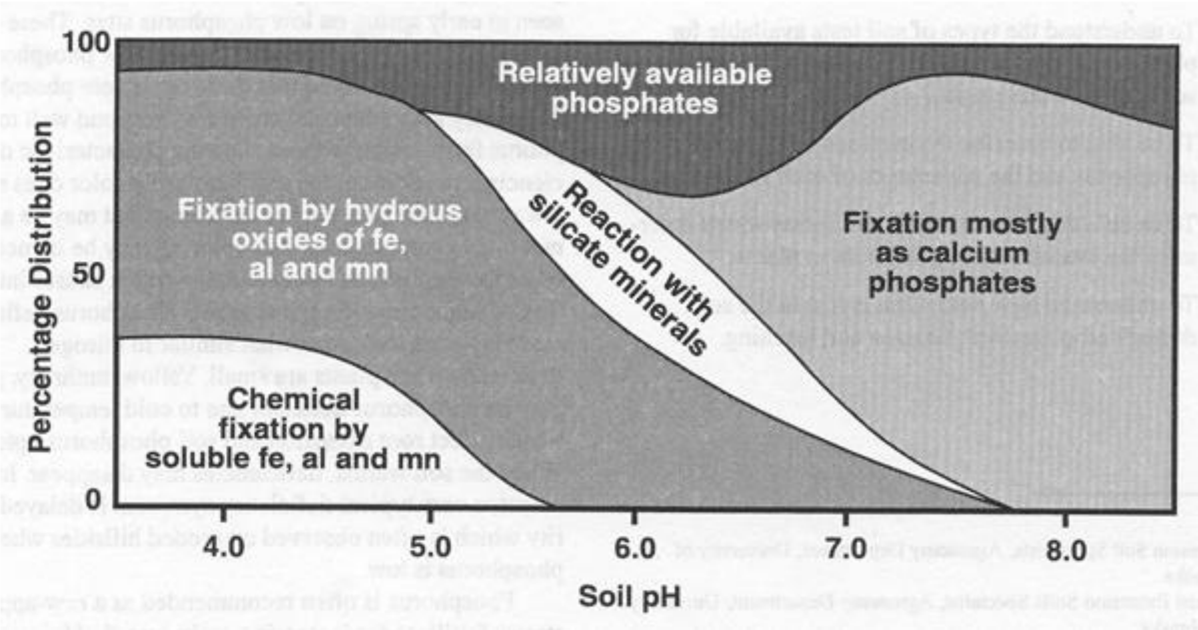
1. IMPROVE DRAINAGE of soil
2. PREVENT SEALING OF SOIL SURFACE (How to deal with sealing/ slaking/capping and crusting)
3. IMPROVE SOILS STRUCTURE soil structure
4. AVOID COMPACTION Compact top soil
5. AVOID DEEP INCORPORATION of too big amounts of green manure residues in layers. Mixing them through top layer helps to reduce denitrification. Incorporate crop residues and manure superficially
6. AVOID FREEZING OF GREEN MANURE CROPS by choosing winter hard green manure crops

AVAILABILITY OF PHOSPHORUS

Soils contain substantial amounts of organic and inorganic phosphorus. Under natural conditions plants transform inorganic phosphorus in organic phosphorus and accumulate it in top soil by taking P from subsoil and accumulating residues on or in top soil. Leaching of P is almost zero in most soils, but P can easily be lost by erosion and subsequently pollute rivers. Under a natural vegetation in a climate with an excess of rain the content of P decreases very very slowly (ultisol).



Every year a small part of the organic phosphorus is mineralised and this fresh inorganic phosphorus is taken by plants and micro-organisms or reacts with mineral components in soil. Phosphorus taken by crops is removed from soil by selling crop products or returned to soil in crop residues and via feed in manure (in faeces). Plants absorb inorganic phosphorus actively from soil solution and reduce its concentration so far that inorganic phosphorus compounds start to dissolve. Some plants are specialist in extracting phosphorus from soil: buckwheat and sweet potatoes in acid soils, cruciferous and leguminous crops on calcareous soils with a high pH. Availability of P depends of soil pH: the optimum is around pH = 6.5. In more alkaline soils P is bound by Ca and Mg and in more acid soils by Fe-oxides and Al-hydroxides. In many arid regions soils tend to become alkaline and in regions with an excess of rain soils tend to become acid as result of leaching. A strong binding of P is called fixation. In acid soils fixation of P is moderated by organic matter, that is fixed instead of P.



Plants can only extract P from soil close to their roots. Mycorrhizas may enlarge a root system and the long and tiny hyphae may enter fine pores in soil inaccessible for roots. Worms accumulate organic phosphorus in their castings and plants develop a more dense root system on such spots where availability of phosphorus is higher. P in clods of manure in a P fixing soil is protected against fixation. Plants may actively increase decomposition of organic matter and stimulate release of N, P and S by exudation of sugars (energy) (rhizosphere priming effect) .

On many organic farms (at least in the Netherlands) more phosphorus has been imported in manure than exported in products resulting in a substantial stock and a high availability of phosphorus. Sometimes resulting in a deficiency of Zinc and a P saturated top soil and loss by leaching. Such soils should temporarily be mined by minimising the P input and maxcimising the P output.

By growing grass clover it is possible to remove an excess of P , albeit that fertilisation with potassium and other nutrients may be necessary to keep the grass clover going.

In most soils the export has to be compensated by an import of phosphorus because weathering of inorganic phosphorus does not suffice to keep the availability at a sufficient high level. Soil tests may give an indication of that level, but the availability of P depends on more soil properties than how much can be extracted with some extraction solution (release of P from organic matter, mycorrhiza, specialised micro-organisms, soil structure, moisture content).

POSSIBLE MEASURES TO IMPROVE AVAILABILITY OF PHOSPHORUS

Total amount of phosphorus is low, P is too strongly bound by soil, C/P ratio of organic matter is very high and/or soil is hardly accessible for roots.

1. IMPROVEMENT OF SOIL STRUCTURE soil structure
2. SUPPORT MYCORRHIZAE by minimising soil tillage and maintaining an almost permanent cover of vegetation, preferably by a biodiverse vegetation of crops and cover crops.

3. INCREASE OF PH OF ACID SOILS . A raise of the pH results in a less strong phosphate fixation. The pH should be raised cautiously, because trace elements such as Fe, Mn, Cu and Zn may become insufficiently available for crops and structure of loamy and clayey soils might be negatively affected. The pH can be increased by applying crushed and milled lime stone, dolomite and rocks with mafic minerals like basalt. The pH neutralising effect of a ton rock dust is about half of a ton milled lime stone. By using rock dust nutrients are added and some CO_2 is removed from atmosphere (https://www.sciencedirect.com/science/article/pii/S221515321400004X)
4. DECREASE OF PH IN ALKALINE SOILS (pH> 7.5). In such soils leguminous plants reduce pH just around their roots resulting in a higher availability of phosphorus around these roots. Also fertilisers like urea and ammonium sulfate lower the pH after nitrification of ammonium-N. It is a special subject how to deal with severely alkaline soils (pH > 8).
5. APPLICATION OF INORGANIC PHOSPHATE FERTILISERS. In organic agriculture the use of natural (= crushed and milled, but not chemically treated) rock phosphate is preferred above that of chemically treated phosphate minerals. The treatment of the rock phosphate is done in soil by crops and micro-organisms. However, TSP and DSP are no poisons and do not affect soil negatively if they are used with caution. In soils with a pH > 6.5 it is more efficient to use Tripel Superphosphate (TSP) or Double Superphosphate (DSP than rock phosphate. In soils with a S deficiency DSP (containing S) should be preferred above rock phosphate or TSP. availability of sulfur. As some natural rock phosphate contain toxic substances like cadmium, it is better to use treated P fertilisers with a guaranteed low Cadmium content than a natural rock phosphate with an unknown content of Cadmium. Soil test laboratories should be able to give an indication how much phosphorus has to be applied to get a higher yield. Usually, yields are improved step by step and amount of P fertilisers is adapted to the higher yields and an increasing availability of phosphorus. If amounts cannot be based on soil tests and there is a clear P deficiency, the amount could be 200% of P demand at the intended yield level and in a crop rotation most P could be given to more demanding crops like potatoes and vegetables.
6. IMPORT OF ORGANIC PHOSPHORUS. All animal feces contain phosphorus, especially chicken manure contains a lot. In regions with an excess of manure (like the Netherlands) organic farmers were used to use manure from conventional farms to ensure a sufficient supply of nitrogen. By doing so they have accumulated phosphorus in their soils.. By supplying sufficient N to their crops they gave unintendedly too much P, because a part of N is lost during storage and application. Nowadays they have to reduce the import of P and to increase on farm nitrogen fixation. In many other regions there is still a shortage of P. There importing feed or manure from elsewhere will improve availability of P and the yield of succeeding crops, albeit it at expense of the availability of P elsewhere.
7. CREATION OF HOT SPOTS, where more P is concentrated and more available and will not be fixed mineral compounds in soil. Such hot spots are created by worms and can be created by placement of composted manure, compost or mineral P fertiliser near young plants or in planting holes. http://www.ipni.net/publication/bettercrops.nsf/0/43A9E1C196950166852579800082O189/$FILE/Better%20Crops%201999-1%20p34.pdf
8. INCREASE OF ORGANIC MATTER CONTENT TO REDUCE FIXATION, to increase release of P in the long term, to improve soil structure and to support the positive rhizosphere priming effect. However, during building up of organic matter content the accumulation of P in organic matter may result in a temporarily lower availability of P, because soil organic matter contains about 0.5% P.
9. INCREASE OF C/P RATIO OF ORGANIC MATTER to increase release of P and to support rhizosphere priming effect by P supplements in feed to animals, by mixing phosphate rock dust through material to be composted and by growing crop and green manure crops, especially green manure crops that are more able to extract P

from soil (cruciferous and leguminous crops on alkaline soils and buckwheat on acid soils).

10. REDISTRIBUTION OF ORGANIC PHOSPHORUS. Phosphorus might be extracted from grazing land and collected in stables or corrals, where animals are confined during the night and winter/dry periods. Often this phosphorus is applied on arable land close to the farm buildings.

    In archaeology a local high content of phosphorus is seen as an indication of a former settlement. In the Betuwe in the Netherlands many former Roman settlements contain still much more P then the surrounding fields. In the Friesland and Groningen former settlements, that had become hills, were dug away to use the soil as a fertiliser elsewhere. Terra preta in the Amazon Basin is the result of such an accumulation. In Ethiopia near Debre Zeit much nutrients are accumulated in the village: all teff ,including straw, was transported to the villages and after threshing the straw is used to feed animals. The manure is not returned to the field. I met a farmer who was almost drowning in all the manure around. Also in Ghana near Tamale the most fertile soils are found in the villages around the houses. They have a dark colour and contain much organic matter due to all manure. These soils are hardly used, only a few tobacco plants are grown there. The soil under sacred groves are also very dark and must be very fertile. I got the impression that these groves were abandoned villages. Unfortunately, it was not allowed to dig a pit in these groves..

AVAILABILITY OF POTASSIUM.

Plants should absorb sufficient potassium, not only to be productive, but also to be more resistant to drought, pests and diseases https://www.cropnutrition.com/soybean-aphids-flourish-where-potassium-is-deficient and to use water more efficiently (http://www.kno3.org/newsletter/html_pna_nl_1_12.html) Sufficient potassium influences taste and colour of fruit and vegetables positively. Leguminous plants need sufficient potassium to be able to supply nitrogen to the whole farm. Primary minerals like feldspars (Orthoclase) and mica contain potassium. On average they are abundant in rocks, but not all soils contain enough feldspars and mica to keep availability of potassium sufficiently high. Potassium is slowly released by weathering of these minerals. This weathering is intensified by plants and micro-organisms in soil. A big part of the potassium taken by crops is returned via crop residues and via manure. It can also be washed out of living leaves. Animals excrete about 80% of the taken potassium in urine and 15%-20% in faeces. Seeds, meat and milk do not contain much potassium, but roots, tubers and vegetables contain a lot. Clay minerals adsorb and exchange potassium from and with soil solution. Clay minerals adsorb potassium strongly, usually more strongly than calcium and magnesium. (see also: http://www.soilminerals.com/Cation_Exchange_Simplified.htm Potassium is therefore not easily lost by leaching if soil contains clay minerals. Organic matter adsorbs potassium as well, but less strongly than clay minerals. There should be a certain balance between available/exchangeable K, Ca and Mg to keep plants and animals healthy. A too high availability of potassium impedes the uptake of Mg and Ca and vice versa. https://agricultureandfoodsecurity.biomedcentral.com/articles/10.1186/s40066-018-0165-5

If export plus leaching of potassium exceeds import and weathering, availability of K decreases. Leaching occurs in case of sandy soils, especially where potassium has been accumulated by farmer. Potassium can be accumulated somewhere within a farm/region/world if manure is not evenly returned to all the land, where feed crops were grown.

In the Netherland regular application of liquid manure (mainly urine) on fields close to stables resulted till about 80 years ago in a high K/Mg ratio in grass with grass tetany for livestock as consequence.

Potassium can be lost from manure heaps on field edges by leaching and wringing out (by its own weight) resulting in a local excess of potassium in case of clayey soils and leaching in case of sandy soils. Growing and selling vegetables, root and tuber crops and growing alfalfa and grass without returning the produced manure result in high export of potassium.

POSSIBLE MEASURES TO REDUCE LOSSES

1. REDUCTION OF LEACHING. Leaching of potassium in case of sandy soils can be reduced by growing catch crops(Growing cover crops), by proper collection and redistribution of manure (Manure and its proper handeling)and by limiting the hours that animals graze just before or during a period of leaching (a long period with an excess of rain).

   According a sophisticated simulation model some potassium and much more calcium and magnesium was leached from the urine patch after excretion of urine by an animal on a shallow soil derived from a granite in the Alentejo in Portugal, because the K in urine was exchanged with Ca and Mg adsorbed by clay and organic matter.

2. GROWING LESS POTASSIUM RICH CROPS (= less leafy crops, roots and tubers) that will be sold. This approach is likely far from profitable for growers of potatoes and vegetables. Farmers that grow and sell alfalfa should take into account the consequences for the availability of K (and P).

POSSIBLE MEASURES TO IMPROVE AVAILABILITY OF POTASSIUM

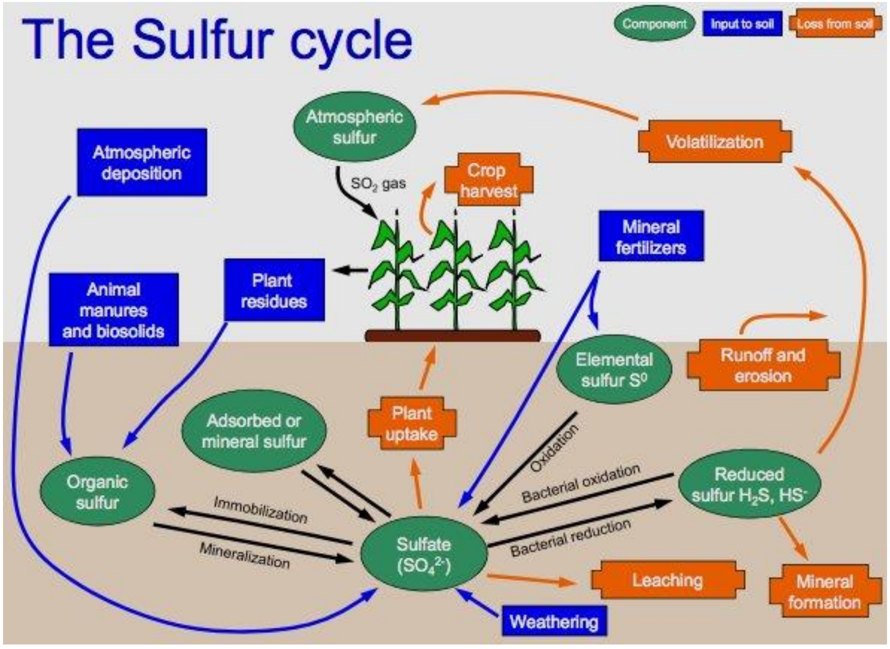
1 STIMULATION OF WEATHERING. If the soil contains feldspars, mica or the clay mineral illite growing alfalfa, grass and beets to feed livestock will result in an intensified weathering and may result in a higher availability of potassium if manure is properly collected and evenly returned to the soil of the whole farm and export does not exceed weathering.

2 IMPORT OF FEED, BEDDING MATERIAL AND MANURE. Potassium content of manure depends on applied feed: more leaves and beets=> more potassium. Organic farmers prefer deep litter stable, where a large amount of straw is needed to keep the animals clean and healthy. If not all the straw can be produced on the farm, a substantial amount might be imported. In this way not only organic matter, but also a substantial amount of potassium might be imported. However, straw from conventional farms may contain residues of pesticides as well. Another option is purchasing organic fertilisers like vinasse and proto-amylase (that may contain residues of pesticides) and inorganic fertilisers like potassium sulfate and potassiumchloride. Inorganic potassium fertilisers are not poisonous, but they contain more anions than will be taken up by crops. Most of the excess is not adsorbed by soil and will be leached together with cations like calcium and magnesium.

3 MORE PRECISE FERTILISATION On sandy soils crops should be fertilised based on their demand for the intended production Almost all potassium in organic and inorganic fertilisers becomes available within one growing season. In case of a shortage each crop could get 30% more than it needs to build up a reserve within the soil adsorbed by the organic matter. On loamy and clayey soils even all potassium needed to balance import and export at the level of the whole crop rotation could be given to most demanding and susceptible crops (vegetables, root and tuber crops and leguminous crops). If there is a shortage two times the amount they need could be applied to build up a reserve on these soils.

4 IN CASE OF POTASSIUM FIXATION: ADAPT CROPS TO AVAILABILITY OF POTASSIUM Some heavy clay soils (not all of them) fix potassium strongly resulting in a poor performance and poor response in a field test even if all nutrients are supplied. Moderate applications do not have much effect. In such situation it is often more profitable to adapt crops to the soil than the soil to the crops. For instance permanent grassland, that will not be ploughed and where in the very top layer availability of potassium can be improved by fertilisation with moderate applications of potassium.)

AVAILABILITY OF SULFUR



The sulfur cycle is similar to that of nitrogen. Organic sulfur is mineralised into sulfate, that can be taken up by plants, leached by percolating water or reduced into sulfide in case of extreme anaerobic conditions (H_2S is toxic for plants) deeper in soil. Via manure and crop residues a substantial part of the sulfur in plants returns to the soil in organic form. Leached sulfate accumulates in swamps, peat, saline soils, in sea water and anaerobic marine sediments after reduction into sulfide that is strongly bound by metals like iron. Only a small part of the sulfide escapes from soil by volatilisation. The somewhere accumulated sulfides return in the cycle of life, when those sediments become aerobic again after reclamation of the land by man, after burning of coal and oil, after been lifted by geological forces or after an eruption of a volcano.

After draining marine sediments in the Netherlands (black) FeS was transformed in (red) Fe-oxides and sulfuric acid. This acid reacted with the lime (from shells) resulting in gypsum (Ca-sulfate), that is more soluble than Ca-carbonate. The higher concentration of Ca-ions in the soil solution resulted in a replacement of adsorbed sodium by calcium and in a leaching of sodium instead of calcium. The adsorbed Ca gave a clay soil a good structure. Under natural conditions the land was flooded more often resulting in a repeated addition of sodium and sulfur. After the stock of lime was exhausted the sodium replaced the adsorbed Calcium resulting in a poor soil structure.

There is a continue supply of sulfur by deposition via air, but the amount differs from place to place: more near the sources: volcanoes, industrial centers and oceans and less far from these sources. Sulfur demand of most plants is about 10% of its demand of nitrogen (in kg).

Till recently S-deposition in Europe exceeded the demand of crops resulting in accumulation of organic sulfur and leaching (and acidification). After the deposition had been reduced, the stock of organic sulfur is diminishing year after year in case of a negative S-balance till availability of sulfur becomes critical. In remote areas far from S sources S deficiency is a common problem.

Some extreme soils (red, acid, old volcanic sediments that contain the clay mineral allophane) fix sulfate resulting in poor response to a moderate S fertilisation.

I visited a farm on the slopes of the mountain Kilimanjaro in Tanzania. Farmers got many years good yields, but after about 50 years yields declined. They had mined the organic stock of nutrients. One of the nutrients that had to be supplied to get good yields was sulfur.

Farmers on the vulcano Merbabu in Indonesia were using expensive ammonium sulfate instead of cheap urea. They discovered that ammonium sulfate was more effective than urea without knowing that they were compensating the strong fixation of sulfate by allophane.

POSSIBLE MEASURES TO IMPROVE AVAILABILITY OF SULPHUR

1 REDUCTION OF LEACHING BY GROWING CATCH CROPS.

See also Growing cover crops

2 IMPORT IN FEED, BEDDING, MANURE AND INORGANIC FERTILISERS. All organic manures contain sulphur. The uptake of S is about 10% of the N uptake. Demand of potassium exceeds demand of sulfur and if potassium fertilisers like K_2SO_4, and patentkali ($K_2SO_4.MgSO_4$) are used to improve availability of potassium, more sulfur might be applied than necessary. Gypsum ($CaSO_4$) can be used where availability of potassium is high. It is a source of sulfur during a long time, because its low solubility and it improves and stabilises soil structure of clay soils. In conventional agriculture 20% of required nitrogen could be applied as $(NH_4)_2SO_4$ to meet the requirement for sulfur.

3 USE LOCAL SOURCES Locally sulfides can be found in bottoms of swamps, peat soils, lakes, ponds, slowly streaming ditches that remain anaerobic during the whole year. However, if there is a deficiency in a region, much S cannot be expected there. The mud contains other nutrients as well.

AVAILABILITY OF CALCIUM AND MAGNESIUM

Availability of Ca and Mg should be considered together because of their different effect on soil structure and because of the antagonism between them in plant nutrition. Ca and Mg are both adsorbed by clay and organic matter and there is an equilibrium between adsorbed and dissolved Ca and Mg. See also : http://www.soilminerals.com/Cation_Exchange_Simplified.htm. Adsorbed Ca has a more positive influence on soil structure of clayey and loamy soils then Mg. Both have a positive influence on the stability of soil organic matter. A deficiency of Ca for plants is rare, but some clay soils may contain too much exchangeable Mg. A Mg deficiency may be the result of a low content of exchangeable Mg and of an antagonism with Ca and also with K. A soil test laboratory should be able to indicate whether the ratio between $Ca_{exchangeable}$ and $Mg_{exchangeable}$ is acceptable from the viewpoint of its effect on soil structure as well as from the viewpoint of their availability for plant nutrition. The $Ca_{exchangeable}/Mg_{exchangeable}$ should exceed 2. The optimal range of this ratio is between 5 and 7. In soils that contain primary minerals or carbonates, the ratio between Ca and Mg is determined by present minerals. Some contain more Ca or Mg and some weather faster than other minerals. This ratio can be changed by adding new minerals, for instance dolomite (a Ca,Mg carbonate) to increase availability of Mg for plants and pure Ca bicarbonate, Ca hydroxide or even gypsum (calcium sulfate) to improve soil structure and/or availability of Ca. Leached nitrate, sulfate and bicarbonate anions are usually accompanied by Ca and Mg cations. Leaching of both is increased by an excess of nitrate and by a high carbon dioxide production in soil and a poor aeration. Leaching of Ca and Mg results in a (slow) acidification of soil. Carbonates of Ca and Mg are used to increase soil pH of acid soils . In acid soils also other rock dusts can be used to increase pH and to improve availability of Ca and Mg.

POSSIBLE MEASURES TO IMPROVE AVAILABILITY OF CALCIUM AND MAGNESIUM

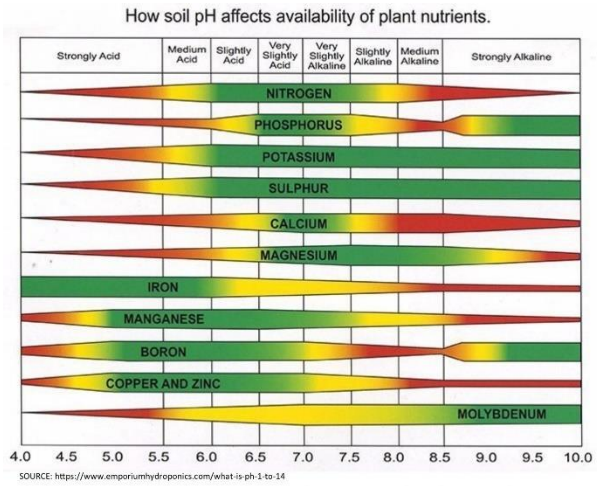
1. CLAY SOILS WITH A PH AROUND 7 that have a poor soil structure because of too much adsorbed Mg can be improved (by applying gypsum (calcium sulfate). Usually considerable amounts are necessary and in remote areas where the costs of these products are high, it is wise to find out if structure can be improved sufficiently without these amendments (more organic matter, minimum tillage, mulching with crop residues).
2. IN SLIGHTLY ACID (6<PHWATER <5) AND ACID (PHWATER< 5) SOILS availability of Mg can be improved and pH can be increased by amending dolomite (Ca,Mg carbonate) or olivine dust. Structure of acid ($pH_{water}<5$) soils that contain many iron oxides and the clay mineral kaolinite, may lose its stability if pH is increased too much.
3. IF PH SHOULD NOT BE CHANGED, availability of Ca and Mg can be improved by applying Ca-sulfate and/or kieserite ($MgSO_4 \cdot H_2O$) respectively.

AVAILABILITY OF MICRO-NUTRIENTS

Micro-nutrients play a major role in many enzymatic processes. A shortage of a micro-nutrient has a tremendous impact on crop performance and in case of Selenium, Cobalt and Copper also on animal and human health. On self-reliant farms a shortage in soil results in a low content of a deficient nutrient in feed and thus also in manure. A shortage of a certain micro-nutrient may be caused by an absolute shortage, by an antagonism between micro-nutrients (Cu, Zn, Fe, Mn) , by a too high availability of phosphorus (usually as result of too heavy fertilisation in the past) and by a too low pH (Mo)or too high pH (B, Mn, Fe, Zn, Cu) or by a too low moisture content (B). See also https://www.tandfonline.com/doi/full/10.1080/00103624.2017.1407429 . A deficiency can start as a sub-clinic deficiency: there is something wrong, growth is stunted, but there are no further clear visible indications. A soil test can give a decisive answer. Otherwise the cause can be discovered by carrying out simple experiments (Diagnostic field experiments/pot experiments) .

POSSIBLE MEASURES TO IMPROVE AVAILABILITY:

1. FOLIAR FERTILISERS Do not hesitate to spray foliar fertilisers containing all micronutrients as a first step to solve the problem. The result may be amazing.
2. SUPPLEMENTED FEED Supplements with micronutrients (composition based on veterinary consult or chemical analysis of animal hair) to keep animals healthy. A part of those nutrients will be added to soil via manure.
3. ADAPTION OF PH OF SOIL
Where availability of micronutrients is related to a high soil pH, it is often too expensive or almost impossible to decrease the pH of the whole soil. There it is still possible to create spots with a lower pH by incorporating compost, manure or green manure crops. Micro-nutrients can be added to compost and manure to avoid the chemical reaction with mineral compounds that make them unavailable. In conventional agriculture pH can be reduced by applying the nitrogen fertilisers, especially ammonium sulfate. In soil it is transformed in sulfuric acid and nitric acid, which reacts with carbonates and bicarbonates. Ca and Mg are removed by leaching together with the excess of sulfate (and nitrate, if too much nitrogen was applied).



4. GROW SPECIAL CROPS All crops extract nutrients and give them back to soil. Some crops are more able to extract micro-nutrients than other crops. Herbs in pastures and shrubs and trees around pastures may contain more micro-nutrients. https://orgprints.org/19333/1/19333.pdf Leguminous crops acidify the soil just around their roots dissolving nutrients. Sunflowers extract more Fe from soil then other crops. By growing fodder crops and mixtures of green manure crops more nutrients are re-cycled in organic matter (from which they are more available)
5. APPLY ROCK DUST OR LOAM/CLAY FROM DEEP LAYERS Rock dusts and a unweathered sub soil may release micronutrients
6. AVOID AN EXCESS OF PHOSPHORUS Further accumulation of phosphorus, already excessive as result of application of huge amounts of manure in the past, should be avoided.
Winterwheat failed to form ears on a Dutch arable farm due to a deficiency of copper as result of yearly applying huge quantities of slurry (because farmer was paid for it), .
7. BORON SHOULD BE MIXED THROUGH THE SOIL , mechanically of by leaching, to avoid that root tips do not find sufficient B in subsoil. B is not transported through the

plant to the root tips. Often signs of a deficiency become visible during dry periods. In case of applying Boron an excess of Boron should be avoided): not more than 10 kg borax per ha ($Na_2B_4O_7 \cdot 5H_2O$) or < 1 kg B/ha.

SOIL STRUCTURE

A good soil structure it is characterised by a stable, heterogeneous, continuous pore system that is open to the atmosphere and is filled with air for about 30% at field capacity. In such soils (if not too poor or toxic) healthy crops develop an extensive root system, that enables them to take up water and nutrients efficiently. Such a structure makes a good aeration and drainage possible. There is a lot of information about soil structure on internet. Herewith a few links:

A short introduction: http://en.wikipedia.org/wiki/Soil_structure or http://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447039&topicorder=4&maxto=10 and a deeply digging overview: http://tinread.usarb.md:8888/tinread/fulltext/lal/soil_structure.pdf

A soil structure is the result of physical, chemical and biological processes. Nice pictures of how soil structure can look like can be found here: https://www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure (download color chart).

A recent sediment gets a new structure by physical forces when it shrinks and swells due to drying and rewetting or to freezing and thawing. The bulk density of a wet clay soil (g dry soil /cm^3 sampled soil) differs from that of a dry soil (soil sample shrinks during drying). All sharp edges of fragments/aggregates are the result of physical forces. The combined activity of roots and soil organisms make a top soil more crumbly. Micro-aggregates are formed by soil fauna. They round off all the sharp edges, they enter the bigger aggregates making bio-pores and crumbling them. Worm casts, especially from endogeic worms (www.earthwormsoc.org.uk/earthworm-ecology_ , are stabile aggregates full of nutrients. In sub soil roots and anecic worms leave open channels that provide crops a highway to the subsoil and improve the drainage and aeration of the sub soil.

All these opening, breaking up and crumbling are counteracted by the impact of rain drops (only at the soil surface), by trampling animals and passing heavy equipment. The overall result does also depend on the drainage of the land, on the moisture content of soil when land is tilled or crop is harvested and on some chemical compounds. A wet soil is much more vulnerable for compaction than a dry soil and growing a crop that is usually harvested under wet conditions has a more negative effect on soil structure, even if the crop itself has a positive influence. After compaction many clay soils recover easily, loamy soils slowly and to a limited extent, sandy soils hardly. Clay content, the clay mineral (and its CEC), pH and proportion of the CEC that is taken by Al, Ca, Mg and Na, all of them have an influence how fast and to what extent soil structure recovers. You cannot change clay content and the type of dominating clay mineral. A soil that contains a great portion of the clay mineral group of smectites (https://en.wikipedia.org/wiki/Clay_minerals) will swell and shrink a lot: they become sticky, almost impermeable and hardly manageable when wet and they may become crumbly in top soil and full of cracks in sub soil when dry. Such a soil becomes less manageable the bigger the proportion of CEC that is taken by Mg and Na instead of by Ca. (further reading: https://www.researchgate.net/publication/228860330_Effects_of_exchangeable_Ca_Mg_ratio_on_soil_clay_flocculation_infiltration_and_erosion . The $Ca_{exchangeable}/Mg_{exchangeable}$ should exceed 2 and the optimal range of this ratio is between 5 and 7. It might be difficult or expensive to change this ratio, especially in subsoil. Na adsorbed at the clay surface has always a negative influence: it makes the structure unstable, when it is remoistened. The occurrence of clay mineral illite (http://en.wikipedia.org/wiki/Illite) has a good influence on the soil structure that is strived for by farmers, if pH ≈ 7 and Ca is the dominating adsorbed cation. Kaolinites (http://en.wikipedia.org/wiki/Kaolinite) stabilises soil structure more if soil pH is rather low (< 5). All clay minerals are a product of weathering of primary minerals. Kaolinite is the succeeding weathering stage of illite and smectite. Kaolinite is often accompanied by red iron oxides and aluminum hydroxides that stabilise soil structure as well. Such soils hardly swell and shrink. They may have a perfect soil structure (for agriculture), but chemical fertility is usually low. Also most types of organic matter have a positive influence on soil structure: they stabilise the structure of the finer aggregates of the soil, they make sandy soils swell and shrink a little bit and make that roots and soil organisms penetrate more easily. Soil organisms need more time to repair a deteriorated soil structure.

It is not easy to describe the visual structure of a soil objectively and precisely, but it is always possible to compare soil structure by a quick scan below a crop and that below a grass strip along the field where the soil is not compacted (beneath an hedge or barbed wire) . By comparing what you see and feel, when you enter a pin or penetrometer into a soil at field capacity Interpretation penetrometer resistance you get an impression to what extent soil structure could be improved. It is easier, but more time consuming to characterise soil structure by physical determinations like bulk density, porosity, permeability. However, the interpretation of the results of these determinations is less clear than the results themselves are.

Soil structure of most arable fields can be improved and such an improvement will result in a more efficient use of water and nutrients and also higher yields. Therefore, it is wise to strive for a better soil structure, but not unlimitedly. Growing very profitable crops like carrots has a negative influence on soil structure and / or on the population of earthworms and farmers have to choose between an extra profit and a better soil structure, when they design their crop rotation. As the consequences of a cropping system on soil structure cannot foreseen completely, farmers in a region have to learn by experience and from each other what compromise is workable.

We will not focus on the proper description of soil structure, but discuss the main problems recognised in the quick scan how to solve them.

HOW TO DEAL WITH SEALING/ SLAKING/CAPPING AND CRUSTING

The formation of a crust can be avoided by

- Preparing a coarser seed bed
- Applying mulch (if possible)
- Increasing soil organic matter content of the very top layer by minimum tillage instead of ploughing (https://www.no-tillfarmer.com/articles/5824-better-soils-with-the-no-till-system) or by applying more organic matter and/or inclusion of grass clover in the rotation
- Applying lime to a clayey soil if pH < 6
- Applying gypsum if the ration of exchangeable Ca and Mg < 2 and if exchangeable sodium is too high (see: https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/exchangeable-sodium)
- Improving drainage
- breaking a crust just before emergence by using a roller (if possible).
- By dibbling more seeds per plant hole (and a wider spacing of those holes than if single seeds are sown). More seeds have more power to break the crust.
- careful irrigation (if possible).

Further reading: http://www.fao.org/docrep/t1696e/t1696e10.htm

HOW TO IMPROVE A COMPACT TOP SOIL

In a compact top soil mineralisation of organic nitrogen may be impeded, nitrate may be denitrified in anoxic hot spots and aeration may be insufficient, especially when soil is moist. Roots cannot grow freely in all directions and total root length per cm^3 is lower (than possible) and roots may temporarily be less active due to a shortage of oxygen. Nutrients and water have to move over a larger distance before they can be taken up by crops. Especially, the uptake of nutrients, that move more by diffusion to roots then by mass flow (for instance of phosphorus) (see also https://nrcca.cals.cornell.edu/nutrient/CA2/CA0209.php) . Permeability is reduced and top soil may remain wet for a long time leaving less time for operations without compacting the soil even more. How to recognise such a soil? For instance Sq4 and Sq5 in the chart of visual evaluation of soil structure (to download via https://www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure see Gallery). In clay soils and loamy soils most roots remain on the surface of clods / sharp-edged (= angular blocky) aggregates and only a few roots and biopores are visible within an aggregate (after breaking). Also in sandy soils the distribution of roots and the number of root (total root length per cm^3) give an indication of the quality of soil structure. Unfortunately, it is difficult to give exact numbers as they depend on crop, stage of development, distance to stem, availability of water and nutrients and growing stage. Only by comparing root systems and yields in/from different fields you can get an impression, whether it might be wise to try improve soil structure. There are several measures possible and farmers can always carry out simple experiments to find out what effect they have on structure and yield. Unfortunately, some measures have an effect in the long term and for a farmer it might be easier and more profitable to apply more fertilisers to compensate the lower nutrient use efficiency due to a poor soil structure. Fortunately, most organic farmers are aware of the importance of a good soil structure.

1. Improve drainage. A poor drainage is caused by a (temporary) high water table, by an impermeable layer within soil profile or just beneath soil profile or by seepage.

2. Avoid sealing of top layer (see above). If aeration is poor due to sealing, roots and soil organisms in soil are less active and less able to create a favourable soil structure.

3. Apply lime or gypsum. In clayey and loamy soils with a pH < 6 that do not contain lime (no bubbles formed when a small fragment is immersed in vinegar) $Ca_{exchangeable}$/ CEC might be too low for a good flocculation of clay particles. Application of lime supports the flocculation at micro-scale and the formation of a better soil structure at macro-scale. In soils with a $Ca_{exchangeable}/Mg_{exchangeable} < 2$ (to be measured in a laboratory) application of gypsum (calcium sulfate) will help to increase this ratio (the optimum is between 5 and 7). The excessive sulfate will be lost by leaching accompanied by magnesium and calcium. Where availability of sulfate was low, yields will increase due to the improvement of availability and a substantial part of applied sulfate may be immobilised by the formation of organic sulfur. In remote areas it might be expensive to apply enough lime or gypsum. Also where exchangeable Sodium is too high application of gypsum will help to leach the excess of sodium.(see: https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/exchangeable-sodium).

4. Apply organic matter. Most organic matters have a stabilising effect on soil structure. By growing more grass, grass clover, alfalfa, cereals, green manure and application of compost and manure organic matter content will increase. However, on a self-reliant farm only a limited amount of manure and compost is available and growing more grass-clover and cereals may reduce the area of more profitable crops.

5. Reduced tillage or zero-tillage. Reduced tillage (only the upper 2 - 5 cm are tilled) results in another kind of compaction compared to conventional tillage with a moldboard plough: although more compact (higher bulk density) more bio-pores and a higher organic matter content allow roots to develop rather freely in the firm soil having a higher carrying capacity without being further compacted by passing machines(if not too heavy). After ploughing a soil has a lower bulk density, but will be more thoroughly compacted by a passage of heavy equipment. Ploughed land is re-set every year, while the recovery of compacted reduced-tilled land is more dependent on the activity of soil organisms and natural physical processes. Ideally, reduced tillage is combined with gps precision farming techniques that allow farmers to use the same tracks for all operations and every year (controlled traffic farming) . Strict zero-tillage in combination with leaving crop residues on soil surface gives a direct protection of soil

by crop residues and after a few years an indirect protection by the higher organic matter content in surface layer and by preserving and stimulating the population of worms, that open the soil surface after sealing. This combination may stimulate population of slugs and snails as well and special equipment is needed to sow between the residues. Conventional farmers can use herbicides instead of superficial tillage to get rid of weeds.

Organic farmers may have problems to get rid of weed if they do not till the soil superficially. If water is not a problem during succeeding period, a heavy cover crop could be grown, that protect the soil surface, smother all weeds , fixes nitrogen, add organic matter and prevent leaching. Such a cover crop can be stopped growing by rolling it (see picture roller crimper) and the residues become a mulch layer. Such a mulch should not decompose too fast, otherwise weeds will grow through the mulch layer and compete with the crop. Cereals decompose more slowly than leguminous or cruciferous cover crops.

However, a heavy cereal cover crop will have exhausted all nitrate-N in soil and the mulch should decompose so fast that sufficient nitrogen is released, unless the soil itself will do that. A mixture of a cereal and a leguminous crop could be a solution. This technique needs fine-tuning.

In case of minimum tillage crop residues are mixed through the upper 2 to 12 cm, where exchange of air is more easy . Weeds can be controlled mechanically. Compared with the conventional system of ploughing up soil from 25 cm depth minimum tillage results in a higher organic matter content in the very top layer and a better preservation of soil organisms that repair a damaged soil structure. With special equipment (chisel plough (at the left) or eco-plough (at the right)

it is possible to till the soil superficially (12 -15 cm) without compacting the layer under the furrow. Where the ploughing can be postponed till spring, soil is more protected during winter and less nutrients are leached if a winter hard cover crop could be grown.

6. <u>Avoid compaction</u>

   a. a better timing of tillage operations before and during growing season. (wait till the soil is dry enough to carry the machines without being compacted too much).

   b. replace crops that are usually harvested, when the soil has become wet by crops that can be harvested in more favourable conditions .

   c. controlled traffic farming. Traditionally, vegetables were often grown on permanent beds, that were never compacted. Nowadays, arable farmers are developing similar systems by carrying out all activities from fixed tracks. Global position systems (GPS) help them to use the same tracks every year. See: http://www.controlledtrafficfarming.com

   d. Using lighter machines (preferably axle load <5 ton and pressure tires < 0.8 bar)

7. Stimulate and protect soil organisms by

   a. Supplying or leaving enough feed: green manure, crop residues, compost and manure. Especially growing grass clover and alfalfa support the activity of soil organisms.

   b. No tillage or reduced tillage.

   c. Avoiding unnecessary compaction.

8. Patience after a rainy period

HOW TO DEAL WITH A PLOUGH PAN

A pan, hard pan, plough pan (or disk pan, traffic pan) is formed just below ploughing depth, where the soil is compacted without being loosened by tillage operations. A severe plough pan impedes drainage of excessive water and the expansion of roots to the sub soil. Such a pan can be recognised easily by digging a pit up to 60 cm deep and observing the appearance of the root system (it cannot expand freely there and it finds its way to the deeper sub soil via few channels or voids). The aggregates in that layer are more sharp-edged and bigger then in layers above and below. In spring when soil moisture is still at field capacity the resistance is higher if you move a penetrometer or a pin into the soil. A plough pan can be broken by deep tillage with a heavy chisel plough, but it is better to avoid the layer becomes so pronounced that it impedes root development and drainage. The formation of plough pans can be mitigated by using lighter equipment, low pressure tyres, by combining operations (see also: https://www.no-tillfarmer.com/articles/7741-avoiding-soil-compaction). Reduced tillage, growing cover crops and leaving crop residues crops spare and stimulate soil organisms that help to keep that layer open and accessible for roots. The formation of such pans can be limited to about 10% of the area by using the same tracks every year (controlled traffic farming). See also : http://www.organicexchange.com.au/all/fw100197.htm

HOW TO DEAL WITH A COMPACT SUB SOIL BELOW PLOUGH PAN

A compact sub soil is difficult to repair. All sub soils (especially sandy sub soils) are easily compacted when the soil is wet. The weight of heavy machines have an influence till 50 – 60 cm deep.

Under the natural vegetation before the land was reclaimed sub soils may have become more dense and less permeable by illuviation (http://en.wikipedia.org/wiki/Illuvium) of clay (texture B) , iron oxides and (in case of sandy soils) amorphous organic matter (Podzol). Also an underlying impermeable rock may make deeper rooting impossible and disturb drainage.

A hard layer due cementation by iron oxides can be caused by capillary rise of groundwater or seepage. The water comes from an anoxic deep layers and contains Ferro-oxides. The ferro-oxides oxidise further into ferri-oxides, that are less soluble and precipitate on soil particles. Such a layer can be broken, if the drainage of the land is impeded during the season when the groundwater level decreases. In many cases it is not useful.

Podzol soils can be improved by deep ploughing to break the hard pan and to mix this pan partly through upper layers. After liming (to increase pH) and fertilisation these soils can be used for agriculture.

In Western-Europe many of such soils were reclaimed during the last century and transformed in fertile agricultural soils. Another part has been reforested. The pan was broken and mixed with top soil, the pH and fertility have been increased by applying lime, manure and artificial fertilisers. It is possible to improve such soils, but a lot of manure and fertilisers are needed and water table should be managed as well. Unfortunately, it is difficult to keep losses of nutrients by leaching at an acceptable level in such soils. Nowadays, such soils are no longer transferred in agricultural soils.

On a farm in Esbeek in the Netherlands the colours of the former natural soil profile faded away during 100 years of cultivation and the soil has become more and more a man made soil with a dark top soil, that is slowly becoming deeper and deeper through the activity of worms.

Clay illuviation can be recognised by checking the change of texture with depth. The illuviation layer (also called B horizon) soil contains more clay than the layers above and below. Aggregates are often covered with clay cutans / clay skins (see: http://en.wikipedia.org/wiki/Cutans). The lower permeability is indicated by "gley ", more precisely by " stagnogley " (see: http://en.wikipedia.org/wiki/Gley_soil) :a grey to greyish coloured soil with red mottles. Illuviation of clay indicates that too much Ca and Mg had been lost from top soil and pH had decreased. This is a result of a natural process during a very long period in the past. Such a layer is often found between 75 and 125 cm. It may swell when wet and become almost impermeable. It contains more clay than the top soil, often visible as a skin on natural soil aggregates , the layer shows more rust mottles. Soil structure is often prismatic (only visible when dry). Roots and worms hardly enter such layers. Adjusting top soil pH to about 7 and keeping pH at that level stops further illuviation. The heavy texture of sub soil can be a result of initial natural sedimentation as well. It is difficult to break such a heavy layer, because it does not work when the soil is wet and the soil is too hard , when dry. If heavy due to sedimentation the layer may be too thick to be opened. Feeding the worms may help to open the sub soil very slowly. After liming the top soil some leached Ca-bicarbonate will reach the sub soil and improve that ratio Ca/CEC. However, such processes take much time and it is almost impossible and very expensive to mix lime quickly through the sub soil. A deep tillage should go deeper than the layer with the low permeability and should be followed by growing a deep rooting crop like alfalfa that stabilises the more open structure by the formation of bio-pores. Trees like alders and willows may improve such soils, but they need a very long time for that.

It is clear that underlying, almost impermeable rocks cannot be changed. Many metamorphic rocks (micaschists et cetera) are stratified and folded. Because of that folding direction of layers may change within a field improving drainage where they stand upright and impeding drainage where they lay horizontally. The timing of operations may be difficult on such a heterogeneous field.

SOIL RELATED WEED PROBLEMS

Many weeds are stronger than crops and most crops need temporary support to be able to dominate over weeds. As soon as crops overshadow weeds, crops can develop their root system faster and compete out weeds in the rooting zone as well. Besides by competition for nutrients and water crops may influence the germination and growth of weeds by an allopathic effect http://en.wikipedia.org/wiki/Allelopathy (and the other way around, of course.) When weeds get the opportunity to produce plenty seed, it takes many years to reduce their number to the original number in soil. Most weeds have to be controlled when crops are still young.

See also: http://weedecology.css.cornell.edu/manage/

CONTROL OF ANNUAL WEEDS

Organic farmers use several types of equipment for mechanical weed control (effect dependent on weather conditions) and also flaming /steaming is used (expensive, but effective and independent on weather conditions). Both methods complement other weed control strategies including:

1. using clean seed
2. tillage
3. stale seedbed (false seedbed) see also: http://en.wikipedia.org/wiki/Stale_seed_bed
4. appropriate planting dates, populations, and row widths
5. diverse crop rotations (winter crop, early sown spring crops and late sown spring crops and summer crops have their own weed communities and by alternating these crops weeds have less chance to produce seed and their number of seeds in soil is reduced naturally.
6. cover (or smother) crops. Especially, grass clover that is mown several time, is a well-known smother crop to get rid of weeds. https://en.wikipedia.org/wiki/Smother_crop
7. controlling weeds in areas adjacent to the field to prevent input by wind

8. hand weeding when needed for problem areas and problem weeds
9. weed scouting and identification of new weeds.

See also: http://eap.mcgill.ca/publications/EAP72.htm

SOIL RELATED CAUSES OF FAILING CONTROL OF ANNUAL WEEDS

If the mechanical control and subsequent manual weeding have left a limited number of weeds, that is able to dominate a crop the following causes can be considered.

1. SOIL IS TOO FERTILE. Leafy weeds thrive and there is not much time to prevent them to dominate crops from the beginning. The weed plants that survive the weeding keep growing even if they are shadowed by a crop. If a soil is too fertile, the crop cannot reduce nitrate-N content sufficiently and weeds keep finding enough nitrogen to overtake the crop when it stops its vegetative expansion and start flowering. Ideally, just enough inorganic nitrogen is and becomes available in soil to allow the crop to develop its optimal leaf area index (depending on conditions). Nitrate-N content in top soil during expansion is continuously about 10- 20 kg N per ha without being exhausted, because just sufficient nitrogen is released during the remaining period and also crops are stimulated to take nitrogen from subsoil (only if sufficient nitrogen is stored in subsoil, relevant in deep soils with a high water and nitrate retention capacity (clay, clay loam, loam). Reducing the application of inorganic nitrogen and the organic matter content of soil (horticulture) may reduce problems with weeds, but may also result in a lower yield level.

   Forty years ago many Dutch organic horticultural farmers were used to apply substantial amounts of manure, up to yearly 100 ton farm yard manure / ha. In this way they stimulated the early growth in spring, but later there was an excess. Their soil became very fertile with many fast growing weeds like *Galinsoga sp* as result.

2. SOIL IS INFERTILE OR HAS A POOR SOIL STRUCTURE. The crop does not develop a closed canopy and remaining weeds get enough light to develop their roots system. Their demand is often lower than that of the crop or they are more able to extract deficient nutrients from soil. It could be tested which nutrient is limiting the development of the crop. Also soil structure can be compared with soil structure beneath a well-growing crop.

   In Peru the dominance of narrowleaf plantain (*Plantago lanceolata)* in a pasture could be broken by applying TSP (triple super phosphate). Clover and grasses could take over without replacing the narrowleaf plantain completely. The new sward was more productive, more palatable and there was a better balance between energy, protein and minerals. Probably, plantain reduces nitrification and loss of nitrate by leaching from urine patches.

3. SOIL OR SEED BORNE PESTS OR DISEASES may have affected the roots of the crop (Affected root system)and for vegetables see https://anrcatalog.ucanr.edu/pdf/8099.pdf It is clear that an affected crop is less competitive. The pest or disease should be detected to be able to find the best remedy. In general, a smart widening of crop rotation will reduce the influence of soil borne pests and disease. The use of seed of a guaranteed quality will reduce seed borne diseases.

CONTROL OF PERENNIAL WEEDS

Once established perennial weeds are strong competitors of annual crops. Arable farmers try to get rid of them by a combination of mechanical and biological measures. Knowledge might be specific for a location. It is important to know in which crop a certain weed get the opportunity to establish itself, in which crops it flourishes and in which crops it suffers. Many perennial weeds get started in cereals, because there are always relatively open patches in a cereal field and weed control in cereals is not very intensive. Some weeds (*Rumex* sp.) can start in grassland, but do not resist frequent ploughing and chiselling.

SOIL RELATED CAUSES OF OCCURRENCE PERENNIAL WEEDS

1. UNDEREXPLOITED SUBSOIL. Many perennial weeds have roots in the deep sub soil and they may compete during dry periods with crops that do not develop such an extensive deep root system (for instance field milk thistle (*Sonchus arvensis*) in onions).

2. WEAK CROPS. Crops with an affected root system, crops that cannot develop an extensive root system because of the poor soil structure, an unbalanced soil fertility. In all these cases crops are less able to compete with perennial weeds.

3. IN NO-TILL AND MINIMUM TILL SYSTEMS perennial weeds are not buried every year and they have a better chance to recover after superficial tillage operations.

HOW TO CONTROL PERENNIAL WEEDS

1. MECHANICAL MEASURES. Perennial weeds are buried, cut and spread by tillage operations and the effect of the operations depends on timing and frequency.

    a. Ploughing helps to burry roots and stolons. A crop can get stronger before it has to compete with the perennial weeds and has a better chance to dominate.

    b. Chisel ploughing bring roots and stolons to soil surface where they may dry under favourable weather conditions in spring or summer (better result with an additional rod weeder https://www.youtube.com/watch?v=yKVFQW9bpVw or https://www.youtube.com/watch?v=Ku-gr1Su-V4)

2. BIOLOGICAL MEASURES are based on a smothering of the weeds by a strong crop or green manure crop

    a. FAST GROWING GREEN MANURE CROPS like yellow mustard may smother weeds in autumn. They will do their job better if the perennial weeds have previously been weakened by mechanical means and if enough water is available and soil is fertile (at least 50 kg nitrate-N/ha in top soil, when the crop is sown).

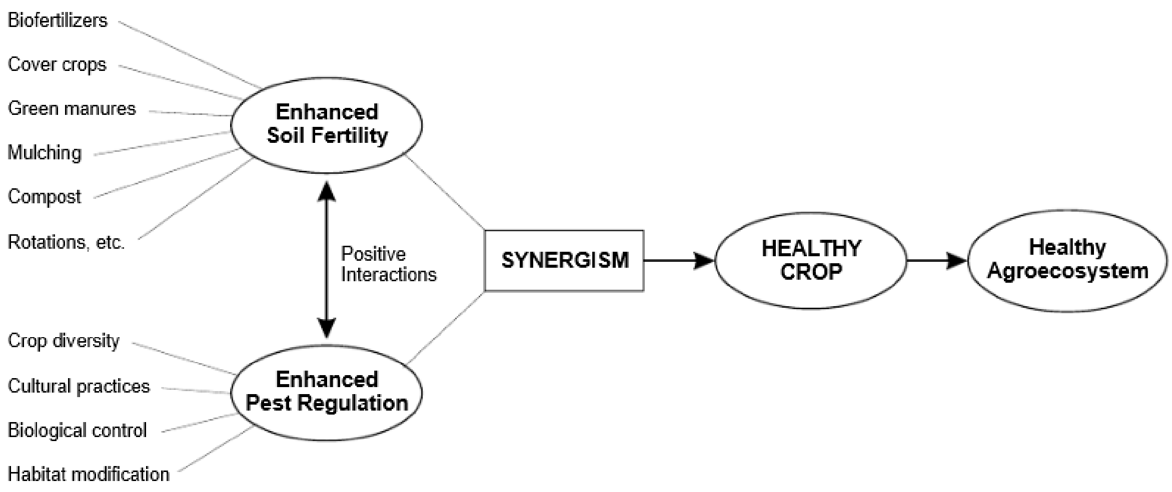
    b. A FAST GROWING SUMMER CROP like buckwheat.

    c. IN A GRAZED TEMPORARY PASTURE many perennial weeds are weakened. However, some weeds are not palatable (for instance Creeping Thistle (*Cirsium arvense*) or bitter dock (*Rumex obtusifolius*)) and are refused or avoided by animals. Bitter dock is only eaten when very young. Continous grazing at a sward-height of 5 cm will suppress bitter dock. Mowing will help to suppress Creeping thistle in a grazed pasture: the first time just before flowering and two extra mowings later in the season. When weakened by mowing they become more susceptible for diseases and these diseases will finish them. Quackgrass (*Elytrigia repens*) disappear more completely if soil fertility keeps other grass species and clover growing and manure patches are quickly 'digested' by soil organisms. Nevertheless, some may survive. Unfortunately, measures to weaken weeds will also weaken beneficial herbs.

    d. IN A TEMPORARY PASTURE FOR MOWING a mixture of alfalfa / red clover and a grass (in Europe Italian ryegrass, where enough water is available and Tall Fescue where a dry period is expected) will smother most weeds if availability of water and nutrients allow them to develop a lush cover. The grass component keeps availability of nitrogen in soil low and the leguminous component ensures the lush vegetative growth. By cutting the mixture several times the weeds are cut as well and they have to exhaust their reserves. They will have more and more problems to keep pace with the grass and alfalfa or clover. They become more susceptible for diseases and these diseases may weaken them till they die. Unfortunately, measures to weaken weeds will also weaken beneficial herbs.

SOIL RELATED PESTS AND PLAGUES

Within organic farming pests and diseases are not controlled chemically. Most pests and diseases are controlled biologically, either consciously by a combination of good farming practices or unintendedly/naturally https://www.researchgate.net/publication/287626679_Soil_Fertility_Biodiversity_and_Pest_Management.)



In many regions in the world soil borne pests and diseases play a crucial role and their presence should always be checked during a quick soil scan.

AFFECTED ROOT SYSTEM

Healthy roots are white or yellowish. Young roots (up to 3 – 4 weeks) should be healthy. Knots, rotten roots, lesions, short thickened roots indicate that roots are infected or affected and they should be examined with more detail: does the disease or pest come from soil or was it brought with the seed ?

1. SOIL BORNE, SEED BORNE OR BOTH*?* By sowing seed in a disinfected soil and checking the roots after 3 weeks, it can become clear where the disease or pest came from. A soil can be disinfected by heating it up to 100 ^{0}C for a half hour by putting a can with soil in boiling water. If an added piece of potato is sufficiently cooked, the soil is disinfected. Compare the root systems in a pot with disinfected soil and that with untreated soil. Sow three seeds per pot and leave the best plant after emergence. Keep moisture content close to field capacity with a complete nutrient solution (can be sold in a supermarket) to prevent stress. The plants should grow unimpeded. Compare the root systems after 2 – 4 weeks depending on crop and further growing conditions. The test might be complicated by an excess of manganese in a treated soil: plants do not grow well, but do not show affected roots. Such an excess of manganese can be expected in red and acid soils.

2. SEED BORNE DISEASES. Seed can be disinfected by a treatment with hot water. The seed is immersed in hot water of about 50 ^{0}C. The temperature and time of immersion are specific for each species. See for instance: http://orgprints.org/7672/. Preferably, farmers purchase seed of good quality if they cannot multiply seed without risks on diseases and a loss of vigour. Seed companies (should) guarantee that their seeds are free of diseases.

Their seeds are usually multiplied in regions where conditions for disease free multiplication are favourable (dry, plenty light and wind, cool nights and not too hot during day time).

3. SOIL BORNE PESTS AND DISEASES*.* There are many soil borne diseases. In sandy soils they have a better chance to become a problem then in clayey soils. The "natural" suppression of diseases and nematodes is not well understood yet. As soon as a disease has become a problem, it might be difficult to get rid of it without re-organising the whole crop rotation . Not only individual farms, but also regions are sometimes organised around one or a few cash crops and in such a situation it is difficult to find alternatives.

   I have seen many vegetable growers all over the world and the main, usually not recognised, problem was the occurrence of soil borne diseases. Strawberry growers in Lanzhou region (China) told me that many of them had to stop growing strawberries. They were used to take the young plants from existing strawberry fields and were transferring and spreading nematodes in that way.

   a. SOIL IN NURSERIES SHOULD BE FREE of parasitic nematodes and diseases. Mixtures of compost, peat, cocos peat and / or forest soil are usually free of diseases.

      In India a nursery was used every year. There rice plants were already infected before planting. By using fresh soil free of diseases in the nursery the plants could given a better start.

      Tobacco growers in Cuntel Central Java were used to use a mixture of soil from a forest and composted manure as substrate in their nurseries . The soil was protected against the heavy rain storms during the rainy season (no saturation of soil and no leaching of nitrate) and the young plants could be planted at the beginning of the dry season

   b. NO SHORTAGE OF NUTRIENTS Crops are less vulnerable if there is no shortage of nutrients. Especially, availability of potassium and phosphorus are important

      Near Salatiga in Indonesia damping off of Amaranthus , a leafy vegetable, was no longer a problem after some triple superphosphate was mixed through topsoil).

   c. ADAPT CROPPING FREQUENCY Sensitive crops like many vegetables should not be grown more frequently than once in 6 growing seasons. Also crops of the same family should not be grown during one cropping cycle if it has become clear that there is a problem.

      In Colombia a well-equipped herb producer was growing a few species of herbs. Climate (intensive sun light, plenty ultraviolet, cool nights) was excellent to get a high quality. Yields had declined after a few years due to soil borne diseases. Growing herbs alternating with grass could solve his problem.

   d. GROWING RESISTANT CROPS and application of organic matter stimulates biological activity in soil. The number of specific diseases or nematodes decreases faster due to all increased activity of their antagonists or predators.

   e. RESISTANT ROOTSTOCKS There are resistant rootstocks available for fruit trees and crops like cucumber, tomato, eggplant.

      In many villages near Lanzhou farmers were growing peppers in solar greenhouses (https://www.resilience.org/stories/2010-04-06/solar-greenhouses-chinese-style/). Most of them had problems with soil borne diseases. In one village resistant rootstocks were used. Somehow the exchange of knowledge between the villages did not work well.

   f. A PROPER CHOICE OF GREEN MANURE CROPS helps to avoid/reduce problems with nematodes and diseases.

      i. Cereals/ *Avena strigosa* in rotations with many dicots.

      ii. *Tagetes patula* against *Pratylenchus penetrans*

g. CREATE ANOXIC CONDITIONS. Temporary flooding results in anoxic conditions in soil and many nematodes and diseases do not survive such conditions. Anoxic conditions can also be created by mixing plenty (80 ton fresh material/ha) of easy decomposable organic matter (a green manure crop for instance) through a moist top soil. After some compaction, soil is covered with a plastic film to minimise the exchange of gasses.

Near Jogjakarta farmers could grow tobacco during the dry season, where they were growing rice during the wet season. The soil consisted of recently sedimented volcanic material and was rather sandy . Soil structure was not a problem and the diseases for tobaco could not survive the the anoxic conditions in the rice fields. On more clayey rice soils the poor soil structure and the plough pan during the dry season made the culture of tobacco impossible.

h. SOLARISATION (= heating the soil under a plastic sheet by sun) is an option for small fields.(http://www.fao.org/3/t0455e/T0455E0f.htm)

i. BURYING OR REPLACING TOP SOIL.

Thirty years ago Javanese tobacco growers on light soils high in the mountains were used to turn their soil after a few years. The top soil was buried about 50 cm deep. Only in that way they could grow tobacco and vegetables like carrots. About 100 years ago also Dutch vegetable growers and bulb growers (tulips) reduced problems with soil borne diseases by replacing the top soil with soil from 50 cm deep. They had to apply a lot of manure to give their crops a quick start. Some Chinese vegetable greenhouse growers replace the soil by bringing soil from elsewhere in their greenhouses.

GROWING CONDITIONS

Speed of growth of a population of plague insects is often limited by a shortage of easy digestible dissolved proteins and amino-acids. Usually, energy is not the limiting factor : some ant species protect aphids to make use of the excessive sugars excreted by the aphids after they have taken the amino-acids and proteins for themselves. Dissolved amino acids occur often where protein synthesis is disturbed.

1. A WELL BALANCED NUTRITION OF CROPS is the most important step to reduce the speed of growth of a pest population : not too much nitrogen, sufficient other nutrients. Especially, a shortage of micro-nutrients and potassium may influence the protein synthesis negatively. Soil structure and availability of nutrients, including that of micro-nutrients, have to be checked in case of systematic problems with insects. See: and https://edis.ifas.ufl.edu/pdffiles/HS/HS118100.pdf)
2. AVOID A SHORTAGE OF WATER. The drier the soil the more difficult for crops to take nutrients from soil and to regulate the temperature of the leaves. Insects and aphids have a better chance to increase their number on stressed plants. Some crops (for instance lettuce) are more sensitive than other crops (for instance cereals). As already explained: in clay soils plants have more time to adapt themselves to drier conditions than in sandy soils. In soils characterised by a unbalanced availability of nutrients plants are more vulnerable than in fertile soils. See also: https://www.researchgate.net/publication/280009828_The_Role_of_Drought_Stress_in_Provoking_Outbreaks_of_Phytophagous_Insects
3. PEST AND DISEASE SUPPRESING ENVIRONMENT Although still many aspects have to be studied, it has become clear that a properly organised biodiversity helps to suppress pests and diseases. The landscape should be given such an ecological infrastructure that relevant predators find a place and food to survive when they cannot find food in the fields. The infrastructure should allow them to reach the fields when necessary. Plants affected by a pest give chemical signals that are recognised by predators of plague insects. The distance between predators and plants should not be too large. Many predators need energy to reach the pest organisms and flowering plants provide them that energy with their honey. Not all flowers are accessible for all predators and there is research to be carried out to find out which flowering species fit in a cropping system.

By growing vulnerable varieties together with less appreciated, but resistant varieties or other crops an explosion of a disease can be slowed down or even avoided. See also: https://library.wur.nl/WebQuery/wurpubs/fulltext/169480 , https://www.topcropmanager.com/strip-cropping-for-pest-management-19842/ or https://www.wur.nl/en/newsarticle/Mixed-and-strip-cultivation-contribute-to-biodiversity.htm

APPENDICES WITH BACKGROUND INFORMATION

QUICK SCAN OF SOIL PROPERTIES

A quick visual soil assessment helps you to have some basic information about the soil in mind when you start to think about possible causes of a disappointing crop growth. Compare soil properties under a poor crop with those under a good crop and under a fence line or an undisturbed grass strip and observe.

You can use the simple way described below, but if you want to go into more detail, you can use the comprehensive field guide of Graham Shepherd
http://orgprints.org/30582/1/VSA_Volume1_smaller.pdf and
https://www.youtube.com/watch?v=DM53uUCQqUg .

SOIL SURFACE

When the soil is still bare and unprotected:

1. do you see signs of slaking, sealing and crusting Picture Slaking . The exchange of gasses is impeded when the soil is moist
2. Are openings in the sealed soil made by worms visible? They restore the exchange of gasses.
3. Is or was a part of the field waterlogged or flooded?
4. Do you see signs of erosion? Picture soil erosion

PLOUGH LAYER.

Preferably, you observe when the soil is moist /close to field capacity (https://en.wikipedia.org/wiki/Field_capacity)

Dig a pit (30 cm length and as deep and wide as your spade is). Do not stand where you want to take a sample. Take a undisturbed sample of the soil as wide and long as your spade is after you have cut the left and right side of the sample with your spade. (on this movie you can see how to do it: https://www.youtube.com/watch?v=VqEj-cAZFO8

Are there visible: grey colours , red mottles (iron oxides) or black mottles (manganese oxides) and check if the odour is pleasing (actinomycetes) or unpleasant ? See: Soil colour and odour: (from http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_interpret_colour)

1. A first impression of soil structure can be got by dropping the undisturbed block taken from top soil with a spade from about 1 meter height on a plastic sheet. A sandy soil with a good structure falls apart in small lumps (like sugar or a bit bigger) and not in loose sand particles. Loamy and clayey soils fall apart in crumbles (optimum) or at least in sub-angular blocky aggregates (irregular blocks with rounded edges). The bigger the aggregates and the sharper the edges are, the poorer soil structure is. Take a picture to compare the structure with those of the other samples. Further reading: https://orgprints.org/30582/1/VSA_Volume1_smaller.pdf or https://www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure/1550/healthy_soils
2. Estimate soil texture by feel according Texture by feel . You can learn to estimate soil texture by feel by watching a 4 minutes movie like https://www.youtube.com/watch?v=GWZwbVJCNec
3. Check the health of young roots (they should be white or yellowish and free of rotten spots and lesions. Older roots may be brownish, but they should not be rotten.
4. Count the number of worms you can find in the dropped soil.

Further information about spade test: (https://www.youtube.com/watch?v=f-kigHj3vbw&feature=youtu.be (choose the English subtitles) or https://www.youtube.com/watch?v=Zj8gHd_TpG8 (in German) or read (in French): http://orgprints.org/32099/1/peigne-etal-2016-GuideTestBeche-ISARA_Lyon.pdf).

PLOUGH PAN

Check if there is a harder layer just below the tilled topsoil.

1. When the soil is near field capacity a first impression can be got by pushing a penetrometer or a pin with a widened tip into the soil. (if you want to know more: look https://www.youtube.com/watch?v=Zq_785JqRq8 .) If the cone of the pin has a diameter of 1.1 cm, the force you have to use is a good indication of how difficult it is for a plant to grow downwards. If sufficient oxygen and nutrients are available, roots grow easily as long as the penetration resistance < 0.5 MPa (5 kg/cm^2) and cannot grow deeper where the resistance > 3.0 MPa. (≈ also our limit when we push such a pin <u>slowly</u> in soil. See also: Interpretation penetrometer resistance It should be borne in mind that in loamy and clayey soils the resistance increases where and when soil moisture content decreases
2. When you deepen the soil pit, you can check if and how roots can penetrate this layer

SUBSOIL

The subsoil can be observed with a soil auger (Picture soil auger) and a penetrometer/pin or in a deep soil pit and sometimes in a steep wall of a ditch.

With soil auger and pin:

Measure or estimate the change of penetration resistance with depth.

1. Observe if and how soil texture changes with depth.
2. Observe till which depth you can recognise fine roots by checking the presence of fine roots in the soil at the tip of the auger (break the soil there open).
3. Observe how soil colour changes with depth. It is difficult to give a precise name to a colour without using colour charts, but you can record the colours by painting the soil profile (including the plough layer) with wetted soil on white paper (use a ruler and tape-measure to make the painting at the proper scale). If there are mottles visible, indicate at what depth they appear and disappear and what colour they have (black, red , grey). In this way you can compare soil colours of different sites
4. Observe if the soil becomes wetter in deeper layers and - if so - where it starts becoming wetter and if roots reach that depth. There capillary rise will contribute to supply of water.
5. If relevant, check the ground water level after leaving open the soil auger hole for a few hours. (take care that animals cannot break a leg)

In a soil pit you can see more details

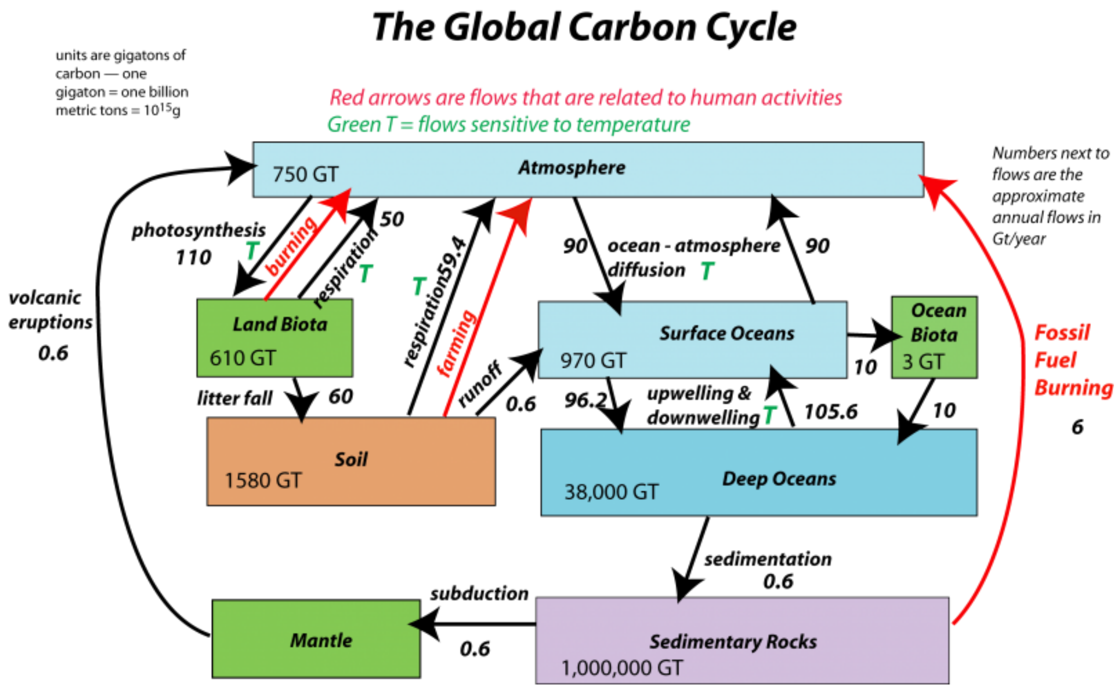
In a soil pit at least 50 cm wide and as deep as you can find fine roots. If useful to get more details, you can deepen and enlarge the pit later. For further details: Mhttps://orgprints.org/30582/1/VSA_Volume1_smaller.pdf

1. Check if the plough pan is visible as a compacted layer , often with a platy structure, where roots bend laterally to find a passage to subsoil. A plough pan impedes root growth and drainage of an excess of water causing the top soil remains longer too wet for tillage, traffic and root growth after a rainy period. Check if and how roots pass the plough pan.
2. Take fragments from each layer of 10 cm and check if fine roots or former root or worm channels are visible (use a magnifying-glass) and check also the health of young roots (

they should be white or yellowish and free of rotten spots and lesions. Older roots may be brownish, but they should not be rotten.

A nice movie for who want to know more about the description of soil profiles: https://www.youtube.com/watch?v=ZlyDyQT6_WE

SOIL ORGANIC MATTER



There is about 2 times more carbon in soil than in the atmosphere and soil organic matter (SOM) contains about 50 % C, 5% N, 0.5 % P and 1% S. Organisms have accumulated most of the atmospheric carbon in sedimentary rocks (mainly limestone, further coal and oil).

The role/effect of soil organic matter is

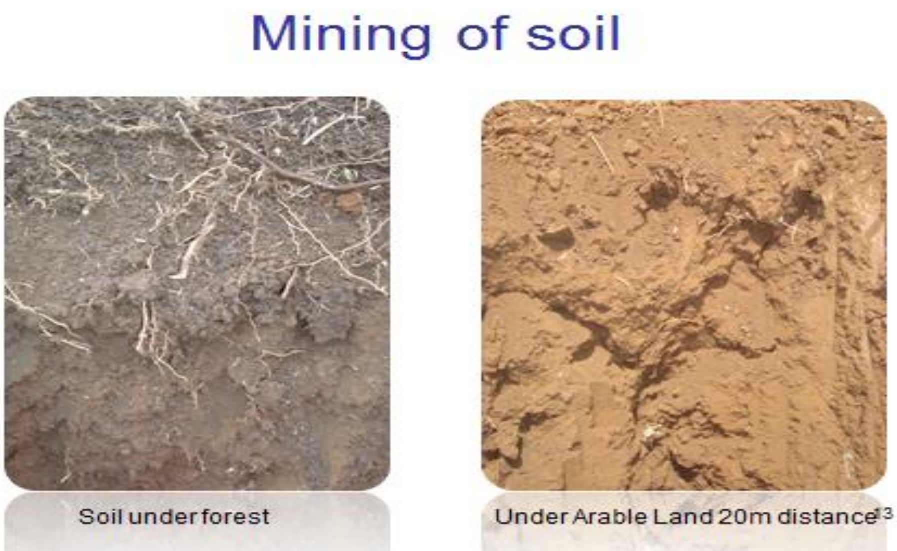
1. Feed for soil organisms
   b. that release N,P and S , accumulated in residues of plants and micro-organisms
   c. that suppress soil borne diseases
   d. that build and stabilise soil structure resulting in a better permeability (drainage, infiltration), aeration (exchange of gasses), workability and deeper rooting
2. Adsorption of cations (http://www.soilminerals.com/Cation_Exchange_Simplified.htm). The CEC of organic matter depends on pH: lower as more acid.
3. Reduction of fixation of phosphorus by iron oxides
4. Increase of water retention: (see also: https://www.researchgate.net/publication/222544140_Effect_of_soil_carbon_on_soil_water_retention
   a. Clay: about 0.2 mm per 1 % SOM in a layer of 10 cm soil
   b. Sand: about 2.5 mm per 1% SOM in a layer of 10 cm soil.

Soil organic matter consists of a wide range of organic compounds of different decomposability. There are several theories how SOM organic matter is formed: just a residue of plants and micro-organisms, newly formed by chemical reactions in soil from decay products or a combination of both. Be it as it may be, there is recalcitrant (difficult to decompose material) organic matter in recognisable residues (=particulate organic matter). Also micro-organisms produce recalcitrant organic matter and a part of organic matter is protected against decomposition in micro-aggregates inaccessible for micro-organisms and another part is chemically protected by clay and iron oxides. See: https://www.researchgate.net/publication/232758678_Mineral_Control_of_Soil_Organic_Carbon_Storage_and_Turnover The protection capacity of a soil is limited and added organic matter will decompose faster and more completely as the soil is more saturated with organic matter. Roots contribute more than leaves to accumulation of soil organic matter. Also simple sugars exudated by roots can be transformed by micro-organisms in stable organic compounds (link: Direct evidence for microbial-derived soil organic matter formation and its ecophysiological controls Nature Communications.htm)

Plants can regulate the decomposition of organic matter (http://wwwuser.gwdg.de/~kuzyakov/K-JPNSS2.pdf): by exudating sugars as source of energy of micro-organisms, that start to decompose available organic matter resulting in a release of nutrients after those micro-organisms are eaten by protozoa. Probably, this process is not relevant in arable fields, where sufficient available nitrogen minimises exudation, but in pastures (if not fertilised too much) and natural vegetation it might be an important process.

Soil tillage stimulates decomposition because protection in aggregates is disturbed, concentration of oxygen may be increased and the equilibrium between soil organisms is disturbed resulting in a massacre in the fauna followed by a built-up of new populations. Moreover, in an undisturbed soil decomposition slows down with depth. Link: Stability of buried carbon in deep-ploughed forest and cropland soils - implications for carbon stocks.htm

Usually, after reclamation of a 'natural' soil arable farming results in a decrease of organic matter content and a more compact soil with a deteriorated soil structure till a new equilibrium is reached between input and decomposition.



Tanzania: Kilimanjaro region : right after 50 years of cultivation

Fig. 4. Cropping over an old fence-line clearly demonstrates the extent to which soil has been depleted by conventional farming practices. Paddocks on either side of the fence have a history of high nitrogen application (Photo Richard May).

On a self-reliant organic farm the import of organic matter from outside a farm is low and organic matter content is the result of which crops are grown, how they are grown, the number of animals, that are kept and how much manure is returned to the soil. Also soil properties have an influence: more clay , a lower pH and a poor drainage result in a higher equilibrium organic matter content, but it might be clear that more available water as result of a higher SOM is not relevant on a wet soil and that the negative impact of a low pH is not always compensated by a higher SOM.

In Southern-Chile you can find trumao soils : developed in volcanic ash. Beautiful structure and with plenty organic matter, but also with a low pH and a strong fixation of phosphorus. This visually perfect soil is without P fertilisation fertile for trees, but not for arable crops.

In a self-reliant farm it is possible to increase organic matter content in the whole soil profile by

1. More ruminants, more grass clover (and less food crops), straw as bedding material in stable and all manure returned to soil.
2. Other food crops: more cereals and less root crops and vegetables.
3. More cover crops
4. Reduction of number and intensity of tillage operations
5. Mixing a part of subsoil through topsoil (less decomposition in deeper layer and more accumulation in top layer in case of minimum tillage (top soil is less saturated with organic matter and further from equilibrium between input and decomposition)

Increasing soil organic matter content may have a price on a self-reliant farm (for instance less crops with a higher return). Increasing organic matter content results in an immobilisation of N, P and S ((because SOM contains about 50 % C, 5% N, 0.5 % P and 1% S) and thus in a lower availability that could affect production level, if this immobilisation is not compensated by extra N fixation, P-weathering and S-deposition or application of P and S fertilisers. Lowering of organic matter content in top layer to protect more organic matter in deeper layers may increase the availability of water (deeper rooting), but also in a the top layer more susceptible to slaking and sealing. The effects of such measures should be tested before application at large scale.

Under pastures SOM increases till the very top soil is saturated with organic matter. From then onwards release of N, P and S equals more or less the yearly input via crop residues and manure. Where worms (or rodents) mix subsoil through the top soil (and top soil through the sub soil) organic matter content of the whole profile may increase during a very long period as the top soil does not become saturated. In this way huge amounts of organic N, P and S can be accumulated. In nature chernozems were formed in this way.
https://www.isric.org/sites/default/files/major_soils_of_the_world/set8/ch/chernoze.pdf

On organic farms that import manure or compost, a faster increase of organic matter is possible. In Europe the amount of organic matter that is allowed to be imported is limited to avoid soils become saturated with P. According the regulations within organic agriculture farmers are not allowed to apply more than 170 kg N in manure/ ha (average of the whole farm). Manure and compost from conventional farms may contain residues of pesticides.

GROWING COVER CROPS

Cover crops /green manure crops / catch crops have several favourable effects on the condition of soil: they reduce the leaching of nutrients (catch crops), they protect soil surface against the sealing/slaking effect of rains, they improve soil structure by stimulating soil organisms (worms, beetles), they may smother weeds and reduce germination of weed seeds, they add organic matter to soil, they may improve availability of phosphate , they may fix nitrogen and they increase evaporation of water. However, some green manure crops stimulate the growth of snails, slugs and unwanted nematodes and some of them may become a weed if tillage operations fail to stop them growing. Some of them can be sown in a crop (relay cropping). The choice of a cover/catch crop should be based on all these functions and properties. It is not easy to find the best compromise in the specific situation of a farm.

LEGUMINOUS COVER CROPS.

Leguminous crops fix nitrogen if inorganic nitrogen content of soil is low (under growing clover only 5 kg inorganic N/ha is found in top soil). After emergence they need some time to start the fixation of nitrogen. Where nitrogen content of soil is low (for instance after harvest of crops like cereals, grass for seed production, flax) , they are able to compete with weeds and other green manure crops. If grown for feed, about 30-50% of the fixed nitrogen is lost/used by volatilisation, leaching and denitrification from manure and in the animal product. If properly and timely incorporated in soil loss of nitrogen is much lower.

1. Clover or a mixture of grass and clover can be grown as a relay crop . https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/relay-cropping Clover is sown in spring between the cereals or flax. It is important that clover (and grass) are well distributed over the whole field ; otherwise they cannot compete out all weeds after harvest of the main crop. Usually, the clover/grass clover plus remaining weeds are mown after they have recovered from the strong competition with the cover crop. This mowing supports clover in its competition with weeds (and grass). After soil has been re-moistened clovers will grow vigorously. Ideally, there is a balance between grass and clover (about 50% of dm each = about 66% clover visually). The grass will take up nitrogen that is released from soil and clover residues during late autumn and winter when clover does not grow anymore. If clover is incorporated in soil before winter, a substantial part of its nitrogen may be released during winter and be lost.
2. Faba beans , peas , lupines and vetch can be sown after harvest of cereals, grass seeds and other crops that do not leave enough nitrogen to give other crops a quick start. The big seeds give the plants a quick start, but they may need some time to start the fixation of nitrogen that enables them to compete with weeds without mowing them. If soil is too fertile weeds may become too strong. Therefore, it is better to sow a mixture of leguminous crops and other species (oats, rye, cruciferous crops, phacelia), that will compete with weeds if availability of nitrogen is rather high. A mixture of cruciferous, leguminous and cereal crops will adapt itself to the situation: if availability of nitrogen is low leguminous crops will dominate and if it is high, cereals and cruciferous crops will dominate. Also these mixtures should be incorporated as late as possible to avoid too much nitrogen is leached, especially in case of soils with a low water retention. Use of winter hard crops and varieties reduces the risk for leaching, but if the subsequent crop will be sown early in the season, they should not take the nitrogen and water from soil after the leaching period is over (March in the Netherlands). In that case it competes with that crop for available nitrogen and water.

CRUCIFEROUS COVER CROPS

Cruciferous crops need enough nitrogen to be able to smother weeds. If top soil contains less than 50 kg N/ha, it is better to grow them in a mixture with leguminous crops. They can take a lot of nitrogen from soil before winter, but a part of this nitrogen might be lost if the crop is frozen or incorporated too early. The C to N ratio of the crops increases, as the crop becomes older. Therefore, nitrogen is more slowly released from older plants.

CEREALS AND GRASSES AS COVER CROP

Cereals and grasses are important as green manure crop in a crop rotation without or with less than 25% monocots. Such green manure crops reduce the risk for soil borne pests and diseases for the main crops. If not fertilised too much, they develop an extensive and dense root system that may temporarily function as a skeleton after ploughing and stabilises soil structure. Especially important in case of soils that are easily sealed by rain drops. Such an extensive root system contributes more to the building up of soil organic matter than leaves produced by other green manure crops. Black oats and spring cereals, , are susceptible for frost. Grasses and winter cereals are resistant, but they do not fit in a strict minimum tillage system as it might be difficult to get rid of them in spring.

INTEGRATION OF COVER CROPS IN THE CROPPING/ FARMING SYSTEM

Timing of sowing. In general, green manure/cover/catch crops should be sown as early as possible to ensure a maximal uptake of nutrients from soil, a maximal fixation of nitrogen and sufficient protection of soil. However, if conditions are not favourable, it is better to postpone sowing:

1. to avoid that an undersown clover (red clover, Alexandrian clover, Persian clover) grows so high in a cereal crop that harvest is hindered,
2. to wait till rains have moistened top soil sufficiently
3. to control weeds mechanically before sowing.

Grazed, harvested, incorporated or mulched.

If grazed, about 20% (dairy cows) to 5% (beef cows, sheep) of N intake is transformed in protein and from remaining 80% or 95 % is excreted about 50% as urine in small spots. From these spots a substantial part may be lost by leaching and denitrification, especially if excreted in the late growing season and if water retention of soil is low and excess of rain is high.

If harvested and fed to animals, manure is stored to be used in next year. Also from manure 10 – 40 % of N can be lost (see Manure and its proper handeling). Green manure could be used to feed bio digesters and in this way nitrogen losses can largely be prevented, if the digestate is diluted and/or is incorporated in soil. https://www.researchgate.net/publication/223160849_Effects_of_biogas_digestion_of_clovergrass-leys_cover_crops_and_crop_residues_on_nitrogen_cycle_and_crop_yield_in_organic_stockless_farming_systems

If incorporated in soil: Some crops are easily killed by freezing (spring oats, yellow mustard, phacelia, Avena strigosa (black oats/ Japanese oats). From cut and/or frozen residues a substantial part of N can be lost by denitrification if % N in DM > 3%. To prevent N loss green manure crops could be incorporated superficially after being mixed through the upper layer. Crops that do not easily die after a superficially tillage, should be ploughed in to cover them with soil. If too much green material is incorporated too deeply, anoxic conditions may develop, where nitrate is denitrified and roots do not want to grow. http://library.wur.nl/WebQuery/wurpubs/396862. From the viewpoint of reduction of leaching preferably winter hard crops are grown that are killed in spring. Some crops are easily killed by mowing, hoeing or rotovating (yellow mustard, crimson clover). If mulch is left on soil surface a part of nitrogen might be lost by volatilisation , more as % N in dm is higher.

At a certain, unfortunately unpredictable moment in early spring evapotranspiration of a cover crop is higher than rainfall and uptake of nitrogen by the cover crop prevents accumulation of inorganic nitrogen in soil that would have given the succeeding crop a quick start. From then the cover crop competes with the succeeding crop. After incorporation or mulching a substantial part of the nitrogen in the residues may be released after harvest if C to N ratio of residues is low.

https://www.researchgate.net/publication/267849019_Decomposition_and_nitrogen_release_by_green_manure_legume_residues_in_different_soil_types ,

SOIL COLOUR AND ODOUR:

Interpretation

Brown to black colours indicate the presence of organic matter, the deeper the colour the more organic matter (in red soils the brown colour may be masked by the red colour).

Bright colours and strong reds indicate that the soil, or horizon, is well drained, or at least rarely suffers from prolonged saturation.

Dull colours: yellows, and greys, often found together in mottled horizons indicate that the soil is not well drained and does suffer from prolonged saturation.

Blue-grey and blue-green colours are a certain indication that the soil is saturated for most of the year. The colours are due to iron (normally red as and oxide) being present in a reduced form (the opposite of being oxidised) and may be combined with sulfur, as a sulfide. Hence, such soils can often give off a bit of a niff like bad eggs.

Precipitation of iron compounds, usually orange or dull red, sometimes in association with manganese (black), is an indication of oxidation occurring in a generally waterlogged environment.. Concentrations of iron may occur as pans, as ironstone and as laterite.

White colours in the subsoil are often due to the presence of *calcium carbonate*. This can be tested for using a little hydrochloric acid. If carbonate is present a few drops of acid will cause the soil to fizz and bubble as carbon dioxide is formed by the reaction of acid and carbonate.

Further reading: http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_interpret_colour# or https://blogs.egu.eu/divisions/sss/2014/03/30/soil-color-never-lies/

ANIMAL HUSBANDERY

Animals produce manure and a substantial part of nutrients can be recycled via this manure. If all feed is grown on farm , only a limited percentage of the nutrients taken up by feed crops is exported in milk (about 20% of N, 30% of P and 5% of K) in case of dairy cows and in meat (5% of N, 10 % of P and 1% of K) in case of beef cattle. The majority of nutrients in feed is returned to soil and all nutrients in roots and residues of the feed crops are returned as well. In nature ruminants eat mainly whole plants, poultry mainly seeds, young leaves and insects and pigs roots and tubers, young leaves and big seeds like acorns.

Where ruminants graze, substantial amounts of organic matter are accumulated in soil via manure and residues of grasses till an equilibrium is reached and input of organic matter just compensates the decomposition. Most roots, other residues and manure are added to the very top soil (5 cm) and worms mix this layer with soil below. A moderate compaction of the top soil by animals stimulates worms to mix the top soil. This mixing results in more physical protection of organic matter within the whole soil profile, because the very top soil becomes less quickly saturated with organic matter. So more organic matter can be accumulated in the whole soil profile. Clover fuels a pasture with nitrogen. Cows cannot select in a sward of grasses and clover. Continuous and intensive grazing by cows (average height of a sward between 5 and 8 cm) gives clover a good chance to survive and stimulates tillering by grasses and intensive rooting (because each tiller has its own root system). Sheep can select and continuous intensive grazing by sheep may lower clover content and nitrogen fixation. Mixed grazing by cows and sheep (ratio ≈ 1:1) results in a better use of the grass production as long as clover content does not decrease too much (see below). Clover in a sward results in more worms and more mixing of soil. The number of worms is negatively affected by prolonged flooding, a too intensive compaction and an excessive application of slurry (> 60 ton/ha). The soil below a pasture becomes more and more fertile, if weathering of minerals, fixation and deposition of nitrogen and sulfur compensate the losses in products plus the accumulation of N,P and S in organic matter (about 50 kg N, 5 kg P and 10 kg S per 1000 kg organic matter) and the loss of N and S by leaching and volatilisation. If not, the production will decrease slowly till an equilibrium has been reached for the limiting nutrient.

If former arable land is transformed in a grass clover pasture organic matter content of soil increases and production will be high during the first years, because clovers are free of diseases and flourish making the pasture productive. After a few years clover content may decrease, because clover might have been affected by soil borne pests and diseases and been overgrown by grasses. N, P and S are still accumulated in soil organic matter resulting in a lower availability of N,P and S. The production decreases and only with extra manure or mineral P- and/or S- fertilisers the pasture will maintain productivity. From then onwards clover starts to grow spot wise and escapes from soil borne diseases by colonising disease and pest free spots via their creeping stolons/runners. After some years less manure is necessary to maintain production at a high level as less nutrients are yearly accumulated in organic matter .

Many organic livestock farms import so much feed in concentrates, that losses of nutrients and accumulation in organic matter are compensated. In many cases production can be increased by proper handling of manure, by stimulating nitrogen fixation and by protecting and stimulating worms and applying mineral fertilisers like lime, potassium sulfate, phosphorus, cobalt, selenium, boron etc.

Poultry is often fed with purchased feed resulting in an excess of manure. If poultry farms are concentrated regionally around all supporting enterprises and facilities, the regional excess can cause environmental problems. Where it is possible to produce a substantial part of the feed on the farm itself only a few products from else have to be added to balance the supply of amino acids and minerals. On such an almost self-reliant poultry farm many cereals and pulses are grown, separately or mixed, and in a temperate climate these crops can be combined with nitrogen fixing cover crops. The extensive root system of cereals together with the straw and cover crops may result in high organic matter content of the soil. Poultry manure (if dried as soon as possible after excretion) contain a lot of almost immediately available nitrogen and phosphorus. This manure can be used to support the tillering and ear formation of cereals in early spring, when the availability of nitrogen is still low (in a temperate climate with an excess of rain in winter). On organic farms chickens get the opportunity to scratch around in the open air, in a pasture or under tall grasses like *Miscanthus* or shrubs. This is not a problem where small groups of chickens (20-200) are housed in mobile houses , that are moved so fast around within an orchard or pasture that the soil remains covered with grass. Predation by foxes and birds of prey should be avoided. However, often the concentration of chickens is so high that leaching of nitrogen, accumulation of phosphorus and contamination of chickens with parasites cannot be avoided resulting in a waste of nutrients, a pollution of environment and weakening of the animals. On a few conventional farms such problems are avoided by keeping them indoors without compromising animal welfare. See https://www.kipster.farm and http://edepot.wur.nl/5545).

Pig farming pm

MANURE AND ITS PROPER HANDELING

By confining animals in stables the animals are given shelter, manure is collected and compaction and/or overgrazing of pastures is avoided. Special buildings, equipment and extra time are needed to conserve feed, to feed animals and to collect, to process and to return manure to the fields. The amount and composition of manure directly after excretion depends on the feed provided. Shortage of any plant nutrient in the feed is reflected in the composition of the manure: if the P content of feed is low, also the P content of manure will be low. The higher the digestibility of the feed the less manure is produced per kg feed, but the concentrations of plant nutrients in manure are higher. If a dairy cow is fed properly (good balance between energy, protein, minerals and fibers) about 1/5 of the N in feed is excreted in milk and 2/5 in urine and dung each. Any excess of N in feed is mainly excreted in urine. In case of meat production only a small part (5%) of nitrogen is accumulated in the body of the animals, that are fed properly. Almost all phosphorus, calcium and magnesium that is not used for milk/meat production is excreted in feces and almost all potassium in urine.

PROCESSES AND LOSSES IN PASTURE

Feces and urine are more or less at randomly and separately excreted in a pasture (usually somewhat more on cow paths, near the gate and under trees) and nutrients and organic matter in both are separated as well: N and S in both, P mainly in dung and K mainly in urine.

In fields where the availability of phosphorus is limiting the production, the nitrogen in the urine cannot be used efficiently and may be leached. In former dung spots, where phosphorus has been accumulated, urine N may give a boost to the grass. In fields where potassium or boron is limiting the growth of clover, clover may grow more vigorously in former urine patches. Animals may accumulate nutrients under trees where they seek shelter and if they trample the sward there , only trees are fertilized. If they accumulate manure near the gate or on tracks and paths, this manure may be lost.

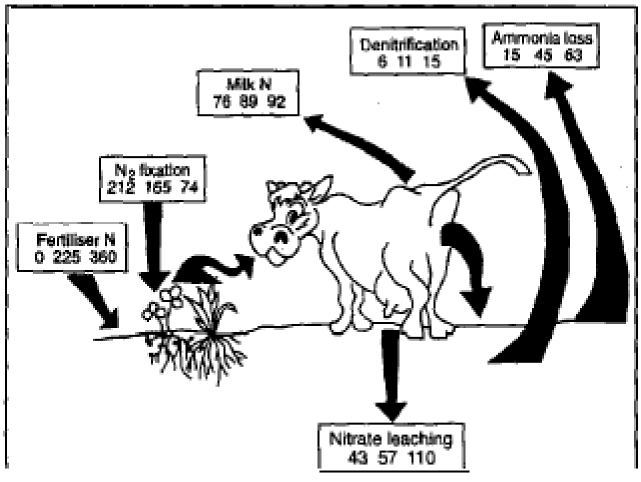
Most urine is quickly absorbed by soil and only a small part will adhere to the vegetation or make contact with dung. A part of excreted urine-N will be lost by volatilization after urea has been transformed into ammonia (≈ 5 % of excreted urine-N depending on soil pH, weather conditions and how much is absorbed by soil or sticks to vegetation). A high clay content of soil, quick absorption via worm channels and voids, low temperature, rain, dew and irrigation reduce these losses. In soil urea is transformed in ammonium and this ammonium plus the potassium in the urine are adsorbed by clay and humus. The high concentration of ammonium and potassium results in a desorption of Ca- and Mg- ions from the clay surface and an adsorption of ammonium and potassium.

As written earlier: once I simulated the leaching of nutrients from urine spots in the shallow soils of agrosilvopastoral system (dehesa) in Portugal. I used a simulation program that included the preference of the dominant clay mineral for Ca, Mg , K and NH_4 respectively. After applying urine to the rather poor sandy loam soil (derived from granite) mainly Ca was leached in case of an excess of rain.

As long as most ammonia is being adsorbed, it cannot be leached. The ammonium will gradually be transformed into nitrate by bacteria. A locally very high concentration of ammonia slows down this nitrification (it is like a poison for nitrifying bacteria). The "*Controlled Uptake Long Term Ammonium Nutrition*" (CULTAN) fertilisation approach is based on this phenomenon (see also : www.cultan.de (mainly in German). However, the concentration in urine is not sufficiently high to stop nitrification completely. Nitrate is easily lost by leaching and if former urine patches are still visible in a dark green color of the grass after a winter with an excess of rain, not all ammonium was nitrified in autumn and winter (temperate climate).

In a productive pasture the N content of the grass and therefore also of the urine is so high, that grasses need a whole growing season to take up all nitrogen, that remain in such patches (corresponding with 500 - 800 kg N/ha). The later in the season excreted the less nitrogen can be used and a substantial part of it will be leached in succeeding wet winter. Another part of the nitrogen may be lost by denitrification. In a pasture where no artificial fertilizers are applied denitrification is usually low. See cartoon :

Figure 1 Nitrogen transformations in farmlets grazed by dairy cows. Data are kg N/ha for year 1 (except for leaching which is the mean of years I and 2) and values from left to right are for 0, 200 and 400 N treatments respectively.



on p.2 of https://www.grassland.org.nz/publications/nzgrassland_publication_696.pdf . Denitrification is higher if soil is treaded by animals under wet conditions. Also from the dung about 5 % of dung-N is lost by volatilisation.

On a productive grazed grass clover pasture in Europe (8000 kg DM intake, 3% N in DM and 10000 kg milk/ha) N- intake is 240 kg N, if no concentrates are supplied and 5% of N intake is lost by volatilisation and another 25% of N intake is exported in milk. Loss by denitrification and leaching may be 10-20% (depending on soil quality and management). All these losses have to be compensated by deposition (10-30 kg N/ha, depending location) , nitrogen fixation by free living micro-organisms (5 kg N/ha) and clover on a self-reliant organic farm and therefore the average clover content of a pasture should be about 20% to keep a pasture producing 8000 kg dm/ha,year. (nitrogen fixation ≈ 6 kg N / 100 kg clover dm). If organic matter content of soil is increasing, fixation should be higher to compensate for the accumulation of N in organic matter.

On old Dutch dikes every year about 5000 kg dm grass is harvested, during at least 20 years. The N content is about 2% and yearly about 100 kg N is harvested, although no manure or fertilisers are applied and clover content of the sward is very low. There non-symbiotic bacterial diazothrophs may have fixed the nitrogen to keep the grass growing. https://publications.csiro.au/rpr/pub?pid=csiro:EP142946 or https://www.researchgate.net/publication/226029154_Non-Symbiotic_Bacterial_Diazotrophs_in_Crop-Farming_Systems_Can_Their_Potential_for_Plant_Growth_Promotion_be_Better_Exploited A similar process could be going on in permanent pastures.

Losses will be lower without a decrease of milk production, if protein content of feed is 25% lower (about 75 g DVE / kg DM instead of 105 g DVE/kg DM)) and energy content does not change. Plant breeders of grass varieties are working on that. Supplementing grass clover with feed with a high energy content and a low protein content (maize, fodder beet, beet pulp) will decrease N losses by volatilisation and leaching from manure, but not necessarily the total losses from the farm as production of maize and beets may result in more nitrogen losses by leaching compared with that of grass clover mowed only.

Figuur 1 compost dairy farm

Figuur2 Deep litter stable

Figuur 3tying stable

Figuur 4 cubicle stable

Figuur 5 slatted floor

There are several types of stables: a compost dairy barn, a deep litter stable/deep pack barn, a tying stable and a cubicle stable , traditionally with a slatted floor.

In a compost dairy barn a thick layer of wood shavings, saw dust and/ or straw is daily mixed with the dung of animals . The decomposing mixture produce a lot of heat that is mainly lost as latent heat c.q. water vapor. (about 5-6 kg water/kg decomposed organic matter). The animals get ample room (about 10 – 15 m^2 per animal and passing dry air takes the produced water vapor away.

In a deep litter stable (deep pack barn) (with about 10 m^2 room/ animal), where every day about 10 kg straw per animal is added as bedding material without daily mixing. There less water evaporates as less heat is developed and more liquid has to be retained by the bedding material. Per kg bedding material more water evaporates when the bedding material decomposes in a compost barn than can be retained by 1 kg bedding material in a deep litter stable (about 6 kg and 2 kg water respectively per kg decomposed or undecomposed bedding material). A compost dairy stable is an option to reduce the need for bedding material and to give animals more room. In both systems solid farm yard manure is produced.

In a traditional cubicle stable (with slatted floor) only slurry is produced, that can easily spread over the fields. Animals are free to move around, but they do not have as much room as in a compost barn or deep litter stable.

The opposite of a compost dairy stable is a tying stable. Animals can be provided a soft, safe and dry place to rest, but they do not get sufficient room to behave naturally. They do not fight and are less stressed after they have accepted their fate.

Animals prefer a soft, safe and dry place to rest and sufficient room to behave naturally. In a compost dairy barn animals find a situation most similar to that in a pasture. Relaxed cows produce more, are more healthy and live longer (if also properly fed). So animal welfare in a dairy compost barn > deep litter stable > cubicle stable > tying stable if freedom to behave naturally is the main criteria. However, in a tying stable cows cannot trouble each other and also lower ranked cows find there a safe place.

Ammonia losses from a tying stable < well managed compost dairy barn < deep litter stable ≈ traditional cubicle stable (with slatted floor). In a modern cubicle stable volatilisation is reduced by technical means (quick drainage of urine to closed tank).

N_2 and N_2O losses from a tying stable< cubicle stable< compost dairy barn ≈deep litter stable

Methane emission (excluding the enteric methane) from tying stable< cubicle stable < compost dairy barn < deep litter stable.

During storage of manure loss of organic matter can be reduced by creating anaerobic conditions by compaction of the manure. In a compost barn more organic matter is lost than in a deep litter stable and during composting of manure more organic matter is lost than in case of compact stacking. Slurry is anaerobic. However, more methane is lost if manure is just stacked.
https://link.springer.com/article/10.1023/A:1012649028772

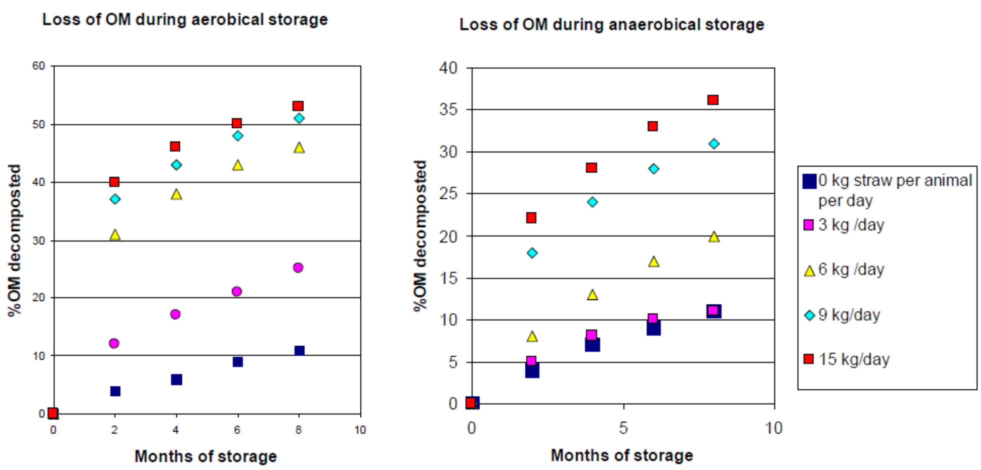


Figure. The proportion of organic matter lost during storage by aerobic (a) or anaerobic (b) degradation in dependence of the amount of straw added.

(based on data from Kolenbrander, G.J. & L.C.N. de la Lande Cremer, 1967, Stalmest en gier, Wageningen)

During storage the loss of nitrogen by volatilisation of NH_3 and denitrification can be avoided 1) by separating the urine from the solid manure directly after excretion, in a cubicle stable and in a tying stable 2) by adding soil or rock dust in a deep litter stable (about 1 kg /animal , day), 3) by adding so much organic matter with a high C:N ratio that the initial C:N ratio of the mixture is about 40 in a compost dairy barn and 4) by applying the resulting compost as soon as nitrate-N is detectable to avoid losses by denitrification. During application loss of N can be reduced by choosing a period with rainy and cool weather, by irrigation (10 mm) just after application or incorporation of manure just after application.

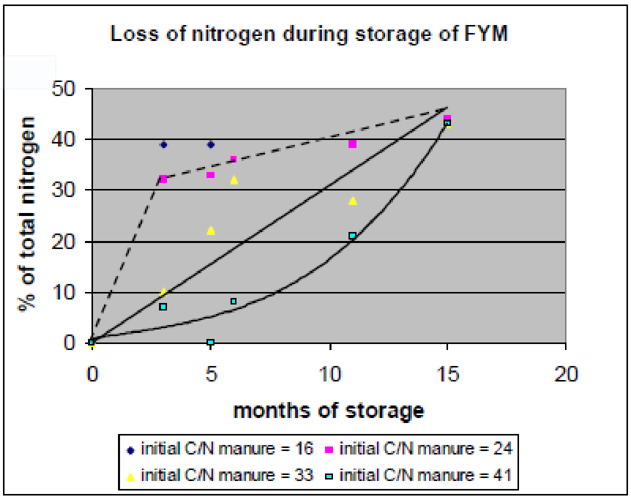


Figure is based on data from Kirchmann, H., 1985. Losses, plant uptake and utilization of manure nitrogen during a production cycle. Acta Agric Scand. Suppl 24, 9-17, 28-39 en 66-71.

Aerobic composting of manure results in higher N losses than anaerobic stacking and lower emission of methane and N_2O

https://link.springer.com/article/10.1023/A:1012649028772

Losses by volatilisation from slurry can be reduced by storing the slurry as quickly as possible in a well closed tank and by injecting the slurry directly in soil or by diluting the slurry before application (1 : 1 or more).

Pigs are clean animals and can be taught to put their excrements in a so called pig toilet, from where these excrements can be transported quickly to a closed tank. They can also be housed in a compost stable, but it is important to keep the nitrate content low by adding sufficient easily decomposable material to prevent denitrification without increasing the temperature too much.

Losses from poultry manure can be minimised by drying the manure as fast as possible.

INTEGRATION OF ANIMAL HUSBANDERY AND ARABLE FARMING AT FARM LEVEL

ARABLE FARMING BASED ON COVER CROPS

Well-chosen cover crops add organic matter to soil, may suppress weeds and soil borne diseases, fix nitrogen and minimise leaching of nutrients. For a long time shifting cultivation was based on a recuperation of soil fertility by a more or less natural vegetation. In regions specialised on crop production organic farmers try to develop or to improve a cropping system, that sustains soil fertility without other external inputs than some minerals or rock dust. Cover crops and green manure crops play a crucial role in such cropping systems. See for instance: Overview-of-Organic-Cover-Crop-Based-No-Tillage-Technique-in-Europe-Farmers-Practices-and-Research-Challenges.pdf or http://orgprints.org/31051/13/PA_036_Cover_Crops_QR.pdf Such a cropping system can be designed by using the program NDICEA, albeit that the exact weather conditions cannot be foreseen. You need a lot of practical knowledge to avoid unrealistic solutions.

An example: after experimenting 6 years in Kollumerwaard, The Netherlands, it became clear that on a good soil (developed on marine deposits) it is possible to harvest good yields of row crops and moderate yields of cereals without any input from outside by using on farm produced grass clover silage as cut and carry fertiliser. The yield level tended to increase through the years. The collected experiences were used to develop a crop rotation based on explorative calculations with NDICEA. The moderate yield of cereals could be explained by the low availability of nitrogen in early spring resulting in poor tillering and the formation of short ears.

MIXED FARMING

On a self-reliant mixed farm soil properties, crop rotation, livestock and manure handling determine the attainable productivity. There is a wide range of mixed farms.

FARMS USED PRIMARILY FOR GRAZING, where a part of the pasture is plowed after 10-15 years of grazing and then 2-3 years is used for crop production. Organic matter content of the soil increases during the long grazing period and decreases during the short arable period with a release of N, P and S , which can be used by crops. There are several positive side-effects: thorny weeds in the pasture are controlled, the cycle of parasites of animals is broken and young trees– if trees are a part of the system- have a chance to bring their branches out of reach of browsing animals. Trees bring up nutrients , lost by leaching or released through weathering, from the deep subsoil to soil surface. In this way poor land can be used for food production.

The traditional dehesa or montado system on marginal soils in Spain and Portugal is a well-described example (https://en.wikipedia.org/wiki/Dehesa). These farms produce a variety of products, including non-timber forest products such as wild game, mushrooms, honey, cork, and firewood. They are also used to raise the Spanish fighting bull and the Iberian pig. The main tree component is oak, usually holm (*Quercus ilex*) and cork (*Quercus suber*). Beef cattle produces calves that are fattened elsewhere on more fertile soils, sheep are milked during the short period that the quality of pasture is sufficient to produce milk, pigs are fed with acorns. Fires during the dry season are rare because the limited inflammable mass of standing hay and the grazing .

FARMS WHERE FERTILITY IS ACCUMULATED ON ARABLE LAND , on a small part of the farm to produce food crops or high-priced crops. Animals are fed from common land or marginal farm land and all manure is applied on arable fields, usually on physically better soils. In this way farmers can/could maintain soil fertility at a sufficiently high level to produce food.

Indonesian smallholders in Cuntel living at 1300 m altitude purchase young bulls from a marginal area (bukit Gedeng) (1-2 animals per farm family). The animals are housed in a deep litter stable. Every day they collect fresh grass from road sites and from nearby forest, the animals select the better part of it and the remaining part is used as bedding material. The feed is complemented with crop residues and purchased rice bran. The manure is applied spot wise near the planting holes of tobacco , potatoes or tomatoes. In this way they can keep fertility of the strongly phosphorus fixing soils at a sufficient high level to grow potatoes, tomatoes, tobacco, carrots as cash crops and maize, sweet potato (*Ipomoea batatas*) and peas as food crops.

For Dutch students: how 200 years ago smallholders in Brabant could produce a surplus of food on poor soils by accumulating nutrients from hay land and common grazing land on arable fields http://www.peelenkempen.nl/frans-aarts/

FARMS WHERE FOOD AND FEED IS PRODUCED ON ARABLE FIELDS, ideally without importing feed, manure and bedding material and where soil fertility is maintained at a high level by a proper choice and organisation of farm components (animals, crops).

Here we focus on a self-reliant organic farm with feed and food production and dairy. In temperate climates grass-clover has several functions on such farms: it provides feed for the animals, it fixes nitrogen, it adds relatively much organic matter to the soil, it feeds and protects earthworms, it suppresses weeds and it widens the crop rotation. On such a farm permanent pastures are usually located on soils less suitable for arable farming (if there) or close to the stable. Usually the grass clover to be conserved for feeding the animals in a cold or dry period is grown on arable fields as part of the crop rotation (= ley farming). Ley farming has a long history (see : http://journeytoforever.org/farm_library/ley/leyToC.html). It is practiced on many organic farms. Red clover (*Trifolium pratense*) and alfalfa (*Medicago sativa*) are the driving species in leys. Red clover where enough moisture is available and 5<soil pH <7 and alfalfa in regions with a dry period, where root zone is very deep and soil pH >6. They can be grown together with a grass species (red clover with Italian ryegrass (*Lolium multiflorum*) and alfalfa with *Dactylis glomerata* (Kropaar, Cocksfoot grass or Orchard grass) or a soft and palatable variety of *Festuca arundinacea* (rietzwenkgras, Tall Fescue) and both together with herbs like plantain (*Plantago lanceolata*) (Plantain reduces leaching of nitrate from urine spots (https://www.tandfonline.com/doi/abs/10.1080/00288233.2018.1461659). Such a combination results in a more balanced feed and reduces the risk of invasion or weed grasses like couch grass. Making hay of clover and alfalfa is risky as their leaves are very brittle and a substantial part (30%-40%) may be lost during field operations, when moisture content < 30%.

Red clover and Lucerne may fix a lot of nitrogen (≈ 450 kg N/ha), where growing conditions are favourable. As a consequence a lot of nutrients are removed in the product. Both crops can be used to mine soils that contain weathering minerals, but where weathering does not suffice to compensate the export of these nutrients, nutrients from else should be imported.

MAKING COMPOST

Well-made compost (dark brown, earthy odour, crumbly structure, moist, but no water can be squeezed out) is an excellent fertiliser, especially for the long term. How it can be made depends on quality and quantity of available material and weather conditions. Compost making should be learned by doing based on the principles described in http://whatcom.wsu.edu/ag/compost/fundamentals/ .

ROCK DUST AND CLAY OR LOAM FROM DEEP LAYERS

Rock dust, clay or loam from layers below rooting depth are a source of nutrients and weathering of primary minerals help to sequester CO_2 (https://www.sciencedirect.com/science/article/abs/pii/S1750583618300057). The effect and the profitability of applying rock dust depend on the type of rock, the size of particles, the price/costs, climate and the current fertility of a soil (https://iopscience.iop.org/article/10.1088/1748-9326/aaa9c4/pdf). In a very fertile soil primary minerals may hardly weather. Rock dust can be mixed with manure to reduce volatilisation of ammonium-N. Iron oxides in rock dust react with H_2S and other compounds taking a way a bad smell.

Specialised laboratories can analyse samples to get an impression of the stock of weatherable minerals and of their weatherability , for instance www.heavymineralanalysis.com .

From: *https://www.wbcsd.org/contentwbc/download/415/4426*
Rock dust (or stone meal) gains momentum due its beneficial spin-offs compared to conventional marketed fertilizer. As a multifunctional fertilizer, it is able to supply,
In addition to the macro-nutrients (N, P and K) required for optimal crop growth, a
Range of other micro-nutrients (e.g. S, Ca,Mg, B, Cl, Cu, Fe, Mn, Mo, Ni, Zn), while
It also improves the physical, chemical and biological quality of the soil. At the field
Level, these effects materialize in multiple profits for users, including an improved
Workability of the heavy clayey soils, improved water retention and water holding
Capacity of the soil (sandy and clay soil),increased (quality of) yields of the cultivated
Crops, and higher farm benefit due to decreased application and purchase cost
Relative to conventional fertilizers. At the local and national level, the use of local available
Rock dust creates employment opportunities, increasing GDP while reducing import costs.
This shift in focus leads to less greenhouse gas emissions through lower demand
For conventional fertilizer. Further climate change mitigation mechanisms reside in its
Capacity to directly sequester carbon and indirectly stimulate tree growth, thus leaving
Them to act as carbon sinks.

See also: https://link.springer.com/article/10.1023/A:1009859309453
Factors_influencing_the_release_of_plant_nutrient_elements_from_silicate_rock_powders__a_geochemical_overview.

INFLUENCE OF TREES ON SOIL FERTILITY

Trees may produce wood, food, feed and shelter. Their roots grow deeper than those of annual crops, if the deep subsoil is accessible. They recycle leached nutrients from that deep subsoil and together with mycorrhizae they speed up the weathering of primary minerals. Via leaves, wood and fruit these nutrients are added to the top soil together with organic matter. Trees differ in their effect on soil properties: coniferous trees make the soil more acid than trees like ash and lime. However, all trees need room, light, nutrients and water. It is not easy to estimate the overall effect of trees: in moist areas arable farmers like wind blowing through their crops to avoid pests and diseases, but in dry areas the reduction of evapotranspiration by windbreaks may be more important for them. Dairy farmers can provide shade to their animals by planting trees, but the animals may accumulate a substantial amount of manure under trees, which is less efficiently used there, especially if there are only a few trees and the vegetation is trampled by the animals under the trees. A successful integration of trees within a farm needs site and tree specific knowledge.

A general view on the influence of trees on soil fertility
https://www.hindawi.com/journals/aess/2012/616383/

About the effect of agroforestry on soil health: https://link.springer.com/article/10.1007/s10457-018-0223-9

SOIL TILLAGE

SEED BED PREPARATION:

In a well-prepared seed bed more seeds will germinate and emerge, especially if almost all of them are sown in the right way and at the right depth. The soil should have the proper firmness to allow capillary movement of water, but not so compact that aeration and rooting is impeded. The upper layer of 1- 2 cm may be loose and dry to reduce evaporation of water. In a flat, fine seed bed with the proper firmness seeds can be sown more precisely. However, a flat and fine seed bed is more prone to slaking and crusting. Therefore, a seed bed made before winter should be as coarse as necessary, especially if stability of soil structure is low. In spring it is very important to keep the soil firm under a loose top layer of about 2 cm. A sandy soil can be compacted after ploughing or ripping, but a clayey of loamy soil cannot. Such soils should not be tilled too deeply in spring. If stability of soil structure is low (big risk of slaking), this loose top soil should not be too fine. If seeds are pressed in the moist soil and covered with dry soil, they will germinate. If seeds emerge in waves, the seed bed was not well prepared and the soil was loosened too deeply. It is clear that a farmer has to learn by experience what mistakes he should no longer make.

Proper Seedbed Preparation is Key to a Successful Planting

by Terry M. Conway, Plant Materials Specialist

Natural Resources Conservation Service (NRCS)

Salina, Kansas

Many times we are in such a hurry to get the seed into the ground that we often ignore one of the more important steps of proper planting. That step is ensuring proper seedbed preparation. Some assume that since we are seeding native plants, those species should be able to readily establish even under unfavourable conditions. This, of course, is a false assumption. Seeding into a loose, rough seedbed will many times lead to failure while a properly prepared seedbed will provide optimum conditions for seed germination, plant establishment, and growth.

A key aspect of seedbed preparation involves the correct soil firmness. Seedbed firmness affects proper seed unit depth placement. If the seedbed is too loose, the seed unit will be planted too deep and the seedling will be unable to emerge. If the seedbed is too compacted, the seed unit will be planted too shallow and the surrounding soil and seed unit will quickly dry out. Depth bands on drill openers do not compensate for a poorly prepared seedbed.

With proper seedbed firmness, the optimum planting depth may be achieved that will place the seed unit in soil that will remain moist and is near enough to the surface to allow seedling emergence. **A good rule of thumb to remember is that proper firmness is achieved when a grown man walking across a properly prepared field will leave a footprint no deeper than 1/8 of an inch (3 mm).**

Seedbed firmness also affects soil moisture relationships. Soil firmness affects capillary pore spaces which directly affects the amount and movement of moisture in the soil. In loose soils, while there is a large amount of pore space, the pores will be too large to serve as capillaries for soil water. Loose soils have few interconnecting pore spaces and will ultimately retain very little water. On the other hand, if the soil is excessively compacted, the total amount of pore space will be significantly reduced resulting in poor moisture availability, as well as moisture movement into and through the soil.

In a properly prepared seedbed, the soil will be firm enough so that there is adequate capillary pore space for maximum moisture storage, as well as moisture movement between wet and dry areas. Soils that dry during the day will be partially rewet during the night and water taken up by seeds and roots will be replaced by capillary water movement. This will result in favorable seed germination, plant establishment, and growth.

PLOUGHING VERSUS REDUCED TILLAGE

A mixed approach of shallow ploughing, deep tillage using a non-inversion technique (picture Paragrubber), shallow tillage using a non-inversion technique and , if necessary, deep ploughing seems to be the best option and the decision is (as always) to the farmer.

Conventional farmers can use herbicides to control weeds and can refrain from any tillage technique. A farmer in Tanzania stopped tilling the soil and started to sow the seeds directly between the stubble of the former crop (wheat, barley, sun hemp, beans for seed). Run off and erosion stopped immediately, but the effect of the use of all herbicides may be negative in the long term. Organic farmers have to till the soil to get rid of weeds. Only if they can grow a cover crop that smothers all weeds and if they can grow a succeeding crop successfully after rolling the cover crop down (sufficient water and nitrogen left), they do not need to till the soil. See Picture roller crimper

https://library.wur.nl/WebQuery/wurpubs/122549 ,

CROP ROTATION

From *Organic Farming* (1990; Nicolas Lampkin), chapter 5, "Rotation Design for Organic Systems," pp. 131–32:

"Usually a rotation contains at least one 'money crop' that finds a direct and ready market; one clean tilled crop; one hay or straw crop; one leguminous crop. . . .

The starting point for the design of a rotation should be the capabilities of the farm and the land in terms of soil type, soil texture, climatic conditions."

Basic guidelines:

- Deep rooting crops should follow shallow rooting crops. . . .
- Alternate between crops with high and low root biomass. . . .
- Nitrogen fixing crops should alternate with nitrogen demanding crops. . . .
- Wherever possible, catch crops, green manures, and undersowing techniques should be used to keep the soil covered. . . .
- Crops which develop slowly and are therefore susceptible to weeds should follow weed suppressing crops. . . .
- Alternate between leaf and straw crops. . . .
- Where a risk of disease or soil borne pest problems exists, potential host crops should only occur in the rotation at appropriate time intervals. . . .
- Use variety and crop mixtures when possible. . . .
- Alternate between autumn and spring sown crops. . . .

Also consider:

- suitability of individual crops with respect to climate and soil
- balance between cash and forage crops
- seasonal labour requirements and availability
- cultivation and tillage operations

Further reading: download free online file from https://www.sare.org/Learning-Center/Books/Crop-Rotation-on-Organic-Farms

ATTACHMENTS

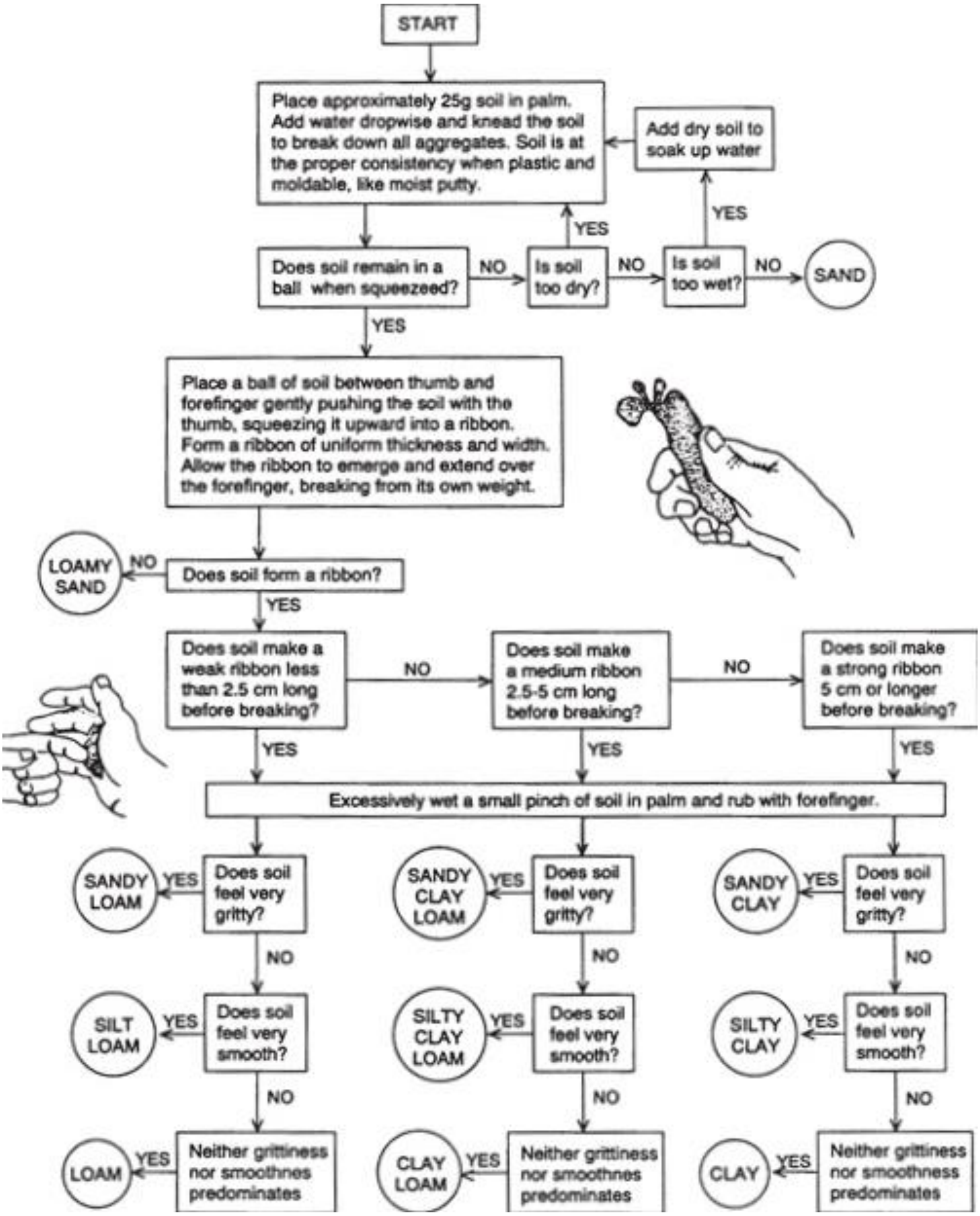
N FLOW DIAGRAM OF A SELF-RELIANT FARM THAT CORRESPONDS WITH EUROPEAN CONSUMPTION PATTERN

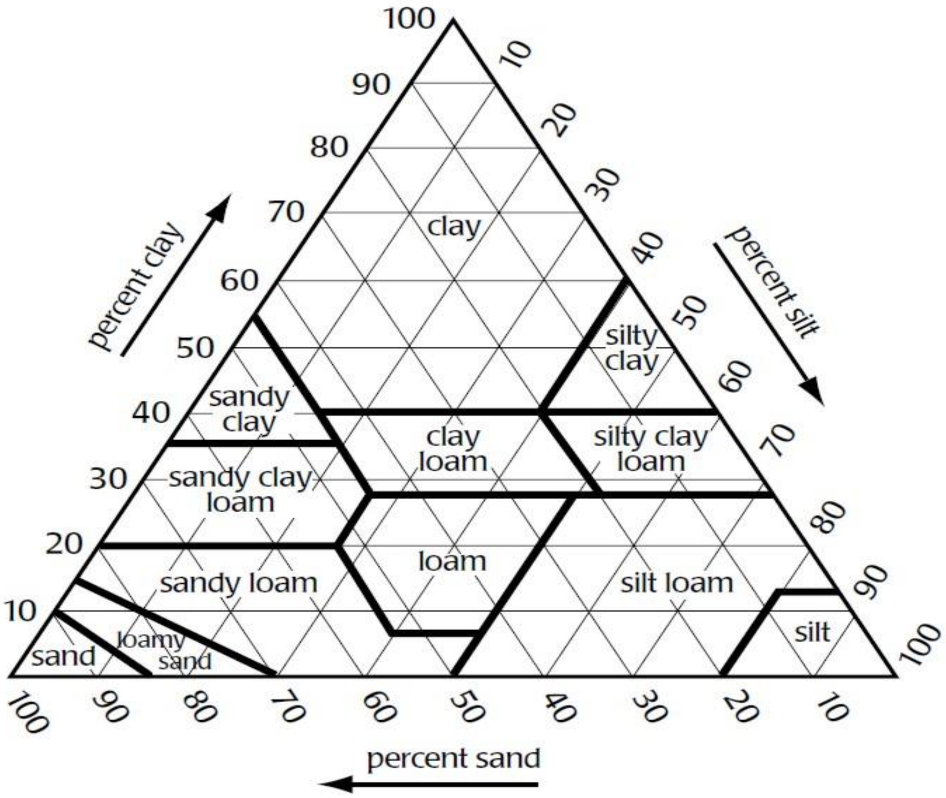
N in crop		Grassclover	cereals	pulses	oil crop	potato	sugarbeet	cabbage			
	yield	10000	6500	4000	3500	45000	50000	50000			kg/ha
	yield in dm	10000	5525	3400	3150	9450	11000	5000			kg/ha
	yield product as % of total yield	0.51	0.41	0.39	0.28	0.7	0.69	0.51			
	total ds yield including residues	19608	13476	8718	11250	13500	15942	9804			kg/ha
product	% dm of total dm yield	0.51	0.41	0.39	0.28	0.7	0.69	0.51			
	% N in dm	0.031	0.021	0.047	0.039	0.0157	0.008	0.0359			
	N in product	310	116	160	123	148	88	180			kg/ha
residu	% dm of total yield dm	0.39	0.28	0.41	0.62	0.25	0.26	0.39			
	% N in dm	0.02	0.006	0.021	0.007	0.022	0.02	0.027			
	N in residu	153	23	75	49	74	83	103			kg/ha
roots	% dm of total dm yield	0.1	0.3	0.2	0.1	0.05	0.05	0.1			
	% N in ds	0.018	0.008	0.025	0.01	0.01	0.01	0.01			
	N in roots	35	32	44	11	7	8	10			kg/ha
total N in crop		498	171	278	183	229	179	293			kg/ha
potential	N fixation	300	0	150	0	0	0	0			kg/ha
total uptake N from soil/ha		198	171	128	183	229	179	293			kg/ha
N in green manure											
yield	3000		3000	2400	3000	2400					kg/ha
residu	% dm		0.84	0.8	0.84	0.8					
	% N in dm		0.04	0.021	0.04	0.021					
	N in residu		101	40	101	40					kg/ha
roots	% dm		0.16	0.2	0.16	0.2					
	% N in dm		0.025	0.01	0.025	0.01					
	N in roots		12	5	12	5					kg/ha
total N in green manure crop			113	45	113	45					kg/ha
from	N fixation		75		75						kg/ha
from	soil		38	45	38	45					kg/ha
N uptake from soil / ha		198	209	174	221	274	179	293			kg/ha
potential	N fixation / ha	300	75	150	75	0	0	0			kg/ha
N in residues back to soil /ha		188	145	164	173	126	91	113			kg/ha
% of area		0.344	0.391	0.083	0.112	0.030	0.020	0.020		1.001	
In one hectare	N uptake	68.1	81.7	14.4	24.8	8.2	3.6	5.9		207	kg/ha
corresponding	potential N fixation	103.1	29.4	12.5	8.4	0.0	0.0	0.0		153	kg/ha
with	N in product	106.5	54.3	13.3	13.8	4.5	1.8	3.6		198	kg/ha
consumption pattern	N in residues back to soil	64.7	56.8	13.6	19.4	3.8	1.8	2.3		162	kg/ha
N to food			20.2	0.0	0.0	4.0	0.0	3.6		27.8	kg/ha
N to feed		110	34	13	14	0	2			173	kg/ha
N to animal product											
			kg	%dm	% N in dm	% N in fresh matter		intake/person			
	consumption/person	milk	240	0.129	0.04			1.2	9.8	kg/ha	
		meat	85	0.25	0.11			2.3	18.4	kg/ha	
		eggs	12			0.021		0.3	2.0	kg/ha	
N in animal product							0.127	ha per person		30.1	kg/ha
N to manure			9							152	kg/ha
acceptable loss from manure			0.25	% N loss from manure				to be realised		38	kg/ha
N in manure to soil										114	kg/ha
acceptable N loss from soil								to be realised		30	kg/ha
N deposition										15	kg/ha
Uptake crop		N-manure-N-loss from soil+ Nin residues + N deposition								262	kg/ha
necessary N fixation	uptake crop-N in residues back to soil - N to feed - N to food									102	kg/ha

potential N fixation (153 kg N/ha) > necessary N fixation (102 kg N/ha)

yields attainable , if losses by volatilisation, denitrification and leaching are limited

TEXTURE BY FEEL





INTERPRETATION PENETROMETER RESISTANCE

Penetrometer resistance is commonly used as an indicator of soil strength and is frequently measured with a standard cone. The standard cone has a 30° angle and a base of 12.82 mm. It conforms to ASAE Standard S313.1 (ASAE 1983) and is similar to that described by Anderson *et al.* (1980). The resistance is commonly recorded initially at 5 mm and then at 15 mm intervals to 440 mm as the penetrometer is pushed into the soil at a rate of 30.5 mm/s. The data is recorded on an electronic data logger.

Root growth may not always directly reflect these limitations because roots can still grow into cracks, fissures and old biopores, which may not be detected by the penetrometer. However, once a penetrometer resistance of 2.4 MPa is reached, root growth is largely restricted to existing pores or planes of weakness. This greatly limits the volume of soil that may be accessed by the roots, particularly in a soil with few existing cracks or pores (see Table 2.23).

Table 2.23. Effect of penetration resistance on root growth

*, the resistance is very dependent on moisture content and technique.

Penetration resistance* (MPa)	Degree of soil consolidation	Effect on root growth
<0.50	loose	not affected
0.50–1.25	medium	root growth of some cereal plants may be restricted
1.25–2.00	dense	cereal root growth badly restricted
2.00–3.00	very dense	very few plant roots penetrate the soil
>3.00	extremely dense	root growth virtually ceases

Adapted from Marshall and Holmes (1979); Ball and Sullivan (1982); Passioura (1991); Hunt and Gilkes (1992) and Cass (1999).

P

CHEMICAL SOIL TESTS, QUICK, DIRTY AND CHEAP.

Introduction By using simple tests (quick, dirty and cheap) the availability of nutrients in soil samples can be compared. Succeeding tests were selected by C.L. Laméris[1] about 55 years ago, especially for agronomists in remote areas in the tropics. Comparing chemical properties of soils will help you to explain differences in crop performance and might give information on how soils can be made more productive. A selection of those tests is described below: for P, K, Mg and Ca and you can use Merckoquant test strips to determine nitrate-N and pH. The tests can be used to find an answer to explain differences between crops and fields and the effect that the landscape (topography, groundwater, soil type) has on these characteristics. The determinations give a rough indication and when availability of a nutrients is low in all samples, you cannot detect small differences.

Picture simple soil test and Picture simple soil test: comparing availability of phosphorus in different fields

Recipe for measurement for pH and nitrate

- Take a composite soil sample (either of the fields or of the layers that you want to compare), dry the soil, crush the soil (by rolling a bottle over the soil), mix the dry soil thoroughly and remove gravel and roots..
- To determine pH, nitrate-N and in the farm lab follow the procedure:
- *Preparation of extract*
    - Add 50 g dry soil to 100 ml of demineralized water or rain water, shake 1 minute and filter the suspension. If the percolated solution is turbid, add it in the funnel again. You need only a few clear drops dripping from the funnel. (Picture simple soil test)
- *Measurement of pH:*
    - Follow the description on the strips to read the pH.
- *Measurement of nitrate-N*

  Put a nitrate-N strip in the liquid during 1 second, shake excessive liquid from the strip . Set a timer and decide exactly 1 minute after immersing which colour on the scale corresponds with the colour on the strip.

- *Calculation of Nitrate-N/ha*: if the soil sample is taken from the layer 0-25 cm and the bulk density of the dry soil 1.4 g/cm^3 (= 1400 kg/m^3), the weight of the sampled layer = 100m*100m*0.25mm*1400 kg/m^3 = 3500000 kg. If the concentration of the solution is **15** ppm nitrate-N , the total amount of nitrate in the 100 ml solution is **15** mg/kg solution* 0.1 kg= 1.5 mg and thus 1.5 mg/50 g dry soil => in 1 ha => (1.5g* 3500000kg)/50kg = 105000g or 105 kg nitrate-N/ha. **In well drained arable soils almost all mineral N = nitrate-N and the result of a test can be used to test or calibrate NDICEA..**
- *Interpretation pH*: depends on crop and soil picture interpretation soil pH and Picture relation pH and availability of nutrients
- *Interpretation nitrate*-N : a crop needs a certain course of available nitrate: sufficient to grow, but not excessive to avoid pests and diseases. Between 20 and 50 kg nitrate-N/ha in top soil during germination and 10 -20 kg nitrate-N in topsoil afterwards. In temperate climates the release of nitrogen in top soil may not suffice to compensate the uptake by the crop, but in a deep soil crops may find additional nitrogen in subsoil. By measuring regularly you get a picture of that course and the reaction of the crop.

Procedure to compare availability of P, K, Mg and Ca

These determinations are comparative, so analyse samples from several soils. One will be your reference, preferably a sample of a good soil in that region/farm. The samples are extracted with a solution that mimics the uptake by plants. There were many discussions about the perfect

[1]C.L. Lameris, 1960, De rapid soil tester als stethoscoop van de planter, Landbouwkundig Tijdschrift, 1960 pp. 567-575

extraction solution. However, there is no perfect extraction solution as you cannot mimic the effect of soil organisms like mycorrhiza, weather conditions and soil structure. Nevertheless, there is a certain relation between nutrients extracted and the availability for crops. Recipe for the "Morgan extraction solution":

- 100 g sodium acetate. $3H_2O$
- 700 ml demineralised water
- 30 ml undiluted acetic acid (glacial acetic acid)
- 1000 ml volumetric flask
- Swirl and fill the solution up to the graduation mark with distilled water).

The Morgan extraction solution has a buffered pH= 4.8 and during extraction the sodium will be exchanged for adsorbed K, Mg and Ca.

- take a 100 g sample from the composite soil sample, let it dry and crush the air dry soil. Dry clods can be crushed by rolling a glass bottle over them. The finer the better. Use 10 g for further analysis.
- Add 25 ml Morgan solution to 10 g dry soil, shake them vigorously during 1 minute, start filtering using folded filters Ø 150 mm, 595½. Make sure that no soil enters the bottle and check if the extract is clear. If not , put the extract on the filter again. The resulting extract should be clear, because in some of the determinations the turbidity is a measure for the concentration of a nutrient. If the concentration of P, K, Ca or Mg is low in all samples, you can repeat the extraction during a long time (for instance 1 hour or a night).

Determination of P

There are 2 reagents:

- P1: a mixture of metol (a reducer and used as a developer in black and white photography) and Sodium Disulfite (to eliminate the interference by silicates and ferri-iron). Dissolve 100 mg of metol and 15 gr Sodium Disulfite in distilled water, make up to 100 ml. Store in a brown bottle)
- P2: ammonium molybdate in 5M H_2SO_4 Dissolve 2.5 g ammoniummolybdate in nearly 50 ml distilled water and pour out, while stirring, into 50 ml 10N H_2SO_4 (10 N H_2SO_4 = 14 mls concentrated H_2SO_4 poured out to distilled water up to 50 ml), be carefull, DO NOT ADD water to concentrated H_2SO_4)

<u>Procedure</u>:

- Add 4 drops of soil extract in a cuvette, add 4 drops of P1 and 4 drops of P2, shake and wait for 15 minutes.
- The blue colour will develop slowly. The more blue the more P: colourless= very low, very light blue= low, light blue = medium, sky-blue=high.

See picture [Picture simple soil test: comparing availability of phosphorus in different fields]

Determination of K

- There are 5 reagents.
  - K1: 38% formaline (toxic !!! to bind NH_4, which interferes with the reaction);
  - K2: $Co(NO_3)_26H_2O$ in water plus acetic acid; (Dissolve 8 g of $CoCl_2.6H_2O$ or 10 g of $Co(NO_3)_2$.6H2O in a mixture of 95 mls distilled water and 5 ml glacial acid)
  - K3: $NaNO_3$ in water; Dissolve 60 grs of $NaNO_2$ in 100 ml water
  - K4: mixture of equal amounts of K2 and K3 , to be prepared just before use, mix not more than you will use;
  - K5: 96% ethanol.
- The formed $Na_3Co(NO_2)_6 + 2K^+$ --> $K_2NaCo(NO_2)_6$ (which precipitates) + 2 Na^+. The precipitate makes the solution turbid.

Procedure:

- Prepare K4 (enough for the number of samples): in case of 10 samples: 12 drops of K2 plus 12 drops of K3. Add 6 drops of K1 to 10 drops of soil extract, add 2 drops of K4, shake well, wait for 1 minute and add 10 drops of K5 and shake again. The more turbid, the more K. Clear solution: low K and if you cannot read through if you look through the solution to a text just behind the cuvette : high.

Determination of Mg

- There are 3 reagents:
    - Mg1: 50% glycerine plus saccharose (100 mls 50% glycerine plus 5 grs saccharose). The glycerine to prevent the formation of coloured $Mg(OH)_2$, that may flocculate and saccharose prevents the formation of $Ca(OH)_2$;
    - Mg2: a saturated solution of titan yellow in 96% ethanol, prepare so much as you need the 2 succeeding weeks
    - Mg3: 15% NaOH to increase the pH.

Procedure:

- Prepare reagent Mg2, if not available: a little bit titan yellow in 1 ml ethanol 96%, shake and leave for 15 minutes.
- Add 4 drops of K1 to 10 drops of soil extract, mix and add 1 drop of Mg2 and 4 drops of Mg3.
- Mix and compare the colours. Carmine red/flocculation= high, yellow orange = low.

Determination of Ca

- Reagent: Ca1 :NH4 oxalate that flocculates after reaction with Ca: $(NH_4)_2C_2O_4 + Ca^{++} \rightarrow CaC_2O_4$ (white) + 2 NH_4^+ (5 grs of NH_4 oxalate in 100 mls distilled water)

Procedure:

- Add 2 drops of Ca1 to 10 drops of soil extract
- shake and wait for 2 minutes, shake again and evaluate immediately.
- If by holding the cuvette with contents near a window against a printed text in incident light is invisible = high , print easy to read = low.
- Compare the turbidity. If all are high, you can repeat the test with 5 drops extract plus 5 drop distilled water and 2 drops of Ca1 and so on till you see a difference between the samples.

PICTURES:

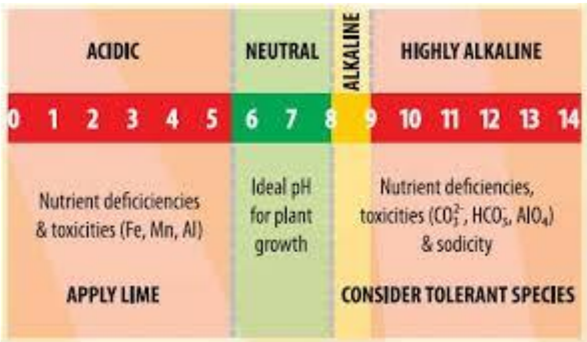
PICTURE SLAKING

PLATE 7 Structural crust, slaking type, developed on a 'mound' in a clay loamy soil in northern Niger under simulated rainfall. Note the surface roughness. Depositional crusts are formed under the water layer

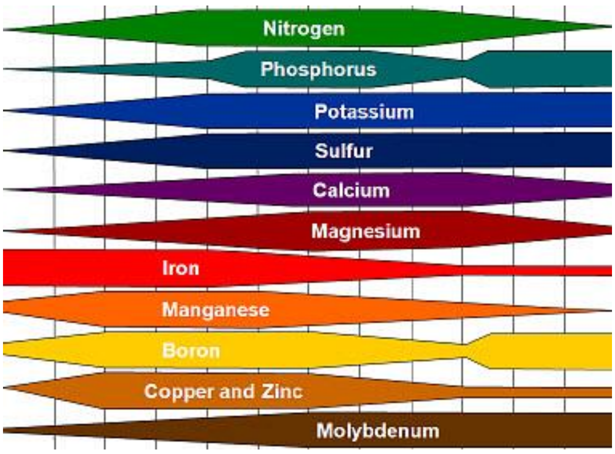
PICTURE SEALING AND CRUSTING:

PICTURE RUST MOTTLES

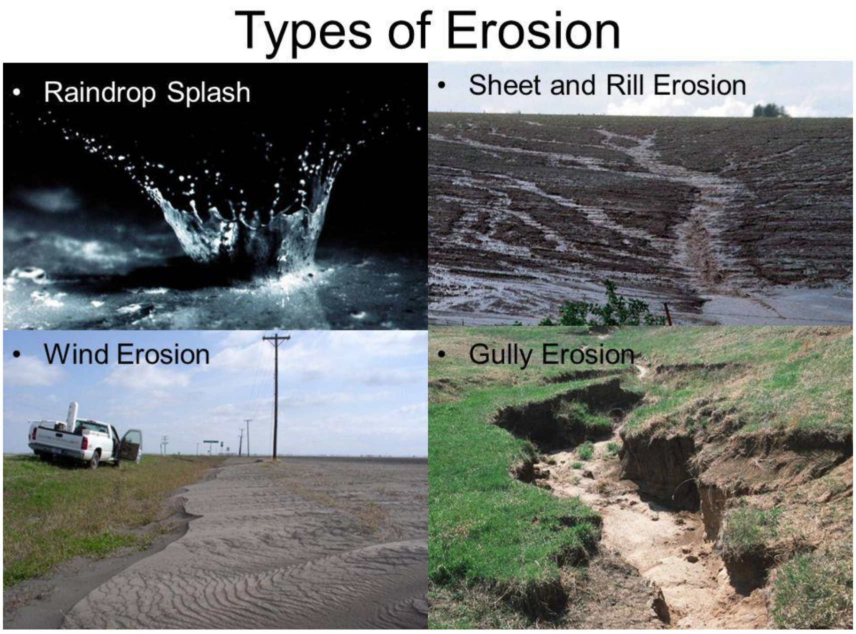
PICTURE INTERPRETATION SOIL PH



PICTURE RELATION PH AND AVAILABILITY



PICTURE SOIL EROSION



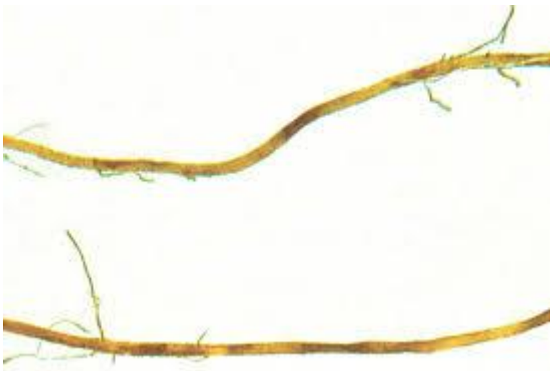
PICTURE LARVAE SOIL PESTS


wireworm/ritnaald larva Agriotes sp.

 cockchafer/May bug/ **engerling**
Melolontha sp.

 leatherjacket/ emelt larva Cranefly

PICTURES AFFECTED ROOT SYSTEM

 lesions

 root knots

 affected roots of maize

MACHINES

SOIL COMPACTOR

LOOSENING OF SUBSOIL

CHISEL PLOW

ECO-PLOUGH

PARAGRUBBER

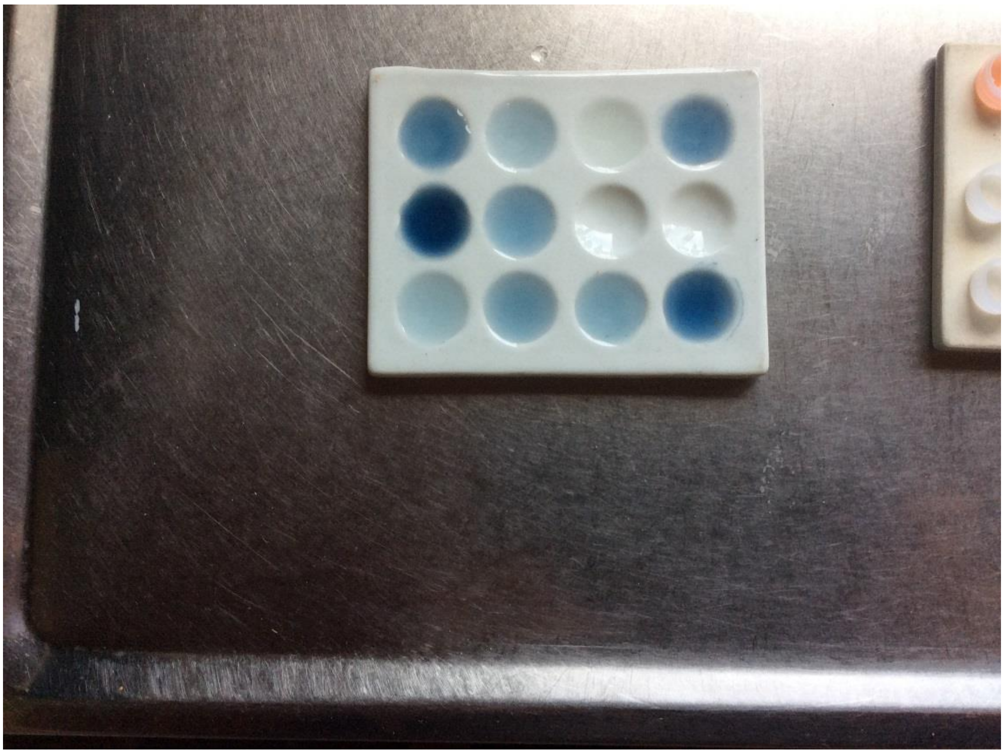
PICTURE SOIL AUGER

PICTURE HOEING MACHINE:

PICTURE ROLLER CRIMPER

PICTURE SIMPLE SOIL TEST

PICTURE SIMPLE SOIL TEST: COMPARING AVAILABILITY OF PHOSPHORUS IN DIFFERENT FIELDS



LINKS:

During my search for relevant links, I found several interesting websites that support farmers in recognising and solving their problems, especially from Australia and New Zealand where distances limit direct contact between farmers, scientists and extension officers. Most practical information for European farmers was not written in English. Therefore, you will have to translate the information from the United States, New Zealand and Australia to conditions elsewhere. A few examples of relevant websites are:

https://www.goedbodembeheer.nl/ voor Nederlands lezenden

http://bettersoils.soilwater.com.au/about.htm,

OrganicExchange.com.au

http://wheatdoctor.cimmyt.org/,

http://www.knowledgebank.irri.org/rice.htm

http://www.soilhealth.com/about/

http://fertsmart.dairyingfortomorrow.com.au/

for clover: http://www.fao.org/docrep/v9968e/v9968e03.htm and

About soil health: https://www.e-education.psu.edu/geog3/node/1163