REGENERATIVE AGRICULTURE GUIDEBOOK FOR DAIRY FARMS

DANONE
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Co-funded by the European Union

REGENERATIVE AGRICULTURE GUIDEBOOK FOR DAIRY FARMS - SOIL

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Danone

Danone fulfilling ***One Planet One Health*** vision, believes that there is no health without valuable food, which depends on condition of the environment. The company takes a broad view of its impact, striving for the most sustainable ways of producing food at all stages of the value chain. Therefore for years, together with milk suppliers in Poland, Danone has been implementing regenerative agriculture solutions. The company develops milk production standards by combining economical, social and quality goals with environmental aspects and focus on the responsible and ethical side of running a farms. Good practices in this area are based on three pillars:

- Protection of soil, water resources and biodiversity by promoting agricultural practices that increase soil organic matter and help sequester more carbon. The company covered 100% of farms supplying milk for the production of Danone dairy products in Poland with a regenerative agriculture audit.
- Supporting current and future generations of farmers in implementing regenerative agriculture as efficiently as possible - while maintaining environmental and cost benefits, and in transferring knowledge to the next generation.
- Care for animal welfare - the company expects compliance with standards in this area throughout the entire supply chain. It also conducts regular welfare audits at all cooperating dairy farms.

The activities carried out by Danone in Poland translate into benefits for the environment, farm efficiency and food quality, which is also important for consumers.

More information at danone.pl

EIT Food

EIT Food is the world's largest and most dynamic food innovation community. We accelerate innovation to build a future-fit food system that produces healthy and sustainable food for all.

Supported by the European Institute of Innovation and Technology (EIT), a body of the European Union, we invest in projects, organisations and individuals that share our goals for a healthy and sustainable food system. We unlock innovation potential in businesses and universities and create and scale agrifood startups to bring new technologies and products to market. We equip entrepreneurs and professionals with the skills needed to transform the food system and put consumers at the heart of our work, helping build trust by reconnecting them to the origins of their food.

We are one of nine innovation communities established by the EIT, an independent EU body set up in 2008 to drive innovation and entrepreneurship across Europe.

The EIT Food Regenerative Agriculture Programme aims to support farmers across Europe in transitioning to regenerative agriculture. It promotes sustainable farming practices that not only positively impact soil quality but also contribute to the production of food with higher nutritional value. The EIT Food Regenerative Agriculture Programme includes on-site training for farmers, advising, as well as webinars and manuals on regenerative practices for specific crops, available to all interested farmers. Furthermore, we organise events promoting regenerative agriculture and carry out educational activities for consumers. Our approach is based on collaboration among various stakeholders, such as farmers, researchers, startups, the processing industry, and consumers, to jointly create beneficial and lasting conditions for the development of regenerative agriculture

More information at www.eitfood.eu

The Terra Nostra Foundation for Agricultural Development

The Terra Nostra Foundation for Agricultural Development was founded in 2019. Its aim is to promote the idea of regenerative agriculture as a holistic resource and environmental management system that takes into account the profitability and competitiveness of the agricultural business in the value chain.

The foundation's activities are based on the knowledge of practitioners and scientists who implement the Integrated Regenerative Production program. It is based on the conversion of farms to regenerative agriculture through training, practical support and the development of a thematic community. The result of the program is the Certificate for Integrated Regenerative Production, which is awarded by an independent certification body - Bureau Veritas. It serves as evidence of regenerative actions on the farm and a way to monitor the environmental benefits of agricultural management, respected by agri-food processors.

The Terra Nostra Agricultural Development Foundation is also the organizer of the International Forum for Regenerative Agriculture BIO_REACTION, which brings together an international group of experts, scientists, farmers and advisors from around the world.

More information at www.fundacjaterranostra.pl

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SOIL

REGENERATIVE AGRICULTURE GUIDEBOOK

FOR DAIRY FARMS

Poznan 2024

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INTRODUCTION

Agriculture today is not only an area of unprecedented technological development, but also of unparalleled challenges. Climate change, which results in droughts, floods and other extreme events, poses a real threat to agricultural production. New regulations mandating environmental care are placing further demands on farmers. Meanwhile, increasingly aware consumers are paying attention to the environmental aspects of the agricultural production. ESG reporting (compulsory reporting of the environmental, social and governance impact of any enterprise) and other legislative changes will make the financing of production potentially dependent on its environmental impact. Therefore, regenerative production is starting to become an attractive choice. A holistic approach to the farm will become the norm. Already, a key element in maintaining soil fertility is the restoration of organic matter. Supporting farmers in the regenerative transformation is key to a successful transition to the new standards. This very resource is not just a handbook, but a guide for farmers, pointing out possible changes and ways to adapt to remain competitive and sustainable in the rapidly changing world of agriculture. Although today's challenges seem extremely difficult, the successful implementation of a regenerative transformation on the farm can be an opportunity to increase profitability and reduce the risks associated with agricultural production.

1 WHAT IS REGENERATIVE AGRICULTURE?

The quality of the food that reaches our tables starts in the soil. Farmers bear the burden of responsibility for food safety.

The nutritional value of the food supplied, as well as its production with respect for the environment and the welfare of farm animals, are also increasingly important in the eyes of consumers. Reconciling the demands placed on modern agriculture - efficient production, high crop quality, as well as animal welfare and conservation of natural resources - requires giving attention to the farm ecosystem. Particular consideration must be given to the primary tool of agricultural production, the soil.

The answer to today's challenges is the idea of regenerative agriculture. It should be understood as a comprehensive way of farm management in which agrotechnical decisions contribute to improving the physical, chemical and biological properties of soils. At the same time, this system prioritises farm profitability and the production of high-quality agricultural products. These objectives are by no means contradictory, but rather in line with each other.

The natural regeneration of soils, which can be understood as restoring fertility, increasing the amount of organic matter and improving the ability to yield crops efficiently, is possible through the comprehensive implementation of regenerative practices. In practice, this means using mainly organic fertilisers, increasing the diversity of crops grown (varied crop rotations and the use of catch crops), minimising activities that can damage soil structure, and maintaining biodiversity on the farm. In other words, management should provide the best for the soil. This will often mean referring to the principle: ‚cultivate as little as possible and as much as necessary'. The purpose of this manual is to present the basic practices of regenerative agriculture and to discuss their impact on the natural regenerative capacity of soils. The manual consists of four topics. The first thematic area deals with water management as a fundamental element without which crop cultivation is not possible. The second topic is the discussion of nutrient cycling in the soil and the parameters that affect nutrient availability to plants. In this thematic area, in line with the idea of a closed-loop economy, we have also included the topic of using waste produced on dairy farms as organic fertilisers. The third thematic area introduces the concept of biodiversity in the agricultural landscape. It discusses a variety of practices to improve and maintain biodiversity so that each farm will be able to select actions according to its capability. The fourth thematic area focuses on farming techniques and soil cultivation systems that do not adversely affect soil structure and promote soil regeneration. Each chapter has a similar structure, starting with a theoretical introduction - ‚I know why' - and ending with specific measures that can be introduced into farming practice - ‚I know how'. Our aim was that after reading the manual, everyone would have a full knowledge and understanding of the basics of regenerative agriculture and would know what to do and how to start applying it on their farm.

SOURCES - READ MORE!

Danone: *regenerative agriculture knowledge center, available at:*
https://regenerative-agriculture.danone.com/

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WATER MANAGEMENT

The availability of water must be considered the most important determinant of crop yields in the field. Every organism needs it, whether it is a plant, animal, bacterium or fungus.

Unfortunately, we have no influence on the primary source of water in the agricultural ecosystem - precipitation. However, the impact of human activity on climate change is extensive, which is evident, among others, in disruption of water cycle. The changes that are taking place in weather patterns are having a huge impact on the environment and our lives. Nowhere is this more evident than on farms. Emerging weather anomalies in the European Union, especially droughts occurring during crop-growing seasons, are very worrying.

Fortunately, there are some factors related to water retention that we can influence. In this chapter, we will discuss the most important considerations related to water management on the farm. We will briefly describe soil structure as well as soil-water relations. We will learn about the role of organic matter in water retention, as well as introduce tools for assessing water runoff. Finally, we will discuss low retention as a whole set of measures we can take to keep water available for our plants.

The reconstruction of drainage ditches to retain water usually does not require specific permits, unlike the construction of new ditches.

2.1 Soil structure and soil-water relations

Soil is a complex system, consisting of mineral particles, organic matter, water, and air. According to some definitions, it should also include the edaphon, which is a term which refers to all living organisms in the soil. We will delve into soil life in a further chapter. In the context of water management, the most crucial aspect for us will be the solid part of the soil, which is divided into mineral and organic components.

The fundamental property of the mineral part of the soil is the size of its particles, also called soil texture. Larger sand grains have more space between them, while smaller silt and clay particles are closer together and more densely packed. Imagine two containers – one filled with basketballs, the other with tennis balls. It's easy to see that the empty spaces will be much larger in the first container. Water will pass through these openings much more easily. Therefore, if we want to retain water, we should choose soils with smaller mineral particles. Unfortunately, our influence on geological soil-forming processes is almost nonexistent, as rock weathering takes millions of years, and the composition and differentiation of the bedrock influence the soil texture. We would like to see results in the field more quickly. Fortunately, the organic part of the soil also can retain water. Humus, which we will discuss in the next chapter, acts like a sponge – it can absorb and release water. This is why the role of organic compounds in water retention in the soil is crucial.

In addition to soil texture, in the fields, we can observe soil structure. This is the way individual components of the soil aggregate. The formation of clods, or small soil aggregates, is a beneficial phenomenon. It is believed that soil with a clod-like structure has an optimal ratio of solid components, water, and air. We have a direct impact on the soil structure, unlike the aforementioned soil texture. Unfortunately, the formation of a structure is a very complicated process. It will be influenced by cultivation, soil pH, calcium and magnesium content, organic matter content, microbiological activity, and many other minor factors. However, it is one of the easiest soil parameters to observe.

The already existing mid-field ponds and ponds will be excellent for water retention purposes.

Farm-scale water retention 2.2

Water resources will vary in the European Union from country to country. It is however safe to assume that more often than not climatic and topographical conditions will make water availability low. Climate change carries the risk of worsening this condition. Therefore, it is reasonable to supply the farm with possibly effective water retention tools. It is worth noting that crop irrigation should only be carried out using surface water. Groundwater should only be used for public supply. Thus, it is an inevitable necessity to consider reasonable investments in water retention facilities. In particular, this will be relevant for farms that irrigate crops with water that is limited due to regulatory action. Most EU countries have a system of law that limits the agricultural use of water sourced from means other than precipitation for field irrigation. It is often the case that this type of investment is not considered because of the expected high costs and problems with necessary permits. However, there are opportunities to use many of the existing elements associated with drainage, as well as works that do not require a permit. As farm-scale water retention is beneficial for both the farmer and the environment, in most EU countries there are multiple facilitation mechanisms for farmers to conduct necessary works.

The basis is a correct diagnosis of the situation, which is then used for investment planning. The farm should keep records of water consumption. This will be one of the components when calculating the water balance. There are free tools available for calculating the water balance on the farm, and it is also possible to have this task carried out by a specialised company. Especially the exact calculations can be quite a challenge, but we recommend doing them yourself or actively participating in the calculation process. An in-depth understanding will help you later at the investment decision stage. The basis for calculating the water balance is to compare the water supplied (in the form of precipitation and irrigation) to the water run-off and evaporation. In this approach, retention is the difference between these values - water that has been delivered to our farm together with rainfall but has not run off or evaporated. We store it for use when the need arises.

The existing resources can also be identified at the stage of diagnosing the situation. The already existing mid-field ponds and ponds will be excellent for water retention purposes. Many farms also have an existing drainage network. The reconstruction of drainage ditches to retain water usually does not require specific permits, unlike the construction of new ditches. It can also be a much cheaper alternative. The construction of dams is an effective method of keeping water in the area for a longer period. Most EU countries also allow the construction of water retention ponds for irrigation. While the EU Water Framework Directive does not specify common facilitation mechanisms for small water retention, most national or local governments publish all necessary information on the websites of bodies that govern water management.

TRENDS IN AGRICULTURAL WATER USE IN THE EU

Countries in Europe are widely varied in terms of both irrigation needs and water use. In the northern countries agricultural use amounts to only a few percent of the total water use. In the Mediterranean, more than 50% of total water use is attributed to agriculture. This makes consistent EU-level policy hard to implement. One of the trends that might be of importance in the coming years is the implementation of the Water Reuse Regulation. While many northern countries opted out of this regulation, in the south of Europe it was readily accepted. The Common Agricultural Policy for the years 2023-2027 is focusing on water resources protection even more than in the previous years. Thus, facilitations of farm-level water management solutions are expected to be available for the farmers in the coming years.

SOURCES - READ MORE!

International Water Management Institute: Water for food, Water for life: *A Comprehensive Assessment of Water Management in Agriculture. Earthscan, Londyn 2007;*

Walker W.R.: *Guidelines for designing and evaluating surface irrigation systems. FAO Irrigation and Drainage Paper 45, Rome 1989.*

3 NUTRIENT MANAGEMENT AND FERTILISATION

Plants build their tissues from the two most important components needed for photosynthesis - carbon dioxide and water.

This, however, is not a complete list of ingredients needed by plants for proper growth and development. It is common knowledge that fertilisation is essential for high yield. Although in the natural environment, plants grow without additional fertilisation, in agricultural systems it is essential. In the course of agricultural production, plants consume some nutrients that will need to be replenished. The substances contained in crop residues will remain in the soil for use, but those used to produce the crop will be taken from the soil along with our harvest. It is worth to observe environmental processes to better understand how to improve our agrotechnology. An important part of rational fertilisation will be taking care of the soil ecosystem, which we should keep in the best possible condition. The processes that happen in the soil and the resources the soil provides will determine the ability of plants to grow.

In this chapter, we will discuss the usefulness of soil testing, and consider its use to rationalise fertilisation. We will also discuss nutrients from a theoretical and practical perspective. Finally, we will focus on the use of specific fertilisers to achieve concrete objectives. First and foremost, we will focus on soil nutrition. Our aim is a high yield achieved with as little input as possible, and healthy and active soil is a great ally in this endeavour.

Sensible nutrient management, including through the management of by-products from animal and plant production, will ensure that the soil is kept in good condition and that all organisms, including our plants, are nourished.

Soil analysis

3.1

Testing allows the determination of individual excesses or deficiencies of macro and micro nutrients before they become visually apparent in the plants.

An essential part of regenerative agriculture is the rationalisation of mineral fertilisation. For years, it has been observed that many farms use larger quantities of mineral nitrogen, phosphorus and potassium fertilisers than the scientifically determined needs of the plants. Fertilisation plans do not take into account the resources already present in the soil, which is the primary source of plant nutrients. Therefore, to make the right decision, both from an economic and environmental standpoint, a soil survey must be carried out. Even if one disregards the environmental aspects, the availability of individual components or the potential damage associated with over-fertilisation, the economic aspect alone makes it worthwhile to check the condition of the soil before applying fertilisers. Testing allows the determination of individual excesses or deficiencies of particular nutrients before they become visually apparent in the plants. Assessing deficiencies by observing plants leads not only to yield losses but also to irrational fertilisation. The range of soil chemical tests on the EU market is extensive, and most companies allow samples to be sent by courier or offer a soil sampling service.

Conducting a soil survey should start with the choice of analysis methodology. It has to be decided where the samples will be taken from, as well as which parameters will be tested. Although this seems very straightforward, it is important to pay as much attention to this step as possible so that the subsequent results represent the reality of the field.

In test-based soil diagnostics, it is important to consistently determine the sampling location, the number of samples tested, and the time of sampling. If we consider all those factors, we will be able to observe the trend of changes in the fields and the impact of our agrotechnical measures on soil parameters. We can carry out the selection of sampling sites based on designated zones. There are several methodologies for delimiting zones, based on soil granulometric composition, satellite-based productivity indices (NDVI index), soil conductivity or topographic data. Regardless of the use of these tools, it is useful to follow some general principles. Standards such as ISO 10381-1:2002 and ISO 18400:2018 define the relationship between field area and sample in detail, but their application is labour-intensive. Adopting one specific value for the maximum area is an effective simplification of the process. Some older standards indicate that the maximum uniform area corresponding to one sample should be no more than 4 ha. In addition to this, it is useful to examine geological maps. Certainly, separate samples should be taken for areas with different bedrock.

Laboratory analyses used in agriculture are very diverse. The most popular tests are soil pH and the abundance of individual nutrients. As the baseline in regenerative agriculture, we recommend an analysis of the exchangeable cations, together with the cation exchange capacity. This is an abundance test for calcium, magnesium, potassium and sodium. It is crucial from the point of view of soil health. By performing it, we can diagnose the content of our soil's storage of nutrients. It is the abundance of these substances that will be decisive in terms of the availability of nutrients for plants. In addition to this, it is useful to regularly test the levels of organic carbon, humus or organic matter. Although these parameters have different names, they measure something very similar - the percentage of organic matter in the soil. However, this is not a complete list of available tools. The electrical conductivity of the soil can be useful in controlling salinity. Nitrogen can be tested in several different forms: ammonium, nitrate and mineral. In addition to this, soil biological tests are beginning to become available. Pathogen detection using genetic methods, assessment of activity and biodiversity using enzymatic or metabolic techniques, or next-generation sequencing are methods that could be the future of soil biological quality assessment.

WHAT SHOULD YOU CHECK BEFORE SELECTING A SOIL ANALYSIS COMPANY?

- Is the testing carried out according to an accepted standard?
Reliable laboratories provide the standard designations for the procedures used.
- Are the results delivered with an indication of what they mean?
Most companies provide reports with information on what level of a particular ingredient is appropriate. It is worth checking whether there is help available with interpretation if we need it.
- Is the completion date known?
Tests are often time-consuming, but good laboratories have established procedures that allow estimations of the lead time - thus incorporating the tests into our schedule.
- Is additional help offered in selecting sampling points or test ranges?
If necessary, it is useful to be able to use additional assistance to optimise the soil testing process in terms of both time and cost.

3.2 Soil nutrients

All mineral nutrients supplied with fertilisers follow the same processes. If the part of the fertilisers that is not used by the plants remains in the soil in an available form - these will be soil nutrients. If, however, these excess nutrients are washed away or bound into an inaccessible form, they will become only an economic loss, an environmental loss and a chemical imbalance of the soil. We aim to minimise these losses, keeping the soil as healthy as possible. We can achieve this in two ways - by encouraging processes that allow nutrients to persist in the soil, and by rationalising fertilisation in such a way as to achieve the right levels and the correct balance of nutrients.

The soil is inhabited by many more different species of organisms than just the plants we grow. Nutrients added in the form of fertiliser provide an attractive food source for them too. However, this does not mean that other organisms deplete the soil of the nutrients. On the contrary, soil organisms will work hard for us to ensure that nutrients are available to plants. For example, soil microorganisms play a key role in the absorption of nutrients by plant roots. Therefore, first and foremost, we will focus on soil nutrition. Sensible nutrient management, including through the management of by-products from animal and plant production, will ensure that the soil is kept in good condition and that all organisms, including our plants, are nourished.

Cation exchange capacity and basic cations

3.2.1

On the surface, nutrient management is very simple. Plants uptake the substances they need for growth from the soil. Providing them with high levels of macronutrients and micronutrients should be enough to produce good yields. However, if the recipe were so simple, we would have long since moved all crops to industrial halls, where we would have machine-dosed the right doses of elements for individual plants. We would have no field production. In the real world, to achieve proper plant development, we need something more - healthy soil. However, before discussing methods for maintaining a properly functioning ecosystem, we need to devote some attention to the theory behind soil nutrient balance.

The most important soil parameter from the point of view of macro- and micronutrient management will be the cation exchange capacity. We also come across the abbreviation CEC (or TCEC for total cation exchange capacity). The soil can bind certain ions, i.e. atoms or particles with an electrical charge dissolved in water. This process is called sorption, and soil can be called a sorbent. Most fertiliser substances are ultimately intended to dissolve in water and be adsorbed onto the surface of fine mineral or organic particles in the soil. This will make the nutrients available to the plants - they will become part of the exchangeable cations. In other words, the greater the cation exchange capacity, the greater the ‚reservoir' or ‚storehouse' for the various substances in the soil. Our task is to get the highest possible CEC value, i.e. the highest possible capacity of our ‚storage'.

If we supply more nutrients than the sorbent can adsorb - we exceed the cation exchange capacity - the excess will be washed away, or go into a state inaccessible to plants. In both of these cases, there will be both financial losses for us and environmental losses for the entire soil ecosystem. It is therefore important to note that a higher CEC value is most desirable in nearly all cases. It depends mainly on the soil texture and soil structure, the humus content and the pH. While the soil texture is unfortunately out of our control, the other factors can be modified to achieve a higher cation exchange capacity.

The most important base cations that will be directly affected by the magnitude of CEC are calcium, magnesium, potassium and sodium. Together, these are referred to as ‚exchangeable bases'. Their desired percentage contribution among all cations, depending on the soil type, should be within certain ranges, which are approximately 60-85% for calcium, 10-20% for magnesium, and 2-5% for both potassium and sodium. We can also specify that the hydrogen cation (H^+) saturation should be around 5-10%. When performing analysis, it is advisable to consult the laboratory for the exact desired values and to consult on fertiliser recommendations.

Under conditions of high soil acidity, alkaline cations will start to be displaced by acid cations - for example, the aluminium cation. This is one of the reasons why a soil pH close to neutral should be maintained. Below a pH of 6, up to 50% of the available space within the sorbent can be occupied by aluminium - thus limiting the plant's ability to take up nutrients.

By knowing the cation exchange capacity and the degree of saturation, we can make informed fertilisation decisions. Unfortunately, these are not all the parameters we need to take into account. A popular model for the relationship between yield and nutrient abundance is the Liebig's barrel. The capacity of the barrel is limited by the length of the shortest stave - just as plant growth is limited by the amount of the least available ingredient. Today, we no longer build water tanks from staves. Similarly, we know that it is insufficient to provide a large amount of mineral fertiliser to achieve a high yield. Liebig's Law of the Minimum, however, still applies. Each of the essential micronutrients and macronutrients must be available in sufficient quantities. The most limiting element for plant growth will be the one that is least abundant compared to demand. Therefore, an intervention should be started from the most necessary element.

On the other side of the scale from Liebig's Law of the Minimum stands Voisin's ‚law of the maximum'. If there is an excess of a nutrient in the soil, it begins to have a detrimental effect and becomes a yield-limiting factor. The mechanism of action, in this case, varies - the problematic element can cause other elements to be bound into inaccessible forms, act antagonistically towards them, as well as exhibit toxic effects on its own when in excessive concentrations. It is therefore worth bearing in mind that for any nutrient, there can also be a situation where there is too much of it.

Both of these laws - Liebig's and Voisin's - should be applied simultaneously. They apply to all nutrients, not just the exchangeable bases. It is with these elements that the effects of imbalance will be most apparent.
It is not always practical to consider whether an ingredient

will be sufficiently available. The availability of manganese at neutral pH may only be 30%, as it is an acidic cation, not an alkaline one. However, care must be taken to supply it to plants, even if much of the fertiliser is leached or bound. This does not mean that we should start massively acidifying the soil.

Knowing about the properties of the sorption complex, we can define the following principle: as a priority, we fertilise to regulate the ratio of exchangeable cations. We aim to ensure optimum levels of nutrients in the soil, as this is where the plants draw their nutrients from. The rational use of mineral fertilisers containing the above-mentioned substances will be discussed in more detail at the end of this chapter.

Liebig's barrel - A model for the relationship between yield and nutrient abundance.

3.2.2 Nitrogen and phosphorous

It is not difficult to note that two very important macronutrients were missing when we discussed exchangeable cations: phosphorus and nitrogen. These are characterised by slightly different physical and chemical processes. Both of these macronutrients have the unfortunate property of ceasing to be available to plants very easily. In the case of nitrogen, this will be a process of release into the atmosphere as nitrogen gas by bacteria in the process of denitrification, or loss through leaching. Phosphorus, on the other hand, depending on the soil pH, binds with iron, aluminium or calcium ions to form water-insoluble salts. Such a form is called immobilised, as it is completely inaccessible to plants. Thus, in the case of these two elements, there is a great economic motivation for optimising - the excess fertiliser will simply go completely unused. In addition, over-fertilisation with just these two elements is responsible for the greatest environmental damage. It can take the form of run-off into watercourses and greenhouse gas emissions. It should be noted that nitrous oxide, which is released as a result of nitrogen over-fertilisation, has four times the greenhouse potential of carbon dioxide and is therefore a very dangerous greenhouse gas.

Fortunately, several factors favour rational management of nitrogen and phosphorus. These are mainly related to the microbiological aspects of soil. Nitrogen can be extracted by specialised microorganisms from the air, as well as supplied together with organic matter in any form. However, all these sources of nitrogen require a very efficient ecosystem in the soil. The totality of these processes is called the nitrogen cycle. Today, we can support the action of these microorganisms with suitable products, including microbial ones, but the core is to maintain sufficiently high activity and biodiversity of the microbiome. In the case of phosphorus, too, there are specialised microorganisms that convert the immobilised form into a plant-available form (PSB - phosphorus solubilising bacteria). In this case, microbial products are also available. However, it should be borne in mind that in most soils, microorganisms with such capabilities are already present, so the core activity is to support the activity and biodiversity of the microbiome and create a favourable environment for its growth. For both of these macronutrients, such an approach can bring significant benefits. The atmosphere consists mainly of nitrogen. Most soils, depending on estimates, can typically contain up to 10 times more bound phosphorus than available phosphorus. It is however necessary to note that this estimate should not be applied to any country, as it is typical in the EU, but not granted.

LEGUMINOUS PLANTS AND NITROGEN FERTILISATION

Plants of the Fabaceae family are considered to be self-sufficient in nitrogen. This is due to their symbiosis (interdependence) with rhizobia, a group of bacteria, which can draw nitrogen from the atmosphere. Fertilising leguminous plants with nitrogen can lead to the destruction of this beneficial bacterial flora, thus doing more harm than good. It is worth bearing in mind, however, that in fields with a long-term monoculture, rhizobia may disappear over time - in which case the first year of using leguminous plants can be disappointing. However, it is better to leave them without nitrogen fertilisation so that a suitable bacterial flora can build up.

3.2.3 Sulphur

Among the nutrients classified as macronutrients, there is one more element, sulphur. In the soil, it is available to plants as a sulphate anion. It is worth noting that there are two types of sulphur fertilisers available on the market - elemental sulphur or sulphates. Unfortunately, it is not difficult to see that, in terms of the amount of sulphur, the elemental form is significantly cheaper. However, this is only an apparent saving, as its application comes at a specific cost. After application, naturally occurring microorganisms in the soil will begin to convert sulphur to the sulphate form. Unfortunately, this process involves significant acidification of the soil - the oxygen atoms needed are taken from the water, leaving an excess of H^+ ions. Sulphates of magnesium, calcium or potassium do not have an acidifying effect on the soil. However, if you decide to use elemental sulphur, it is important to remember that the processes involved in converting it into a plant-available form only occur at temperatures above 13°C.

3.2.4 Micronutrients

Micronutrients, as the name suggests, are found in very small quantities in soil and plants. This alone can make managing them surprisingly difficult. Their deficiencies can manifest themselves through visible plant defects, but can also go unnoticed until summarising the harvest. However, one bold thesis can be made: even the best micronutrient management will not help if macronutrient problems are present. When exchangeable cation ratios are regulated, and phosphorus, sulphur, and nitrogen abundances are correct, then it pays to look carefully at micronutrients. This is not, of course, advice to stop using any micronutrient fertilisers when you are short of potassium. Rather, this is an observation, that there are always limited resources available to you on the farm, be they financial, or time and attention. Macronutrients must be regulated first, as the functioning of the soil as a whole system will depend on them.

At the same time, it is worth bearing in mind that micronutrients are essential for plant growth. The advantageous circumstance is that they occur in all organisms, so there is a very effective source of micronutrients that does not require special attention - organic matter that comes from outside the field. All organic fertilisers that do not come directly from the field we are applying them on have the potential to provide some micronutrients. For example, boron is present in living plants in amounts ranging from 30 to 100 mg/kg of dry weight, depending on the species, conditions and method of estimation. Although this does not sound impressive, according to these estimates, together with a tonne of typical compost we can provide up to 30 grams of boron. Of course, the point of such activity is only if it is only a side effect - to provide boron itself, it would not be very effective. Nevertheless, the sources of micronutrients are varied, making it possible to manage them effectively while paying relatively little attention to them.

3.3 Soil pH management

In the first part of this chapter, it was repeatedly stated that soil processes depend on the soil's pH. One of the most important regenerative practices will be the regulation of soil pH. A key technique needed for effective pH regulation is liming. To carry it out properly, the need for the treatment must first be confirmed. Then, the correct dose, form and timing must be chosen. However, this is not straightforward. Fortunately, soil testing is very helpful here.

From the perspective of maintaining a healthy soil, the need for liming can be determined using three parameters: pH measured in aqueous solution (pH in H_2O), pH measured in KCl solution (pH in KCl), and the proportion of calcium among exchangeable cations. Here, one doubt generally arises - the pH value in H_2O and the pH in KCl differ by 0.5 to 1 unit. The difference in these values is an additional hint about the need for liming. The soil pH measured on the pH scale is nothing more than the determination of the amount of H^+ ions in an aqueous solution. As we already know from the previous information on the sorption of soil nutrients, cations can be adsorbed to particles in the soil. In a pH measurement in H_2O, they will not be visible, whereas they are revealed in a pH measurement in KCl. Thus, it can be said in simple terms that a pH measurement in H_2O shows the actual acidity of the soil, while a pH measurement in KCl indicates the acidification potential. Knowing these two values, you can already determine the need for liming. However, it is also worth considering the proportion of calcium among the exchangeable cations, as applying lime fertilisers will supply a very large amount of calcium in addition to changing the soil pH. If the proportion of calcium among the exchangeable cations is too high and you want to carry out a liming treatment, you should also supply magnesium. The dolomite fertilisers discussed below can help with this.

Another aspect of liming is the dose of calcium fertiliser and its form. The dose should be chosen according to the analysis carried out. The dosage given by the fertiliser manufacturer may be based on radically different assumptions regarding treatment frequency, soil parameters and soil structure. Unfortunately, it is possible to apply too much calcium fertiliser. Precision in dosing will be particularly important if the oxide form - CaO - is chosen. It should be remembered that this form is very risky. Its use may lead to severe soil microorganisms extinction. It does, however, act very quickly. The most commonly suggested form is calcium carbonate - $CaCO_3$. The release process of calcium from the fertiliser is somewhat slower, allowing adequate time for all organisms in the soil to adapt. In addition to this, dolomite (containing magnesium) and gypsum (containing sulphur) fertilisers are also used. These are controversial because the change in pH after their application is often small and slow. However, it should be noted that we aim to regulate the soil pH in the long term, not to suddenly switch the pointer to the magic number of 7 - neutral pH.

The choice of liming time is also quite important. It is generally accepted that liming should be carried out immediately after the main crop is harvested. However, it should be noted that if the treatment calendar indicates that organic animal manure and lime fertiliser should be applied at the same time, at least a minimal interval is necessary. The recommended sequence is as follows: first apply the organic fertiliser, mix it into the soil and then carry out the liming after a minimum of two weeks.

DIY SOIL PH MEASUREMENT

Measuring soil pH is one of the tests we can carry out ourselves. This is not recommended mainly because of the economic factor - it is quite labour-intensive to do at home, while a laboratory test is generally relatively inexpensive. However, knowing how to perform the test, as well as being able to perform it at any time, can be very valuable. It is important, however, to use a good instrument - a ‚soil acid meter' from a garden shop is generally subject to high error. It is also a good idea to confirm your precision while conducting the first measurements. Concurrently, we can measure samples and send them to the laboratory. This way, we can easily calibrate our measurements.

3.4 Organic matter content

In an earlier chapter, we mentioned that the soil consists, among other things, of an organic part, which is very important. It should be given a little more attention, as it is the organic part that is responsible for the soil being soil and not desert sand. The concept of organic matter in soil is not well defined, as it exists in many forms. Most of those forms are not permanent and participate in the continuous carbon cycle. Soil organic matter includes all plant and animal residues, metabolic products of soil organisms, as well as humus, i.e. the part of organic matter that has undergone humification. Although definitions can be vague, many facts about soil organic matter are indisputable. It consists mainly of carbon compounds, so you may also encounter the term: soil organic carbon content. It is the amount of carbon in the soil that will be determined during testing in the laboratory. As a result of the action of soil organisms, organic matter is transformed in the soil. In the decomposition process, the larger organic parts are broken down into amorphous mixtures of different organic particles. However, soil organisms do not stop there. Organic matter can undergo further processes of mineralisation and humification. The former will be responsible for releasing some of the nutrients that will become available to plants. This will unfortunately result in the loss of organic matter. However, we are most interested in the latter, which is responsible for the formation of humus: fulvic and humic acids and humin. These form the basis of the organic part of the soil, being the source of its fertility. Their sorption capacity is responsible for the soil's ability to retain plant nutrients. Interestingly, fungi - more commonly associated with plant diseases - are largely responsible for the humification process. This is not a valid association, as pathogenic fungi are rare. From an agricultural perspective, mycorrhizal fungi - the invisible ‚associates' of plants - are the most relevant. They are a source of both essential plant hormones, such as auxins and gibberellins, and nutrients for plants, especially phosphorus and nitrogen.

Regardless of how organic matter is supplied to the soil, the processes it will undergo will be very similar. Fresh or partially decomposed organic residues will be subjected to the action of decomposers, i.e. organisms specialised in processing dead matter. At the start of this process, the benefits of organic matter in the soil will be very small. Only after successful humification, when all the processes have come to an end and no organism has anything left to do, will the humus created play its part. Due to their structure, humic and fulvic acids effectively hold a large amount of water, as well as form the base of the sorption complex, increasing the cation exchange capacity. It is humus that is the main source of the soil's ability to hold ions of various nutrients that plants can take up. The cation adsorption ability of humus is up to three times that of the finest mineral fractions in the soil.

Successful soil regeneration therefore requires the provision of sufficient organic matter, the promotion of natural biological processes and, finally, the gentle channelling of these processes towards humification. In addition to this, there are still temporary solutions to shorten this complex path. Humic acid preparations are available on the market, the use of which can sometimes be justified. However, as the cost of such treatments is relatively high, in the following we will mainly focus on supporting natural processes. On most arable fields in the EU, the aim will be to achieve a higher humus content. A level of 3-4% on most soils will already be a success. Care should be taken at all times to maintain a high humus level, as humus takes a very long time to form, but can be destroyed in a very short time.

HUMIFICATION FACTOR

Concerning organic residues, we may come across the term ‚humification factor'. This is an expected percentage value, indicating the amount of organic matter that will be transformed into humus. It is very high, for example, for lupins and serradella (around 40%) and manure (around 35%), and very low, for example, for root crop residues (around 8%). This illustrates the differences between organic fertilisers.

Fertilisation plans do not take into account the resources already present in the soil, which is the primary source of plant nutrients. Therefore, to make the right decision, both from an economic and environmental standpoint, a soil survey must be carried out.

3.5 Organic fertilisers

Organic matter, regardless of form, can become a fertiliser if we manage it properly. In this chapter, we will use the general phrase ‚organic fertilisers', irrespective of the terminology sometimes adopted for defining the particular characteristics of these fertilisers - natural, organic, biological. From the perspective of regenerative agriculture, organic fertilisation refers to any treatment aimed at supplying organic matter to the soil.

3.5.1 Organic fertilisers of animal origin

Organic fertilisers of animal origin - manure, slurry and others - are very valuable sources of both organic matter and mineral nutrients. This is not secret knowledge - the vast majority of farmers know this, as well as apply at least one of the listed forms of organic fertiliser. Fertilisers of animal origin, however, are more complicated both to apply and to operate than is generally acknowledged.

The underlying mechanism that justifies the use of manure is the circular economy. It is a simple but extremely important concept. The more efficient the use of resources, including the waste generated, the less input is needed in production. Thus, not only economic but also environmental benefits can be achieved. So, there is no doubt that the use of animal waste is beneficial.

The amount of nutrients contained in manure or slurry will depend, among other things, on the diet of the animals. However, the differences will be small, so the use of ready-made tables should be sufficient for the estimation of nutritional content. The exception may be nitrogen, the content of which can vary greatly. It is worth noting that most of the nitrogen excreted by animals is in the urine and not in the faeces. This can be of crucial practical importance if one is keen to keep the nitrogen content of organic manure as high as possible.

The application of animal-derived organic fertilisers should be done with one very important principle in mind: you should wait patiently. Time is an ally. Whenever possible, manure should be fermented before treatment. This process, sometimes called manure composting, takes about 4-5 months. The changes taking place in the manure are very beneficial to the soil, both from the perspective of nutrient availability and the microbiological composition of the manure. For example, the carbon-to-nitrogen ratio changes during fermentation, from as high as 30:1 in fresh manure to only 15-20:1 in fermented manure.

In the EU, the use of animal manure is regulated by law in terms of storage, application method, and maximum application rate. While the specifics vary from country to country, some regulations are very similar or the same. The spraying of manure in bulk on the soil is subject to strict restrictions, due to the possibility of groundwater contamination. Slurry and manure should be stored in sealed containers. The date of application is regulated in most countries, usually based on either temperature or vegetation season average timing. The calculated nitrogen application rate must not exceed 170 kg/ha per year. The approximate limit dose for manure is about 40 tonnes/ha, and for slurry depending on the exact form from about 30 m^3/ha to about 45 m^3/ha. Specific tables according to local regulations should always be consulted before application.

In addition to this, certain rules related to the most efficient use of organic fertilisers should be followed. Soil mixing should be done no later than the day after application to limit nitrogen losses. Heavy, clay-rich soils should be fertilised with manure in autumn, while light sandy soils should be fertilised in spring. Uniform distribution over the field surface is most beneficial - as far as possible with the tools we have. Fermented manure has a more uniform structure that is easier to spread.

The use of animal-derived organic fertilisers is quite challenging, both because of the high technical requirements for storage and application, as well as usually strict regulations. However, it should be noted that they can be one of the most valuable fertilisers. The obvious argument in favour of organic fertilisers of animal origin is that they are cheaper than mineral fertilisers. They provide partial independence from market fluctuations, as well as the ability to deliver multiple nutrients in a single application. From a soil perspective, however, their greatest value is related to carbon. We have already discussed the importance of organic matter in agriculture. Without it, there is no soil, and without soil, there are no crops.

REGULATIONS ON THE USE OF ORGANIC FERTILISERS OF ANIMAL ORIGIN

The basic regulations on the use of animal organic fertilisers can be found in the following legal acts:
-Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources
-Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003
A lot of information can be usually found in the national-level legal act that adopts the ‚nitrate directive' (91/676/EEC) to use in a specific country. Usually, the Ministry of Agriculture of a specific country or other governing authority publishes brochures or manuals on storing, managing and applying organic fertilisers of animal origin. Special care should be taken when applying fertilisers in close proximity to water bodies, as strict rules apply in every EU country.

Other organic fertilisers 3.5.2

Organic fertilisers of animal origin are not the only sources of organic matter that can be supplied to a field. The second main source of carbon will be organic fertilisers of plant origin. Two main types of plant-derived organic matter should be distinguished: intercrops (catch crops and cover crops), and composts and digestates.

The use of composts and digestates works on a similar principle to that of organic fertilisers of animal origin. In both cases, the applied fertiliser is simply plant matter that has been converted by organisms into another form. In fertilisers of animal origin, these organisms are livestock and their intestinal bacteria, whereas, in composts and digestates, it is only microorganisms that convert the organic matter. It is worth noting, however, that compost is a very valuable source of beneficial soil microorganisms.

Calling catch crops and cover crops ‚fertilisers' may seem a little controversial. After all, by sowing intercrops we are not supplying any substance to the field. However, they are undoubtedly fertilisers and unique ones at that. What they provide is organic matter. During growth, plants take up carbon dioxide from the atmosphere, building it up into their stems and leaves in the form of more complex organic substances. The use of catch crops results in an increase in organic matter, with no loss of other nutrients. Since the plant residues will remain in the soil and decompose, all the substances they have taken up will return and be available for the next main crop. The main effect will therefore be to improve the organic matter balance, as plant growth - and therefore the building up of the organic carbon content - will take place over a longer period than just the vegetation of the main crop.

The use of catch crops and cover crops also has several additional advantages. Uncovered soil can be eroded very quickly by weathering. The plants prevent water and wind erosion. At the same time, the presence of plants in the field reduces evaporation, reducing water loss. The roots in the soil help to maintain proper structure by, among other things, increasing soil aeration and reducing soil compaction. The soil microbiome is largely dependent on plants, so sowing catch crops helps to keep it healthy. The use of leguminous plants can also have the added benefit of increasing nitrogen content.

The most important parameter to pay attention to when selecting plants for catch crops will be the speed of growth, both of the green part and the roots. A short growing season and the ability to form biomass quickly will have a positive effect on the overall amount of organic matter supplied. In particular, the plant should be matched to the period for which the catch crop will remain in the field. Individual species may also have desirable non-biomass-related properties, such as the nitrogen-acquisition capacity of leguminous plants or the phytosanitary effects of oilseed radish (*Raphanus sativus var. oleiformis*) and white mustard (*Sinapis alba*).

The use of intercrops requires a great deal of commitment. Unlike mineral fertilisers, we do not have the opportunity to carry out soil analysis, after which we would receive a recommendation to sow a particular crop. There are many formulas for catch crop mixtures, which have to be adapted to one's own needs. Local climatic conditions, the growing season of the main crop, the timing of other treatments, as well as many other factors must be taken into account. The work, however, will be an excellent investment. Catch crops and cover crops are a very effective method of soil regeneration without requiring a lot of investment.

CATCH CROP MIXTURES FOR SPECIFIC FOLLOWING CROPS

One of the most important factors in the selection of plants for a catch crop mixture is the next main crop. It is the successor plant that we want to prepare the best possible conditions for. Below, we suggest compositions of catch crop mixtures for specific plants, which are designed to be as universal as possible. We encourage you to adapt them to your conditions and experiment with them.
Before beet: peas (*Lathyrus*), oat (*Avena*), sunflower (*Helianthus*), oilseed radish, phacelia (*Phacelia tanacetifolia*)
Before potatoes: peas, oat, sunflowers, oilseed radish, buckwheat (*Fagopyrum esculentum*)
Before maize: buckwheat, peas, oat
Before legumes: buckwheat, oat, sunflower, oilseed radish, phacelia

3.6 Mineral fertilisers

Applying mineral fertilisers should be regarded as nutrient supplementation. The basis of the ‚diet' for plants should be what is already present in the soil. This is why so much attention is paid to the properties of the sorption complex and organic matter, as well as alternative ways of supplying nutrients. For the highest possible yields, however, mineral fertilisation may be necessary. The basic principle for treatments will therefore be rationalisation - only apply as much fertiliser as is necessary.

The use of mineral fertilisers should in any case be based on soil analysis. This approach allows us to determine the needs in a precise manner. Once all the

If we supply more nutrients than the sorbent can adsorb - we exceed the cation exchange capacity - the excess will be washed away, or go into a state inaccessible to plants.

factors discussed earlier in this chapter have been considered and the need for fertiliser has been established, we must decide on the method of application. There are a few general principles that can be derived from simple calculations on the cost-effectiveness of treatments. Firstly, in fields that vary in nutrient abundance, it will be more advantageous to apply single-component fertilisers, at an appropriate rate. If the field is homogeneous, a multi-nutrient fertiliser may be a more cost-effective option. This is due to the cost of separate trips to the field for application. At the same time, the increasing price of fertilisers always tips the scales in favour of single-component preparations - because in this case, precise dosing saves more money.

The most effective method of making fertilisation decisions is to calculate financial efficiency. In the vast majority of cases, the most cost-effective solution will also be the most beneficial for the environment and the soil. The procedure for calculating the cost of fertilisation in different scenarios is relatively uncomplicated. The first step is to summarise the resulting necessary doses of each component for each zone. This results in a value for the demand, which then needs to be recalculated into a specific dose of fertiliser - either on a constant basis for the entire field, using the average nutrient abundance, or on a variable basis for individual zones, using the abundance at a particular point. Next, the costs of the application procedure and individual fertilisers must be determined. We will not be able to vary the dose of individual components of a multi-nutrient fertiliser, but we will apply it in fewer passes. For single-nutrient fertilisers, we will be able to apply it in variable doses, but it requires more passes. We therefore sum up the costs of application and fertilisers to arrive at the total cost of fertilisation.

It should always be borne in mind that mineral fertilisation is a treatment carried out either to make up for the current shortage of plant nutrients, in terms of one season only, or to adjust the ratio of exchangeable cations. It is neither possible nor sensible to fertilise on top of this if the soil has no nutrient storage capacity.

FERTILISATION COST CALCULATIONS IN FIXED AND VARIABLE APPROACHES

The use of a spreadsheet helps to determine the potential costs in detail. Once the analysis has been carried out, we will obtain nutrient abundance values for each sampling point. We can translate those into the rate of fertiliser needed. Written as a formula in the spreadsheet, the calculation for a fixed fertiliser application might look like the following:

Fertiliser rate determined for the average abundance in the field x field area x fertiliser price + application costs

For variable fertilisation, the calculation will be slightly more complicated. A number of fertilisation levels need to be selected and then the field area for which we will be applying a particular rate summed up. With these values, we can once again use the universal formula:

Application rate x application area x fertiliser price.

Then, sum up the individual results and add the costs of the passes, in this case multiplied by the number of passes required.

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4 BIODIVERSITY

Biodiversity - everyone has heard of it, but few really know what it is. This is understandable, given the extreme popularity and overuse of the term in all agricultural and environmental discussions.

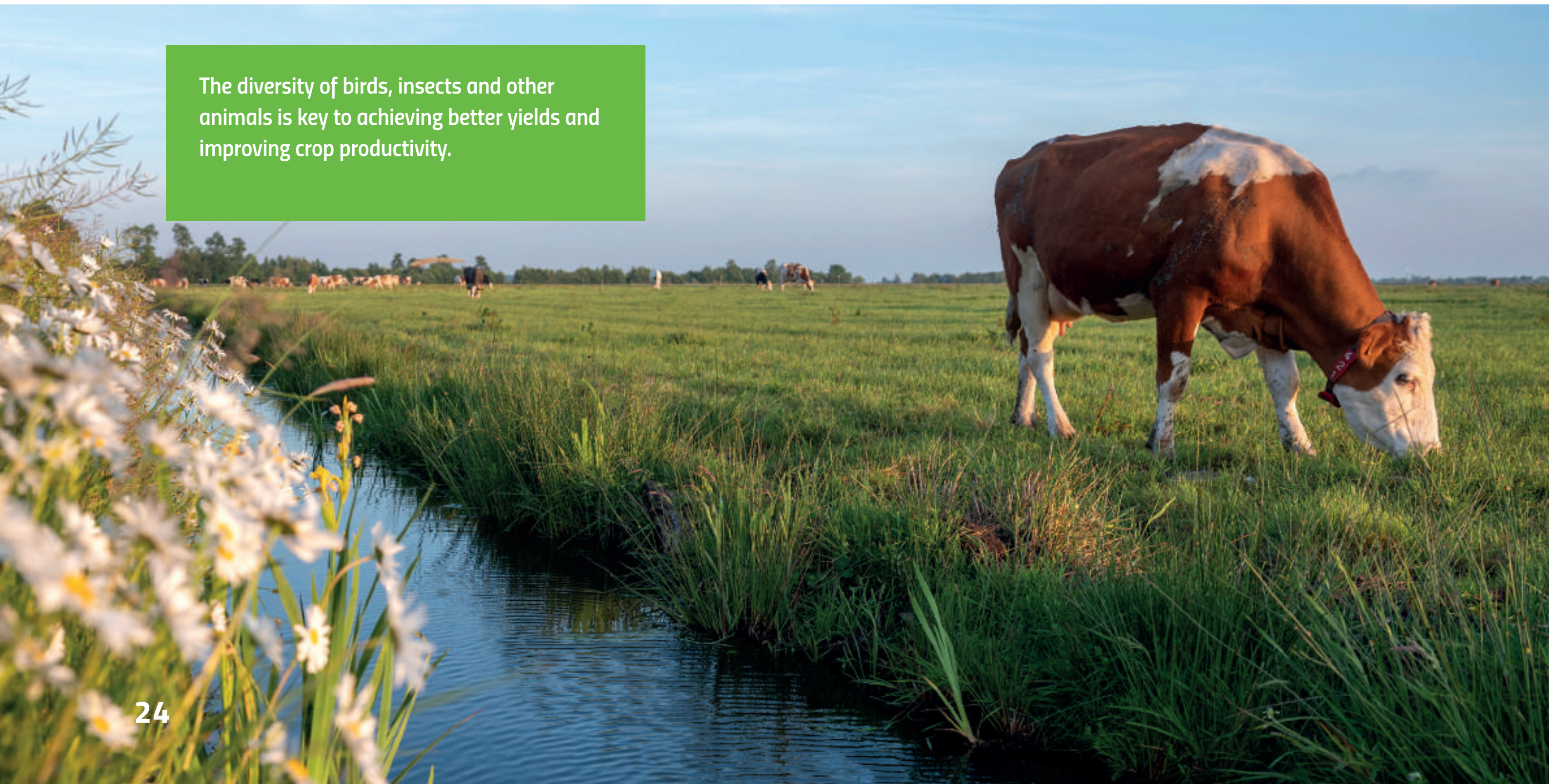
In such a situation, the best solution is to look at the word itself and break it down. The term ‚biodiversity' was first used in 1985 and was coined as a combination of the words ‚biological diversity'. It refers to the variety of organisms, both visible and invisible to the naked eye, and their interactions in the environment.

In this chapter, we will try to introduce this term by showing the value of biodiversity to agriculture and how it can be measured. We will then look at ways in which biodiversity can be supported on the farm. Although we will be discussing three aspects of biodiversity - plant, animal and microbial - it is important to remember that they are interdependent and that a change in one implies changes in the others.

4.1 Importance of biodiversity in agriculture

Due to intensive human intervention and the simplification of the environment for efficient production, farmland is characterised by low biodiversity. It may seem that every farm's overriding goal of maximising productivity has stifled any chance of improvement. In fact, biodiversity plays a key role in agriculture and has several important benefits.

A fundamental practice in regenerative agriculture is crop rotation. Increasing plant diversity by growing a variety of plant species and varieties counteracts soil exhaustion and promotes soil regeneration. Different plant species respond differently to the same pathogens. Eliminating monocultures prevents the excessive spread of pests and increases crop resistance to



The diversity of birds, insects and other animals is key to achieving better yields and improving crop productivity.

disease. Increasing crop diversity also provides additional financial security for the farm in case of extreme weather events. A good strategy, especially given trends in recent years, is to use varieties with improved drought resistance.

A significant proportion of plants require the support of pollinating insects to produce a crop (85% of the 264 plants grown in Europe benefit from animal pollination). The diversity and size of pollinator populations are adversely affected by climate change, pesticide use and habitat destruction. Meanwhile, the diversity of birds, insects and other animals is key to achieving better yields and improving crop productivity. Birds and insects are natural enemies of many pests. Their presence provides biological control of pests and, to some extent, reduces the use of chemicals. Equally important are soil-dwelling animals such as protozoa, nematodes and earthworms. They feed primarily on dead organic matter (plant and animal remains), converting it into simpler compounds. In this way they participate in the nutrient cycling process in the soil. In addition, as they move through the soil in search of food, they loosen the soil, which has a beneficial effect on its structure and the availability of oxygen for plant roots.

The last group of organisms that contribute to the biodiversity of the agricultural landscape are the microorganisms, i.e. bacteria, fungi and actinomycetes. It is difficult to see them, and even more difficult to measure their abundance and activity, but one thing we can easily imagine - crop production could not exist without their participation. Soil microbial diversity can be considered in two ways: how many different species and genera live in the soil, or how many different functions they perform. The latter is known as functional diversity. More and more research suggests that it is functional diversity that has a huge impact on the proper functioning of the soil ecosystem. Microorganisms participate in the decomposition of organic matter and the provision of nutrients to plants. The large number of different microorganisms also provides natural competition for food and living space, keeping potentially harmful organisms in check.

Improving and conserving biodiversity 4.2

In addition to production areas, farmland contains many facilities that provide habitats for a wide variety of plants, animals and microorganisms. Ecotones, the transition zones between farmland and natural habitats, are also characterised by much higher biodiversity. For this reason, most biodiversity conservation efforts focus on the protection and maintenance of areas such as hedgerows, roadsides, ditches, water reservoirs, meadows or wetlands.

Groups of shrubs and trees, or individual trees, growing on verges, roadsides and byways provide shelter for a variety of plant species, pollinating insects, birds and other animals. As areas of particular value to the local landscape, they require appropriate protection and care. In addition, shrubs and trees are one of the best ways to prevent soil erosion and protect crops from adverse weather events such as heavy rain and strong winds. Trees also provide localised shade, which reduces the evaporation of water from the soil.

Measures to improve biodiversity are also possible in production areas. An important improvement in biodiversity in areas adjacent to agricultural fields is the creation of buffer zones around the edges of fields where no pesticides are used. The introduction of three-metre buffer zones supports biodiversity and protects local plant species that are often considered unwanted weeds.

The use of catch crops is another practice that supports both biodiversity and soil fertility. The best results are achieved by using legumes or mixtures of them. They provide additional nitrogen to the soil. Legumes also stimulate soil microorganisms, increasing soil biological activity. Left on the field as green manure or stubble, they are a natural source of nutrients and organic matter, helping to nourish the soil and enrich it with valuable humus.

Approximately 30% of the world's land is used for pasture and fodder crops, resulting in habitat alteration. Therefore, growing a variety of crops on grazed land and avoiding monocultures can help to maintain biodiversity and also ensure effective soil regeneration. The introduction of extensive grazing (pasture grazing, continuous from spring to autumn over the entire pasture area) or rotational grazing (where successive paddocks are grazed gradually) can also improve the situation. Such grazing systems help to maintain healthy vegetation and biodiversity in pastures.

Agroforestry is a form of agriculture that harmoniously combines forestry with crop or livestock production (also known as silvopasture). This integrated practice aims to make the best use of the landscape and minimise negative environmental impacts while providing economic benefits. Agroforestry can help diversify farm income sources. It recommends the use of trees and shrubs that provide a variety of products including firewood, fruits and nuts, biomass for feed and fibre. In the case of silvopasture, livestock welfare is also improved. This system mimics nature - grazing animals, when given the opportunity, will choose areas covered with trees and shrubs rather than open areas. Trees and shrubs provide shade and shelter from rain and wind. They also supply an additional source of food in the form of fruits, nuts and twigs.

The concept of rewilding aims to combine quality food production with the restoration of biodiversity. It aims to achieve a balance between food production and environmental protection, promoting long-term sustainable practices that benefit nature as well as farmers and consumers. Rewilding in agriculture can be implemented in several ways. Depending on the capacity of the farm, it may involve the reintroduction of plant and animal species into production areas, the restoration of river courses and wetlands, or the creation of ecological corridors. For dairy farms, rewilding can involve extensive grazing of animals on low-quality agricultural land, increasing productivity and improving the biodiversity of that land.

GOOD AGRICULTURAL AND ENVIRONMENTAL CONDITIONS (GAEC)

GAECs are principles and requirements for agricultural practices that aim to ensure environmental compliance and sustainable management in agricultural areas. Under the agreement on the Common Agricultural Policy 2023-2027, compliance with standards relating to soil and water conservation, biodiversity or animal welfare is one of the conditions for receiving CAP support. These standards form a basic level of the Green Architecture of the CAP called conditionality. The conditionality provisions include basic management requirements under EU law and GAEC (good agricultural and environmental conditions) standards established at the national level. Each EU country's CAP Strategic Plan sets out the specific requirements of the GAEC standards.

4.3 Methods for assessing biodiversity

Assessing biodiversity on the farm as a whole is difficult due to the broad definition and complexity of the concept. However, monitoring biodiversity is essential to assess the effectiveness of measures taken to improve it. In the introduction to this chapter we mentioned that all organisms in an ecosystem are linked by a web of interactions and that a change in one area affects the functioning of the others. Everyone has learnt about food chains at school - if the fox population in the area decreases, this will be the best year of the rabbits' lives. This is of course an oversimplification, but it gives an idea of what is meant by a ‚web of interactions'. This causality has been used to define biodiversity indicators, i.e. organisms or functions that play an important role in an ecosystem. By measuring these indicators, it is possible to make a rough estimate of the biodiversity of a given environment. However, it should be borne in mind that such calculations only allow the assessment of a certain ‚slice' and that biodiversity itself can be considered at many levels.

For the purposes of the farm, it is generally sufficient to determine biodiversity based on daily observations. Attention should be paid to the number of habitats (ecosystem diversity) and the number of species and individuals (species diversity or species richness). Particular attention should be paid to the presence of rare and endangered plant and animal species. Obviously, the more different species on a site, the better, but the population ratios of each species to each other are also important. Imagine two fields - let's call one ‚behind the woods' and the other ‚behind the hill'. Each field contains 10 different species of insects, including the mole cricket (*Gryllotalpa gryllotalpa*). Based on this information, we can say that the biodiversity of the two fields is similar. However, in the field ‚behind the woods’ the mole cricket represents 10% of all insects, whereas in the field ‚behind the hill’ there is a real scourge - 90% of the insects in this field are mole crickets. Such a high dominance of one species over others results in less biodiversity in the field ‚behind the hill’, even though it has the same number of insect species as the field ‚behind the woods’. It is worth pointing out that the usefulness of a species from an agricultural point of view is irrelevant when assessing biodiversity. Even if the good old seven-spot ladybird (*Coccinella septempunctata*) made up 90% of the insects in the field ‚behind the hill’, the biodiversity in that area would still be lower. Finally, it should be noted that production plants and animals are also part of the biodiversity of the agricultural ecosystem. Therefore, keeping an inventory of the plant species and varieties grown and the animals kept is an additional tool for monitoring biodiversity on the farm.

There are also strictly mathematical ways of assessing biodiversity. Diversity indices based on the number of species observed or the number of individuals of a species are used for this purpose. A commonly used index is the Shannon diversity index. The Shannon index is not complicated to calculate, but the data collection process is very time-consuming - it is necessary to determine the exact number of individuals present in a given area. Diversity indices such as the Shannon index are used within a kingdom - they can be used to determine the diversity of plants, animals or microorganisms.

Determining the diversity of microorganisms, the bacteria and fungi that live in the soil, is an extremely difficult task. It is estimated that there are up to a billion bacteria in one gram of soil, comprising tens of thousands of species and genera. In addition, bacteria and fungi perform several important functions in soil and are involved in fundamental soil processes. Determining the diversity of species and functions gives us information about the stability of the soil ecosystem and its productivity. To illustrate this relationship, we can compare the soil to a city. There are many people living in a city and each resident has an important role to play - there are teachers, policemen, doctors, shopkeepers and so on. The city can function efficiently thanks to the people in these professions. If one of the doctors is ill, the patients are referred to another doctor. The city is resilient to such situations because of the large number of inhabitants with different professions. The same applies to the soil. The high diversity of species and functions gives the soil stability in the face of external changes. If conditions change to the detriment of some organisms, others can take their place and do their job.

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5 FARMING TECHNIQUES - SOIL CULTIVATION SYSTEMS

Soil cultivation is one of the oldest ways of influencing the properties of arable fields.

In the past, before the advent of artificial mineral fertilisers and synthetic plant protection products, cultivation was the most important part of agrotechnology. Today, the tasks of cultivation are somewhat different, but of equal importance. By choosing the right technique, cultivation can minimise the loss of water and organic matter, prevent erosion and improve soil structure, as well as increase the biological activity of the soil. This is helped by the variety of tools, cultivation methods and systems available. Conventional wisdom about tillage is as applicable today as any time in the past. It must be noted, however, that both technical resources and knowledge in this area are developing quickly.

In this chapter, we will discuss the basic cultivation methods and their effects on the soil. We will divide cultivation systems according to their actual effect on the soil, taking into account both the physical effects visible to the naked eye and the impact on the soil microbiome. We will devote slightly more attention to simplified cultivation systems, as they have much more potential for regenerative agriculture than ploughing.

Ploughless cultivation (sometimes also known as no-till, but this term should be used with caution, as it can be easily mistaken with zero tillage) is a set of cultivation systems in which mechanical intervention is made in the soil but no plough is used.

Cultivation systems

5.1

The first cultivation system in use for hundreds of years was the tillage (plough) system. Full tillage or traditional tillage, as this system is also called, is based on the traditional plough. The loosening depth is about 25-30cm and the soil is turned over during the procedure by the mouldboard. In regenerative agriculture, ploughing is not a recommended treatment. However, it should be noted that it has been used for hundreds of years, so it must exhibit some advantages. The soil is aerated evenly during ploughing and all organic matter present on the surface is effectively covered and evenly distributed in the cultivated layer. Unfortunately, the ploughing system is characterised by a very serious impact on the soil. In the long term, it leads to a reduction in organic matter content. When ploughing, the upper protective layer consisting of plant residues is destroyed, exposing the erosion-prone soil of the deeper layers. On top of this, the impact of such a procedure on microbial life in the soil is enormous. Although there is an apparent increase in biological activity due to aeration, how this happens during ploughing is detrimental. Organisms accustomed to anaerobic conditions from the deeper layers are thrown upwards, while oxygen-based organisms from the surface are buried deep. This does not cause an increase in the desired activity, but rather a panic that can result in an additional reduction in organic matter.

The complete opposite of the plough system is zero tillage. In this system, no mechanical treatment is carried out. Weeds are generally eradicated by chemical treatments and the only mechanical soil intervention is sowing. This system is often also referred to as direct drilling. The unquestionable advantage of zero-tillage is the very low input due to the low number of passes necessary. The soil is perfectly protected from erosion by the organic matter residues constantly present in the surface layer. Many proponents of this system also point out its similarity to natural ecosystems in which there is no human intervention in the form of ploughing. However, it should be noted that this system often leads to a decrease in yields. In the time immediately following the switch to zero-tillage, an increase in soil compaction can be expected. On top of this, the incorrect choice of rotation in this system can lead to major phytosanitary problems. It can be described as the exact opposite of the plough system - it is very challenging, but the reward is to protect the soil from degradation. The plough system is easy to use but can lead to a lot of damage to the fields.

It is therefore easy to see that a system combining the advantages of the two aforementioned would be optimal from the perspective of regenerative agriculture. The results of the search for a compromise are often referred to as simplified cultivation systems. These include simplified plough systems, in which, for example, the depth of treatment is reduced. However, they have similar disadvantages to conventional cultivation. Several ploughless cultivation systems were also developed. Although strip-till and ridged cultivation are interesting and potentially beneficial directions, for practical reasons, we will focus on full-surface ploughless cultivation.

5.2 Ploughless cultivation

Ploughless cultivation (sometimes also known as no-till, but this term should be used with caution, as it can be easily mistaken with zero tillage) is a set of cultivation systems in which mechanical intervention is made in the soil but no plough is used. It should be made very clear that the definition of this term neither states that it is shallow cultivation nor that it is not intensive. The depth and intensity of cultivation should be chosen according to the needs and conditions in the field. It is also worth noting that these systems cannot be used in all conditions. Although ploughless systems seem optimal from the point of view of regenerative agriculture, they are only a tool in the broader concept of regeneration. The common denominator of all ploughless systems is that the location of plant material in the soil is close to the surface. As the soil is not turned over, the residues are not mechanically placed deep but only mixed near the surface. The organic matter forms a protective layer to prevent erosion. At the same time, however, the soil is loosened and aerated for optimum structure. Thanks to the reduced interference with the deeper layers, organisms in the soil can develop more efficiently. Plant residues are thus decomposed more quickly close to the surface.

A few simple rules can help in choosing the right cultivation system. It is generally accepted that very wet soil should be cultivated shallower, while dry soil should be cultivated deeper. Loss of humus over time may suggest that we should reduce the intensity of cultivation. Lighter, sandy soils should be cultivated with a denser spacing of working elements, while on heavier, clay soils working elements can be spaced wider. The overriding principle, however, is observation. Each treatment should have a specific objective from the perspective of soil structure and soil-water relations. There should always be a verification of the effects performed post-season. Cultivation systems, including no-till, have been developed to have a deliberate effect on the soil.

CONSERVATION TILLAGE

A particular classification of cultivation systems is according to the distribution of plant residues. This is the origin of the term ‚reduced tillage'. It can be carried out with any tools and can be said to be reduced if part of the plant residues remain on the surface. A more developed approach in this respect is conservation tillage, in which a minimum of 30% of the plant material remains in the surface layer, usually as mulch. This allows faster decomposition of plant residues, as well as protects the soil from erosion. In conservation tillage, there is usually only one shallow treatment. Most of the plants used are spring crops, sown after an intercrop is mixed in with the soil at a shallow depth. It is a difficult system to apply, but elements of it are worth using, especially in fields with high exposure to erosion.

SOURCES - READ MORE!

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Cultivation systems, including no-till, have been developed to have a deliberate effect on the soil.

6 REGENERATIVE AGRICULTURE AS A WAY OF FARMING

It is not uncommon to come across the term ‚regenerative practice', referring, for example, to no-till, catch crops or rational liming. However, it is not the depth of cultivation that determines the essence of regenerative agriculture.

Each of the methods of supporting soil cited above should be applied consciously, in a targeted manner and tailored to the individual farm. This is where the essence of regenerative agriculture lies. At the very beginning of this handbook, we quoted the principle: cultivate as little as possible and as much as necessary. It does not only apply to cultivation or fertiliser doses. Every activity undertaken in the field - cultivation, fertiliser application, plant protection product application - has an impact both on the farm's finances and on the health of the soil and ecosystem.

Regenerative agriculture is a way of farming that puts the soil and its health at the centre of attention. It is neither a ready-made fertilisation protocol nor even a set of tools. There is a reason why so much attention has been paid in this manual to diagnosing the situation, in terms of water, nutrients, as well as biodiversity. Regenerative agriculture begins with undertaking conscious, deliberate work on the condition of the soil using the resources at hand. Agronomic decision-making in regenerative agriculture is based on maximising long-term benefits. Adopting this perspective helps create a farm that is resilient to changes in economic and environmental conditions, and that interacts with the natural ecosystem to deliver high yields of good quality.

If there is one bracket that ties together the entire content of this short guide, it would be the immense weight of knowledge. Agriculture is chemistry, physics and biology, as well as civil engineering, mechanics and technology, and in the application of modern agriculture methods, even computer science. Regenerative agriculture is also about drawing as much as possible from available sources to take the best possible care of the soil and crops. The wealth of information available today is vast, so we encourage you to explore the topic further, as well as to share the knowledge you have. Regenerative agriculture as a concept was created in response to specific challenges faced by farmers. It was farmers who created the concept together with scientists, researchers, agronomists and advisors. It is not detached from the reality of agriculture. On the contrary, it is an invaluable treasure trove of tools to address the challenges of agriculture in the 21st century.

SOURCES - READ MORE!

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Every activity undertaken in the field - cultivation, fertiliser application, plant protection product application - has an impact both on the farm's finances and on the health of the soil and ecosystem.

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