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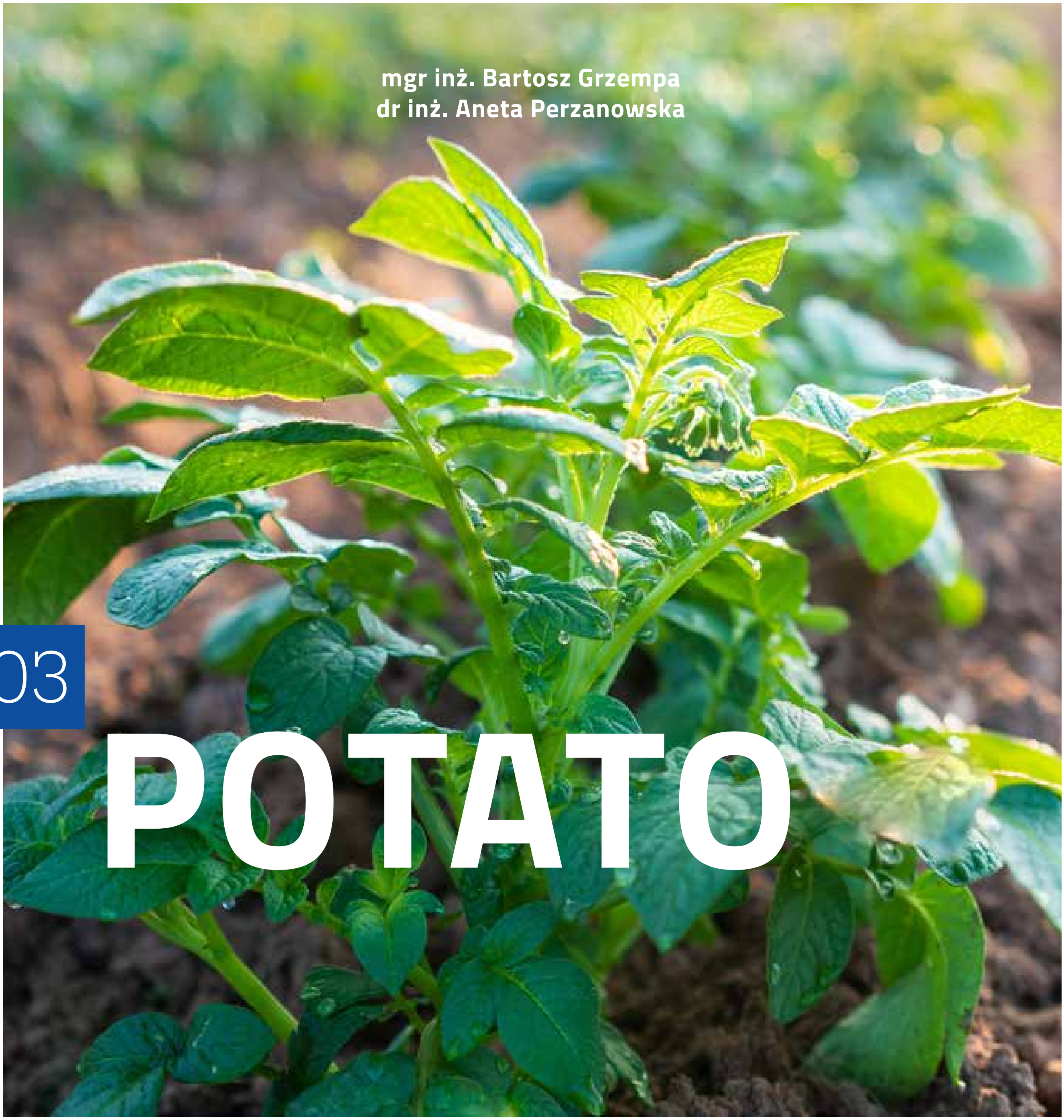

03

POTATO

CEE REGENERATIVE AGRICULTURE GUIDEBOOK

TERRA NOSTRA FUNDACJA

eit Food REGENERATIVE AGRICULTURE REVOLUTION

Co-funded by the European Union

CEE REGENERATIVE AGRICULTURE GUIDEBOOK POTATO

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03

POTATO

CEE REGENERATIVE AGRICULTURE GUIDEBOOK

Poznań 2023

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INTRODUCTION TO REGENERATIVE FARMING

In the face of climate change, which puts an increasing pressure on our environment, we must realize that we, as humanity, are its main driver.

3.1

Our impact is present both through daily routine choices, such as a drink in an easy-to-dispose or multiple-use packaging but also through the place we work. Agriculture is a special branch of the economy, which affects the environment quite extensively. Its impact is on the hand negative, but on the other positive and remedial, for example in the context of climate change. Every farmer should be aware of the important role he or she plays in shaping the environment. The farmer is not only a producer of food for others to consume, but also someone who can, and in fact should, have a positive impact on the environment in which the community lives.

Looking at the environmental criteria to be attained by the farmer as a food producer, they should operate so that to ensure healthy and quality food, but also produce it in a way which benefits the environment. Regenerative farming seeks to introduce practices that meet these criteria. The regenerative approach to growing crops is different from conventional. Its main focus is soil condition. Soil is the plant's living environment that needs to be taken care of. Some of its aspects can be defined in 5 points, which are called 5(C) practices:

- Right amount of calcium **(Calcium)** in the soil, as this element is special to plant life and the functioning of the soil environment. Calcium affects the pH value, which is the most important for proper plant growth and biological life in the soil. It also affects the structure of the soil through its contribution to the binding of soil colloids. And finally, calcium is a necessary ingredient of plant life, because it forms parts of cell walls and performs a regulatory function in plant cells.

- Management of organic matter in the soil **(Carbon)** - the greater the amount of organic matter in the soil, the better the plants grow, the higher the yield and the better their condition. A larger amount of organic matter also translates positively into water retention by the soil. In addition, organic compounds that build organic matter are a source of energy for other organisms living in the soil.

- Cultivation of cover crops **(Cover crop)**. The cultivation of cover crops significantly increases the organic matter content in the soil, and in addition cover crops protect the soil against wind erosion, against leaching of nutrients and provide an additional source of organic substances necessary for the life of soil organisms.

- **(Cultivation).** Cultivation plays a very important role in shaping soil properties. On the one hand, cultivation seeks to prepare the soil to create proper conditions for the growth of cultivated plants, and on the other, it is one of the factors that disturb the biological balance created in the soil, e.g. as a result of increased aeration. In regenerative farming, the concept of cultivation can be summed up as "as little as possible, as much as necessary".

Impact of agricultural activity on the external environment **(Culture)**. This refers to how agriculture affects the profile of the external environment. In this context, regenerative agriculture pays special attention to aspects that indirectly affect agricultural production, but significantly affect the external environment. These aspects include, for example, the creation or maintenance of existing mid-field woodlots, which has a positive effect on the birds that find shelter in them. In addition, birds are often predators that feed on pests. The creation of artificial water reservoirs and the protection of the existing ones also has a positive effect on the environment, and the sowing of cover crops has a positive effect on pollinating insects, which use them as food.

The above practices in the context of cultivation of particular species should be considered in their totality. The respective crops in the crop rotation system are only one part of regenerative practices, and full benefits of regenerative farming are achieved for the entire rotation mix.

5C CODE

NUTRIENT AND SOIL REQUIREMENTS

3.2

Potato can be successfully grown in various soil conditions.

However, medium-compacted soils are best for its cultivation. It is important that the soil is rich in nutrients, because the potato absorbs them from the beginning of its growth, but its roots do not go too deep. Stolons, or modified underground shoots, at the ends of which tubers develop, also grow in the surficial layer of the soil. Roots, stolons and new tubers need oxygen for their growth, and therefore they react adversely to its periodic shortage. For that reasons, heavy, drainage and impermeable soils are not recommended for potato cultivation. These soils, in addition to the periodic flooding risk, can also cause deform the developing tubers. In addition, heavy soils tend to clump too much, which is also unfavourable for potato cultivation. Undamaged clumps present at the beginning of the cultivation can remain in the soil until the end of the season, which in turn has a significant impact on the potato harvest -if soil is clumped to much, it can cause excessive tuber bruising during the harvest, which affects their quality.

Table 1 shows the values of macronutrients that the potato uses to produce 1 tonne of tubers. The presented data show that, to produce one tonne of tubers, the potato needs approx. 3.5 kg of N, 1.3 kg of P_2O_5 and approx. 6 kg of K_2O. The values given in the table are average values for potatoes grown until the end vegetation. Potato grown for early harvest has slightly different, lower nitrogen requirements. For its cultivation, the potato requires approx. 1.5 kg of N per 1 tonne of tubers. Potatoes grown for chips (French fries) also need slightly higher doses of nitrogen and this value can be as much as 4.5 kg N (depending on the variety).

Table 1. Quantities of individual macronutrients extracted from 1 t of tubers ha^{-1} (average values)

Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Calcium (CaO)	Magnesium (MgO)	Sulphur (S)
3,5 kg	1,3 kg	6 kg	0,5 kg	0,5 kg	0,6 kg

Source: Author's own work

3.3 REGENERATIVE CULTIVATION TECHNOLOGY

LOCATION AND FORECROP

3.3.1

The cultivation site aspect in regenerative farming places emphasis on those factors that are directly habitat-related, such as the topography.

Potatoes should be preferably cultivated on sites with favourable topography. Depressions in the ground should be avoided. They carry the risk of water stagnation after heavy rainfall or sprinkling. Such depressions are also more likely to get frost in early spring, which the potato does not tolerate well. Another aspect related to the habitat is the regulation of water relations. Potatoes cannot be grown in fields where there is no proper water management. In fields where there is stagnant water, potatoes not want to grow well, are in poor condition, which significantly affects their yield and sensitivity to infection by pathogens, and thus the subsequent intensity of protection.

Photo 1 - Drainage works ensure appropriate air and water parameters of the fields, which are necessary in regenerative agriculture

From the point of view of the site, the best forecrops for potatoes are cereals and legumes. In the regenerative approach to crop, care should be exercised when establishing the crop rotation to keep the plant roots alive and healthy in the soil for as long as possible, preferably without interruption. The soil can be thought of as a large „stomach" that must feed the organisms that live in it - both plants and microorganisms. Growing plants carry out photosynthesis, they have living roots that partially decompose in the soil, thus providing a medium for microorganisms, and the roots secrete various substances that are beneficial for the life of soil microorganisms. Soil microorganisms are consumed by macroorganisms such as beneficial nematodes and earthworms. That is why it is important that there are living plants in the field after the forecrop is gone. Living roots guarantee the survival of organisms living in the soil and thus maintain the biological balance that has been created there. In regenerative agriculture, it is necessary to act in such a way as to interfere with this balance as little as possible. Therefore, in the regenerative approach, it is important what site a given species takes over, and basically what we are able to do with it, including how to prepare it for the successive one. If we grow potatoes after plants that leave the field early, e.g. cereals or others, cover crops should be used. The cultivation of catch crops in crop rotation has several tasks, one of them is to ensure that living roots remain in the soil between the cultivation of the next species, which, as mentioned earlier, is important for the survival of biological life in the soil. We do not sow cover crops if we grow potatoes after sugar beets. Importantly, beets remain in the soil almost until the end of vegetation, and so nourish microorganisms living in the soil in that period.

Other aspects should also be taken into account when arranging a crop rotation. Potato should not be grown after rape and other plants from the cabbage family, mainly due to the potential presence of nematodes. In turn, after winter rape, there are also many volunteers, which are quite difficult to eradicate. In principle, there is only one active substance to chemically control those volunteers, namely rimsulphuron . It should be noted that this substance does not destroy the potato, but it is not indifferent to it in the context of its growth, and any stress adversely affects the condition of the plant. In regenerative agriculture, we try to create the best conditions for the growth of the cultivated species, based on the assumption that the better its condition, the greater the chance of it using its natural resistance mechanisms. Another very important aspect is what site parameters are left by the preceding cultivar. Potato peculiarly favours those species that reduce organic matter in the soil. Therefore, the site for the crop rotation should be prepared so that potatoes can be cultivated after fertilisation with manure, and if potato leaves the field early, cover crops are to be sown. This approach guarantees better conditions for potato growth and a better site for the successive plants.

SELECTION OF VARIETIES

3.3.2

The potato currently cultivated is derived from two species of *Solanum tuberosum ssp. andegenuum* with red skin and croissant-shaped tubers, coming from the borderland of Peru and Bolivia and *Solanum tuberosum ssp. tuberosum* - having white skin, flat and round tuber shape, and probably coming from Chile.

A number of parameters is considered in the selection of potato varieties for regenerative farming. The first is the purpose of the potato. There are varieties intended for the fresh market, the starch industry, French fries and crisps. The specific usage entails some differences in the level of fertilisation, especially with nitrogen. For example, varieties intended for French fries have slightly higher requirements for nitrogen fertilisation than varieties for the fresh market or crisps.

Another important parameter is disease resistance. The main pathogens infecting potatoes are Phytophtora nfestans, Alternaria solani and Alternaria alternata. There are differences among varieties available on the market in their level of resistance to these pathogens. Appropriate selection of a variety with high resistance can significantly affect the intensity of protection against diseases. Where possible, varieties that have moderate or low susceptibility to infection by these pathogens should be selected. And where it is impossible to select a suitably resistant variety, e.g. if a specific variety is imposed on us by the employer, the inspection of the plantation should be particularly focused on other early disease symptoms, and the related tools, such as e.g. disease models, should be used.

Currently, the importance of the origin of tubers (or in fact the condition of parent plants) is highlighted in the acquisition of plant resistance to pathogens. It turns out that a certain acquired immunity can be passed on to offspring. Therefore, the origin of seed potatoes may become more important in the future.

Other potato diseases include blackleg, common scab, with individual varieties showing different resistance to them. The other are of lesser importance than the two previously mentioned diseases, therefore they are not taken into account in the selection of varieties for regenerative cultivation of potatoes.

There is also a number of potential pests in potato cultivation. However, no significant resistance to pests was demonstrated among the cultivars. In terms of pest resistance, the condition of the plants and the location are more important than the variety, e.g. on light sandy soil is more likely to have nematodes of the genus Trichodorus, which are a vector of the dangerous TRV virus.

An important feature of the cultivars taken into account during their selection is the sensitivity to the active substance referred to as metribuzin. Different varieties show different sensitivity to this substance. Metribuzin is a very useful post-emergence herbicide for post-emergence weed control in potatoes. In regenerative cultivation, potato varieties susceptible to metribuzin should be located in fields less exposed to weed infestation. This allows better and more effective weed control, since the use of metribuzin often allows post-emergence control of weeds.

SOIL CULTIVATION

3.3.3

The soil cultivation strategy for regenerative farming is as little as possible and as much as necessary.

This seeks not to interfere with soil properties of the crop too extensively. Each cultivation treatment changes conditions in the soil, such as it increases porosity, aeration and partially mixes the soil. It is important to realize that these properties directly affect the organisms living in the soil. Each cultivation treatment of the soil changes the air and water conditions, and thus disturbs the biological balance that has developed in the soil. In regenerative cultivation, it is important to interfere with this balance as little as possible. In addition, each soil tillage increases the mineralization of organic matter by aerating the soil, while we want to preserve it as much as possible. On the other hand, we also want to create the best possible growth conditions for the cultivated plant, because only when our cultivated plant is in good condition will it be more resistant to all adverse abiotic and biotic factors, and that is another point of our focus in the context of the subsequent intensity of protection treatments, as well as the yield level and quality.

Cultivation for potatoes begins just after the fall of the forecrop. The first treatment is fertilisation with natural fertilisers, preferably manure, but slurry can also be used. Immediately after natural fertilisation, medium tillage up to 15 cm should be performed, along with the possible sowing of cover crops if, for example, we grow potatoes after cereals (early forecrop). Sowing cover crops makes sense until mid-September. This procedure can be done with a cultivator for no-till cultivation. Some of the companies producing such cultivators offer the option of seeder connection. This solution is the most advantageous, because both the sowing of cover crops and the cultivation of the soil are combined in one pass (photo 2). This is consistent with the „as little as possible" principle.

Photo 2 - Cultivating unit with the option of medium-depth cultivation and sowing cover crops in one pass

Photo 3 - Roller for cutting cover crops

If we do not sow cover crops because it is too late, the manure or slurry should be immediately covered with shallow cultivation. This can be done with a disc harrow. If cover crops have been sown in the field, we leave them until the end of vegetation, then we destroy them using a mulcher or special rollers that cut them into small pieces (photo 3). The next cultivation procedure is ploughing. In general, tillage should be avoided in regenerative cultivation. However, potato is a plant that requires loose soil and the right structure for proper growth. Too compacted or lumpy soil is not suitable for growing potatoes. Winter ploughing both properly loosens the soil and, if it is lumpy, gives the opportunity to break up larger lumps during the winter. For this reason, ploughing is usually necessary, although on some light soils, not prone to lumping, potatoes can be successfully cultivated without ploughing. In this case, however, in the fall, a subsoiler should be used, which should loosen the soil to at least 45 cm. In the spring, if necessary, the soil should be dragged. We carry out dragging in fields where there may be a problem with too much clumping of the soil. We do not perform it where not necessary. Another treatment is cultivation to a depth of 18-20 cm. It is intended to prepare the soil for planting potatoes, i.e. it should properly loosen it and break up larger lumps. Well-prepared soil for potato cultivation is very well loose (photo 4).

Photo 4 - Till before potato planting

In exceptional cases, it is necessary to remove rocks the field. In potato cultivation, too many rocks can cause excessive tuber bruising during harvesting, which affects the quality of the yield. When choosing a site for potato cultivation, those that have few rocks are preferred. If you decide to grow potatoes on a rocky site, the rocks should be removed. The procedure is performed by special machines to a depth of 20 cm. After the treatment, the soil is very loose, so the cultivation before planting can be slightly shallower.

PLANTING POTATO TUBERS

3.3.4

Seed potatoes in regenerative cultivation must always come from a qualified plantation.

Such seed potatoes are free from diseases and pathogens and guarantee well-balanced emergence. They enable us to produce plants in good condition. If unqualified material is planted, a large share of the plants may be infected with viral, bacterial and fungal diseases. The latter are particularly dangerous, as there are no effective methods to fight them. That is why prevention is so important.

We start planting potato tubers when the soil warms up to a temperature of about 10°C. Planting potato tubers in colder soil results in slower development of shoots, which are also more exposed to infection by Rhizoctonia solani. This fungus infects young shoots growing from the tuber, and strong infection can even cause their death. Appropriate formulations are used to reduce infestation by *Rhizoctonia solani*. It is best to use one of the preparations based on bacteria of the genus *Pseudomonas* sp.

Photo 5 - Planting potatoes

Row spacing of 75 cm or 90 cm is used for potato growing. Smaller spacing (75 cm) is used in for potato intended for the earliest harvest. Smaller ridges ensure faster heating of the soil. A larger spacing (90 cm) is used for crops intended for later harvesting. The number of planted tubers depends on the size of the seed potatoes - the larger they are, the fewer are planted. However, regardless of the size, the density of 16 shoots per m^2 is always attempted. The spacing table is shown below.

Table 2. Spacing of tubers in the ridge depending on different tuber sizes

Seed potato size range [mm]	The average number of shoots growing from a given size of seed potato	Plant density [No. of tubers per m^{-2}]	Number of target shoots [No. of shoots per m^{-2}]	Spacing of the tuber in the ridge [cm]	
				Row spacing of 75 cm	Row spacing of 90 cm
28 - 35	3	4,9	14,7	27	23
35 - 45	4	4,1	16,4	33	27
45 - 50	4,5	3,6	16,2	37	31

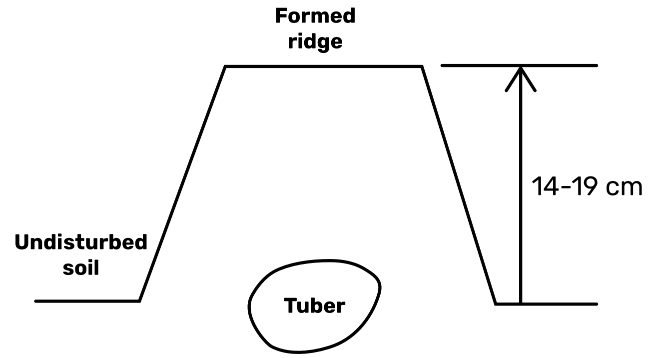
Source: Author's own work

What is important in regenerative farming is to plant the tubers precisely so that they are planted at a certain distance from each other. Too dense or too sparse planting of seed potatoes causes problems. Too dense planting creates unfavourable conditions for shoot growth and excessive plant competition. In addition, the leaves are kept moist in a canopy of plants that are too densely planted, which usually causes a higher incidence of diseases. Too sparse planting, in turn, results in a lower yield, and failure to utilise all nutrients from the soil, which unnecessarily burdens the environment. The planting density should ensure the proper structure of the crop, depending on its purpose. For example, potatoes for French fries are desirable in the size of 45-60 mm with a length of about 10 cm. If you plant French fries too densely, you will get the intended yield, but the potatoes will not be the right size.

The sizes of seed potatoes are within a certain range, i.e. the sizes of individual seed potatoes are not identical, and so tubers planted at a certain spacing sometimes give the number of shoots other than expected. This problem is typically solved by the use of a specialized (structural) planter. This planter is able to plant tubers appropriately depending on their size. This process is automatic and the planter itself changes the spacing of the tuber in the ridge depending on which seed potato sizes it is currently planting.

It is also necessary in the planting to correctly determine the planting depth. Seed potatoes should be planted so that the tuber is level with the soil between the ridges. After trimming, the potato should be 14 to 19 cm below the top of the ridge (Figure 1).

Figure 1. Properly planted tuber after ridge ridges



IRRIGATION

3.3.5

As already mentioned, the condition of plants is very important in the regenerative cultivation of potatoes

That condition, apart from proper plant nutrition or protection, is also affected by water management. Climate change entails periods of both long and large water shortages, as well as extreme periods with a significant excess of water in the habitat.

Potato has relatively high water requirements and is sensitive to water deficiency in the soil, especially in certain growth stages. Potatoes generally need around 200 mm of water during the growing season, of which only 50% is covered by rainfall in many areas. Potato sensitivity to water shortage is largely related to the fact that it has a fairly shallow root system and is grown on ridges, which significantly increase the surface area for water evaporation from the soil. In the initial period of growth, the potato absorbs water from the mother tuber, while the increase in the demand for water in the potato progresses as the plant grows. The critical phases of water shortage are the beginning of tuber formation and flowering. Shortage of water in these periods means a decrease in plant yield and deterioration of its quality. The decrease in potato yield may range from 10 to as much as 50%. It depends on the year and the region being compared.

Before the cultivation of potatoes in the regenerative system, access to water should be ensured for potential irrigation. Water collected in artificial ponds or water directly from wells can be used for that purpose. Artificial reservoirs can be created by damming up various watercourses and canals. Deliberately created retention basins (photo 6 on next page), apart from being the reservoir of irrigation water, also perform other positive functions in the agricultural environment. They improve biodiversity, because ponds are a habitat for various birds and other organisms, often under protection. Such ponds also affect the microclimate of the area where they are located. They improve the water balance by increasing the infiltration of groundwater into the surface layers of the soil, which may affect other crops in their vicinity.

Photo 6 - An artificial retention basin is, on the one hand, a water reservoir for irrigation, and on the other, a perfect habitat for birds and other organisms.

Drip irrigators or sprinklers can be used for irrigation. Drip irrigation has many advantages, such as improved irrigation efficiency. However, this method is not widely used due to its high cost and problems with disassembling and reusing the installation. For this reason, sprinklers are most often used to irrigate potatoes (photo 7). They are used for surface irrigation. During potato cultivation, about 150 mm of water is used for sprinkling. Currently, work is underway to improve the efficiency of the use of reel sprinklers. Work is currently pending to improve the efficiency of sprinklers, focusing for example on the application of precising sprinkling sprinkler. The goal is to apply different water doses at different locations. Before sprinkling, a soil and terrain map is created. In places where there are depressions in the ground, the winding of the sprinkler is accelerated in order to avoid their excessive flooding. On the other hand, water sprinkling rate can be increased on very poor soil in the field

Photo 7 - Sprinkler systems used for irrigation and the irrigation of potato plantations using sprinkler systems

VARIABLE FERTILISATION OF PLANTS AND SOIL

3.3.6

Fertilisation is very important in regenerative cultivation. The regenerative approach requires that it should be based on chemical test of the soil.

The test is performed based on the basis of the Mehlich method. Using this method, the respective ingredients can be tested in the same solution. It is also possible to determine the content of calcium, organic matter and the sorption capacity of the soil as well as the quantitative relationship of individual ions saturating the sorption complex. All this is of paramount importance in determining the quantity and quality of fertilisation. Fertilisation as such should be divided into fertilisation with natural and organic fertilisers and mineral fertilisation.

Use of natural and organic fertilisers

In regenerative cultivation, the use of natural fertilisers is crucial. According to this principle, apart from the fact that the natural fertiliser introduces nutrients into the soil and organic matter necessary for the proper growth and development of the crop, it also has an additional function: it stimulates the activity of all other organisms living in the soil that affect the growth of the plant. Both microorganisms and other soil organisms, such as earthworms, need organic matter for their growth. We try to provide them with organic compounds together with natural fertilisers.

In potato cultivation, natural fertilisers should be applied in the form of manure, preferably cattle manure in the amount of 25-35 $t{\cdot}ha^{-1}$. Slurry may also be used in an amount not exceeding 20 m^3. If it is not possible to use manure or slurry, chicken manure in the amount of 6 $t\ ha^{-1}$ can be used. We always use natural fertilisers in autumn, covering them immediately after application.

Organic fertilisation involves, among others, the use of cover crops on green manure. Cover crops, as mentioned earlier in the chapter on the location and forecrop, play an important role in preserving living roots in the soil, and are also a source of organic matter and indirectly affect the soil's nutrient content. Properly deep-rooting plants sown as a catch crop mix take up ingredients from the deeper parts of the soil, incorporate them into parts of their tissues above the soil surface, and so these ingredients are not washed out beyond the rooting area of the plants. An example of the composition of such a cover crop mixture dedicated to potato cultivation is shown in table 3 and in photo 8.

The role of cover crop cultivation can be described as follows:

- *They increase the availability of nutrients*
- *They increase the amount of organic matter in the soil*
- *They reduce soil erosion (especially from wind)*
- *They reduce the intensity of weed infestation (by shading the soil and increasing competition, they do not allow common weeds to develop)*
- *They improve the biological life of the soil*

Table 3. Composition of the cover crop mix proposed for potato cultivation

Type	Amount in the mix [$kg \cdot ha^{-1}$]	Remarks
Oat	10	It creates biomass, has phytosanitary qualities
Buckwheat	5	It has a positive effect on phosphorus management
Sunflower	10	The species is deeply rooted and extracts nutrients from deeper layers of the soil
Radish	5	It creates biomass
Marigold*	3	It reduces the presence of nematodes

***Add to the mix only if necessary**
Source: Author's own work

It is also important to leave post-harvest residues on the field for organic fertilisation, and in fact to increasing the organic matter in the soil. In the regenerative approach, by-products should be left directly in the field where possible and treated as a fertiliser.

In addition, molasses, which contains simple sugars, can be used to increase organic matter and nourish microorganisms living in the soil. Beet molasses or other molasses can be added to herbicide spraying or when fertilising plants with microelements. Adding molasses, in the amount of about 10 $l{\cdot}ha^{-1}$, is also one of the strategies in regenerative agriculture that positively affects the biological life in the soil.

Photo 8 - Cover crop growing one year before potato cultivation.

Mineral fertilisation

Mineral fertilisation for potato cultivation should be applied in precise doses (photo 9). In order to carry out such fertilisation, you must have:

- suitable tools equipped with a GPS device and a spreader with a precision application function, which, among other things, must have a scale
- a map of the abundance of nutrients in the soil
- other sources of information on field variability

Photo 9 - Precise fertiliser spreading - you can see the application map in the background, different colours correspond to different doses of the fertiliser.

In standard precision fertilisation, the first two bullets are not surprising. The third bullet, that is other sources of information on field variability, concerns, among others, information on the variability of granulometric composition of the soil. Soil scanning service providers can supply us with information on the grain size of the soil in the field. An important source of information about the soil are also satellite images, mainly those based on NDVI (Normalized difference vegetation index). NDVI photos for planning mineral fertilisation for potatoes should be from the previous crop, where differences in the vegetation index (in the previous growing season) should be observed, to adjust mineral fertilisation of potatoes later.

Information on the yield map may also be useful - here we also use (if possible) yield maps of plants preceding potato cultivation. As discussed in the chapter „Introduction to regenerative farming", the individual cultivated species are only a part of the overall regenerative approach to soil cultivation, which is holistic in nature.

Nitrogen fertilisation

Nitrogen fertilisation should be considered in terms of the requirements for this component from individual potato varieties. There are cultivars with requirements of only 80-100 kg N·ha^{-1}, medium: 120-150 kg N·ha^{-1} and large: 200-250 kg N·ha^{-1} (dose for potato cultivation with irrigation). Nitrogen is an important yield-promoting ingredient in potato cultivation. However, over-fertilisation may cause excessive exuberance of plants, which results in greater susceptibility to diseases, deterioration of the quality of potato tubers - for example, increasing the content of reducing sugars in tubers, which are not favourable in the industry in which tubers are fried. Therefore, when planning nitrogen fertilisation for potatoes in the regenerative approach, a laboratory analysis of the mineral nitrogen content in the soil should be performed in spring, and the previously mentioned forecrop yield maps and NDVI maps from the previous crop should also be taken into account. In the soil abounds in this ingredient, and if the NDIV and yield maps of the plant preceding potato indicate that it is not fully used, nitrogen fertilisation should be abandoned or limited to specific parts of the field only. It is also recommended not to use the entire dose of nitrogen fertilisation at once, as it is preferable to divide it into two parts and apply the first one just before planting, and the second during the growing season. This split allows for possible correction of the second dose. As for the type of fertiliser for regenerative cultivation, UAN, UANS, urea or saletrosan in the first dose are recommended, and UAN or UANS in the second dose.

Potassium fertilisation

Potato absorbs about 6 kg of K_2O to produce 1 ton of tubers. It is easy to calculate that, for the production of 50 tonnes of tubers, potato will take about 300 kg of this ingredient from the soil, which is a very large amount. Potassium fertilisation is planned based on soil fertility maps and the planned yield. Examples of potassium doses are given in table 4. Table 4 shows potassium fertilisation with manure. However, if such fertilisation was not used, these values should be increased by about 20% in relation to each of the individual fertility grades.

Table 4. K_2O fertilisation values in potato cultivation depending on the content of this ingredient in the soil if natural fertilisers are used

Assumed yield of potato tubers [t · ha^{-1}]	K_2O content in the soil				
	Very low	Low	Average	High	Very high
30	160	140	110	70	40
40	220	190	150	100	50
50	270	240	180	120	60

Source: Author's own work

Taking into account the type of potassium fertiliser, potassium sulphate is preferred. Potassium salt is less recommended. Generally, chlorides are not desirable for fertilisation in regenerative crops, as they can form soluble salt calcium chloride in the soil and thus contribute to leaching of calcium into deeper soil levels. As mentioned in section 3.9, calcium is of particular importance in regenerative cultivation, so its losses from the soil are very unfavourable. Potassium fertilisation is divided into autumn and spring fertilisation in the amount of 40% in autumn and 60% in spring. If you decide to use a potassium salt, use it only in the fall, avoiding its use in spring.

Phosphorus fertilisation

A potato needs about 65 kg of P_2O_5. This is not a lot compared to potassium. In the case of fertilisation with this macronutrient and taking into account its poor mobility in the soil and continuous fertilisation with natural fertilisers, which is one of the basic regenerative practices, it often turns out that the abundance of phosphorus in soils is high or very high. If that is the case, mineral fertilisation with this ingredient can be abandoned. In the case of lower soil phosphorus content, phosphorus fertilisation should be applied in the quantity as indicated in Table 5.

Table 5. Fertilisation values of P_2O_5 in potato cultivation depending on the content of this ingredient in the soil if natural fertilisers are used

Assumed yield of potato tubers [t • ha^{-1}]	P_2O_5 content in the soil				
	Very low	Low	Average	High	Very high
30	120	80	50	40	30
40	160	100	65	50	40
50	200	130	80	65	50

Source: Author's own work

Superphosphates and polydap can be used for the fertilisation. Precise fertilisation is also preferred for this ingredient, taking into account the soil fertility in individual parts of the field.

Sulphur fertilisation

Sulphur is an important plant component. It is part of many proteins, and increases the dry matter content in the plant. The plant absorbs sulphur from the soil as anions. Anions are negatively charged, so, unlike cations, they are not retained by the sorption complex, which also has a negative charge. Sulphur is therefore an ingredient that easily migrates in the soil and in effect it is difficult to determine its variable abundance. In regenerative agriculture, fertilisation with this ingredient is based on nitrogen fertilisation, because the plant is unable to assimilate nitrogen if there is no access to sulphur. For every 1 kg of N, about 0.25 kg of sulphur should be used (4 times less than nitrogen). For sulphur fertilisation, fertilisers such as: saletrosan (also contains nitrogen), UANS, potassium sulphate or kieserite are used.

Magnesium fertilisation

Magnesium plays an important role in potato cultivation, as it increases the content of dry matter and is also necessary during photosynthesis. Potato takes up about 25 kg of MgO to produce 50 t of tubers. When planning fertilisation with this ingredient, chemical analysis of the soil should be relied on, because too much of this ingredient in the soil reduces the uptake of potassium. Therefore, as a result of over-fertilisation with this ingredient, the uptake of potassium can be blocked. It often happens that the magnesium content in the soil is optimal, in which case, we skip this fertilisation procedure, In the case of low magnesium content in the soil, kieserite can be used.

Fertilisation with microelements

Fertilisation with microelements in potato cultivation takes place three times. The first is when the potatoes cover the rows, the second when the plants start to set tubers (flowering), the third when the flowers set fruit. We fertilise the plant with microelements, applying them in a solution. Micronutrients used in potato cultivation are: B, Mn, Fe, Cu, Zn, Mo. Molasses can be added to the solution during fertilisation with microelements.

PEST AND DISEASE CONTROL

3.3.7

In the regenerative approach to plant protection, preventive measures are important next to the conventional plant protection products.

Mid-field woodlots are also important in protection against pests (photo 10). They are a natural habitat for beneficial organisms, which are often predators of crop pests. For example, mid-field woodlots provide a refuge for birds of prey, which later hunt rodents in the fields adjacent to the woodlots, as is the case with beneficial butterflies. In addition to mid-field woodlots, watercourses, both large and small, are also important as a favourable habitat for beneficial organisms. In the regenerative approach, they are cared for and maintained in good condition (Photo 11).

Photo 10 - Mid-field woodlots are a natural shelter for beneficial organisms.

The condition of the cultivated plant is also important in plant protection. All regenerative treatments and techniques improve the condition of the cultivated plant. Direct plant protection is only to supplement all other treatments used to improve the condition of plants. It is important to realize that the use of chemical plant protection products is the last resort

Photo 11 - Proper maintenance of water reservoirs as an example of creating appropriate conditions for the life of water birds.

Pest control

Significant pests in potato cultivation are:

- ***nematodes***
- ***wireworm soil pests***
- ***Colorado potato beetle***
- ***aphids***

Crop rotation is of great importance in reducing the occurrence of nematodes. Potatoes should not be grown after brassica, especially if there is a suspicion that the field may have a nematode problem. Particular attention should be paid to this, also if we decide to grow potatoes after root crops. A laboratory test should be performed to determine the presence of nematodes in the soil. Dangerous species of nematodes in potato cultivation are golden nematodes, stem nematodes, and trichodorus. The harmfulness of the latter results from the fact that it is a vector for the TRV virus, which causes discoloration of the potato flesh. Apart from crop rotation, sowing plants limiting the occurrence of nematodes in the cover crop may be helpful for the protection against this pest. Such plants include marigolds, which should be sown in the cover crop mixture with other species in the amount of 3 $kg \cdot ha^{-1}$, or nematocidal species. Another method is chemical control. There are several nematode control agents on the market. Always use them as directed on the label.

In addition to preventive methods, plant protection products are used to control potato pests. The most dangerous pest in potato cultivation is the Colorado potato beetle, which, unfortunately, has no effective natural enemies in European conditions, apart from birds, which in some years may contribute to a significant reduction in the presence of this pest. Farmland birds that feed on the Colorado potato beetle include partridges and pheasants. The Colorado beetle as an insect originating from North America has its natural enemies there, which, unfortunately, have not been successfully introduced to Europe. For this reason, in most cases, classic chemical plant protection products are used to control this pest.

Protection against diseases

It was mentioned in the chapter on the selection of varieties that one of the methods of reducing the incidence of diseases on a potato plantation is the appropriate selection of a variety resistant to a given pathogenic organism. It is one of the basic non-chemical methods of disease control. However, for various reasons, it is not always possible to select the right varieties

In potato cultivation, economically significant diseases caused by various pathogens are:

- ***rhizoctoniosis***
- ***potato blight***
- ***alternariosis***
- ***common scab***
- ***blackleg***

These diseases can be transmitted with seed material. For this reason, the purchase of certified seed potatoes is of great importance in reducing the incidence of these diseases. In regenerative cultivation, only good quality certified material is planted.

In addition to good-quality seed potatoes, proper crop rotation is also important in reducing the incidence of rhizoctoniosis . Chemical treatment of tubers can also be used for the same purpose. However, it should be remembered that such treatments may result in a slower initial growth of the potato. In addition to chemical agents, biological agents are also available, based on bacteria that do not inhibit plant growth. You can also plant potatoes a little later, i.e. in order for the soil to have a higher temperature after planting. At a higher temperature, shoots grow faster and more evenly, which reduces infection by this rhizoctonia.

Potato blight is a very dangerous disease that can completely destroy the potato crop. Selection of cultivars and certified seed material are important in non-chemical methods of controlling this disease. However, the primary way to control late blight is using the chemical methods. There are many active substances on the market used to control it. They should be used alternately so that there is no acquired resistance of potato plants. In the use of plant protection products in regenerative cultivation against late blight, a disease model is used that indicates the level of risk. This model is based on environmental parameters such as temperature, humidity, wind speed, leaf wetting length, etc. With such data, this model indicates the risk of late blight hazard. Chemical treatment should be performed when high risk of the disease is identified.

The decision to spray against Alternaria is based on similar factor, i.e. the appropriate disease model. Alternariosis is also a disease that can develop both in the field as well as later, in storage.

Common scab and blackleg are diseases caused by bacteria. Properly selected crop rotation and good quality of seed potatoes are important in reducing the occurrence of these pathogens. In the case of the risk of common scab incidence, adequately high soil moisture during the period of initiation of tuber formation is important.

Weed control

Mechanical methods are very important in the control of weed infestation in potato cultivation. Spring tillage destroys weeds emerging during this period and earlier. The use of cover crops is also important in reducing weed infestation. As mentioned earlier, cover crops sown after the cultivar preceding the cultivation of potatoes compete with common weeds and limit their emergence. Chemical methods are recommended as an addition to non-chemical methods in regenerative cultivation. However, special attention should be paid to the conditions in which the chemical treatment is performed. In regenerative farming, of primary importance is the pre-emergence treatment, which should be performed immediately after the formation of the ridges. This treatment should substantially eradicate most weeds. Post -emergence treatments are only to supplement the first treatment and are not performed in all fields, but only where necessary. Sometimes post-emergence treatment is performed only on a part of the field, and a satellite image in NDVI technology can help us determine the level of secondary weed infestation. ON NDVI imagery, the weedy areas are greener than other parts of the field. Then, post-emergence treatment is performed only where higher weed infestation is identified.

HARVESTING AND STORAGE

3.3.8

The regenerative approach does not differ significantly from the conventional in terms of potato harvesting (photo 12).

Preparation for harvesting covers both the plant, the location, and the harvesting process as such. In terms of preparation of the plant, it is necessary in particular if it is intended for storage. Such plants should be desiccated first, and prior to desiccation, a late blight treatment should be performed with agents that reduce the formation of float spores (e.g. with cyazofamid). In order to limit the germination of potatoes in storage, a treatment with a sprouting inhibitor based on melanin hydrazide can be performed. This treatment should be performed when at least 80% of the potato leaves are still alive. As for the location and the harvest itself, sometimes when it is too dry and there are a lot of lumps in the field that can cause excessive tuber bruising, the field affected should be irrigated before harvesting. This procedure will facilitate the harvest of potatoes and reduce the bruising of potato tubers. It is also important to properly set the harvester, eliminate all irregularities that may cause too much bruising of potato tubers, which affects their quality and storage value. During harvesting, an artificial potato tuber is used to check the correct settings of the combine. It is an electronic tuber fitted with sensors, which is inserted into the ridge, then the tuber is collected by the harvester and goes through the working elements of the harvester and the entire harvesting process, finally landing in the storage room. The computer graph can then identify the points in the harvesting process where the tubers are particularly vulnerable to bruising. In the indicated places, the combine settings should be adjusted, e.g. belt speed reduced, the amount of soil on the belt increased, or the height from which potatoes fall on the conveyor belt decreased. In regenerative potato cultivation, it is also important to obtain yield data at a specific place in the field in order to create a yield map. Modern harvesters have such options, so it is advisable to use them.

Photo 12 - Harvesting potatoes

Before potato tubers go into storage, they must be properly prepared. In order to eliminate the risk of pathogens that may remain in the store from the previous year, the store should be disinfected using an appropriate disinfectant, for example based on hydrogen peroxide. This treatment is a preventive treatment, reducing the risk of storage rot of tubers, thus contributing to their better quality.

There are two stages in the storage of potatoes: drying, healing and cooling and storage. The first stage begins as soon as the potato tubers enter storage and takes place at higher temperatures, around 13-15°C and relative humidity of around 97%. After the drying and healing stage, which lasts up to 3 weeks, depending on which potatoes are stored, the process of cooling and then storage takes place. The storage temperature depends on the purpose of the potato tubers. Edible potatoes are stored at a temperature of approx. 4-5°C, while tubers intended for French fries or crisps are stored at higher temperatures, around 10°C. This difference follows from the behaviour of potato tubers at lower temperatures. It turns out that at low temperatures, the potato tuber deposits more simple sugars in its tissues, and these sugars are not desirable in tubers that are to undergo the frying process. However, in tubers intended for the fresh market, these sugars are not so important. The germination of the tubers is also related to the storage temperature. It is important that the tubers do not germinate in storage. Germination is more intense at higher temperatures, therefore potato tubers stored at 10°C start sprouting after dormancy. To prevent sprouting, treat them with a sprout inhibitor. These agents are administered using fogging

Loading of potato storage

PH REGULATION AND ROLE OF CALCIUM IN THE REGENERATIVE CULTIVATION OF POTATO

3.3.9

Potato is a species that does not have particularly high requirements as to the pH of the soil. It can be grown in soils with pH between 5.5 and 6.5

However, a more acidic soil may cause unfavourable root growth, excessive amounts of available micronutrients, and thus their phytotoxic effect. On the other hand, if pH is greater than 6.5, there is a greater risk of common scab on tubers, and thus deterioration of their quality. Soil pH is known to be affected by alkaline ions such as Ca2+, Mg2+, K+, Na +. Of these elements, as mentioned earlier, calcium is very important from the point of view of regenerative cultivation. Calcium performs many important functions in the life of every plant. The first function is to nourish the plant - because calcium is a microelement, significantly affects the resistance of plants, and participates in the proper formation of the structure of the cell wall. The plant cell wall is the first natural layer of protection against the external environment. Calcium is involved in the regulation of physiological processes inside the cell and is the only element that the plant absorbs in an upward trend until the end of vegetation. The second function of calcium is to regulate soil pH. Appropriate soil acidity is very important in the cultivation of each plant, and it also affects the availability of individual nutrients for plants. Too high pH results in the unavailability of micronutrients (except Mo), while too low pH causes the release of toxic aluminium ions and excessive supply of micronutrients, which adversely affects the physiological condition of the cultivated plant. In addition, the pH value also creates an environmental regime for the development of all soil organisms. Low soil pH is unfavourable for the development of earthworms and beneficial bacteria, and the activity of these organisms is particularly important in regenerative cultivation. In addition, calcium binds mineral and organic particles that build the soil - it is a cementing agent for soil aggregates. The presence of calcium in the soil affects the formation of a well-developed, stable structure in the soil, and this is very important in maintaining an appropriate soil culture.

Owing to the many functions of calcium in regenerative cultivation, special attention should be paid to fertilising the soil and plants with this element. Obviously, where we need to regulate the pH, when pH of the soil is too acidic, we use lime for fertilisation. The type of fertiliser lime we use is very important. For deacidification purposes, we use chalk or sugar lime. These limes are relatively fast-acting, that is, they are active in the soil shortly after their application, which is good for pH regulation. Dolomitic lime, which acts relatively slowly, is not suitable for quick pH adjustment.

A question can be asked what to do if we have the right pH of the soil, Should we not use calcium fertilisers then? In the regenerative approach, fertilisation with this ingredient should not be abandoned in this case. Here, we can use calcium sulphate (gypsum) or calcium nitrate. Calcium sulphate should be applied immediately after harvesting the crop preceding the cultivation of potatoes. Such an early application of this fertiliser is necessary because calcium sulphate is relatively poorly soluble. Calcium nitrate can be used during chemical treatments directly on the plant. it is recommended to use calcium nitrate with each micronutrient fertilisation in regenerative potato cultivation.

SUMMARY OF PRACTICES AND ANALYSIS OF BENEFITS

3.4

In the regenerative cultivation of potatoes, as well as any other crop, it is important to realize that it essentially is a holistic approach to growing crops.

Its full objectives cannot be achieved by implementing regenerative practices only in the cultivation of one species and not in others. Full success in the implementation regenerative practices will be there if the practices are applied for each crop.

A number of important points should be mentioned in relation to regenerative potato farming:

- when choosing a site, the terrain should be taken into account, along with the abundance of specific nutrients in the soil, which should be determined using the Mehlich method; in addition appropriate crop rotation should be determined in order to prevent the development of diseases and one-sided use of nutrients
- it is absolutely necessary to cultivate cover crops with a specific composition of plant species in order to introduce additional organic mass into the soil; and reduce soil erosion
- natural fertilisers such as manure, slurry should also be used where possible
- soil cultivation should be approached with caution and with its biological life in mind, so as to disturb the soil biological balance as little as possible, and on the other hand, ensure appropriate conditions for the development of the cultivated plant
- in the context of plant protection, the plantation should be run so that the condition of potato plants is as good as possible, because the better the plants are, the more resistant they are to adverse external factors; it is also necessary to take care of the specific surroundings of the fields, such as mid-field woodlots or water reservoirs, which are conducive to the presence of organisms useful from the agricultural point of view
- remember about the appropriate level of calcium in the soil as it is an often-underestimated macroelement

A clear advantage of regenerative practices is that they make soil in the field healthier, and allow better production performance and more repetitive yields over the years, under changing environmental conditions.

One of the effects of regenerative practices in potato cultivation is the reduction of the decrease in the content of organic matter in the soil compared to conventional cultivation of this plant. More organic matter in the soil means less carbon dioxide in the atmosphere. By increasing the content of organic matter in the soil by 1%, we bind 60 to 70 tons of carbon dioxide.

In regenerative cultivation, we try to create the best conditions for the growth of potato plants, which results in their better health and, consequently, lower consumption of plant protection products, which reduces cultivation costs and has a positive effect on the environment. It is also possible to reduce the costs of fertilisation by applying precision fertiliser dosing techniques.

All regenerative treatments seek to improve the condition of the natural environment, plant yield, while reducing production costs and obtaining a high-quality and healthy final product.

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