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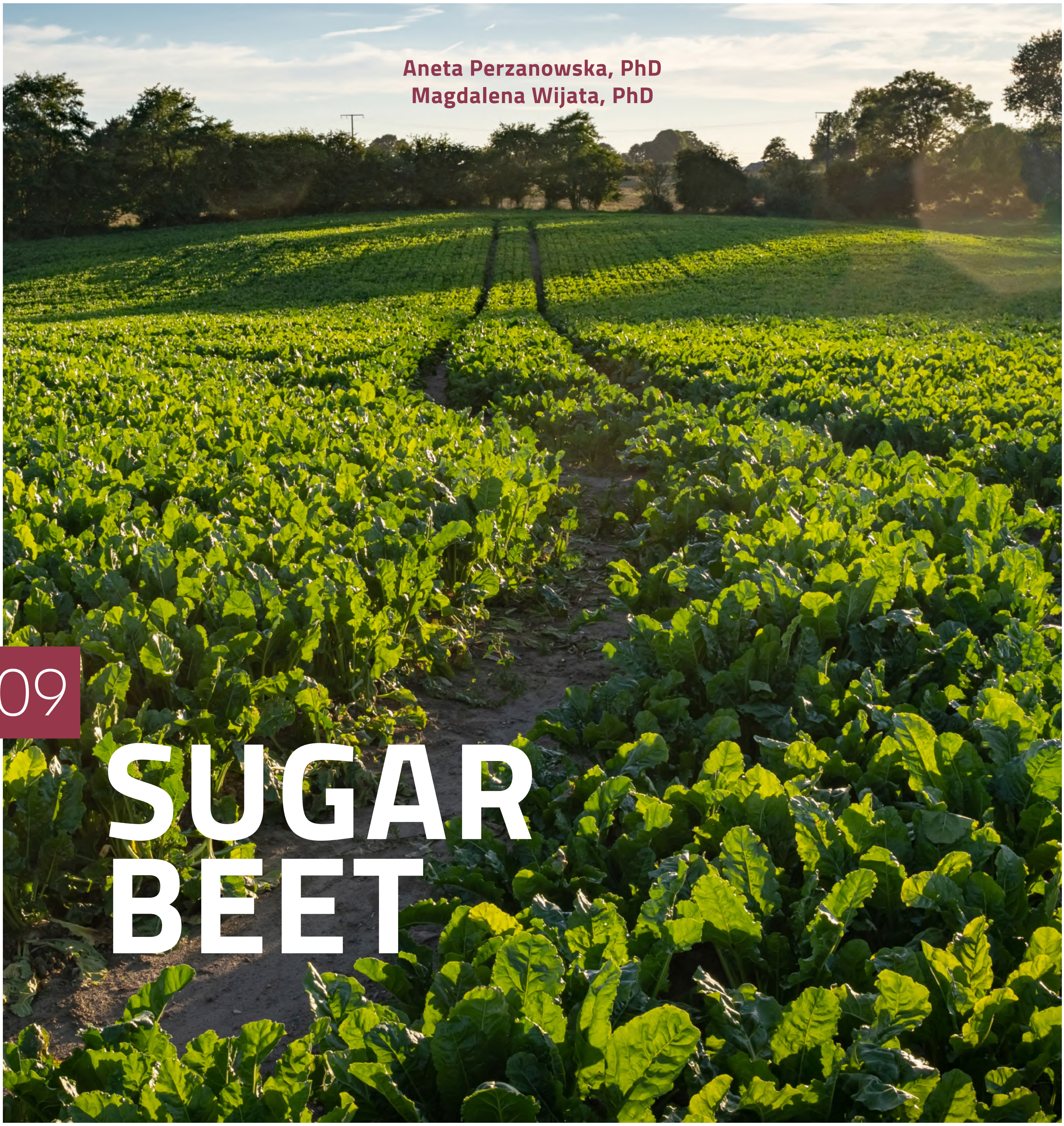

09

# SUGAR BEET

## CEE REGENERATIVE AGRICULTURE GUIDEBOOK

TERRA NOSTRA FUNDACJA
eit Food
Co-funded by the European Union

# CEE REGENERATIVE AGRICULTURE GUIDEBOOK - SUGAR BEET

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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.

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# SUGAR BEET

## CEE REGENERATIVE AGRICULTURE GUIDEBOOK

Poznań 2024

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# REGENERATIVE SUGAR BEET GROWING



## INTRODUCTION TO REGENERATIVE FARMING

**Sugar beet (*Beta vulgaris L. subs. vulgaris*) is a sub-species of the common beet (*Beta vulgaris L*), belonging to the amaranth family. It is a biennial plant which means that in the first year it grows vegetative organs in the form of a storage root and a rosette of leaves (fig. 1), and in the second year it produces seeds.**

Sugar beet is the second most important source of sugar in the world (23% of the total production) after sugar cane. In Europe, sugar beet is the only source of sugar production. The sugar beet root, which weighs on average 500-800 g, is characterised by a high saccharose content (on average approximately 18-19.5%). Additionally, in the processing of sugar beet there are valuable by-products (molasses, pulp, beet leaves). Although the area of sugar beet cultivation in Poland is only about 2% of the total area for growing crops, its economic significance is still high. Poland is among the ten largest sugar beet producers in the world. Sugar beet plantations are mostly located in the vicinity of sugar factories due to high costs of transport of the main crop at large distances.

Regenerative farming is the answer to climate change and the new expectations of consumers from agricultural production and its environmental impact which are the challenges for contemporary agriculture. One of the assumptions of the regenerative approach is the diversification of crop rotation and introducing non-cereal crops as a break crop in cereal mono-cultures which have come to dominate the arable land. Nowadays cereals account for more than 70% of crops in Poland, which generates many problems, both for the soil environment and in terms of crop health and biodiversity of agroecosystems. This leads to an excessive soil exploitation through one-sided uptake of nutrients and disturbed soil balance. As a root crop, sugar beet is an important part of modern crop rotation, benefiting the phytosanitary condition of the soil and leaving high quantities of nutrients in post-harvest residues. Therefore, this species fits in perfectly in the crop rotation recommended as part of regenerative agriculture, which by definition should be diversified and include many crops. The presence of sugar beet in the field requires taking care of the soil quality, in particular physical soil quality at the stage of planning the entire crop rotation.

**Figure 1. A field of sugar beet in rotation with winter and spring wheat.**
*Photo by A. Perzanowska*

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# CLIMATIC, NUTRITIONAL AND SOIL REQUIREMENTS

**Sugar beet should be grown on soils rich in nutrients and organic matter, with a deep humus horizon and well-regulated water and air properties.**

The highest yields are achieved on very good wheat complex soils, good wheat complex soils, and very good rye complex soils. Sugar beet does not tolerate excessively compacted soils, therefore too tight clay soils or lighter soils with too heavy-clay subsoil are not suitable for growing this crop. The exception are heavy soils with a high humus content thanks to which they gain appropriate structure which decreases their compaction and coherence. Sugar beet is sensitive to unregulated soil pH – a site for growing sugar beet should have a neutral or alkaline soil pH. The optimum soil pH for sugar beet is 6-7.2.

Sugar beet has high requirements for water due to a high weight of the primary yield (sugar beet root) and the secondary yield (sugar beet leaves) produced during the growing period. The optimum total precipitation during the growing season is 600 mm. Apart from the total amount of rainfall, also the distribution of rainfall throughout the growing season affects the yield of sugar beet and the content of sugar in the roots. Sugar beet has the greatest requirement for water in the spring, during the emergence, and from June to August, at the time of intensive transpiration and accumulation of dry mass. If water requirements are satisfied in a better way as early as the stage of germination and emergence, it leads to a faster growth of roots and their better development. Poorer development of roots of young plants caused by water deficiency may have undesirable consequences – slower and uneven emergence, lower plant density (fig. 2), and shallower root system which will not be able to take up water energetically enough in the later stages of growth. There may also be a reduced water uptake from water reserves stored in the deeper soil layers, which is very detrimental from the point of view of the ability of the sugar beet plants to survive periodic rainfall deficit and the proper growth of the plants in general.

It should also be remembered that sugar beet has high nutritional requirements and, at the same time, makes poor use of less available forms of nutrients. This means that in conditions of lower moisture content of soil they perform less well compared to many other crops, and the disturbed water balance and water conditions within the plant may lead to a significant lowering of sugar beet productivity. Droughts in the summer contribute to a fall in the root yield and sugar content. Therefore, it is crucial to improve soil water retention and minimise the effects of atmospheric and soil drought, which is ensured by the practices of regenerative farming, through cultivation methods reducing tillage, supporting the gathering of organic matter in the soil, and creating a stable soil structure, to name only a few.

**Figure 2. Soil moisture deficiency in the spring results in slower and uneven emergence and lower final plant density.**
*Photo by A. Perzanowska*

Sugar beet is a temperate climate crop and optimum average daily temperatures for sugar beet are 12-16°C. However, it is characterised by a high sensitivity to daily temperature fluctuations. In order to germinate, sugar beet seeds need temperatures of 5-6°C. Sugar beet is particularly sensitive to below-zero temperatures in the first days after the emergence. At this stage frost below -3°C may be harmful to sugar beet seedlings. The roots which remain in the soil are resistant to low temperatures. After producing the first pair of leaves sugar beet withstands temperatures up to -5°C. The fall in the average temperature from April to July by 10°C compared to the multi-year average results in the reducing of the sugar content in roots. This is due to leaves growing too slowly. However, usually as the plants grow the optimal temperatures increase and they decrease in the second half of the summer. Large daily temperature fluctuations in the final stage of the growth period are beneficial for the sugar content in sugar beet roots due to inhibition of leaf growth. On the other hand, low temperatures in the first year of the growth period, in the early development stages, increase the risk of bolting, that is producing flowering shoots in the first year of sugar beet growth (fig. 3). Bolters grow in rows, they have thin, hard, and fibrous roots, do not have any agricultural value and hinder the mechanical harvest of typical beetroots, therefore a large number of bolters in a sugar beet plantation is not desired. Seeds produced on bolting shoots may ripen and fall into the soil, enriching the weed seed bank. Plants germinating from such seeds will cause weed infestation of the beet plantation in the next rotation of sugar beet in the field as weeds which are very difficult to control. For this reason bolters growing in a sugar beet field, as well as weed beet, should be removed from the field before they produce seeds.

Sunlight exposure is an important factor for sugar beet, which determines the quality of the primary yield. Sunny April has a beneficial effect on soil heating – it speeds up germination and emergence of sugar beet. At the initial developmental stages, when sugar beet leaves are not yet fully formed, they may use up no more than 30% of the available radiation. High exposure to sunlight in the period from mid-August until the end of September benefits assimilation and favours the increase in sugar concentration in beet roots. Due to a positive response of sugar beet to good sun exposure of the stand it is advisable to sow the plants in the north/south direction which is also recommended in growing other crops.

Sugar beet has high nutrition requirements as it builds a large biomass, both above- and underground. In recent years the average yield of sugar beet in Europe approximates more than 65 tonnes per hectare.

**Figure 3. Sugar beet bolters in the first year of growing.**
*Photo by A. Perzanowska*

# 3 TECHNOLOGY OF REGENERATIVE FARMING

## 3.1 Site and forecrop

In regenerative farming, attention should be paid to the crop's place in a crop rotation sequence. What matters is both the type of forecrop and the conditions this plant creates for the successive crop. Sugar beet grown as a forecrop has many advantages. It leaves a rich site when it is grown on manure and its leaves are left as residue, which is a standard practice nowadays with mechanical harvesting of sugar beet root. Beets used to be topped before harvest, i.e. the rosette of leaves with the top part of the root (epicotyl) was cut off and this biomass was used as fodder on a farm (fig. 4). Traditionally, natural fertilisers have been used for sugar beet, which compensated for the removal of secondary yield from the field. Fertilising sugar beet with manure is beneficial not only for the sugar beet itself, but also for the successive crops. Thanks to these advantages growing sugar beet in crop rotation still fits very well in the principles of regenerative farming in which it is often perceived as a site improving crop and a break crop for cereals in crop rotation. However, growing sugar beet has an adverse effect on physical soil properties, therefore in crop rotation with sugar beet various methods should be implemented to improve the physical quality of soil.

**Figure 4. Topped sugar beet roots.**
*Photo by A. Perzanowska*

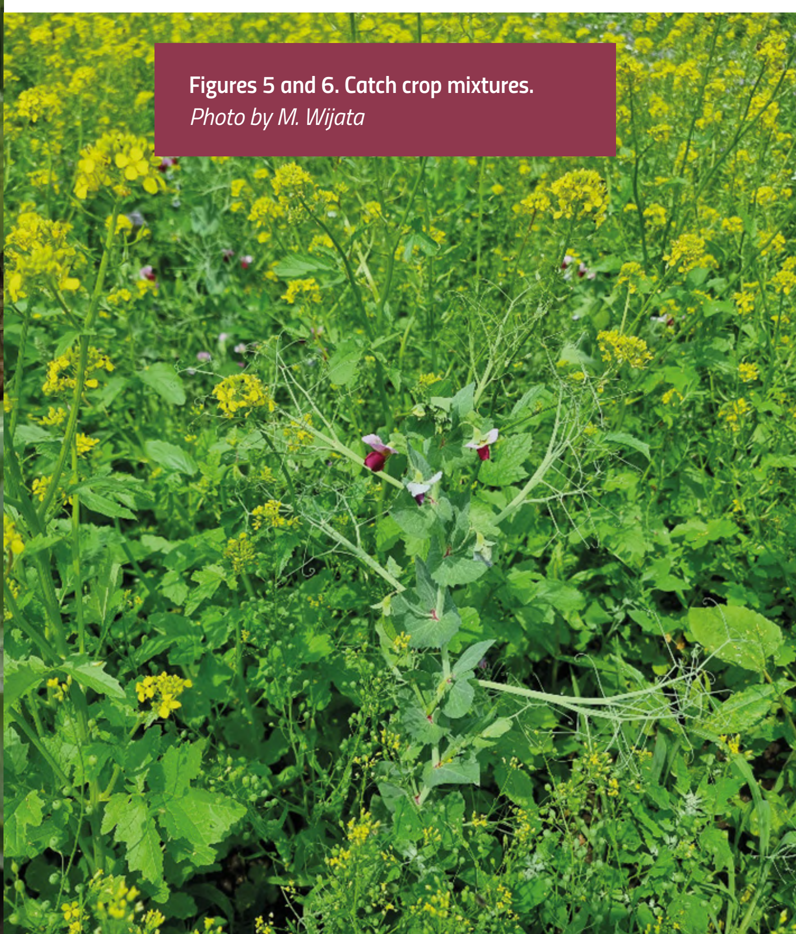
Sugar beet has high requirements in terms of a forecrop. Several crops can be distinguished after which sugar beet should not be grown. These exceptions are due to excessive pathogen intensity occurring if these crops are grown in rotation with sugar beet. Crops not recommended include rapeseed, due to the pressure of self-sown (volunteer) rapeseed and sugar beet cyst nematode. Sugar beet plantation should not be established directly after ploughed meadows, temporary grasslands, and legume-grass mixtures introduced to arable land due to more intensive drying of soil and the risk of wireworm occurrence, which can damage sugar beet roots. The forecrops recommended for sugar beet are legumes, e.g. pea, faba bean, soybean, which have similar soil requirements to sugar beet, leave a site rich in nitrogen and in case of deeply rooting faba bean also loosen deeper soil layers (phytomelioration effect).

In order to minimise potential problems with nematodes or root rot of beet seedlings it is best to plan sugar beet growing in at least 4-year rotation. Growing beet at shorter intervals and in rotation with soybean leads to a high risk of beet sickness of soil, that is proliferation of pests and diseases typical for beet. In case of a high pressure of pests and diseases it is recommended to extend sugar beet cropping intervals.

As a crop sown in the spring, sugar beet offers extensive possibilities of choosing forecrop and planning intercrops which will be left in the field for winter, thus providing soil protection against erosion. The best for many reasons and the most frequently chosen forecrops are cereals, in particular winter wheat. After the harvest of this cereal, there is still enough time to sow a catch crop.

The site after the harvest of sugar beet is well suited to growing cereal crops. Depending on the time of harvest of sugar beet roots the site may be used for growing winter, and spring wheat or other spring crops. A good choice among spring crops, apart from spring wheat, is also corn or spring fodder varieties of spring barley. Due to a high nitrogen content in soil from decomposed leaf biomass after growing sugar beet, it is not recommended to sow malting barley, as it may result in excessive levels of protein in grain which is detrimental to the brewing process.

Applying the principles of regenerative farming makes it possible to lower the negative effect of growing sugar beet on soil organic matter. After one growing season of sugar beet on average 1.5 tonnes of organic matter per hectare is eliminated from the soil (0.76 – 1.84 t·ha-1 depending on the soil and type of management). One of the options to improve the balance of organic matter in crop rotation with sugar beet is leaving the straw after the harvest of forecrop in the field and leaving the sugar beet leaves as green manure, however, these measures may be insufficient to fully compensate for the losses of soil organic matter caused by growing sugar beet. A simple and beneficial solution is growing stubble catch crops as a source of soil organic matter. In regenerative farming growing



**Figures 5 and 6. Catch crop mixtures.**
*Photo by M. Wijata*

catch crops is an important measure which improves the soil structure, has a positive effect on the balance of organic matter and accumulation of nutrients, and making them available to successive crops. The catch crop biomass has a fertilising effect, but also through increasing the content of organic matter, stimulates the activity of soil microorganisms. The most recommended catch crops used before sugar beet are white mustard, radish, and phacelia. Although growing brassica crops in rotation with sugar beet is not recommended due to them being hosts of sugar beet cyst nematode, their nematicidal varieties, showing phytosanitary effects, are used for sowing before sugar beet. Also, nematicidal phacelia can be used as a catch crop. A good solution is also using mixtures of several crops as a catch crop which increases the chances of success of the catch crop and provides better scope for using its production and natural functions (figs. 5 and 6). An additional advantage of multi-species mixtures is their attractiveness for bees and other pollinators as they are usually nectar and honey-producing plants.

Another disadvantage of introducing sugar beet to crop rotation is its negative effect on soil structure, in particular its destruction at the time of harvesting sugar beet root. Therefore, in the regenerative approach to sugar beet growing the risk of damaging soil structure and texture should be minimised (see chapter 3.10) and the reconstruction of the structure and other physical properties of soil in subsequent stages of crop rotation should be ensured.

In farms producing bulky feed on arable land using small seed legumes or legume-grass mixtures in ground cultivation, it is recommended to grow them on sites directly after root crops. This is due to the fact that root crops, such as sugar beet, leave a relatively weed-free site which significantly reduces the risk of overwhelming small seedlings of grasses and legumes by much more quickly growing weeds. However, first of all, perennial legumes and their mixtures with grasses should be seen as structure-forming plants in crop rotation, rebuilding the stability of soil aggregates and the soil organic matter resources following the growing of crops contributing to soil structure destabilisation and depleting soils of organic matter, such as root crops. Good soil coverage, an extensive root system with a large number of small rootlets, nitrogen rich root exudates, and a large amount of organic residues deposited in the soil which stimulate the biological life of soil are factors responsible for the development of a lasting soil structure during growing grasses and legume-grass mixtures. A lasting soil structure protects also particles of organic matter against quick decomposition and mineralisation. Similar reasoning applies to the addition of legumes and other species which grow through soil well to catch crop mixtures grown in rotation with sugar beet.

## 3.2 Selection of varieties

The selection of a variety is the first key decision to ensure the success of growing sugar beet and in regenerative farming, there is a great focus on this aspect. In the selection of the variety the root yield, biological and technological sugar yield, and increased resistance to or tolerance of pests and diseases should be taken into consideration. In regions with a higher incidence of diseases, e.g. Cercospora leaf spot of beets (e.g. southern Poland), varieties with an increased resistance to this pathogen should be selected. The selection of a variety resistant to diseases or with an increased tolerance is one of the methods of pathogen control, recommended in regenerative farming and significantly reducing the use of pesticides.

Currently sugar beet plantations in Poland are located near sugar factories. Therefore, sugar producers in a given region, in agreement with the growers, select the varieties recommended for growing. Good quality certified seeds are necessary for the single-grain sowing of sugar beet, but also in the initial stages of the development of plants the properties of the seeds may affect the development of seedlings. The range of sugar beet varieties is very extensive and the progress in breeding of this crop is very dynamic and focused mainly on increasing its tolerance of diseases, drought, and herbicides as well as increased root and sugar yield. Work is also conducted to obtain winter forms of sugar beet which is aimed to increase its productivity.

# Soil cultivation 3.3

Traditionally in ploughing cultivation of sugar beet deep pre-winter tillage with the moldboard plow is used as the basic cultivation measure. In the regenerative approach to cultivation, autumn soil cultivation and preparation of soil for sowing beet seeds should be simplified as much as possible, therefore tillage should be replaced with reduced tillage. Conventional tillage is a very cost and energy-consuming practice and moreover it destroys the soil structure and disturbs its natural texture. After plowing it is necessary to apply several seedbed preparing measures which additionally causes excessive drying of soil and mechanical destruction of soil aggregates and combined with tillage it adversely affects the biological activity of soil. Traditional tillage also promotes the formation of a plough pan, that is a soil condition which occurs in ploughing soil management system. A plough pan is a compacted layer of soil directly under the ploughing layer which is formed as a result of the furrow bottom being compacted with tractor wheels and the plough skids sliding on the furrow bottom. It is formed if ploughing at the same depth is performed in successive seasons. This condition makes proper development of sugar beet roots and other crops difficult. A properly developed sugar beet root system reaches the depth of even more than 100 cm and consists of the storage root and deeper reaching root hairs. The presence of a plough pan in subsoil causes proper roots of sugar beet to bend and fork (fig. 7) and at the same time the possibility of the lower part of the proper root and side roots growing into the soil profile is significantly limited.

**Figure 7. Typical symptoms of plough pan – a soil condition related to ploughing cultivation.**
*Photo by A. Perzanowska*

**Figure 8. Problems with infiltration of water after heavy rainfall may indicate a plough pan and subsoil compaction of the field.**
*Photo by A. Perzanowska*

Disturbance in root development caused by a plough pan may increase the sensitivity of sugar beet to periodic water deficiency in soil and exacerbate the negative effects of drought stress, as well as lower the effectiveness of nutrient uptake from the soil. A plough pan may significantly impair ground water ascension from lower soil layers to the surface and infiltration of rainwater into the soil profile, which negatively affects water retention and moisture content of the topsoil. Both the limiting of the capillary ascent to the soil surface in the periods between rainfall (increasing the drying out of topsoil) and limiting the water outflow from topsoil deeper into the soil in rainy periods (stagnant rainwater on the surface of the field) results in adverse water and air conditions for the development of plants. In case of finding a plough pan in the field (when a large number of forking or bent roots are noted in the yield – fig. 7 and when stagnant water is found on the field after heavy rain – fig. 8), it is absolutely necessary to perform sub-soiling. Sub-soiling is best carried out with a relatively low moisture content of soil, preferably directly after the harvest of early harvested crops. If the field is situated on a slope, sub-soiling should be performed along the contour lines in order to prevent erosion, and on meliorated land the measure should be carried out at the right angle to draining pipelines.

Traditional ploughing cultivation used in particular on soils with a negative balance of organic matter, may lead to an easy destruction of the soil structure by rain and easy crusting of the topsoil deprived of forecrop residues after heavy rainfall. After drying out, the washed out soil structure forms a hard crust (fig. 9), approximately 1 cm thick near the soil surface. Crusting of soils entails a risk of slowing the growth of sugar beet plants at the time of emergence, accelerates drying of soil, limits gas exchange between the soil and the atmosphere, and increases the exposure of emerging seedlings to fungal diseases such as root-rot. Heavier soils on which sugar beet is usually grown are particularly exposed to the formation of hard crust if proper balance of organic matter is not ensured and the structure-forming crops are not introduced to crop rotation. If the formed crust is not soaked in time with successive rainfall, there is a risk of large losses of emerging seedlings and in density of sugar beet.

**Figure 9. Soil crust is formed as a result of drying the washed topsoil and it provides mechanical resistance for the emerging plants.**
*Photo by A. Perzanowska*

In order to eliminate the adverse effect of ploughing on soil in regenerative farming it is recommended to replace this measure with reduced tillage at each stage of preparation of soil for sowing. A wide range of agricultural machines and tools for reduced, ploughless soil cultivation come in useful here. In ploughless tillage systems basic soil cultivation is performed usually using various types of cultivation units, cultivators, and harrows. Working parts of the cultivation tools and machines of this type do not ensure precise turning over of the cultivated soil layer and no residues of forecrop in the soil surface which is the case in conventional moldboard ploughing cultivation (fig. 10). Thank to this during the whole growing period of sugar beet some forecrop residues stay on the soil surface playing a protective role for the soil (fig. 11). The introduction of reduced tillage on the field should be preceded by subsoiling, in particular if the future reduced cultivation will be performed at the depth similar or smaller than the tillage used so far.

The first step recommended in reduced regenerative soil cultivation is fast shallow loosening of the field surface and mixing crop residues using a cultivation unit based on a cultivator, coulter harrow, spring-tine rotary harrow (works well on average and heavy soils) directly after the forecrop harvest. When fertilising the field with straw, shredding it well and spreading evenly on the field before the start of the soil cultivation should be ensured. After loosening the field, a catch crop is sown, if the timing of forecrop harvest makes it possible to introduce catch crops to the forecrop-sugar beet part of crop rotation. The catch crop can also be sown on the field surface before performing shallow cultivation, as sowing a stubble catch crop as soon as possible is more important than preparation of the soil for its growing. Cultivation and sowing units are also used. From the perspective of regenerative farming, the use of catch crops before sugar beet is a very important measure which should not be omitted. Particularly due to the fact that usually between the harvest of forecrops, which normally are cereals, and the sowing of sugar beet, there is sufficient time to grow catch crop mixtures. Catch crops improve the balance of organic matter in crop rotation with sugar beet as well as en-

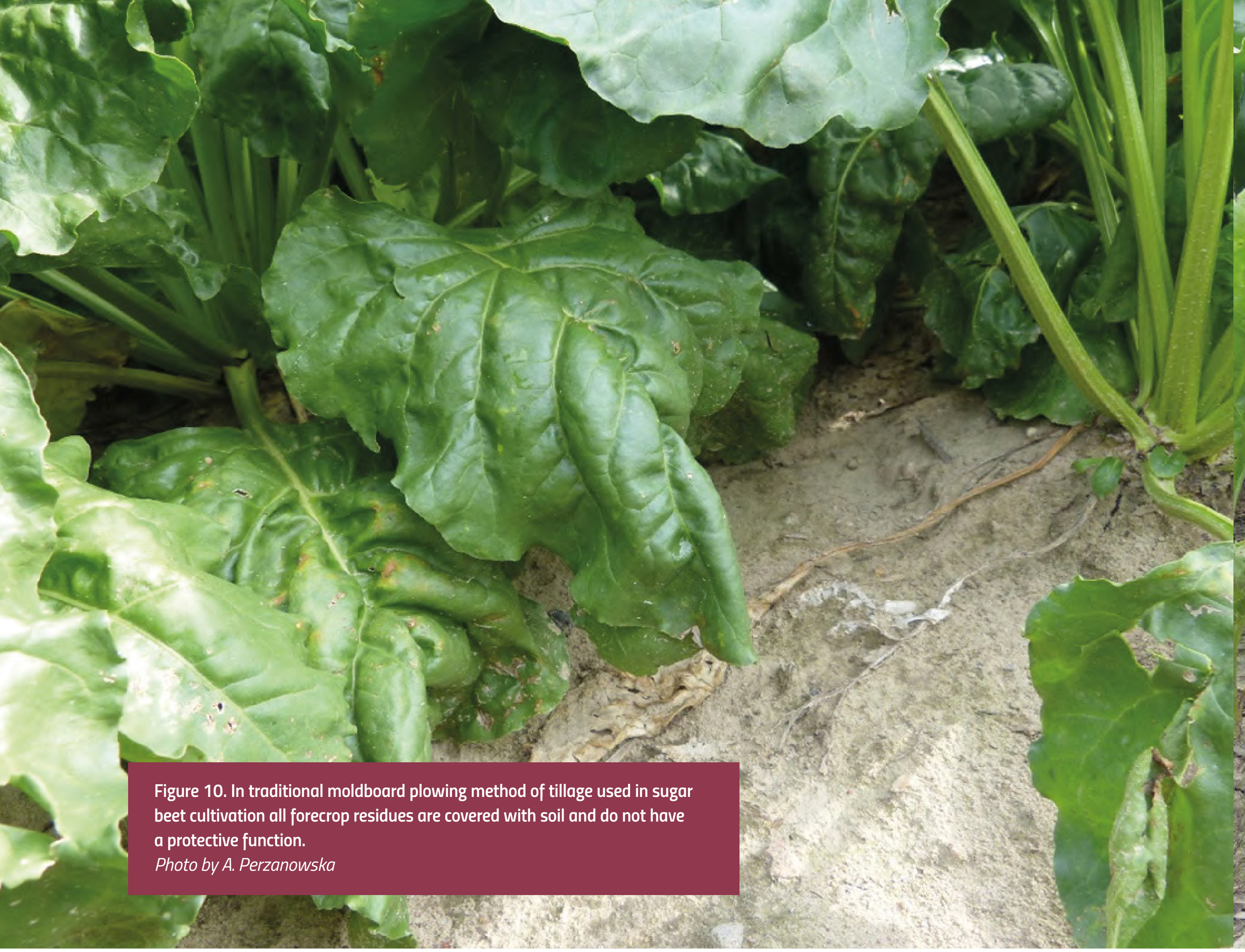


**Figure 10. In traditional moldboard plowing method of tillage used in sugar beet cultivation all forecrop residues are covered with soil and do not have a protective function.**
*Photo by A. Perzanowska*

able the productive use of nutrients remaining in soil and soil water in the pre-winter period. These resources are not unproductively lost as a result of evaporation and leaching when the soil surface is not covered with plants, but are used for the production of successive biomass which will eventually return to the soil in the form of green manure and feed the reserves of soil carbon and nutrients. Also soil water used for the production of catch crop biomass is replenished in the autumn and winter season when the plants dye off. In reduced tillage systems plants grown as catch crops are left on the field for winter to protect the soil against erosion and leaching of nutrients from autumn to spring. Appropriate management of forecrop residues and catch crops contributes to an improved structure stability of topsoil which without the protective function of crop residues is constantly exposed to structure destroying factors such as rainfall and wind, which contributes to soil crusting. Soil deprived of cover easily loses water and dries out.

The next step involves pre-sowing measures performed in the spring. They differ depending on the applied sowing method. Single-grain sowing of sugar beet is possible after mixing mulch with soil using a cultivation unit, as well as sowing seeds directly into the mulch without disturbing the soil through any tillage (direct sowing less frequently used in sugar beet growing) or stripe sowing.

In regenerative agriculture deep reduced tillage of the whole surface of the field can be successfully used in sugar beet cultivation, and strip-till is also recommended, that is cultivation of only narrow strips on which beet seeds are sown. In strip-till soil loosening, sowing the seeds, spreading the fertiliser (side dressing), and sweeping the forecrop residues are performed during one passage of the cultivation unit, while forecrop residues and undisturbed soil texture remain on uncultivated strips. From the point of view of sustainable regenerative cultivation it is a very beneficial solution, on the one hand reducing the time and energy expenditure for cultivation and improving the effectiveness of fertilisation, and on the other hand increasing soil water reserves while ensuring the appropriate texture, loosening and faster heating up of soil in spring

**Figure 11. Residues of forecrop (winter wheat) on the surface of soil in ploughless sugar beet tillage system.**
*Photo by A. Perzanowska*

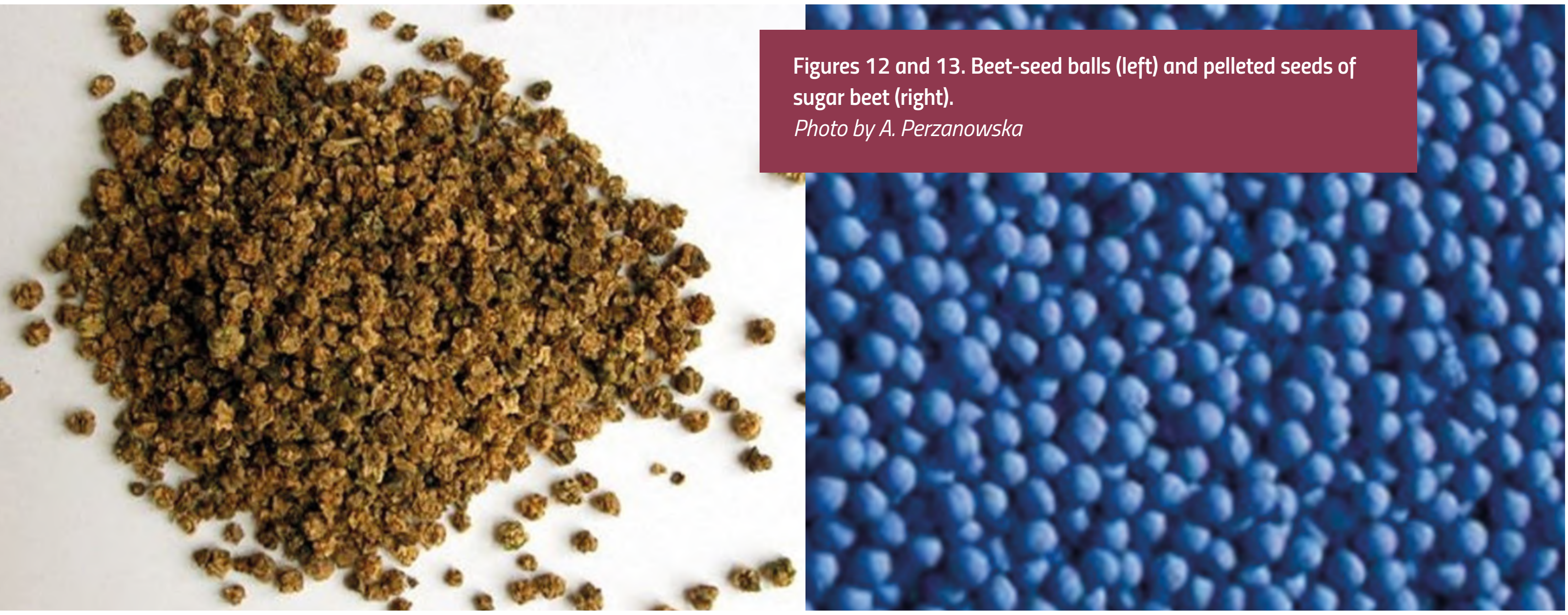
for the developing sugar beet seedlings and roots in the loosened strip. The presence of forecrop residues in uncultivated strips reduces water evaporation from soil. No-tillage means also that the proper soil structure is maintained in the strips, playing a retentive and protective role for organic matter build into the structure of soil aggregates and for soil organisms which are negatively affected by mechanical cultivation.

Both research and agricultural practice show that sugar beet is a crop which may successfully be grown in reduced tillage systems, in particular in strip-till, achieving similar of even higher yield of roots and sugar. This is an argument for the application of regenerative agriculture solutions of this type in growing sugar beet, which in long-term perspective brings only benefits. With the application of reduced ploughless soil cultivation we can positively affect the soil structure, soil moisture content, organic matter content, thanks to which sugar beet plants and successive crops can grow in more favourable soil conditions.

Regardless of the type of cultivation on the field, all measures should be carried out in optimum soil moisture. In order to verify whether soil has reached optimal moisture content simple organoleptic test can be performed on soil samples taken with a spade from the whole depth of the topsoil. With optimum moisture content the soil crushed in a hand is not sticky, but crumbly and falls into lumps when dropped freely from a height of 1 m. This level of moisture content ensures obtaining the best results of mechanical cultivation and minimises the risk of soil diseases related to the passage of tractors on the field and the effect of cultivation machines and tools.

## 3.4 Sowing

Sugar beet seeds are its fruits, so-called beet-seed balls (fig. 12). Sowing is carried out using a single-seed drill, therefore it is important that seeds are of equal size and shape. To ensure this, seeds are coated which makes them uniform while the fungicides and insecticides contained in the coating protect them from the moment of placing them in soil (fig. 13).



**Figures 12 and 13. Beet-seed balls (left) and pelleted seeds of sugar beet (right).**
*Photo by A. Perzanowska*

The timing of sugar beet sowing is closely related to soil temperature. Sugar beet is sown when the soil temperature at the depth of 5 cm reaches 5-10°C which in Polish conditions falls from mid-March to mid-April. Sugar beet seeds should be sown at the depth of 2-4 cm. On heavier soils, the depth should be smaller (2-3 cm) than on lighter soils (3-4 cm). The higher the average soil temperature after the sowing, the shorter the emergence time (Table 1).

**Table 1. Duration of field emergence of sugar beet depending on the average daily soil temperature**

| Range of average soil temperatures [°C] | Duration of emergence [days] |
|---|---|
| 3,3-7,2 | 21 |
| 7,3-11,1 | 10-20 |
| 11,2-15,6 | 7-12 |
| 15,7-21,0 | 5-7 |

Source: Authors' own work on the basis of Podlaski et al. (2017)

In Poland several sugar beet growing regions are distinguished. The timing of sowing is largely determined by the climate and soil region. For south-western Poland the optimal timing of sowing in late March and early April, for central, eastern and north-western Poland – it is the first half of April, and for northern Poland – the second half of April. Practically, irrespective of the region, the following principles is applied: the sowing of sugar beet takes place as soon as it is possible to carry out spring field work and the risk of strong frost passes. This allows for the maximum extension of the growing period for sugar beet which needs from 180 to 190 days from sowing to harvest.

On a properly prepared field, 1.1-1.2 seed units per hectare are sown (1 seed unit = 100,000 seeds), which is 110-120 thousand seeds per one hectare. The spacing of rows is 45-50 cm, depending on the drill used. Seeds are placed individually in a row, approximately every 18 cm, but they can also be spaced every 21 cm or even every 24 cm. Such sowing parameters ensure the final density of 8-10 plants per 1 $m^2$ (Tab. 2).

**Table 2. Standards of sugar beet sowing in seed units per 1 hectare**

| Spacing of seeds in a row in cm | Demand for seeds in seed units |
|---|---|
| 16 | 1,4 |
| 18 | 1,2 |
| 20 | 1,1 |

Source: Authors' own work on the basis of "Metodyka integrowanej produkcji buraka" (2023)

A relatively high sugar beet density has many advantages. First of all, it improves the use of water from deeper soil layers. With a higher density sugar beets shade the soil better during the growing period, which reduces moisture loss through evaporation from the soil surface and with heavy rains prevents their destructive effect on the soil structure. Proper sugar beet density affects also the size of roots, increases the share of root in optimal weight and reduces the number of roots which are too small and too large. Roots weighing 500-700 g are of the highest quality and their share in the yield should be the greatest. Table 3 presents percentage share of roots of different weight depending on the density.

**Table 3. Share of sugar beet root weight (%) depending on the density**

| Density in thousands · $ha^{-1}$ | Root weight (g) | | | |
|---|---|---|---|---|
| | <800 | 800-1200 | 1200-1600 | >1600 |
| 60 | 3 | 18 | 50 | 29 |
| 75 | 18 | 57 | 25 | - |
| 90 | 58 | 42 | - | - |

Source: Authors' own work based on Ostrowska (2001)

# 3.5 Irrigation and water management

In planning irrigation of crops it should be noted that water resources of the Earth are limited. The regenerative approach proposes solutions aiming to increase the amount of water retained in soil thanks to which irrigation can be avoided. Water retention of agricultural soil can be influenced through practices which restore soil organic matter reserves and stability of soil aggregates (e.g. reduced tillage, leaving post-harvest residues, use of catch crops, organic and natural fertilisers, properly composed crop rotation). The selection of crop species for the site is also important. Sugar beet has high water requirements and is sensitive to water deficiency in critical periods, therefore it should be grown on the best soils with high retention capacity, which are less sensitive to periodic rainfall deficit.

Sugar beet needs most water in the spring, during emergence, and in the summer when it transpires and grows the most. Water deficiency at this time results in a lower yield and reduced sugar content in roots. The highest sugar beet yield is achieved in the years when the total rainfall is approximately, 600 mm during the growing season ensuring sufficient water supply in the spring and at the time of the greatest growth of biomass. In the critical 30-day period of growth (21 July to 20 August) the maximum consumption of water by sugar beet plants is 6 mm per day. On the hottest days of the summer, when the sugar beet root system is already fully developed, the consumption of water may reach 7 mm per day. This shows that in order to satisfy those demands sugar beet needs large quantities of water available for plants practically throughout the whole growing period. Water consumption by sugar beet depends on the size of the yield. With the root yield of 50 tonnes per hectare the plants use up approximately 500 mm water, whereas with the yield of 60 tonnes per hectare water consumption is approximately 730 mm. In the Polish conditions water requirements of sugar beet in relation to rainfall are 385-450 mm in the period from the start of growing to harvest. The rest of water requirement is covered by sugar beet from soil water resources and from capillary ascent of water from deeper soil layers.

If the decision to irrigate is made, it should be adjusted to the actual needs of the crop, taking into account critical periods when the demand for water is the highest and with precisely set water rates. Research shows that the water content in soil optimal for the development of plants and root yield is at least 70% of field water capacity of soil. Field water capacity of soil (FC- field capacity), that is its maximum retention capacity, should also be the basis for establishing the irrigation dose. The irrigation dose complementing the deficiency of current moisture content compared to field capacity in a given soil layer should be established based on the following formula:

**D = (field capacity – current soil moisture content) · h**
**where:**
**D – irrigation dose in cubic metres**
**h – thickness of the irrigated layer in metres**
**The size of the irrigated area should also be taken into account.**

Thus, assuming that the current volumetric moisture content of the soil is low due to drought at the critical stage of sugar beet development and amounts to e.g. 0.10 $m^3/m^3$ (10% by volume), while the field water capacity of this soil is 0.30 $m^3/m^3$, the calculation of the irrigation dose for the area of 1 hectare is as follows:

Deficiency of current soil moisture content in relation to field capacity = 0.30 – 0.10 = 0.20 $m^3/m^3$
Irrigation dose used for irrigation (D) of a layer of 30 cm thickness on the area of 1 ha (10,000 m2) is therefore:
D = 0.2 $m^3/m^3$ · 0.3 m · 10,000 sq. m = 600 $m^3$/ha
Such an irrigation dose corresponds to 60 mm of rainfall.

Sugar beet responds very well to irrigation. Irrigation of sugar beet plantations contributes to long-term stabilisation of yields. However, excessive irrigation shortly before sugar beet harvest adversely affects the content of sugar in roots. In the temperate climate irrigation of sugar beet plantations should only be an emergency measure, that is it should be applied when the crops are threatened by drought. Only in dry and semi-dry climate regions regular irrigation should be a permanent agricultural practice in growing sugar beet. Irrigation of sugar beet should be based on modern, water- and energy-saving irrigation systems and on developing more and more precise irrigation schedules and control methods.

## Fertilisation of crops and soil 3.6

Sugar beet is definitely a crop with high nutritional requirements. In the regenerative approach, fertiliser doses should be established on the basis of testing the nutrient content in soil. In case of sugar beet, taking care of soil fertility is extremely important, as the crop responds to soil fertility more strongly than to the application of fertilisers or methods of cultivation. Thanks to a root system reaching even more than 100 cm deep, sugar beet may take up water and nutrients from deeper soil layers. When establishing fertilisation doses, nutritional needs of plants adequate to the yields obtained on the farm should be taken into consideration. Assuming the root yield of 60 tonnes it can be estimated that sugar beet will take up 324 kg of potassium, 300 kg of calcium, and 210 kg of nitrogen. Other macrominerals that sugar beet will take up in smaller quantities are sulphur, magnesium, and phosphorus. In terms of microelements, sugar beet has the greatest demand for manganese and boron, and – in smaller amounts – zinc and copper. Table 4 presents data concerning mineral nutrient uptake with the primary yield of sugar beet.

**Table 4. Uptake of minerals with the primary yield of sugar beet depending on the assumed root yield**

| | Uptake of macrominerals in kg | | | | | | Uptake of microminerals in g | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Mg | Ca | S | B | Cu | Mn | Zn |
| Use per 1 tonne of yield | 3,5 | 0,7 | 5,4 | 1,1 | 5 | 1 | 7 | 1,2 | 11,8 | 5,8 |
| Uptake with assumed root yield of 60, 65 and 70 t/ha | | | | | | | | | | |
| 60 t/ha | 210,0 | 42,0 | 324,0 | 66,0 | 300,0 | 60 | 420 | 72 | 708 | 348 |
| 65 t/ha | 227,5 | 45,5 | 351,0 | 71,5 | 325,0 | 65 | 455 | 78 | 767 | 377 |
| 70 t/ha | 245 | 49 | 378 | 77 | 350 | 70 | 490 | 84 | 826 | 406 |

Source: Authors' own work on the basis of IUNG https://dpr.iung.pl/potrzeby-pokarmowe-roslin/

# Natural and organic fertilisation

In the growing of root crops, fertilisation with manure is of high significance. Already in the first year after applying manure plants take up from it on average 30% of nitrogen, 40% of phosphorus, and 70% of potassium. Fertilisation with manure is used in regenerative farming, as apart from providing valuable nutrients it enriches the soil with humus, improves soil biological properties, absorption capacity, structure, as well as water and air properties of soil.

The type and form of natural fertilisers affect their nutrient content. Table 5 presents average contents of selected nutrients for various types of natural fertilisers. However, it should be borne in mind that the actual composition of the fertiliser used on a farm may be determined only by analysing its sample in a laboratory.

**Table 5. Average nutrient content in various types of natural fertilisers.**

| Type of fertiliser | Mineral content in natural fertilisers | | | | | |
|---|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | CaO | Mg | Na |
| **Manure:** | $kg \cdot t^{-1}$ | | | | | |
| **cattle** | 4,7 | 2,8 | 6,5 | 4,3 | 1,5 | 1,0 |
| **pigs** | 5,1 | 4,4 | 6,8 | 4,4 | 1,8 | 1,1 |
| **horses** | 5,4 | 2,9 | 9,0 | 4,3 | 1,6 | 0,6 |
| **sheep** | 7,5 | 3,8 | 11,9 | 5,8 | 1,9 | 1,2 |
| **Slurry:** | $kg \cdot m^{-3}$ | | | | | |
| **cattle** | 3,4 | 2,0 | 3,7 | 2,1 | 0,8 | - |
| **pigs** | 4,3 | 3,3 | 2,3 | 2,8 | 0,8 | - |
| **Liquid manure:** | $kg \cdot m^{-3}$ | | | | | |
| **cattle** | 3,2 | 0,3 | 8,0 | 0,6 | 0,4 | - |
| **pigs** | 2,8 | 0,4 | 4,1 | 0,8 | 0,3 | - |
| **Poultry dung:** | $kg \cdot t^{-1}$ | | | | | |
| **hens** | 16 | 15 | 8 | 24 | 7 | - |
| **ducks and geese** | 5-10 | 5-14 | 6-9 | 8-16 | 2-3 | - |

Source: Authors' own work on the basis of Maćkowiak and Żebrowski (2000), Maćkowiak (2004), Kropisz (1997)

At the same time it should be noted that only a part of nutrients contained in natural fertilisers will be available to sugar beet plants in the first year after the application of organic fertilisation, and the remaining part will be released in the successive years after the application of fertiliser, which is shown in table 6.

**Table 6. Rates of use of nitrogen (N), phosphorus (P), and potassium (K) from specific types of natural fertilisers (cattle).**

| Type of fertiliser | Nutrient use efficiency – 1st year after the application | | | Nutrient use efficiency – 2nd year after the application | | |
|---|---|---|---|---|---|---|
| | N | P | K | N | P | K |
| **Manure** | 0,35* - 0,40** | 0,4 | 0,8 | 0,15 | 0,3 | 0,1 |
| **Slurry** | 0,50*- 0,60** | 0,7 | 0,8 | 0,1 | 0,1 | 0,1 |
| **Liquid manure** | 0,55* - 0,75** | - | 0,8 | - | - | 0,1 |

*autumn application, **spring application

Source: Authors' own work on the basis of Maćkowiak (1999); Journal of Laws 2018, item 1339 and Journal of Laws 2023 item 244

To fertilise sugar beet, fermented manure is spread evenly on the field in the autumn in the dose of up to 30 t·ha$^{-1}$ (which ensures that the allowed nitrogen amount provided with natural fertilisers = 170 kgN·ha$^{-1}$ is not exceeded), then it is immediately mixed with soil. It is not recommended to delay the introduction of manure to the soil, due to the loss of nutrients. For fertilising purposes, composted manure should be used, as during composting weed seeds and pathogens are rendered harmless. Liquid natural fertilisers (slurry and liquid manure) should be applied into the soil (not splash application). Such a practice significantly reduces the loss of nitrogen from fertilisers (through emission of ammonia) and its dispersion into the environment. Soil application of liquid fertilisers does not have such a destructive effect on the structure of top soil layers, which is of special importance in growing sugar beet. In application of natural fertilisers the guidelines of the Nitrate Programme should also be complied with.

Taking into consideration the chemical composition of the fertilisers and the nutrient use efficiency in the first and second year after application, it is possible to establish the approximate amount of the form of a given nutrient available for the plant which is released during the transformation of natural fertilisers in the soil. Table 7 presents calculations for available nitrogen from natural and organic fertilisers.

**Table 7. Examples of calculation of available nitrogen on the basis of data from tables 5 and 6**

| Type of fertiliser | Nitrogen use efficiency [A] | Fertiliser dose [t·ha$^{-1}$, m$^3$·ha$^{-1}$] [B] | Total nitrogen content in [kg N·t$^{-1}$ of organic fertiliser] [C] | Amount of available nitrogen taking into account use efficiency [kg N·ha$^{-1}$] [A·B·C] |
|---|---|---|---|---|
| **Cattle slurry applied in the spring** | 0,60 | 20 | 3,4 | 40,8 |
| **Cattle manure applied in the autumn** | 0,35 | 25 | 4,7 | 41,1 |

**Source: Authors' own work on the basis of the Journal of Laws 2018 item 1339 and Journal of Laws 2023 item 244**

Another way of introducing nutrients to the soil is the use of catch crops before growing sugar beet and using forecrop straw in the field as organic fertiliser.

Using the straw of cereals after which sugar beet is most commonly sown in crop rotation is also a valuable source of organic matter. It should also be remembered that before mixing straw with soil a small dose of nitrogen fertiliser should be applied in order to narrow down the C:N ratio < 33.3:1. The critical value of nitrogen in organic fertilisers, protecting against permanent immobilisation of mineral nitrogen in soil is 12 kg·t$^{-1}$ of organic fertiliser, therefore each organic fertiliser applied to the soil should contain a higher amount of nitrogen than the critical value. In order to calculate the nitrogen dose which compensates for the nitrogen deficiency in straw, the following formula is used (Grzebisz, 2009):

**Dkn = Pno · (12 – Nno )**

**where: Dkn – compensating (supplementary) dose of nitrogen (kg·ha$^{-1}$)**

**Pno – straw weight (t·ha$^{-1}$)**

**Nno – current nitrogen content in straw (kg·t$^{-1}$)**

Table 8 presents the basic properties of secondary yield (straw) of selected cereal crops.

**Table 8. Basic properties of secondary yield of selected cereal crops**

| Crop | Secondary yield : primary yield | Nitrogen content ($kgN \cdot t^{-1}$) | Nitrogen deficiency ($kgN \cdot t^{-1}$) |
|---|---|---|---|
| **Winter wheat** | 1,1 : 1 | 4-7 | 5-8 |
| **Winter rye** | 1,5 : 1 | 4-6 | 6-8 |
| **Winter barley** | 1,0 : 1 | 6-10 | 2-6 |

Source: Grzebisz (2009)

For example, calculating the compensating nitrogen dose (Dkn) for winter wheat straw left after the harvest of grain, containing 6 kg of nitrogen per tonne, with a yield of 8 $t \cdot ha^{-1}$ is as follows (straw yield/grain yield ratio = 1.1): straw yield = 8 $t \cdot ha^{-1} \cdot 1.1$ = 8.8 $t \cdot ha^{-1}$. Dkn = 8.8 · (12-6) = 8.8·6 = 52.8 $kgN \cdot ha^{-1}$. Application of nitrogen with straw fertilisation protects the fertilised plant against nitrogen deficiency which is caused by excessive retrogradation of mineral nitrogen in soil.

So-called green manure, i.e. fresh plant mass introduced into the soil in order to increase its fertility, may be a valuable source of nutrients in growing sugar beet on various types of farms. The most valuable plants grown for green manure are legumes and it is worth ensuring that species from this family are present in catch crop mixtures. Legumes may be an important source of nitrogen for the successive crop. For this reason, growing legumes as forecrop should be considered when planning nitrogen fertilisation of sugar beet grown after such crops. The amount of available nitrogen left over after growing legumes is presented in table 9.

**Table 9. Amount of available nitrogen left over after growing legumes and root crops.**

| Type of forecrop | Legumes in pure sowing | | Legumes in mixed sowing with grasses or cereals | | Leaves of root crops mixed with soil |
|---|---|---|---|---|---|
| | Main crop | Catch crop | Main crop | Catch crop | |
| **Post-harvest residues mixed with soil** | 30 kg | 15 kg | 20 kg | 10 kg | 25 kg |
| **Whole plants for green manure mixed with soil** | Yellow lupine – 74 kg<br>Pea – 77 kg<br>Serradella – 65 kg<br>Other – 60 kg | Red clover – 30 kg<br>White clover – 27 kg<br>Serradella – 33 kg<br>Other – 30 kg | 50 kg | 20 kg | - |

Source: Journal of Laws 2018 item 1339 and Journal of Laws 2023 item 244

An additional source of nutrients in crop rotation with sugar beet, in particular potassium, are properly shredded beet leaves left in the field. Leaves of sugar beet have a high fertilising value, comparable even to the fertilising value of manure. The leaf yield accounts for 40% to even 60% of sugar beet root weight – it depends on the weather in a given year. With the leaf yield of 40 tonnes · ha-1 approximately 189 kg of nitrogen, 16 kg of phosphorus, and 211 kg of potassium get into the soil. Moreover, studies show that using sugar beet leaves on the field improves soil structure, which is very significant in the aspect of the need to regenerate the soil structure of the site after growing sugar beet.

Fertilising sugar beet with mineral fertilisers should necessarily be balanced and carried out on the basis of the nutritional needs of sugar beet and the availability of nutrients in the soil. Particularly important in the regenerative approach for complementary mineral fertilisation of sugar beet is carrying out regular and cross-sectional soil tests, the results of which are the basis for planning a balanced fertilisation. Data in table 1 and tables 5-9 show clearly that nutrient resources of the soil depend on the uptake of nutrients by plants correlated with the potential yield and the history of natural and organic fertilisation on a given field. The presence of available forms of nutrients in the soil is also determined by the weather conditions. Regular soil testing makes it possible to determine precise fertilisation doses in any given year, which in case of such a fertiliser-demanding crop as sugar beet is of crucial importance for the profitable success of its cultivation.

## Nitrogen fertilisation

Nitrogen is the most important yield-forming nutrient. It has many important functions in a plant – building amino acids, nucleic acids, and chlorophyll. However, in growing sugar beet nitrogen fertilisers should be applied with care, taking into consideration its soil resources and nitrogen introduced with manure and other natural and organic fertilisers. From the production point of view, this is due to unfavourable effects of over-fertilisation of sugar beet plants with nitrogen. Excessive doses of nitrogen cause over-growth of the aboveground part (leaves) at the expense of sugar beet roots. As a result beet plants are more vulnerable to diseases and pests, while the root yield and sugar content in roots are reduced. Over-fertilisation with nitrogen may also cause an increase in molasses-forming substances in roots, e.g. alpha-amino nitrogen.

Sugar beet takes up a relatively large amount of nitrogen (tab. 4). Nitrogen fertilisation of sugar beet is usually applied in two doses, the total of which is normally 100-150 kg·ha$^{-1}$, depending on the use of nitrogen from other sources (natural and organic fertilisers). The first dose of 70-100 kg·ha$^{-1}$ is applied before sowing, and the second dose (50%) – in the phase of 2-3 pairs of true leaves. Dividing the doses in the 70% (before sowing) – 30% (after sowing) ratio is recommended when the total dose of applied mineral nitrogen exceeds 90 kg·ha$^{-1}$. The condition for effective uptake of this yield-forming nutrient is very good nutrition of sugar beet with all other nutrients in the initial stages of growth and a good supply of the sugar beet plantation with water available for the plants (ensuring that measures beneficially affecting retention properties of soil are applied throughout the crop rotation cycle).

According to the Nitrate Programme applicable to farmers, the total available nitrogen from all sources in the cultivation of sugar beet should not exceed 180 kg·ha-1. Detailed information concerning nitrogen concentration in natural fertilisers depending on the type of livestock, its age and capacity, the livestock system, and information concerning the resources of mineral nitrogen in the soil in spring, the unit uptake of nitrogen by plants and nitrogen fertilisation equivalents from various sources is contained in appendices to the applicable regulations published in the Journal of Laws concerning the "Programme of measures to reduce water pollution by nitrates from agricultural sources and to prevent further pollution" (Journal of Laws 2018 item 1339; Journal of Laws 2023, item 244), which was also used for the purposes of the current work. On the basis of these data the total amount of available nitrogen from all sources for sugar beet growing can be calculated, like in the example below (on the basis of the Journal of Laws 2023 item 244).

A farmer plans to apply 30 tonnes of manure from shallow-bedded barn (from feeder cattle more than 1 year old) and 140 kgN·ha$^{-1}$ in mineral nitrogen fertilisers on average soil.

In this case the amount of available nitrogen (Nd) is the total of: Nd from manure + Nd from the soil + Nd from mineral nitrogen fertilisers, where:

**- Nd from manure = 30 t·ha-1 · 2.7 kgN·ha$^{-1}$ (concentration of nitrogen in manure from feeder cattle more than 1 year old) x 0.35 (fertiliser equivalent of nitrogen from manure applied in the autumn) = 28.35 kgN·ha$^{-1}$**

**- Nd from the soil = 60 kgN·ha$^{-1}$ (resources of mineral nitrogen in the spring in average soil in the layer 0-60 cm determined in a laboratory) x 0.6 (fertiliser equivalent of mineral nitrogen for spring crops) = 36 kgN·ha$^{-1}$**

**- Nd from mineral nitrogen fertilisers = 140 kgN·ha$^{-1}$ (N dose in mineral fertiliser)**

The total available nitrogen from all sources is: Nd = 28.35 + 36 + 140 = 204.35 kgN·ha$^{-1}$

**Conclusion:** Total Nd is greater than the maximum available nitrogen dose from all sources = 180 kgN·ha$^{-1}$ by 24.35 kgN·ha$^{-1}$. The farmer should therefore decrease the dose of mineral nitrogen by this amount (that is by 24.35 kgN·ha$^{-1}$).

If no mineral fertilisers are applied, calculating Nd is limited to determining Nd from the soil, for example: Nd from the soil = 50 kgN·ha$^{-1}$ (mineral nitrogen resources in spring in average soil in the layer 0-60 cm determined in a laboratory) x 0.6 (fertiliser equivalent of mineral nitrogen for spring crops) = 30 kgN·ha$^{-1}$

**Conclusion:** The amount of Nd from the soil = 30 kgN·ha$^{-1}$, therefore the farmer may apply a maximum of 150 kgN·ha$^{-1}$ as mineral fertiliser (180 kgN·ha-1 – 30 kgN·ha$^{-1}$ = 150 kgN·ha$^{-1}$).

Where high yield is achieved on a farm, the uptake of nitrogen by sugar beet often exceeds 180 kgN·ha$^{-1}$. For example, for the yield of 65 t·ha$^{-1}$, the uptake of nitrogen is 65 t·ha$^{-1}$ · 3.5 kgN·ha-1 (uptake of one kg of N per each tonne of yield) = 227.5 kgN·ha$^{-1}$. In this case the farmer may use simplified nitrogen balance on the basis of the actual nitrogen uptake by sugar beet, provided that the nitrogen fertilising plan is also made for other crops on the farm. A possible adjustment for sugar beet growing after legumes (grown as the main crop or as catch crops) and the nitrogen use efficiency from mineral nitrogen fertilisers should also be taken into consideration. Calculations are made according to the following formula:

N min dose = [yield achievable on a farm (t·ha$^{-1}$) unit nitrogen uptake (kgN·t$^{-1}$) (for sugar beet it is 3.5 kgN·t$^{-1}$) – total N from other sources · fertiliser equivalent – adjustment for crops grown after legume forecrops or catch crops (see table 9)]/0.7 (nitrogen use efficiency from mineral nitrogen fertilisers).

Farmers with farms of the area ≥ 10 ha of agricultural acreage or those who keep livestock of ≥ LSU according to mid-year status, are obliged to have a nitrogen fertilisation plan or to calculate maximum nitrogen doses and to maintain a register of all agricultural practices related to nitrogen fertilisation. The activities of this kind are to increase the effectiveness of nitrogen fertilisation and reduce nitrogen dispersion into the environment. Nitrogen which is not taken up by crops is very reactive in the environment and, as it passes through successive biogeochemical pathways, is easily transformed. As a consequence, the same nitrogen atom may cause a sequence of adverse effects in the atmosphere (nitrous oxide is a very strong greenhouse gas), in land and water ecosystems (e.g. nitrogen in nitrate and ammonium forms used on arable land) which is described as the nitrogen cascade. Therefore, in the regenerative approach to growing crops, plans of nitrogen fertilisation should be made, its content in soil should be monitored, the principles of good agricultural practice should be observed and maximum nitrogen doses from all sources for the main crop should not be exceeded.

## Phosphorus fertilisation

Phosphorus plays an important part in processes related to energy transformations, it also takes part in photosynthesis. Before the application of mineral phosphorus it is worth checking its availability in soil – it should be at least at a medium level at the time of sowing sugar beet. Critical soil phosphorus content, irrespective of the agronomical category of soil, is 15 mg $P_2O_5$/100g. Phosphorus reserves in soil are often very high, in particular on farms applying the principles of regenerative agriculture, and it may not be necessary to replenish them. If, however, the soil phosphorus reserves are insufficient, phosphorus fertilisation should be applied in the autumn (a full dose), adjusted for the nutritional needs of the crop or slightly exceeding them, so that phosphorus missing from the soil is replenished. If soil phosphorus content is low, phosphorus should be applied in the amount of 125% the amount calculated on the basis of the expected root yield. The condition for proper working of the fertiliser is its thorough mixing with soil in the whole topsoil layer, as this nutrient is not mobile in the soil. For the yield of 60 t·ha$^{-1}$, sugar beet takes up on average 42 kg of phosphorus (see table 4).

## Potassium fertilisation

Sugar beet has extremely high requirements for potassium. It is assumed that the critical value for potassium is 15, 20, and 25 mg/100 g for light, average, and heavy soil, respectively. Sugar beet plants take up this mineral in large quantities. For example, in order to produce a yield of 60 t·ha$^{-1}$ sugar beet needs 324 kg of potassium (tab. 4). Potassium regulates the carbohydrate management, that is directly affects the content of sugar in the roots, as well as alleviates the stress related to water deficiency. In drought conditions potassium stimulates the resistance of sugar beet plants to diseases. An appropriate amount of potassium available in soil positively affects the uptake of nitrogen by sugar beet which accelerates the increase of sugar beet biomass, in particular in the initial stages of the development. According to the principles of regenerative farming it should be remembered that there may be many sources of potassium in soil – natural fertilisers, catch crops, straw, and mineral fertilisation, as all sources of organic matter in soil are rich in this macronutrient. When determining the dose of potassium fertilisation all sources of potassium introduced to the soil should be taken into account and soil testing should be carried out. In order to ensure an appropriate supply of potassium for sugar beet, the potassium content in soil at the time of sowing should be high for average soils and medium for heavy soils. Therefore, potassium fertilisation should be planned as early as the sowing of forecrop. Sugar beet plants have the highest demand for potassium in the summer months. This is when potassium deficiency may cause extended leaf growth, which results in a lowering of the technological yield of sugar.

## Fertilisation with microelements

Sugar beet has high requirement for microelements. It is particularly sensitive to boron and manganese deficiency. Boron deficiency contributes to diseases, e.g. dry-rot of seedlings, and it may cause lowering in the yield of roots and sugar content, therefore sugar beets should be fertilised with this mineral. Growing sugar beet with insufficient supply of boron increases its sensitivity to water deficiency in soil and tendency to wilt. When growing sugar beet on soils with pH close to neutral, manganese deficiency may be dangerous for the normal development of crops. If symptoms of manganese deficiency are noted (small lighter spots between the nerves of younger and medium leaves) foliar application of the mineral should be started, as this nutrient is not transferred from old to newly developing leaves. Foliar application with microelements should be performed several times, in moderate doses. The first application should be performed at the stage of 6-8 leaves, another one after 10-14 days and then plants should be fertilised in later development stages, if needed.

With natural fertilisation, which is recommended in the regenerative approach, the problem of micronutrient deficiency occurs less frequently. Latest research shows that sugar beet also takes up significant amounts of silicon.

## Fertilising with sulphur and magnesium

Most soils are deficient in sulphur, therefore monitoring the soil content of this nutrient is so important. It contributes to the effectiveness of nitrogen use and thus the quality of sugar beet roots, by lowering the content of non-protein nitrogen compounds, including alpha-amino nitrogen. Sulphur can be supplied to the soil with multicomponent fertilisers, but also in the form of kieserite (20% S and 15% Mg). For high-yielding sugar beet, sulphur doses amount to 20-70 kg·ha$^{-1}$.

Magnesium is an important element taking part in the photosynthesis. Sugar beet demand for magnesium, in terms of the elemental form, is higher than the demand for phosphorus. The symptoms of magnesium deficiency in sugar beet are noted often on acidic soils, with a low content of organic matter. Insufficient supply of magnesium to plants may also be a result of over-fertilisation with potassium and calcium, therefore in sugar beet growing adequately balanced fertilisation with these nutrients is particularly important. Magnesium can be supplied in the form of magnesium lime on soils which require balancing their pH. On sites with the pH level close to neutral and magnesium-poor, it is recommended to apply typical magnesium fertiliser, such as kieserite, before sowing.

When fertilising sugar beet, it is also important to remember the macronutrient sodium. Fertilising with sodium has a beneficial effect on root and sugar yield, however beware of the risk of soil salinisation.
The need for fertilisation to regulate the content of key micronutrients and macronutrients such as magnesium, sulphur, and sodium in the soil is particularly important when sugar beet is grown without manure or other natural fertilisers, which are a good source of these nutrients. These nutrients significantly contribute to the effectiveness of nitrogen fertilisation and the effectiveness of nitrogen management in a sugar beet plant. If symptoms of deficiency are observed during the growing period, it is necessary to carry out foliar application. It is also very important to monitor soil content of these nutrients by soil testing.

# 3.7 pH regulation and the role of calcium in regenerative sugar beet farming

One of the basic regenerative practices is the regulation of soil pH. It is significant not only from the point of view of changing the pH from acidic to near-neutral, as calcium fertilisers also affect the availability of macro- and microelements, the sustainability of soil structure, and microbiological activity of soil. Sugar beet is a crop sensitive to acidic soil pH, therefore it is particularly important to ensure regular liming of fields. The optimal soil pH for sugar beet is 6.0-7.0. Growing sugar beet on acidic sites increases the risk of diseases, e.g. root-rot of beet seedlings. Lime doses are usually adjusted to the soil content of this mineral, soil pH, and soil category. Lime should be well mixed with soil. Liming should not be combined with the application of manure and these measures should be separated in time.

Soil liming also contributes to the restoration of soil structure on acidic and easily crusting soils and to biological activity of soil, provided that appropriate amount of organic matter is supplied to the soil simultaneously.

# Protection against weeds, pests and diseases 3.8

Crop protection in regenerative agriculture is based on minimising the use of crop-protection preparations in favour of preventive measures. Implementing agricultural engineering practices complying with the principles of regenerative farming leads to good health of plants, their quick growth, and high availability of nutrients and water in soil. As a result costs related to chemical protection of the plantation are reduced significantly. The pressure from pathogens may be prevented as early as the stage of planning a sugar beet plantation, which significantly facilitates further protective measures. Great emphasis is on correct planning of balanced crop rotation and the selection of the variety resistant to or tolerant of pests and diseases as well as balanced crop fertilisation.

## Weed control

Sugar beet as a crop grown in wide rows, sown late and growing slowly in the initial development stages, is at risk of pressure from weeds. Weeds compete with sugar beet for water, light, and nutrients, but may also contribute to the development of diseases and pests. Weeds pose the greatest risk for sugar beet before it reaches the stage of 6-8 leaves. Most troublesome weeds in sugar beet farming are white goose-foot (fig. 14), creeping thistle, field bedstraw, and redroot pigweed.

**Figure 14. White goose-feet presents a great danger for a sugar beet plantation as it is a host of fungi causing root-rot of beet seedlings.**
*Photo by A. Perzanowska*

Weed-beets, i.e. hybrids of the annual subspecies of sea beet and sugar beet, may also be a problem in sugar beet growing. Unlike sugar beet bolters, they often grow in patches, outside rows and have branching, purple-coloured shoots at branch angles. As they are closely related to sugar beet, there is no effective chemical protection against and control of these weeds, and the only method of removing them from the field is pulling them out by hand. Fields where large quantities of weed-beet seed are gathered in soil weed bank are at risk of being eliminated from sugar beet production.

The prevention of weed infestation in a sugar beet plantation starts as early as growing the forecrop. Systematic weed control in a forecrop and appropriate selection of the forecrop which leaves behind a weed-free site reduce the occurrence of weeds in a sugar beet plantation. Growing crops in varied crop rotations in terms of species and forms (winter and spring varieties) prevents weed compensation, as it often happens in monocultures.

Sowing catch crops which is recommended in regenerative farming, may also have a beneficial effect on the reduction of weed infestation. Plants with allelopathic effect on some weeds, used as forecrops, reduce their numbers. These plants include white mustard, buckwheat, radish and facelia.

The mechanical method of weed control is still a frequently used solution in sugar beet growing. Wide rows make it possible to use various types of weeders, which effectively destroy weeds. Solar-powered, emission-free robots for precision seeding and weeding of sugar beets are also available on the market.

In the regenerative approach, the use of herbicides should only be an addition to preventive and non-chemical methods. It is important that herbicides are used according to the instructions on the labels, at the right developmental stages of sugar beet and weeds, which is crucial for their effectiveness. Chemical weeding methods are used during sugar beet emergence when weeds are at low stages of development. Herbicides are most effective when the majority of the weeds are at the cotyledon stage. Soil-application (pre-emergence) and foliar application in divided doses and even microdoses is recommended as well as the combined application of herbicides and adjuvants which makes it possible to reduce the doses of crop-protection preparations. It is also recommended to limit the number of applications of the same herbicide or one with a similar mode of action on weeds and to use mixtures of herbicides with different modes of action. Foliar application of herbicides, unlike soil application, makes it possible to adapt the active substances to specific species of weeds infesting sugar beet stand.

Chemicals in which the active substance is glyphosate should be avoided. In order to group herbicides with the same mode of action the HRAC classification was created (Herbicide Resistance Action Committee). To avoid weed resistance, chemicals with different mode of action should be used alternately. Table 10 presents examples of active substances of herbicides useful for sugar beet, classified by mode of action.

**Table 10. Examples of active substances of herbicides allowed for use in sugar beet**

| Active substance | Mode of action according to HRAC | Weeds (M – monocotyledonous, D- dicotyledonous) |
|---|---|---|
| Metamitron | C1 | D |
| Ethofumesate | (K3/N) | D |
| Triflusulfuron-methyl | B | D |
| Phenmedipham | C1 | D |
| Lenacil | C1 | D |
| Clopyralid | O | J+D |
| Fluazifop-P butyl | A | J |
| Quizalofop-P ethyl | A | J |

Source: Authors' own work on the basis of Krawczyk and Kierzek (2023)

In weed control with the use of chemical methods also the techniques of precision agriculture may be used, which is beneficial for the effectiveness of the chemicals and lowers the environmental risk related to their application.

# Pest reduction and control

The intensity of pest infestation in sugar beet plantations depends first of all on the frequency with which sugar beet is reintroduced to the same field, and in planning crop rotation it is necessary to make sure that sugar beet is not grown on neighbouring fields in successive years. In this way pests which overwintered in beet residues are prevented from moving to the end rows of the new stand. Pest pressure depends also on the region, weather conditions, the activity of natural enemies of pests, and the system of cultivation.

Inspecting the plantations and frequent control of pest numbers makes it possible to react quickly. In the regenerative agriculture, like in control of other pests and diseases, chemical methods are taken into consideration in the first place. Only when these methods fail and the risk of exceeding the economic threshold is high, it is necessary to use insecticides. In Poland the most important sugar beet pests are sugar beet cyst nematode, grubs and wireworms, dart moth, beet flea beetle, peach and bean aphid (fig. 15), and silver Y moth.

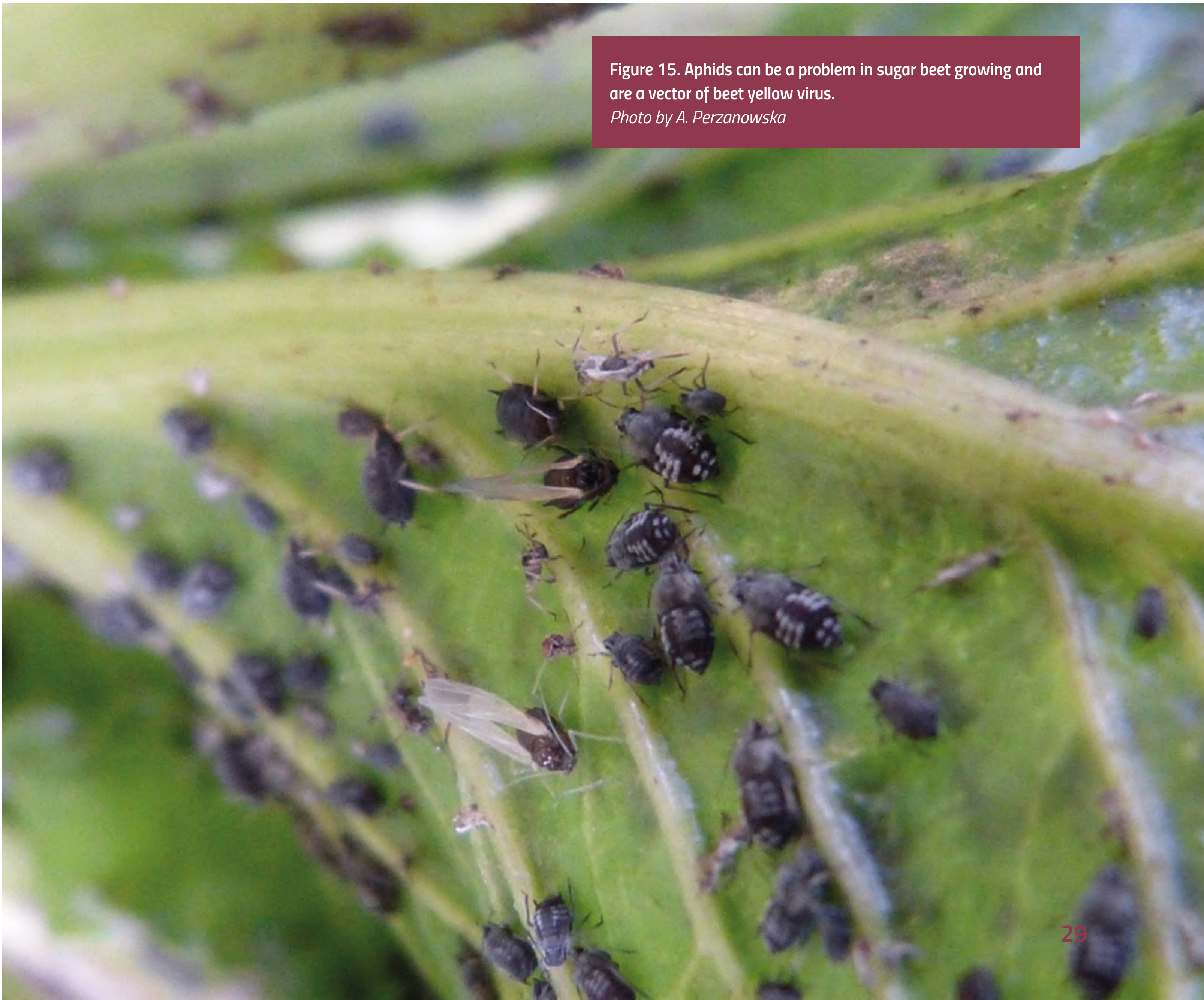


**Figure 15. Aphids can be a problem in sugar beet growing and are a vector of beet yellow virus.**
*Photo by A. Perzanowska*

The first group of methods applicable in regenerative farming for pest control are methods of agricultural technology. The selection of appropriate place in crop rotation for sugar beet may significantly reduce the pressure of pests. Another way is controlling weeds which could transmit diseases and pests to the sugar beet plantation. In case of occurrence of sugar beet cyst nematode, it is effective to add straw and manure to the soil, as it increases the organic matter content and improves the conditions for fungi parasitising pathogenic nematodes. Helpful in reducing the occurrence of sugar beet cyst nematode is also growing nematicidal varieties of white mustard, radish, and facelia as catch crops, as well as including crops which are not eelworm hosts in the crop rotation with sugar beet, such as corn, rye, and lucerne.

Sugar beet plantations are habitats for many beneficial organisms which are natural enemies of sugar beet pests. They include ground beetles, dragonflies, heteropteran bugs, green lacewings (Chrysopidae), ladybirds and their larvae, reptiles, birds, mammals and many more. They can act as predators or parasites of pests, helping to protect the plantation. Therefore, according to the guidelines of integrated agriculture which apply to every farmer, it is so important to look after the population of these organisms. If the presence of natural enemies in the plantation is noted and the pest infestation is not too high, chemical protection can be withheld. In the regenerative approach to crop protection, it is crucial to look after the habitats of beneficial organisms in the areas surrounding the fields, which is linked to the appropriate development of the agricultural landscape. Such biotopes include various mid-field stands of trees, unmown roadsides, field boundary strips, bogs and peatlands, meadows and pastures used extensively, idle land etc. Plants flowering in the early spring on this type of idle land are necessary to produce several generations of beneficial insects thanks to which their effectiveness in controlling pests is higher. For example, the larvae of the Chrysopidae insects are predators of aphids and other pests – a single larva can eat even up to 100 aphids and hunts spider mites which are dangerous pests of sugar beet. Also, sparing tillage promotes the existence of beneficial insects in the fields.

With the high pressure of pests on a sugar beet plantation, often caused by inappropriate management of cultivation technology and agricultural space, it is necessary to apply chemical methods. Table 11 presents examples of active substances used for control of sugar beet pests. When applying plant protection treatments, label instructions and the principles of good agricultural practice should be followed.

**Table 11. Examples of active substances in insecticides recommended for sugar beet pest control**

| Active substance | Pest |
|---|---|
| acetamiprid | sugar beet weevil |
| deltamethrin | black bean aphid, brassy flea beetle, silken fungus beetle, beet leafminer |
| tefluthrin (seed dressing) | wireworms, brassy flea beetle, silken fungus beetle |
| fenpyroximate | red spider mite |
| flonicamid | aphids |

Source: Authors' own work on the basis of Mrówczyński and Strażyński (2023)

# Disease limitation and control

In all regions of sugar beet growing there is a high risk of diseases. The pathogens which most frequently cause disease symptoms are fungi, bacteria, and viruses. Table 12 presents the economic significance of sugar beet diseases. The diseases most commonly occurring in sugar beet growing are Cercospora leaf spot of beet, beet yellow virus, and Ramularia leaf spot (figures 16 and 17) as well as root-rot of beet seedlings and root-rot caused by fungal pathogens.

**Table 12. Potential risk of occurrence of sugar beet diseases**

| Disease | Potential risk |
|---|---|
| Root-rot of seedlings | ++ |
| Root-rot | ++ |
| Bacterial leaf spot of sugar beet | + |
| Cercospora leaf spot | +++ |
| Ramularia leaf spot | + |
| Powdery mildew | + |
| Rust of beet | + |
| Beet yellow virus (BYV) | +++ |
| Beet mild yellowing virus (BMYV) | + |
| Beet necrotic yellow vein virus (BNYVV) | + |

+ local disease, ++ significant disease, +++ very significant disease

Source: Authors' own work on the basis of Integrated Methodology of Sugar Beet Production GIORiN 2023

Figure 16. Cercospora leaf spot and beet yellow virus are diseases which damage the assimilation apparatus, the leaves. Their reconstruction takes place at the expense of sugar collected in the roots.
*Photo by A. Perzanowska*

**Figure 17. Cercospora leaf spot – an affected sugar beet leaf.**
*Photo by A. Perzanowska*

The knowledge of disease risk in a given region makes it possible to select the variety with the highest resistance to a given pathogen. The breeding method, that is selecting a resistant variety is the first step recommended in the regenerative approach to control sugar beet pathogens. For example, the methodology of the COBORU within the framework of Post-registration Variety Experimentation (PDO) assesses varieties in terms of resistance to Cercospora leaf spot and Ramularia leaf spot on a nine-degree scale.

The application of principles of appropriate, nature-based crop rotation and correctly positioning sugar beet in crop rotation is the first step to reducing the pressure of diseases in regenerative agriculture. It is the cheapest and very effective method of disease control in growing sugar beet. It is recommended to avoid growing sugar beet after sugar beet, and sugar beet after rapeseed. Also sugar beet fields should be isolated from beet and rapeseed fields, prior year's beet fields, and sites where sugar beet was previously stored in piles. It may be helpful to ensure than pathogens are not transferred through working parts of tools and machinery (root-rot of seedlings) from one field to another. Affected fields should be tended to last.

In sugar beet plantations chemical disease control may be necessary. The plantation should be regularly monitored for diseases in order to ensure fast response. Timely application of a crop protection preparation in accordance with the label instruction is necessary for it to work properly. One or two applications are performed during the sugar beet growing season. Table 13 presents examples of active substances for disease control in sugar beet.

**Table 13. Examples of active substances for disease control in sugar beet**

| Active substance | Disease |
|---|---|
| difenoconazole | Cercospora leaf spot |
| azoxystrobin + difenoconazole | Cercospora leaf spot, rust of beet, powdery mildew, Ramularia leaf spot |
| tetraconazole | Cercospora leaf spot, powdery mildew, rust of beet |
| mefentrifluconazole | Cercospora leaf spot, Ramularia leaf spot, rust of beet |
| fenpropidin | Powdery mildew, Cercospora leaf spot, Ramularia leaf spot, rust of beet |
| boscalid + pyraclostrobin | Cercospora leaf spot, |
| tebuconazole | Cercospora leaf spot, powdery mildew |
| azoxystrobin | Cercospora leaf spot, powdery mildew, Ramularia leaf spot |

Source: Authors' own work on the basis of Krawczyk and Kierzek (2023)

# 3.9 Harvest and storage

The harvest of sugar beet is an important stage, determining the quality of the root yield. The timing of the harvest is decided on the basis of the processing maturity of beets, but also the readiness of the sugar factory to process the roots. Sugar beets reach their processing maturity after 180 days of growing and this is the optimum time to harvest them. Usually, the time falls in October but sometimes moves to November or even December for organisational reasons.

Unfortunately, the later the time of the harvest, the worse the weather conditions for field work. The use of heavy machinery during the harvest leads to excessive soil compacting and destroys soil structure (fig. 18 and 19). Therefore, it is not recommended to harvest sugar beet roots on a field that is too wet. In modern technology, the harvest is carried out using a self-propelled harvester, usually with 6 rows. Such harvesters with roots may weight 65 t  for three-axle machines and 45 t for two-axle machines, which exerts the pressure of 22.5 t per axle and pressure on wheels of approximately 11 t.  Passage on the field causes not only compacting of topsoil, which can be loosened with cultivation. Multiple passages on the field, in particular with an excessive moisture content of the soil, may cause compaction of deeper layers of the soil. The compacting effect on subsoil may be permanent and may irreversibly change the soil texture even on deeper levels of the soil profile. This phenomenon has a very detrimental effect as it may impair the circulation of water in the soil, its availability for plants, and the deep development of the plant root system, which reduces their resistance to drought. Modern harvesters are equipped with special, low-pressure tyres reducing soil compacting and design solutions, which aim to decrease soil compacting caused by passage of wheels. It is also important that, if possible, sugar beet harvest should not be carried out at the time of high moisture content in soil. Using no-till cultivation for sugar beet and crops grown before and directly after sugar beet is a good tool to mitigate the negative effect of sugar beet growing on physical condition of soil, in particular its structure.

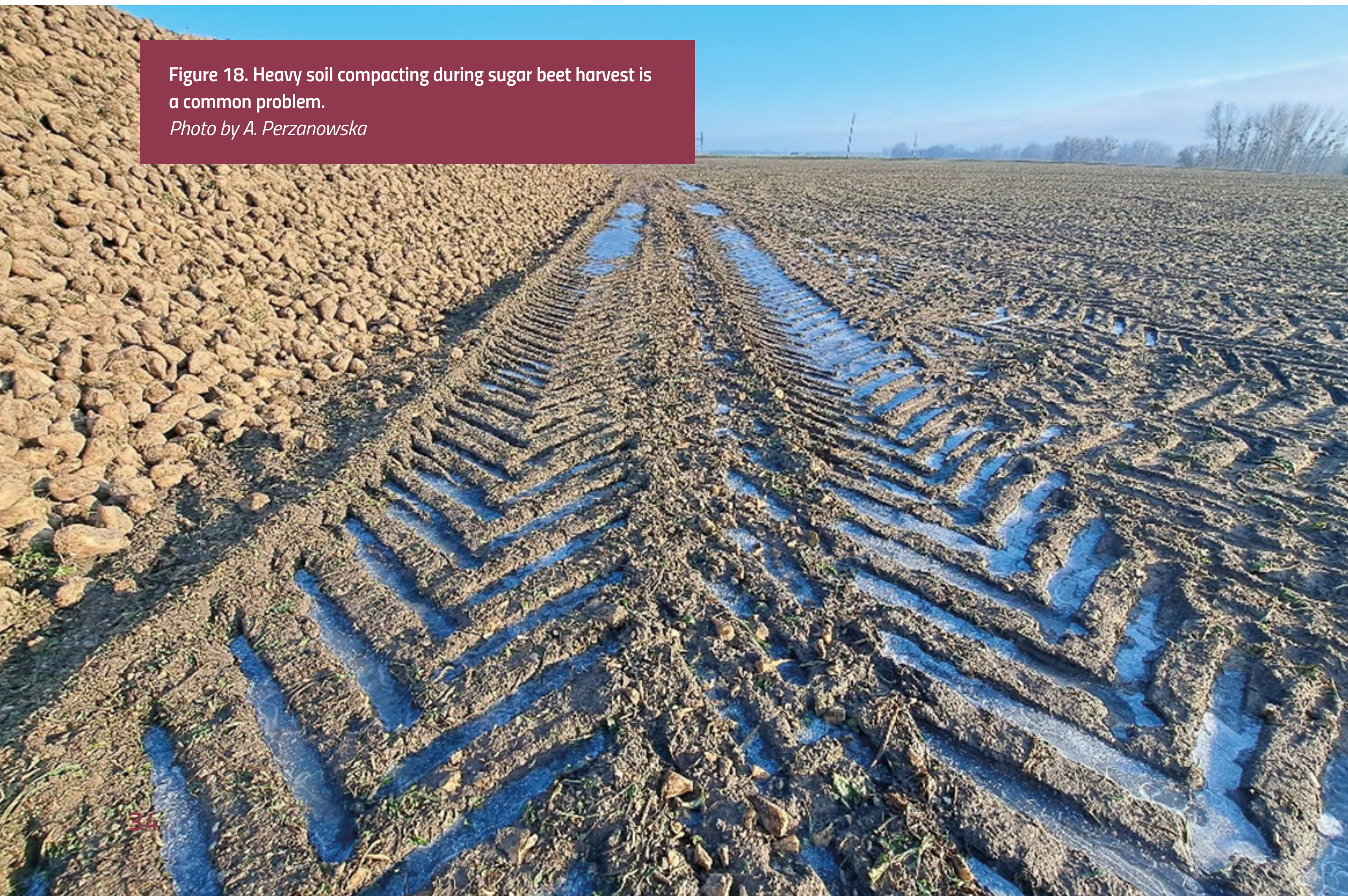


**Figure 18. Heavy soil compacting during sugar beet harvest is a common problem.**
*Photo by A. Perzanowska*

Figure 19. Shredded leaves left on the field may compensate to a certain degree for the deterioration in physical properties of soil after growing and harvesting sugar beet.
*Photo by A. Perzanowska*

In order to obtain the highest processing value of beet roots it is important to ensure the correct topping of roots and limiting their mechanical damage. Overtopped beets lower both the root and sugar yield. On the other hand, undertopping results in more difficult sugar extraction and the risk of regrowth of leaves during the storage in a pile (beets use up the sugar stored in the root for the regrowth). During the harvest and loading of beets, the contamination of roots with soil must be avoided. The soil contaminating the roots after harvest should stay on the field, especially as sugar beet is grown on fields with good quality soil.

The final quality and weight of sugar beets depend on how they are stored in a pile. A correctly formed pile should be 2 metres high and 7.5 metres wide. A pile should be placed on a flat surface, close to a paved access road to facilitate loading of roots. The pile should be covered with a special, waterproof non-woven crop cover. Dug out beet roots are sensitive to temperatures falling to -1°C. If sugar beet roots in a pile are damaged by frost (fig. 20), they should be processed as soon as possible. Heavily frozen and then defrosted sugar beets are not suitable for sugar processing due to too high losses. Roots should be stored in a pile at the temperature of 2-3°C.

Figure 20. Undertopping and freezing sugar beet roots contributes to the lowering of their processing value.
*Photo by A. Perzanowska*

As a result of sugar production valuable by-products are made, namely molasses and beet pulp. Molasses is used for the production of baker's and fodder yeast and alcohol. It is also commonly used as high-energy fodder, as 80% of dry mass of molasses is saccharose. Its addition to fodder mixtures improves the taste of fodder and stimulates the appetite. It works well as a high-protein, low-sugar silage additive. Moreover, molasses is used in microbiology laboratories to grow bacteria and produce bacterial preparations. In the regenerative agriculture it may be used as a fertiliser, it is a great source of carbohydrates for soil microorganisms improving the soil quality.

Beet pulp consists of beetroot slices left over after extracting sugar from the roots. It may be used as fodder, dried or fresh. It is used for feeding milk cows, feeder cattle, and sheep.

# 4 SUMMARY OF TREATMENTS AND ANALYSIS OF BENEFITS

**To summarise, in regenerative sugar beet cultivation special attention is paid to such aspects as:**

**- sugar beet has an important place in crop rotation,** as a break crop in cereal monocultures,

**- before sugar beet is grown, there is sufficient time to grow catch crop mixtures recommended in regenerative agriculture which should include nematicidal varieties of plants,**

**- appropriate preparation of soil to growing sugar beet, in terms of cultivation and fertilisation should be planned as early as the growing of forecrop,**

**- reduced soil cultivation and introduction of structure forming crops in crop rotation with sugar beet,** grown as the main crop and as catch crops, limits the occurrence of plough pan and soil crusting which impair the normal development of sugar beet from the early growth stages,

**- using ploughless tillage in crop rotation with sugar beet** positively affects the balance of organic matter in soil and soil biological activity,

**- sugar beet fertilisation should be balanced** and carried out on the basis of nutrient content in soil and nutritional needs of plants at various levels of yielding; in sugar beet growing natural and organic fertilisation should be applied as well as foliar feeding,

**- for plant protection non-chemical plant protection methods should be used in the first place,** including selecting varieties with increased resistance to pests and diseases, appropriately planned crop rotation, proper timing of treatments, application of biological and mechanical methods of protection as an alternative to pesticides, protection of natural beneficial organisms, isolation from plants which may be sources of pathogens,

**- it is recommended to regulate the soil pH** by liming which benefits the development of plants and the uptake of nutrients as well as soil biological activity and soil structure,

**- soil cultivation treatments should be carried out with the optimum moisture content in soil** to reduce the destruction of soil structure and texture and to avoid the excessive compacting of the topsoil and subsoil,

**- the quality of the sugar beet yield is determined not only by agricultural treatments used in its cultivation,** but also the method of harvesting the roots and their storage,

**- sugar beet leaves left on the field and mixed with soil** provide a source of nutrients and to some extent compensate for the deterioration of the physical soil quality caused by growing sugar beet.

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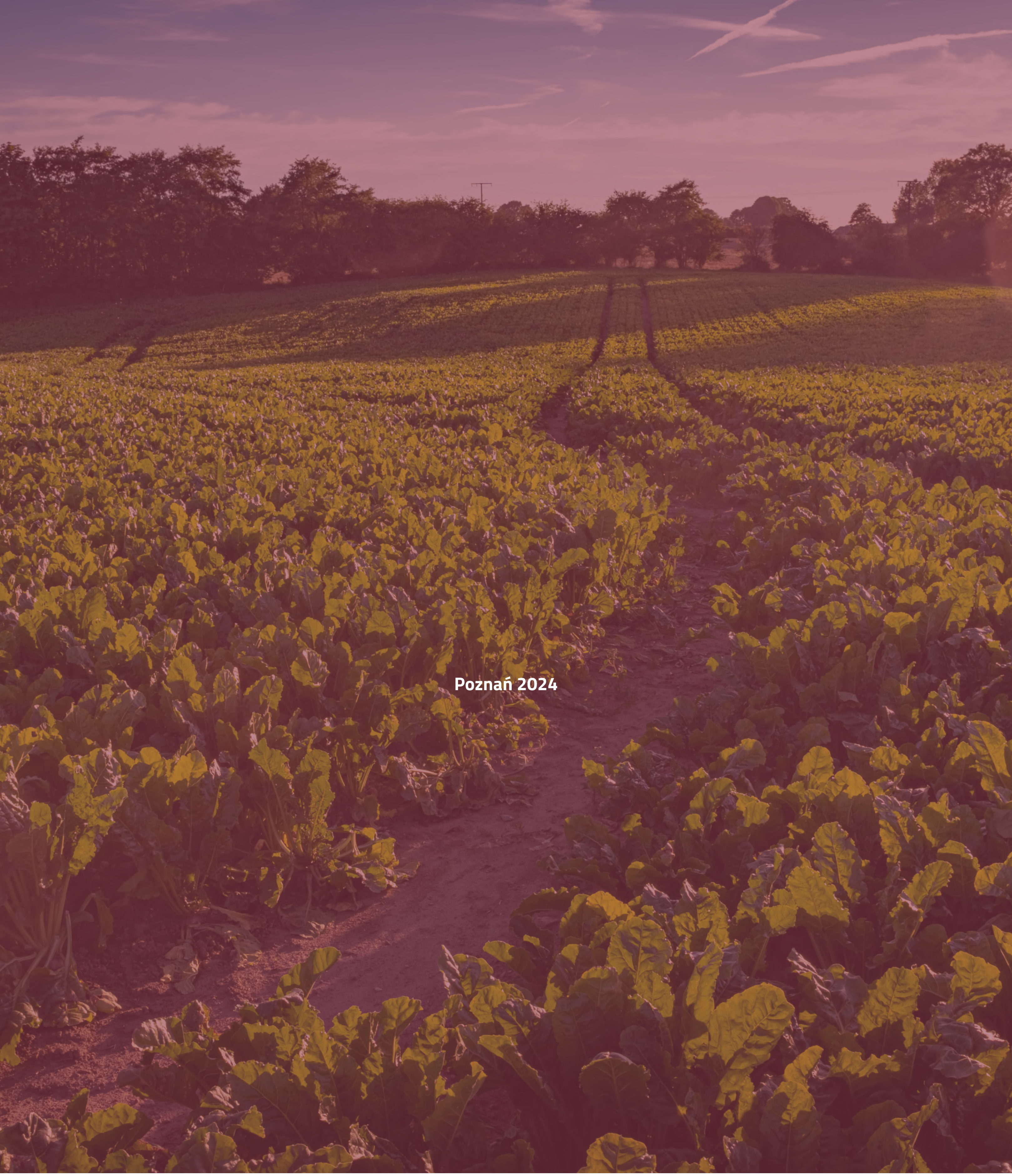

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