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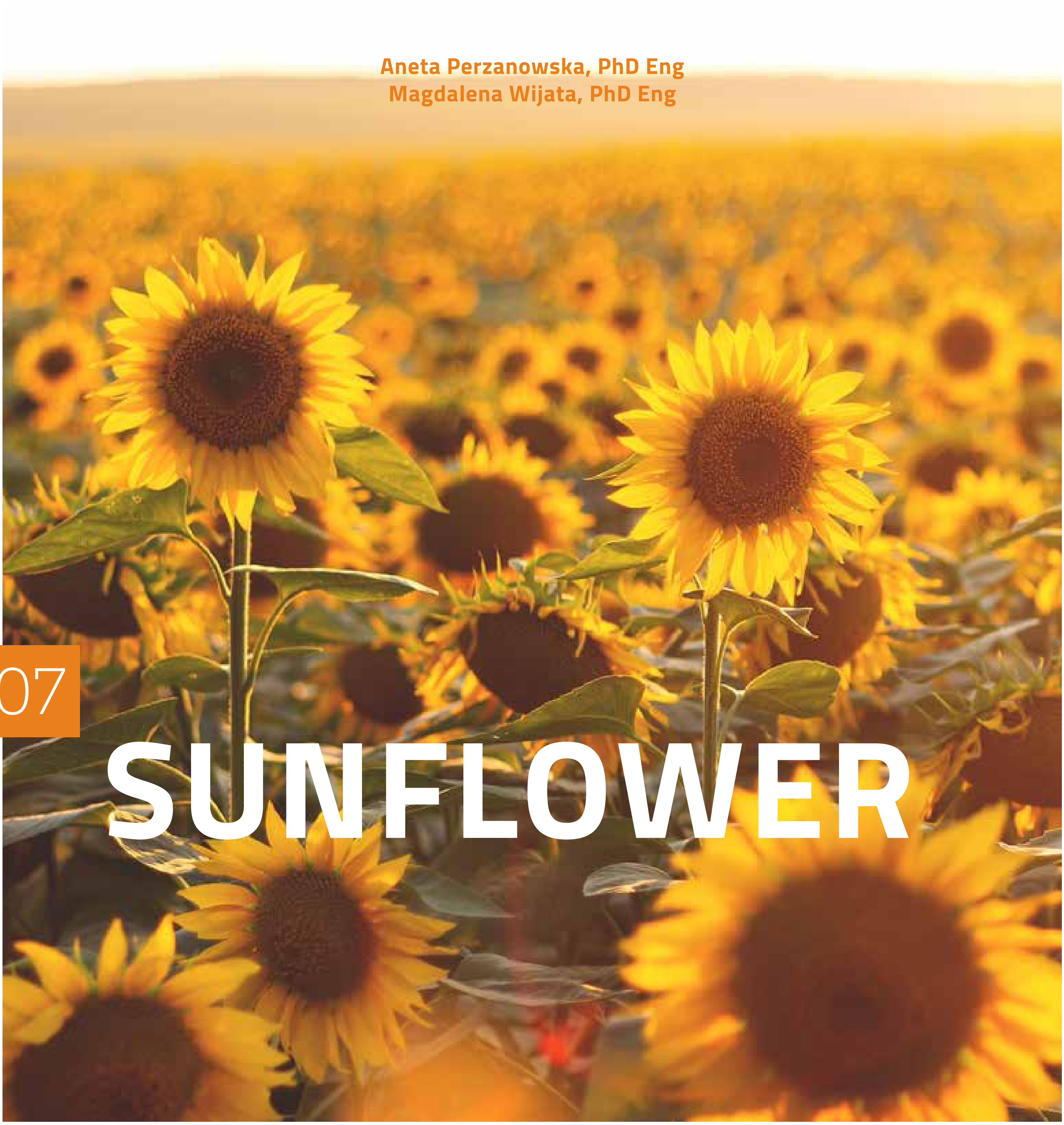

07

SUNFLOWER

CEE REGENERATIVE AGRICULTURE GUIDEBOOK

TERRA NOSTRA FUNDACJA

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CEE REGENERATIVE
AGRICULTURE GUIDEBOOK - SUNFLOWER

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

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The Terra Nostra Foundation for Agricultural Development

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

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

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

More information at www.fundacjaterranostra.pl

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Poznań 2023

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REGENERATIVE SUNFLOWER GROWING

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INTRODUCTION TO REGENERATIVE FARMING

Sunflower (*Helianthus annuus L*) is a perennial plant in the Asteraceae family whose Latin name is derived from two Greek words – *helios* (sun) and *anthos* (flower).

The inflorescence of sunflower is a capitulum, or flower head, filled with achenes with a high fat content (fig. 1). Sunflower seeds contain 50-53% fat, which is the highest content among oilseed crops (rapeseed – 46-48%, soybean 17-26%). Sunflower is one of the oilseed crops of highest importance in the world. It ranks third among oilseed crops in terms of production volume (51 million tonnes), after soybean and rapeseed.

Figure 1. The inflorescence of sunflower.
Photo credit: M. Wijata

In 2021 the production of sunflower oil was 20.5 million tonnes, which is approximately one tenth of the oil produced in the world (FAO, 2023). Sunflower oil has a number of beneficial properties, thanks to a high content of alpha-tocopherols (vitamin E) as well as other ingredients beneficial for health, such as folic acid and selenium. Thanks to its beneficial properties sunflower oil is used in human diet, but also as an additive to animal fodder. Poultry breeders often use sunflower oil as a source of vitamins and fatty acids in feed. Sunflower seeds can also be used for the production of food and fodder. Sunflower seeds are a popular component of feed for wintering birds and pigeons. Thanks to its high content of fibre seed hull is used as a fodder additive in feeding horses, improving bowel peristalsis. Its additional application is a production of sunflower hull pellet which has a high calorific value (18-19 MJ·kg^{-1}). Additionally, dried stems and sunflower oil can be used in the production of sustainable energy – biofuels. Sunflower can also be grown as an ornamental plant for cut flowers.

As a dicotyledonous plant, adapted for various soil conditions, sunflower may be a valuable element of crop rotation, interrupting cereal monocultures which in recent years have dominated the agricultural production. Sunflower is an allogamous plant, pollinated by insects, mainly bees and bumblebees (fig. 2). Therefore, sunflower which more and more often appears in a field landscape, is also significant as a melliferous (honey bearing) and polliniferous (pollen bearing) plant. Its melliferous potential is not high compared to rapeseed, for example, and amounts to 30-40 kg·ha^{-1}, however its polliniferous potential reaches up to 65 kg·ha^{-1}. What is important, the flowering of sunflower falls in July, therefore it provides a source of pollen for insects when the majority of melliferous plants have overblown and farming sunflower as intercrop additionally ensures autumn benefits for insects. Sunflower can be sown as a component of multi-species mixes for flowering strips, enriching the countryside landscape and increasing biodiversity, as well as providing forage source for pollinators.

Figure 2. Sunflower is an allogamous, melliferous and polliniferous plant, pollinated mainly by bees and bumblebees and enriching modern ecosystems dominated by cereal plants.
Photo credit: A. Perzanowska

As can be seen, sunflower is an economically important crop, but also multifunctional in terms of nature and ecology. Thanks to its many advantages, including this plant in the crop rotation fits in perfectly with the idea of regenerative farming.

At the same time, sunflower production faces challenges of biotic and abiotic stress, as the area of sunflower cultivation is spreading from the regions with a high productivity to regions with a lower yielding potential. Therefore, regenerative farming may prove to be useful in sunflower farming, presenting solutions beneficial both for ecological and conventional farms and supporting soil health, biodiversity, increasing organic matter content and water availability in soil which will make it possible to meet the challenges facing modern agriculture.

2 CLIMATIC, NUTRITIONAL AND SOIL REQUIREMENTS

In recent years, due to high prices of the means of production, sunflower has become a perfect alternative for rapeseed, the growing of which is associated with high expenditure.

All thanks to a better use of nutrients, but mainly thanks to sunflower's ability to take up water from deep soil layers. This makes sunflower suitable for growing on lighter soils. Sunflower is farmed in regions located up to 53-54°N, that is much further north than soybean or corn grown for seeds, which shows that it is a very flexible crop, easily adapting to various soil and climate conditions. This explains the fast rate of spreading of sunflower cultivation, also in European countries. In the south of Europe sunflower is a prevailing oilseed crop, even rapeseed ranks second.

Sunflower adapts to various soil conditions, but grows best on well-permeable soils with a high water capacity and almost neutral pH (pH 6.5 -7.5). It will grow best on chernozems and black earths, but it can also be successfully cultivated on brown soils and light loamy sands. Naturally, sunflower grown on higher class soils will return the favour with higher yield, but it is not recommended to grow it on sites with typically light soils. Similarly, it is not recommended to grow sunflower on heavy loamy and clay soils. Sunflower plantations should be located on friable soils, which warm up fast in the spring, therefore establishing sunflower plantations on sealing, waterlogged, easily crusting soils should be avoided. In areas affected by drought or salinity, sunflower yields decrease, but still compare favourably with other crops. Sunflower grown for seeds has higher requirements compared to sunflower grown for biomass.

Sunflower has a deep root system and takes up water from depths unreachable for most of other crops, therefore it is resistant to drought. At the same time, it has high water requirement – 350-400 mm of precipitation. In dry conditions sunflower uses well moisture stored in soil, and any, even the smallest precipitation. Both in Germany and in Hungary sunflower yield is more stable than that of corn in dry years and in areas more exposed to drought. Even in the conditions of unlimited access to water, sunflower plants manage water much more economically than soybean, corn or sugar beet. A deep reaching root system allows the plant to take up nitrogen and other nutrients from deeper soil layers which could have been leached into the soil in the period prior to sunflower cultivation and reintegrate them again into the circulation of chemical elements.

In case of severe drought at the beginning of the flowering stage, there is a high probability that empty seeds will be produced due to partial or total failure of the plants to flower. This results in a significant fall in the weight of seeds per plant which negatively affects sunflower seed yield. Sunflower uses 23% of its total water consumption in the period from the germination to the formation of capitula (flower heads), as much as 60% on the period from forming capitula to flowering, and 17% from flowering to harvest. It is important to apply agronomic treatments that will ensure that as much water as possible is retained in the soil, in particular in the period from the emergence to the flowering. The optimal water reserve in the soil at the time of sunflower sowing is 180-200 mm. Therefore, during sunflower cultivation, in particular in dry areas, it is important to collect moisture in the soil by retention of snow and thaw-water, irrigation and other methods improving the water regime. Cultivation practices recommended in regenerative farming, such as leaving stubble residues on the surface of the soil for the winter and limiting tillage to a minimum, increase water retention and availability of water in soil, positively affect water soil infiltration and limits evaporation from soil, which as a consequence benefits sunflower cultivation. In the areas where post-harvest residues are managed properly, surface runoff is limited and rain water drainage is improved, there is an increase in moisture stored in soil, which is beneficial for growing deep-rooted crops, such as sunflower. On soils without structure it may be necessary to carry out cultivation treatments. Post-harvest residues (mulch on the surface) may slow down the heating up of the soil. In these conditions, a slight delay in the sowing should be considered, until the soil reaches appropriate temperature.

Heat requirements of sunflower are similar to those of corn with FAO number of 280, that is in cultivation for seed total temperatures of 2000°C are to be ensured throughout the growth period and depending on the variety the recommended total of effective temperatures may vary from 1400-2300°C. Sunflower seeds germinate at the optimal soil temperature of 8-10°C at the depth of placing the seeds. An increase in temperature significantly speeds up the emergence of seedlings. At the temperatures of 8-10°C seedlings emerge 15-20 days after sowing, at 15-16°C after 9-10 days and at 20°C as soon as after 6-8 days. Germinated seeds tolerate temperatures up to -10°C and the swollen seeds up to -13°C. Sunflower seedlings can withstand short-term temperature fall even to -8°C without great damage, while frost of -4°C is completely safe for the plants. Heat requirements of the plants increase after the emergence. The best temperature for sunflower in the flowering stage and in subsequent development stages is 25-27°C. Temperatures above 30°C significantly impede sunflower growth, disturb the ratio of fatty acids – causing an increase in oleic acid and a decrease in linolenic acid content. The highest fat content in sunflower seeds is reached in sunny weather with temperatures below 28°C.

Sunflower is a heliophilous plant. Shade and cloudy weather delay the growth and development of plants, result in the formation of small leaves, which reduces the size of assimilation apparatus, and consequently adversely affects the yield. Sunflower should be sown in lowland areas or on south-facing slopes to enable proper heliotropism (flower heads turning towards the light – fig. 3). Shaded and north-facing sites should be avoided, as well as dense sowing.

Figure 3. Sunflower field during flowering. The photo shows the phenomenon of heliotropism (flower heads directed towards the light). *Photo credit: M. Wijata*

Determining nutrient requirements of plants is very important from the point of view of regenerative farming, in order to plan fertilisation in a comprehensive way. Sunflower is a rather demanding plant in terms of nutrients. To produce 1 tonne of yield (primary and secondary yield) it takes up approximately 61 kg of nitrogen (according to the Nitrate Programme 50 kg/tonne), 47 kg of potassium, and 23 kg of phosphorus (Igras, 2013). This means that in order to produce a yield of 3 $t \cdot ha^{-1}$, it needs more than 180 kg of nitrogen, 140 kg of potassium, and 70 kg of phosphorus. Sunflower grown for green mass has much lower nutritional needs.

Sunflower's deep root system ensures the uptake of minerals, even from the deeper soil layers. This makes it possible to activate soil micro- and macro-element resources unavailable for other crops. Table 1 presents the uptake of minerals with the primary and secondary yield in the cultivation of sunflower, compared to corn and rapeseed. Sunflower cultivated for seeds takes up much more nutrients than corn or rapeseed. Sunflower has also a greater ratio of the primary to secondary yield, which means that a significant part of nutrients remains in the field with post-harvest residues. This compensates for the high extraction of nutrients with the yield. The greatest demand of sunflower plants for nutrients occurs during the flowering stage, as does its highest water requirement.

Sunflower also takes up relatively high amounts of microelements, which was presented in table 2.

Table 1. Uptake of macroelements with sunflower yield [in $kg \cdot t^{-1}$ of yield]

Type of cultivation	Crop	Primary to secondary yield ratio	Primary and secondary yield		
			Nitrogen	Phosphorus	Potassium
For seeds	Sunflower	1,8	50*	23	47
	Corn	1,0	26	12	28
	Rapeseed	1,5	50	22	40
For green matter	Sunflower	-	4	2	5
	Corn	-	4	1	5
	Rapeseed	-	5	1	6

Source: Authors' own work after Igras et al., 2013; * per unit of primary product (grain), with an adequate amount of secondary product (straw) according to the Nitrate Programme 2023

Table 2. Uptake of microelements by sunflower [in $g \cdot t^{-1}$ of yield]

	Copper	Boron	Manganese	Zinc
Nutritional needs	17	113	118	99
Uptake	7	23	12	42

Source: authors' own work based on Farzanian et al., 2010

3 TECHNOLOGY OF REGENERATIVE FARMING

3.1 Site and forecrop

Balanced crop rotation, based on a wide variety of species selected for soil and climate conditions is one of the pillars of regenerative farming. Sunflower, as a plant in the Asteraceae family is a very good crop to interrupt cereal monocultures which have dominated modern farming.

In the fields where the growing of sunflower is planned, both forecrop and successive crop should be carefully selected. Sunflower has a highly branched root system, which on the one hand helps it cope well in droughty conditions, but on the other hand dries out the soil, taking up water from deeper layers. The deep root system of sunflower favours also the extraction of significant amounts of nutrients from soil which may be detrimental for the successive crop. After sunflower harvest normal moisture content of soil is restored after 2-3 years. Therefore, sunflower should not be sown after crops which significantly dry out deep soil layers, e.g. perennial grasses. The best forecrops for sunflower are winter cereals, spring cereals (wheat, barley), legume-cereal mixtures, legumes, corn, late harvest potatoes or vegetables on manure, for which no intensive nitrogen fertilisation was carried out.

Sunflower as a spring crop presents wide possibilities for growing catch crops between forecrop and sunflower sowing. As this crop-rotation element stubble catch crops can be sown (preferably multi-species mixtures), but also winter catch crops after which sunflower is grown as the so called second crop. In this case at the turn of August and September and before sunflower such plants as winter rye or a mixture of rye and villous vetch are sown as winter catch crop. Earlier sowing of rye and vetch means that in the spring their development is more advanced, they grow more quickly and may be used as early as in April (as fodder or green manure) and sunflower grown for seed can be sown on time. The plants of the winter catch crop should be destroyed mechanically, preferably using a knife roller working together with a disc aggregate and deep no-till cultivation should be carried out before sunflower sowing.

If rye grown as winter catch crop is intended for silage, it is harvested later (mowed before or during the formation of ears) and fertilised with nitrogen in early spring. In the regenerative approach it is recommended to apply manure for forecrop or winter catch crop, which will also be used by plants grown as the second crop, for example sunflower, with the possibility of decreasing mineral fertilising at the same time. After harvesting rye for silage, sunflower can be grown for green matter and silage. Sunflower is harvested for silage in the phase of so called "yellow capitulum", when seeds are already filled and there is sufficient dry matter, carbohydrates and fats in the plants. Sunflower is harvested for silage using the same machines as for corn harvesting. Sunflower can be sown in mixtures with the papilionaceous plants for which it acts as a supporting plant. Also mixtures of sunflower and corn can be sown, which enriches the silage mass with carbohydrates. Examples of mixtures of sunflower with papilionaceous plants recommended for sunflower cultivation as the second crop for fodder are presented in Table 3.

Table 3. Composition of sunflower mixtures cultivated as second crop

Mixture	Seeding rate in kg·ha^{-1}
LIGHTER SOILS	
Yellow lupine + field pea + sunflower	**75 + 60 + 12**
MEDIUM SOILS	
field pea + sunflower	**130 + 12**
field pea + spring vetch + sunflower	**75 + 60 + 12**
HEAVIER SOILS	
Field pea + spring vetch + faba bean + sunflower	**60 + 60 + 60 + 12**

Source: work based on Hołubowicz-Kliza, 2004 and Hryncewicz, 1985

For phytosanitary reasons, rapeseed, soybean, and tobacco are inappropriate forecrops for sunflower, due to the risk of fungal disease transmission. However, definitely the worst forecrop for sunflower is sunflower itself. It is recommended to sow sunflower on the same field no earlier than after 5-7 years, to prevent the spreading of pests and diseases. In particular planting potassium-loving plants after sunflower should be avoided, as it extracts significant amounts of potassium from soil.

Before sunflower began gaining importance as an oilseed crop, it was grown in stubble catch crops for green matter and silage. Nowadays growing sunflower as catch crop is gaining importance as an interruption of cereal monocultures and the tool to protect soil health, including a source of organic matter in crop rotation. Sunflower may play a part of a catch crop sown on its own or in mixtures.

Sunflower grown as stubble catch crop should be grown after early harvested forecrops, as it should be sown in late July or early August. Such forecrops include for example early potatoes, winter and spring rapeseed, garden radish, and white mustard grown for seeds, phacelia grown for seeds, early pea varieties, and in some years winter and spring wheat. Earlier sowing of sunflower as catch crop ensures a much more intensive growth of its biomass in the autumn compared to sowing taking place in mid-August. In case of sowing sunflower as stubble catch crop, the seeding rate should be 25-30% greater than in case of growing it as the main crop, that is for sunflower it should be 35 kg·ha^{-1}.

In regenerative farming it is recommended to use catch crop mixtures in which sunflower may play important parts. The roots of individual species go through different layers of soil, they also compete better with weeds. Thanks to its stiff stem sunflower is an excellent supporting plant for species with a flaccid stem, such as vetch, field pea, and grass pea. Papilionaceous plants respond badly to sowing as late catch crops, therefore post-harvest mixtures with the Papilionaceae should be sown by the end of the first decade of August at the latest. Catch crops with sunflower may be used as valuable green manure.

In the cultural landscape of the countryside, sunflowers are a welcome sight, they are pleasing to the eye during the flowering and an attractive alternative to other crops, which is the added value of the expanding area under sunflower cultivation.

3.2 Selection of varieties

An increasing number of sunflower varieties and the progress in growing result in spreading of the range of this crop to the areas with less favourable conditions. Nowadays, the varieties used in Poland and other EU countries come from the EU Common Catalogue of Varieties of Agricultural Plant Species (CCA). The countries carry out exploratory studies to determine which varieties are suitable for cultivation in specific regions which differ in terms of soil and climate. The selection of varieties suitable for soil and climate conditions is crucial for the success of sunflower farming and recommended in regenerative agriculture.

To answer the question what should be considered in the selection of the variety, one should certainly pay attention to several aspects that are important from the point of view of sunflower cultivation. The yield of seeds of the crop is always of crucial importance for the producer, and additionally in case of sunflower, its seed fat content. Moreover, the FAO number of the selected sunflower variety should be checked, as it indicates the number of days to maturity. This should be the basic criterion in the selection of the variety for the climate conditions of a given region. Equally important is the resistance of the variety to fungal diseases which often affect sunflower plantations.

Sunflower is a large plant and it may tend to lodge, especially with excessive doses of nitrogen fertiliser. Lodging-resistant varieties have been developed through breeding. A large problem in sunflower cultivation, in particular in the early development stages, is weed infestation. Therefore, the offer of seed producers includes also cultivars resistant to herbicides, in cultivation of which foliar applied herbicide (tribenuron-methyl) can be used.

3.3 Soil cultivation

Sunflower plants, similar to other crops sown in single-seed sowing, require appropriate preparation of soil for their optimal growth. According to the principles of regenerative farming, the purpose of autumn cultivation for sunflower should be retaining as much water in soil as possible, accumulation of nutrients, and activation of biological processes in soil. In order to meet these objectives turning the soil over and excessive tillage should be avoided as they destroy soil structure, cause loss of organic matter, significant compaction, problems with crust formation, and limit water infiltration. Such conditions are conducive to infection by downy mildew or other soil-borne diseases, and result in a reduced uptake of nutrients and water, thereby decreasing sunflower seed yield.

Shallow (maximum 15 cm) stubble cultivation is recommended after the harvest of forecrop in order to cover crop residues and facilitate their mineralisation. This treatment destroys weeds and regulates soil water and air properties. If it is possible to sow stubble catch crop before growing sunflower, it should be sown during the first loosening and mixing post-harvest treatment. In case of sowing stubble catch crops, the early timing of sowing is definitely more important than careful cultivation before sowing. The earlier the stubble catch crop is sown, the greater biomass it forms. With this approach the soil does not lose water unproductively, as the soil moisture is quickly taken up for the production of biomass and actually involved in catching atmospheric carbon which will return to the soil in the form of catch crop residues after it is destroyed and feed the soil organic matter, the key component determining soil quality. Catch crop may be destroyed mechanically in the autumn or left until spring as cover crop and mixed with soil after winter.

Before sowing sunflower, deep, no-till cultivation is carried out using a cultivation unit, without overturning the soil. Studies confirm a number of benefits of giving up tillage in favour of full-surface cultivation with a cultivation unit. This allows for loosening and aerating of soil without interfering with the soil coherence and structure. Moreover, after no-till cultivation, as opposed to tillage, part of post-harvest residues stays on the surface of the soil and plays a protective role (fig. 4). According to the principles of regenerative farming, soil which is too dry or too moist must not be cultivated, the number of passes should be reduced, cultivation machines and tools should be aggregated, to avoid damage to soil structure and subsoil compaction.

More and more often sunflower is also sown in strip-till technology. This type of sowing is characterised by deep cultivation of only narrow strips of land combined with the application of fertilisers at the depth of the loosened layer, while the remaining field surface is not cultivated (fig. 5). Plant residues are removed from the tilled strips, ensuring that sunrays reach the uncovered soil, which combined with good loosening of soil speeds up its warming. This is particularly important in cultivation of thermophilic sunflower in moderate climate, where rapid warming up of the soil after sunflower sowing is beneficial for the speed of emergence and the development of roots, before soil moisture content deteriorates. Uncultivated strips, covered with the residues of forecrop (the crop cultivated as the main crop or as catch crop) protect the field surface between rows of plants against water loss and excessive warming up in the periods with high temperatures. Untilled strips, thanks to no interference in soil coherence and the presence of significant amount of plant residues near the soil surface are sites where soil structure is reconstructed and the soil biological life is conserved. The presence of post-harvest residues on the surface, ensuring at least 30% coverage makes this a conservative cultivation. The purpose of this type of cultivation is the protection of crucial physical (water retention, soil structure), chemical (preservation of soil nutrients and organic matter), and biological properties of soil.

Sunflower may be sown by direct sowing or strip sowing into forecrop plants destroyed mechanically using packers, forming a layer of compact mulch. Such management of forecrop residues, e.g. catch crop plants, may work in sunflower cultivation in regions with warm springs and deepening moisture deficiency in spring and summer. Seeders should be equipped with elements enabling effective sowing of seeds in mulch composed of unshredded residues.

Figure 4. Crop residues left after the harvest of forecrop.
Photo credit: M. Wijata

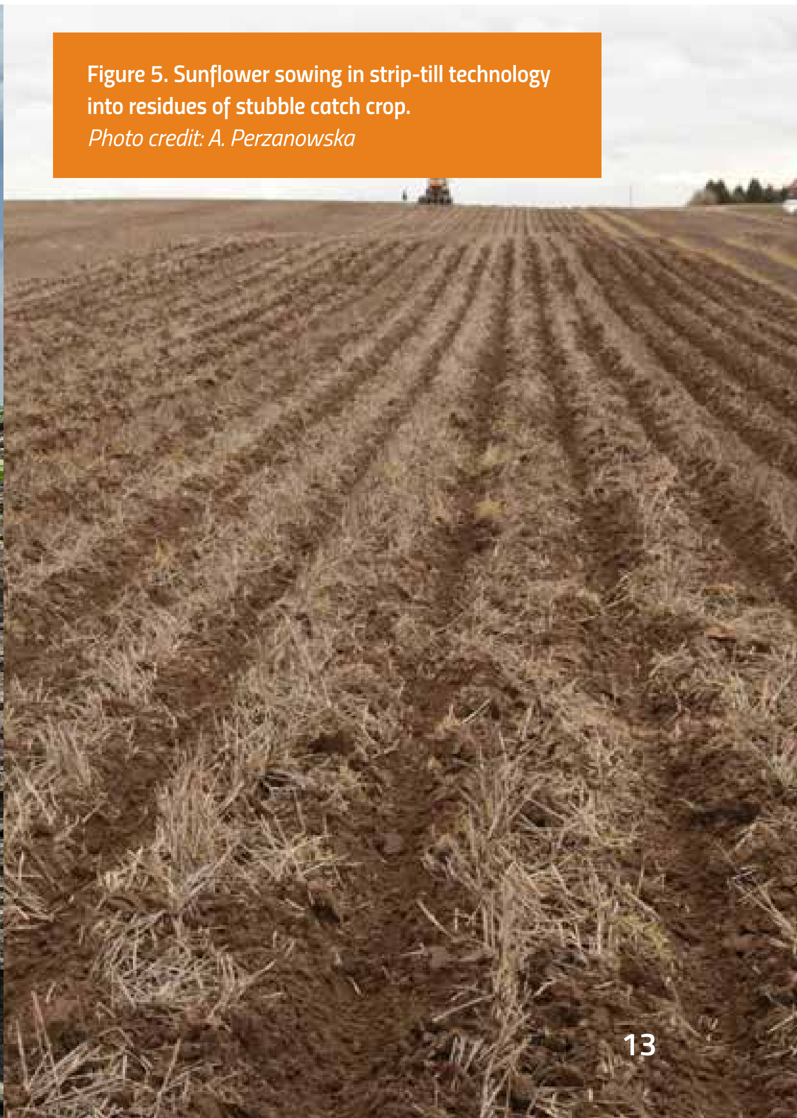


Figure 5. Sunflower sowing in strip-till technology into residues of stubble catch crop.
Photo credit: A. Perzanowska

3.4 Sowing

Mistakes made during sunflower sowing may affect the development of plants during the whole growing season. The optimal timing of sowing is closely related to soil temperature at the time of sowing. The optimal time for sowing sunflower is when the soil temperature reaches at least 8°C. In Polish conditions this falls usually between the 20th and 30th of April and varies from year to year. For seeds to germinate the temperature around 10°C is required. Periods with soil temperatures below 10°C delay germination and extend the period in which seedlings are susceptible to disease such as downy mildew, and to damage caused by herbicides.

It is recommended to sow sunflower using a pneumatic single-seed drill. Row spacing may be similar to spacing of beet (45-60 cm) or corn (75 cm). Thanks to the extensive root system of sunflower, the plants do well with wider row spacing (fig. 6), but then weed infestation may be intensified in the initial development stages. The recommended space between seeds in a row is 20-25 cm. Sunflower grown for seeds should be sown in the amount of 70-85,000 seeds per hectare, which ensures the final density of 60-75,000 plants per hectare. Too high a plant density per unit of area may result in intensifying fungal diseases and a greater tendency to lodging, as well as competition between individual plants for light. For lodging resistant varieties the density of 7-8 plants·m^{-2} can be adopted. In photophilous plants, such as sunflower, even access to light is important for the proper development of the stand. The timing of sowing should also be taken into account when determining the seeding rate. With delayed sowing it is justified to increase the seeding rate slightly.

Figure 6. Wide-row sunflower sowing.
Photo credit: M. Wijata

The optimal sowing depth for sunflower seeds is 5-7 cm. On lighter soils deeper sowing is recommended than on more compact soils. Sowing too deeply may result in delayed emergence, greater pressure from weeds and diseases, while sowing too shallow exposes the seeds to lower temperatures and being pecked out by birds.

In sunflower cultivation in stubble catch crop the timing of sowing falls at the end of July and beginning of August and sunflower can be sown in narrower rows than when it is grown for seed, every 15-25 cm. Higher density of plants per unit of area ensures higher yield of biomass. Sunflower is also a useful plant as a second crop, that is after the harvest of winter catch crop. The sowing of sunflower as the second crop should be performed from April to mid-June, and the harvest should fall at the end of August and beginning of September. Sunflower grown in this way may be harvested for green matter or introduced to the soil as green manure. The yield of sunflower green matter is approximately 50-60 t·ha^{-1}. To achieve the best quality parameters of green matter, sunflower harvest should take place directly before the flowering (9% of dry mass, 13% of protein). Sunflower for silage is harvested at the stage of "yellow capitulum" (18% of dry mass, 10% of protein). In order to increase the forage value of green matter or silage, mixtures of sunflower and corn or other crops are used, including papilionaceous plants (see chapter 3.1.).

Irrigation and water management 3.5

As a plant with a deep root system suflower uses water from the soil very well. Therefore, watering this crop is not too common, even in very dry areas. The decision to water should be determined by plant density, soil granulometric composition in specific layers of the soil profile, sunflower variety, and environmental factors. The regenerative approach emphasises the significance of all treatments reducing soil water loss, both those focused on a specific field and those affecting hydrological conditions on the macro scale. This is one of the most important principles of regenerative farming, making it possible to avoid watering in ground cultivation, in particular of sunflower which can use water sparingly.

If it is necessary to water sunflower, irrigation should be provided to the plants at the time when they need it most – during the emergence and flowering. Ensuring adequate moisture content of the soil in spring is very important, as it leads to proper emergence and good development of roots, which boosts sunflower resistance to environmental stress in the later stages of development. The critical period in sunflower cultivation, in terms of the demand for water, is also the period between the flowering and seed filling and usually these stages take place in the conditions of lower moisture content of soil and higher temperatures which creates risks. However, due to sunflower susceptibility to sclerotinia rot, excessive watering of the plantations should be avoided. Additionally, excess water may cause sunflower lodging as a result of the heavy weight of the flower head and the lack of support in the soft soil. This applies in particular to furrow irrigation. In order to take full advantage of the irrigation of sunflower, the plants' demand for nutrients must be met to a satisfactory degree and effective methods of supplying water to sunflower root zone should be used.

First of all, however, soil management has to be taken care of, which improves soil capacity for retaining precipitation water, improves capillary rise of soil moisture from deeper soil layers, and reduces evaporation from the surface. Agrotechnical measures which improve soil water retention capacity and reducing water loss from field soil include:

- **shallow no-till cultivation** with such management of post-harvest residues to ensure that they are always present near the surface of soil – such measures should be a part of after-harvest cultivation and spring cultivation before the start of sunflower sowing;

- **abandoning tillage in sunflower cultivation** and replacing it with no-till cultivation as the main treatment, which ensures leaving appropriate amount of plant residues near the surface, protects soils structure, reduces crust-formation on the surface of soil, and reduces evaporation from the surface;

- **in sunflower cultivation in hilly areas, terrace farming and cultivation** across the slope should be introduced, as it significantly improves infiltration of precipitation water, reduces water runoff and water erosion as a result, and feeds soil water storage used by deep-rooting sunflower plants;

- including in crop rotation all possible treatments aiming to improve the balance of organic matter in soil: application of organic (including straw and catch crop biomass) and natural (in particular manure) fertilisers, additives containing carbon, reduced tillage in order to protect the soil structure and slow down mineralisation and biological decomposition of organic matter.

Developing soil water retention capacity and protecting water resources of fields in regenerative farming involves mainly protection of soil organic matter storage, natural soil coherence and structure, and appropriate development of agricultural landscape. Organic matter plays a crucial part in forming a stable structure in soil and a related stable network of pores of different sizes, playing various functions in soil. Small capillary intra-aggregate pores ensure water retention in the profile against the gravity, while larger inter-aggregate pores facilitate infiltration of precipitation water and access of oxygen to roots and soil organisms. Smaller pores ensure also the upward water movement from above ground water table to rhizosphere, which provides water for the plants and is crucial in the periods between rainfall. It is very important that the unique, to a large extent biological, soil coherence is not damaged by intensive soil cultivation, which happens in tillage technology. Intensive tillage contributes to the destruction of soil aggregates which play an important protective function for soil organic matter and as a consequence leads to depletion of soil organic matter in arable soils.

Apart from providing typically agrotechnical treatments, it is very important to retain water in the agricultural landscape, which is linked to the reconstruction or redevelopment of old drainage systems in order to create drainage and irrigation systems, and the reconstruction and maintenance of natural retention basins in the agricultural landscape, such as waterholes, ponds and various kinds of swamps. Non-production elements of this type are valuable biotopes which increase the biodiversity of farmland. Artificial water reservoirs for storing rainwater which may be used for irrigation during critical periods may also become important in the future.

3.6 Fertilisation of crops and soil

In regenerative farming before determining the dose of sunflower fertiliser it is recommended to test nutrient resources of soil and establish soil pH which significantly affects their availability to crops. For this, soil samples should be taken and analysed in terms of nutrient content and pH, to assess the initial condition of soil for sunflower cultivation. Because of the deep root system of sunflower, soil analysis on which rational fertilisation can be based should be performed on samples taken from the depth of up to 120 cm.

Additionally, in the regenerative approach it is recommended to use precision farming tools for the application of mineral fertiliser doses determined on the basis of the current nutrient resources of soil. This technique makes it possible to reduce the leaching of ground water nutrients and helps to manage fertilisers more economically. Providing appropriate amount of specific nutrients in the form of fertilisers is extremely important for sunflower plantation. From 1 hectare of sunflower approximately 10 tonnes of biomass can be harvested, which means that in order to achieve a satisfying yield of seeds the plants need significant amounts of nutrients.

According to the principles of regenerative farming, the main purpose of the application of fertilisers is feeding the plants, but also soil microorganisms. In order to achieve this, natural and organic fertilisers and supplementary mineral fertilisers should be used, in doses adapted to the current soil fertility and nutritional needs of plants and in a form which is friendly to the soil microflora. Sunflower yield increases with a joint application of organic and mineral fertilisers. Also foliar application of micronutrients results in a noticeable increase in sunflower productivity.

Natural and organic fertilisation

Thanks to the application of organic fertilisers for forecrop, the yield of sunflower seed may increase by 2-3 $t \cdot ha^{-1}$. However, manure should not be applied directly before sunflower cultivation, in particular on heavier soils, as it delays its development. It is also not advisable to apply manure after papilionaceous plants, due to the risk of nitrogen over-fertilisation of sunflower. For sunflower it is best to apply manure in crop rotation for sunflower forecrops, in particular those which make good use of nutrients from natural fertilisers. Sunflower responds very well to manure applied for forecrops in the dose of 30-40 $t \cdot ha^{-1}$. The use of nitrogen and phosphorus from manure is about 40%, whereas potassium is used in approximately 80% in the first year after the application of organic fertiliser (tables 4 and 5) and in the following years some portion of nutrients provided with natural fertilisers is also released into the soil solution and some of them return with post-harvest residues of plants grown on manure, which should be taken into account in fertilisation of crops, in particular with nitrogen (table 6).

The fundamental benefit of application of manure and organic fertilisers on fields where sunflower is grown is an improvement of organic matter balance and a widely defined soil quality, in particular water retention. Therefore, on lighter soils of rye complex, with a lower capacity for nutrient storage and water retention compared to heavier soils, it is recommended to apply small autumn doses of manure of 20-25 $t \cdot ha^{-1}$ or spring doses of slurry. Sunflower should not be grown after beet, the leaves of which were used as fertiliser. If sunflower is sown on such a site, nitrogen fertilisation should be carefully planned (table 6). The data presented in tables 4-6 indicate that mineral fertiliser doses planned for sunflower cultivation should take into consideration current soil properties, resulting from the regime of application natural and organic fertilisers in crop rotation, as well as the amount and quality of organic residues remaining in the soil after forecrops. Although when planning the fertilisation it is possible to determine approximate doses of nutrient that should be supplied to the soil on the basis of field history and obtained yield, it should be remembered that the actual nutrient content may vary from year to year. Therefore, in the regenerative approach to growing crops the basis for planning any fertilisation should be a regular and detailed analysis of soil properties. Precision farming tools are also useful in the assessment of nutritional status of a stand of plants.

Table 4. Average contents of minerals 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

Table 5. 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 and Journal of Laws 2018, item 1339

In practice sunflower is usually grown after cereal crops. In the regenerative approach straw of cereal forecrop should be used for fertilisation purposes. Due to a high C:N ratio in cereal straw, compensating doses of nitrogen should be applied at the same time to avoid immobilisation of nitrogen by soil organisms decomposing straw biomass (which occurs with the C:N ratio > 33.1:1). The following formula can be used to calculate a compensating dose of nitrogen in straw fertilisation (Grzebisz, 2009):

$$Dkn = Pno \cdot (12 - Nno)$$

where: Dkn – compensating (supplementary) dose of nitrogen ($kg \cdot ha^{-1}$)
Pno – straw weight ($t \cdot ha^{-1}$)
Nno – current nitrogen content in straw ($kg \cdot t^{-1}$)

Nitrogen fertilisation

Nitrogen is the most important mineral for all crops, including sunflower. Studies show that the maximum nitrogen uptake occurs in the flowering stage of sunflower plants. In order to produce 1 tonne of seeds, sunflower plants take up approximately 50 kg of nitrogen. Nitrogen increases the protein content in sunflower seed, but on the other hand the content of oil in sunflower seeds decreases with the increase of nitrogen dose. It should be remembered that excessive doses of nitrogen lead to an excessive increase of vegetative mass, delay the formation of generative organs, cause lodging and diseases. Moreover, excessive feeding of sunflower with nitrogen increases the content of linoleic acid by as much as 10%, which is undesirable in the cultivation of high-oleic sunflower. Sunflower plants excessively fertilised with nitrogen lodge easily, are more often affected by fungal diseases, and delay their growth. The above phenomena indicate clearly that nitrogen fertilisation in growing sunflowers should be balanced.

On average the doses of nitrogen fertiliser usually range from 60 to 80 $kg \cdot ha^{-1}$, depending on the soil nitrogen content determined by soil testing. For reasons related to soil and water protection and potential leaching of fertiliser nitrogen from soil, the dose of nitrogen from all sources (natural, organic, and mineral fertilisers) in sunflower cultivation should not exceed 130 $kg \cdot ha^{-1}$. Mineral nitrogen is usually applied in divided doses – the first nitrogen dose is recommended in the spring during sowing, and the second dose of fertilisation – in the V4 stage (four-leaves). In the event of nitrogen deficit in a sunflower stand, intervention nitrogen dose of 30 $kg \cdot ha^{-1}$ can be applied in further stages of development. In this case nitrogen is applied up to the stage of 14 leaves at the latest, preferably in the form of nitrochalk. Also inter-row application of soil-applied UAN (urea-ammonium nitrate) (not splash application) may also be considered. In cultivation of sunflower after crops such as root crops on manure or legumes, the soil mineral nitrogen content can be high enough to significantly reduce fertilisation with mineral nitrogen or not to apply it at all (table 6).

Table 6. Doses of nitrogen for sunflower on average soil depending on the site

Expected yield	Total uptake (in kg N ·ha^{-1})	Mineral N (in kg N ·ha^{-1})	N from crop residues or manure (in kg N ·ha^{-1})	N from matter mineralisation (in kg N ·ha^{-1})	Net N dose (in kg N ·ha^{-1})	Recommended gross N dose (in kg N ·ha^{-1})
After cereals (collected straw)*						
2,0	120	55	0	40	25	42
2,5	138	55	0	40	43	71
3,0	150	55	0	40	55	92
After root crops on manure						
2,0	120	65	25	40	0	0
2,5	138	65	25	40	8	13
3,0	150	65	25	40	20	33
After legumes						
2,0	120	65	30	40	0	0
2,5	138	65	30	40	0	0
3,0	150	65	30	40	15	25

*in case of sowing stubble catch crop after cereals, nitrogen dose can be reduced
Source: Taboła, 2010

Phosphorus fertilisation

Phosphorus plays a very important part related to accumulation of energy in a plant. Sunflower has an average demand for phosphorus compared to nitrogen and potassium. As a standard practice, phosphorus fertilisers are applied in the autumn and/or spring. Pre--sowing dose of the fertiliser is usually 60-90 kg·ha^{-1}. Moreover, sunflower responds very well to localised, side-dressing with phosphorus.

In farms using regenerative farming practices, the availability of phosphorus in soil increases due to a high microbiological activity of soil and in justified cases it is possible to eliminate the application of this mineral. If there is a need for fertilisation on soils of low fertility, it is recommended to apply phosphorus with the use of precision farming techniques, adapting it to the soil content of this mineral and nutritional requirements of plants. The maximum uptake of phosphorus by sunflower plants occurs from the seed germination to the beginning of the flowering stage. This element is responsible for the formation of extensive root system and inflorescences (a large number of flowers in a flower head). With sufficient nutrition with phosphorus the development of plants is accelerated, soil moisture is used more effectively, and plants are better equipped to survive drought. Excessive application of this element significantly reduces water use by sunflower plants. Phosphorus and potassium fertilisers have beneficial effect on the quality of sunflower seeds – they increase the fat content and the linoleic acid content in seeds.

Potassium fertilisation

Sunflower is a crop with a high potassium requirement, therefore potassium-deficient soils are not suitable for sunflower growing. Potassium is an important element in the formation and transport of carbohydrates in sunflower plants, which helps to decrease the plants' susceptibility to diseases. Potassium is taken up by sunflower plants throughout the growing season, but particularly intensively before the flowering. Insufficient feeding with potassium leads to the formation of seeds with a low oil content, the yield is reduced and the proportions of saturated and unsaturated fatty acids change. It is recommended to apply potassium fertilisers as early as the autumn cultivation of soil after forecrop.

Potassium is taken up by sunflower plants in excess, therefore the nutritional needs of sunflower may be adjusted by 20-30%. Potassium fertilisers for sunflower are usually applied in the dose of 120-180 kg·ha^{-1} of pure ingredient, depending on the soil content of this mineral and the expected yield. The preferred form of fertiliser potassium in the regenerative approach is potassium sulphate which is not only a source of potassium, but also another valuable macroingredient – sulphur.

Fertilisation with microelements

Sunflower requires also fertilising with microelements. It is most sensitive to boron and manganese deficiency, but also needs copper and zinc for good development. In order to produce 1 tonne of yield, sunflower needs 118 g of manganese and 113 g of boron, as well as 99 g of zinc and 17 g of copper (table 2). The actual uptake of these microelements from soil is much smaller, hence the need to additionally feed sunflower with soil-applied fertilisers containing microelements or microelement-based preparations for foliar application.

Sunflower is sensitive to boron deficiency. Boron fertiliser can be applied both in the autumn during tillage and in the spring during sowing. Boron plays an important part in regulating carbohydrate metabolism, synthesis of amino acids, proteins and chlorophyll. It is also important for the development of the root system of sunflower. It improves the flow of carbohydrates to the roots and activates their growth. Boron is not mobile inside the plant, therefore it should be applied throughout the growing season, in particular before the flowering. The sensitivity of sunflower to boron deficiency increases in particular at the time of water deficiency in soil or in case of excessive nitrogen fertilisation. As a result of boron deficiency apical buds of sunflower wither and the yield is reduced by as much as 10-12%.

Fertilising with sulphur and magnesium

Sunflower responds very well to the application of sulphur and magnesium. Sulphur may be applied to the soil as potassium sulphate, ammonium sulphate, kieserite, calcium sulphate or elemental sulphur. Sulphur improves nitrogen uptake by plants, increases the fat content and the yield of sunflower. Sulphur deficiency is visible on light, acidic, poorly aerated soils, with a low content of organic matter. Therefore, it is important to test soil for nutrient content before the application of fertilisers and building resources of soil organic matter.

Sunflower may also react to a magnesium deficiency, of which it takes up approximately 12 kg of MgO·ha^{-1}. Therefore, a good solution is to apply fertilisers in the form of kieserite which contains magnesium oxide and other fertilisers enriched with magnesium.

pH regulation and the role of calcium in regenerative sunflower farming

3.7

Properly regulated soil pH is a very important aspect, which is often touched upon in the context of regenerative farming. Soil liming positively affects soil pH, but also improves the quality of organic matter, soil structure and soil biological life, which indirectly affects also water retention. Soil pH affects soil absorption complex and the capacity of cation exchange which are a certain kind of indicators of soil fertility, as they determine the soil capacity to retain crucial nutrients such as K^+ , $NH4^+$, Ca^{2+} ions in a form available to plants.

Sunflower is sensitive to soil pH, therefore it is important to sow it on a site with regulated soil pH. Optimum soil pH is 6.5-7.0. In order to ensure properly regulated soil pH liming should be applied as early as sunflower forecrop (fig. 7).

Figure 7. A field after the application of calcium fertiliser.
Photo credit: M. Wijata

3.8 Protection against weeds, pests and diseases

In regenerative farming crop health is very important. Plants kept in a good condition, growing in favourable conditions stand a better chance of being protected against plant pests and diseases. Therefore, in the regenerative approach preventive action is so important. Unfortunately, sunflower is a high risk crop due to damage caused by disease, pests, weeds and birds, thus protective action has to be comprehensive and integrated.

In the concept of regenerative agriculture crop protection against plant pests and diseases starts with correct crop rotation which beneficially affects crop health and weed control, ensuring soil health, however in justified cases a reasonable use of pesticides, both biological and chemical, is allowed. In this case the bottom line is maximising the effectiveness of pesticides, with maximal reduction of the harmful effect on soil organisms and the environment.

A comprehensive approach to regenerative farming and implementing its principles as early as the beginning of plantation planning leads to good health of the field with minimum chemicalisation.

Weed control

The preventative action in protection against weeds includes shallow cultivation using a disc harrow after forecrop harvest, which is the start of post-harvest cultivation and limits weed infestation of the future sunflower plantation. After the germination, in favourable weather and soil conditions, sunflower grows quickly and relatively quickly covers the inter-rows, shading the weeds at the lower level, which limits their further development. However, weeds with a growth rate similar to that of sunflower can be a threat – and they include scentless mayweed, white goose-foot, bristle-stem hemp nettle, pigweed, and others. In case of pressure from this type of weeds post-sowing care treatments are necessary. Mechanical weeding should be carried out for the first time when plants form first leaves apart from cotyledons, and the weeding can be repeated as weeds emerge, until inter-rows are covered by sunflower leaves. Mechanical weeders are used for weeding which loosen the inter-rows and destroy the weeds. Inter-row cultivation should be carried out on clear and sunny days, preferably in the afternoon, when plant turgor pressure is lower and plants are more flaccid. Including in the crop rotation elements of post-harvest and pre-sowing measures, that is shallow cultivation in the period after the harvest and before the sowing of crops, aiming to destroy weeds germinating from the soil weed bank and triggering the germination of next weeds, is a strategy to reduce the weed pressure on fields. Weed infestation should also be fought using catch crop mixtures containing fast-growing species which successfully compete with the germinating weeds. Consistent reduction of the weed seed bank in the topsoil without feeding it with new seeds leads to a reduction of the weed pressure in the conditions of no-tillage, no-inversion cultivation recommended for regenerative farming.

If chemical weed control is necessary, the choice of sunflower variety resistant to tribenuron-methyl is crucial, as it will allow for using foliar-applied herbicide. Very often due to the drought in the spring, soil herbicides are not effective in sunflower cultivation. Therefore, when sunflower is grown in wide rows the mechanical method is recommended for weed control (weed removal using a weeder). With a variety which is not resistant to tribenuron-methyl, this may be the only effective way of weed control. Table 7 presents currently approved active soil-applied substances, used for weed control in sunflower, with timing of application and sensitive weeds.

Table 7. Examples of active substances useful for application to the soil before sunflower emergence

Active substance	Timing of application [BBCH]	Weeds
Pendimethalin	BBCH 00-01	**SENSITIVE:** barnyard grass, annual bluegrass, field violet, three-coloured violet, common chickweed, henbit, white goose-foot, burning nettle, birdeye speedwell, bird's knotgrass, redshank, jointed charlock, field mayweed, shepherd's purse **MODERATELY SENSITIVE:** small-flowered crane's-bill, wild mustard, common stork's bill, purple deadnettle, common stinging nettle, bristle-stem hemp nettle, field bedstraw, black-bindweed, common chamomile, pigweed, field pennycress.
Prosulfocarb	BBCH 00-02	**SENSITIVE:** wind-grass, common chickweed, purple deadnettle, white goose-foot, ivy-leaved speedwell, birdeye speedwell, field bedstraw **MODERATELY SENSITIVE:** annual bluegrass, field violet, corn poppy, black-bindweed, common chamomile.
Aclonifen	BBCH 00-08	**SENSITIVE:** barnyard grass, fingergrass, annual bluegrass, field violet, common chickweed, white goose-foot, saltbush, false mayweed, Canadian thistle, bristle-stem hemp nettle, field bedstraw, field mayweed, redshank, jointed charlock, self-sown rapeseed, pigweed, herb mercury, ¬ field pennycress, smallflower galinsoga.
Metobromuron	BBCH 00-08	**SENSITIVE:** wild oat, annual bluegrass, common fumitory, field violet, wild mustard, common chickweed, purple deadnettle, white goose-foot, small bugloss, scentless mayweed, bristle-stem hemp nettle, birdeye speedwell, curltop knotgrass, bird's knotgrass, self-sown rapeseed, common groundsel, pigweed, shepherd's purse, field pennycress, smallflower galinsoga. **MODERATELY SENSITIVE:** barnyard grass, small-flowered crane's-bill, field bedstraw, black nightshade, black-bindweed, redshank, black knotgrass, herb mercury.
Dimethenamid-P + Pendimethalin	BBCH 00-09	**SENSITIVE:** barnyard grass, common chickweed, white goose-foot, field bedstraw, bird's knotgrass, field mayweed, field pennycress.

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

If the application to the soil is ineffective, foliar application may be used. This concerns in particular monocotyledonous weeds and with the varieties resistant to tribenuron-methyl it is possible to control dicotyledonous weeds by foliar application. Table 8 presents active substances useful for foliar weed control in sunflower, with timing of application and sensitive species of weeds.

Table 8. Examples of active substances for foliar application

Active substance	Timing of application [BBCH]	Weeds
Quizalofop-P-ethyl	BBCH 10-16	Self-sown cereals, wind-grass, foxtail grass, and ryegrass
Clethodim	BBCH 10-30	Wild oat, wheat grass, self-sown cereals
Cycloxydim	BBCH 12-19	Ryegrass, wheat grass, grasses
Tribenuron-methyl	BBCH<18	Small-flowered crane's-bill, field violet, common chickweed, white goose-foot, corn poppy, scentless mayweed, field forget-me-not, Canadian thistle, speedwell, field bedstraw, field mayweed, self-sown rapeseed, shepherd's purse, field pennycress

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

Pest reduction and control

Pests in sunflower cultivation are not as problematic as weeds or fungal diseases, however they also require constant monitoring, preventative treatments and, if necessary, pest control. The problem with most sunflower pests can be solved using non-chemical methods, which is in line with the principles of regenerative agriculture.

The biggest problem in sunflower cultivation is the birds, in particular families of Passeridae, Corvidae, and Columbidae, which cause damage directly after the establishment of a plantation by pecking the seeds from the soil and at the stage of fully formed flower heads, resulting in the lowering of seed yield. Sunflower plantations should be established on larger areas, as in small plantations the damage caused by birds is much more severe, as they mainly feed along field borders. Additionally, it is not recommended to locate plantations near forests which are a natural habitat of birds. Effective deterrents are also bird scare cannons, bird noise tapes and sonic bird repellents with predator calls.

Other significant pests in sunflower cultivation are slugs which can also be controlled using non-chemical methods, such as full post-harvest cultivating measures, large plant spacing, post-sowing rolling, using various species in crop rotation, application of biopreparations based on parasitic nematodes. As a last resort chemicals are available with metaldehyde or iron(III) phosphate as the active substance, applied in BBCH stages 01-15.

There are years when sunflower plantations are infested with aphids, which may transmit sunflower mosaic virus. An effective method to manage the problem is spatial isolation from rapeseed and root crops, as well as balanced nitrogen fertilisation. If non-chemical methods fail, there are available preparations based on acetamiprid which may be used in BBCH stages 10-65. These chemicals are also effective to control lygus bugs which can also feed on sunflower crop.

In the regenerative approach to crop protection it is very important to ensure the protection of beneficial organisms, which is linked to appropriate development of agricultural landscape. Biotopes located near the fields, not used for farming or used extensively are the habitat and breeding ground for many beneficial organisms. For example, the larvae of hoverflies, green lacewings (Chrysopidae), ladybirds or beetles feed on aphids and can effectively control their populations. For this reason it is necessary to provide sites in close vicinity of fields where adult insects can winter, forage and breed from early spring, before they move their foraging activity to the fields. Reduced tillage cultivation also favours the habitation of insects in the fields.

Chemical pest control in sunflower should be applied only in justified cases and when economic thresholds are exceeded.

Disease limitation and control

The diseases of the greatest economic significance in sunflower cultivation include sclerotinia rot caused by *Sclerotinia sclerotiorum* fungus and grey rot caused by *Botrytis cinerea Pers. syn Botryotinia fuckeliana*. *Sclerotinia sclerotiorum* may survive in the soil for many years in the form of sclerotia, that is a tuberous mass of fungal mycelium formed from densely tangled hyphae. This pathogen has been found on many crops: rapeseed, tobacco, beet, soybean, sunflower and many vegetables such as carrots, parsnip, cucumber, tomato, bean. In the control of sclerotinia rot according to the principles of regenerative farming the correct crop rotation ranks first – due to the fact that this disease can be also encountered in rapeseed or soybean, therefore growing sunflower directly after these crops should be avoided, as well as growing them on the same field more than every four years. The pressure of fungal disease may be greater in sunflower cultivation on more moist sites, characterised by humid and cool weather before, during or after sunflower flowering, including not only precipitation, but also fog and heavy dews. Sunflower should not be introduced to a field with such a microclimate.

The timing of sunflower sowing, in optimal soil heat and moisture conditions, is also very important. Sowing the sunflower too early in insufficiently warmed soil extends the time of emergence which may lead to seedlings being struck by damping-off. However, delaying the sowing too much may adversely affect sunflower yield. Like in the case of other crops, optimum sowing parameters combined with balanced fertilisation, meeting the plants requirements, significantly improve crops resistance to abiotic and biotic stress, including disease.

Another way of avoiding fungal disease is seed dressing to protect seed material. It protects against grey rot, seedling damping-off, Alternaria blight and fusarium wilt (fusariosis). Sclerotinia rot can be also controlled using a biological preparation based on *Trichoderma asperellum*. In wet years and with a large stand density sclerotinia rot intensifies and poses a serious problem. It is then necessary to apply crop protection chemicals. Active substances approved for control of sunflower diseases and the timing of their application are presented in table 9.

Table 9. Examples of active substances necessary to control sunflower disease

Disease	Active substance	Development stage [BBCH]
Sclerotinia rot of sunflower, seedling damping-off, Alternaria blight of sunflower, grey rot	Fludioxonil	Seed dressing
Sclerotinia rot of sunflower	Azoxystrobin + difenoconazole	BBCH 16-69
	Prothioconazole	
	Fluopyram + prothioconazole	
Grey rot	Fluopyram + prothioconazole	BBCH 16-69
	Prothioconazole	
Powdery mildew of sunflower, Alternaria blight of sunflower, rust of sunflower, Phoma black stem	Azoxystrobin + difenoconazole	BBCH 16-69
	Prothioconazole	

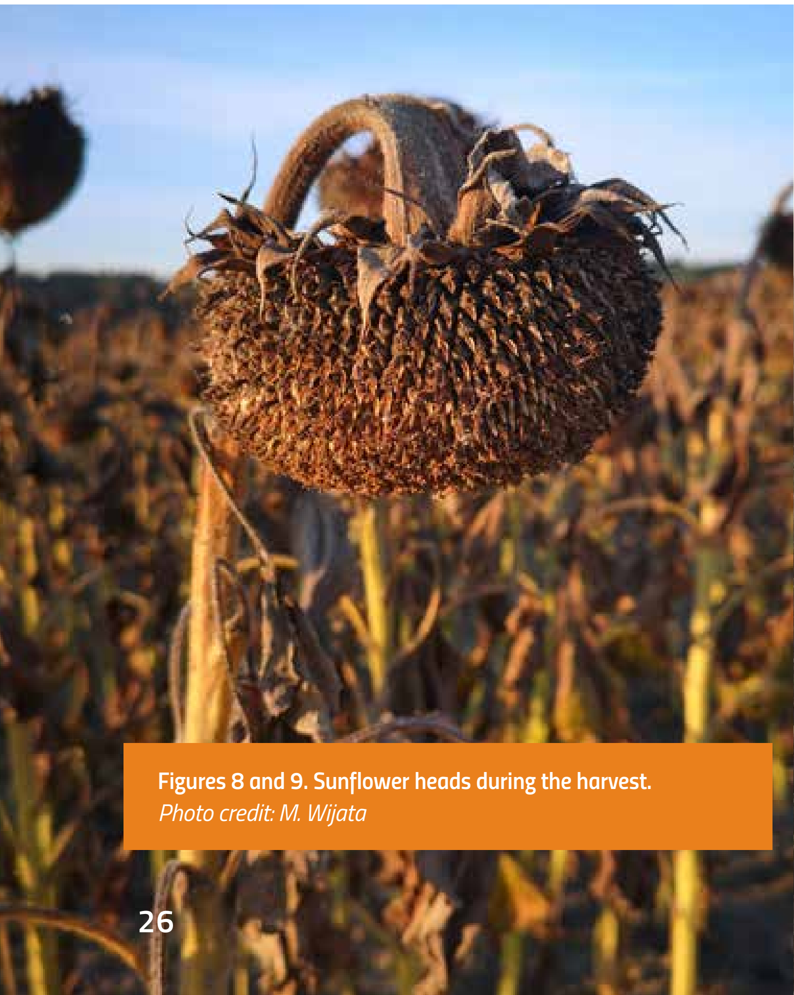
Source: Authors' own worn on the basis of Krawczyk and Kierzek, 2023

3.9 Harvest and storage

The harvest of early sunflower varieties grown for seeds falls in late September and early October. The plants are ready for harvest when bracts surrounding the capitulum (flower head) are brown, the spongy bottom of the inflorescence makes a hollow sound, and the whole plants dry out (figures 7 and 8). Sunflower may be harvested using a combine harvester with a corn attachment, however the attachment must be adapted by fitting a special adapter shortening the gap and an additional knife driven by a chain (figures 9 and 10). Thanks to this solution, flower heads are cut high and do not hit the attachment with great force which could cause them to break. Flower heads fall into the feeder and threshing takes place. This technology makes the sunflower harvest more efficient, reducing loss during harvest and is less expensive than special sunflower headers. In farms specialising in sunflower and growing it on large areas a special header, designed for harvesting sunflower only, may be purchased, however this option is much more expensive. All attempts to harvest sunflower using a cereal header are unsuccessful.

According to the principles of regenerative farming, post-harvest residues of sunflower grown for seeds should be utilised in the field. Depending on the applied harvesting method, post-harvest sunflower residues should be properly shredded. After the harvest with a header specially adapted for sunflower, treatment with a disc harrow is sufficient, and in case of a harvest with an ordinary cereal header or using makeshift adapters, a treatment with mulcher may be necessary.

Post-harvest sunflower residues are rich in nutrients. The sunflower plant takes up a lot of water and uses large quantities of nutrients, in particular potassium, leaving little in the soil for aftercrops, but utilising post-harvest residues in the field compensates for this loss. According to the Institute of Soil Science and Plant Cultivation (IUNG) sunflower leaves 74% of nitrogen, 54% of phosphorus and 94% of potassium. Table 10 compares the return of nutrients to soil with 1 tonne of post-harvest residues with other plant species.



Figures 8 and 9. Sunflower heads during the harvest.
Photo credit: M. Wijata

Figures 10 and 11. Sunflower harvest using combine harvester with a corn attachment equipped with an adapter for sunflower harvest.
Photo credit: M. Wijata

Table 10. Nutrient content in post-harvest sunflower residues compared to other crops

Crop	Return of nutrients to the soil from 1 tonne of post-harvest residues [kg·ha^{-1}]		
	Nitrogen	Phosphorus	Potassium
Sunflower	15,6	7,6	45,2
Rapeseed	14,5	6,5	11
Soybean	12	3,1	5,0
Corn	7,5	3	16
Wheat	5	2	9

Seeds ready for harvest should reach the moisture level of 8%. In years when sunflower harvest is delayed and falls in later months in the autumn, its harvest with optimal moisture level of 8% is more difficult, due to short days, low temperatures, and morning fog and dew. In this case it is necessary to provide additional drying of sunflower in driers and harvest may commence when sunflower moisture reaches less than 20%. Drying temperature may not exceed 50°C, as higher temperatures adversely affect the quality of oil obtained from sunflower.

In harvesting sunflower biomass for silage or green forage, machines used for corn and other crops are used.

4 SUMMARY OF TREATMENTS AND ANALYSIS OF BENEFITS

To summarise, in regenerative sunflower cultivation special attention is paid to such aspects as:

- including sunflower in crop rotation as an interrupter to cereal monoculture, which increases biodiversity of contemporary agroecosystems saturated with cereals, as well as prevents transmission of diseases and pests typical for cereals;

- sunflower as an oilseed crop is a cheaper alternative to rapeseed on lighter soils, and in dry years it may have more stable yield than corn;

- sunflower is also a plant of great importance from the environmental point of view – it is melliferous (honey bearing), may be successfully grown as catch crop, in flower strips and provides benefits for pollinators until late autumn, when there is already a scarcity of flowering plants in nature;

- in the regenerative approach cultivation of soil for sunflower is limited to a minimum, aggregates for deep cultivation should be used, instead of turning over the soil. Such an approach reduces intensive interference with soil coherence and soil biological balance and slows down the decomposition and mineralisation of soil organic matter, as well as retains soil moisture;

- sunflower fertilisers should be applied based on the soil nutrient content and the nutritional needs of plants, natural and organic fertilisation should be applied to sunflower and its forecrop, and, if possible, precision farming techniques should be employed for mineral fertilisation in order to improve the effectiveness of fertilisation and reduce the amount of mineral fertiliser used;

- regular soil liming is recommended to regulate soil pH, but also to improve the quality of organic matter, soil structure and soil biological and chemical properties;

- in order to protect sunflower against plant pests and diseases all non-chemical protection methods should be used in the first place, including selecting varieties resistant to herbicides and diseases, properly planned crop rotation and site selection, the right timing of treatments, biological and mechanical protection methods as an alternative for pesticides, isolating sunflower from plants which can transmit pathogens, and preserving in the agricultural landscape biotopes which are habitats and breeding grounds for beneficial organisms;

- during the harvest of sunflower for seeds, shredded post-harvest residues should be left in the field in order to compensate for the loss of nutrients taken up by sunflower plants and improve the balance of organic matter in crop rotation involving sunflower.

Sunflower can be sown as a component of multi-species mixes for flowering strips, enriching the countryside landscape and increasing biodiversity, as well as providing forage source for pollinators.

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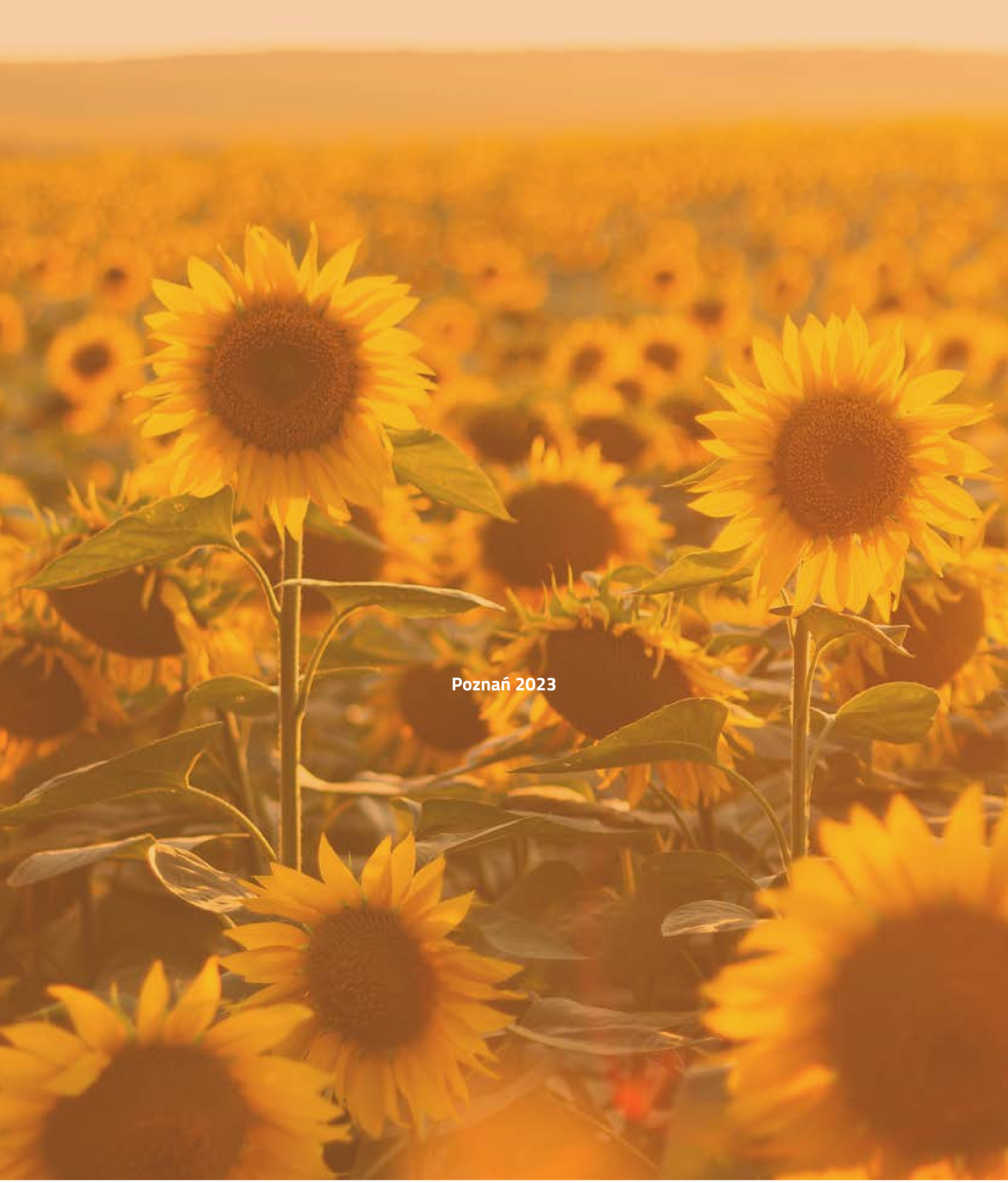

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