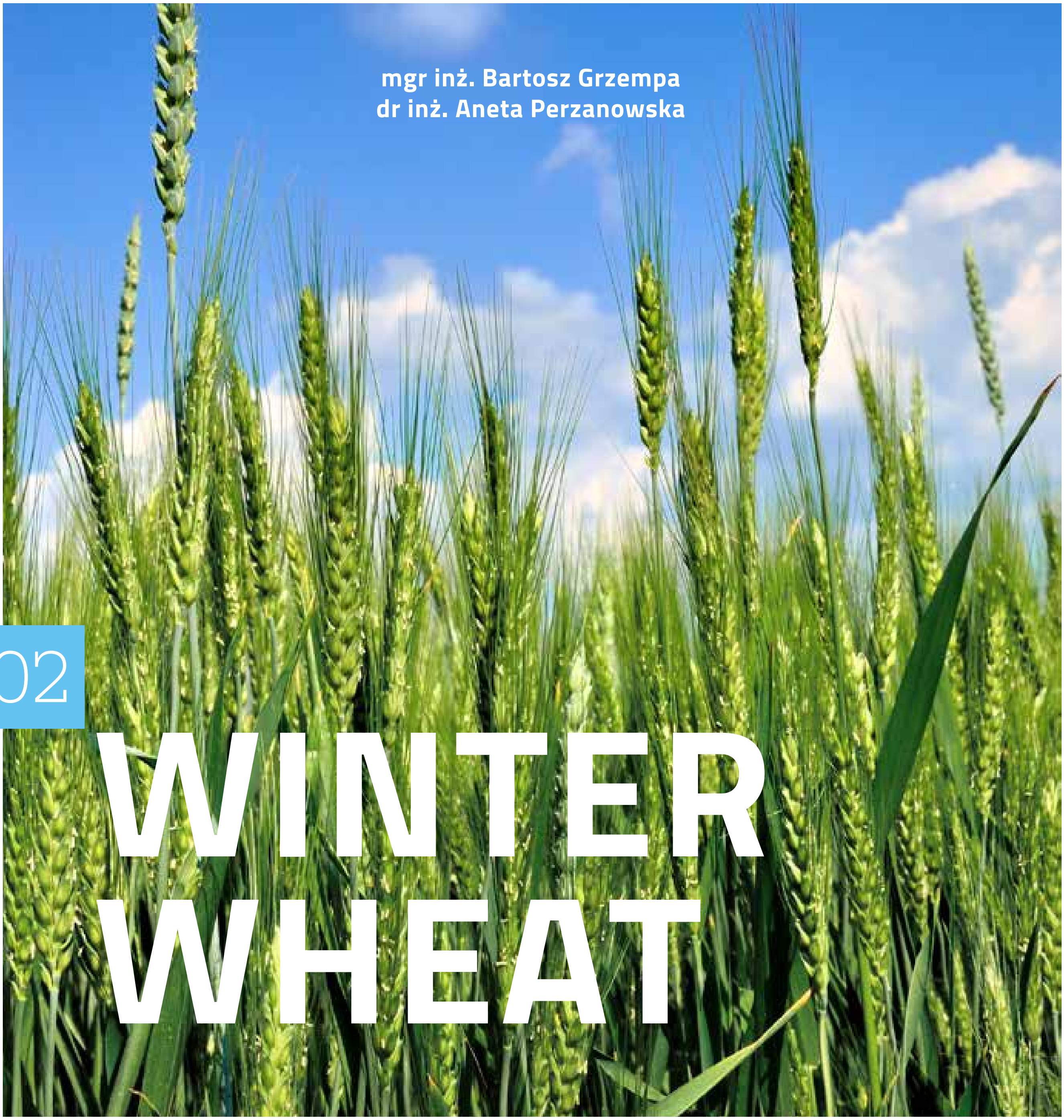

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02

WINTER WHEAT

CEE REGENERATIVE AGRICULTURE GUIDEBOOK

TERRA NOSTRA FUNDACJA

eit Food REGENERATIVE AGRICULTURE REVOLUTION

Co-funded by the European Union

CEE REGENERATIVE
AGRICULTURE
GUIDEBOOK
WINTER WHEAT

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WINTER WHEAT

CEE REGENERATIVE AGRICULTURE GUIDEBOOK

Poznań 2023

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INTRODUCTION TO REGENERATIVE FARMING

2.1

Common winter wheat *(Triticum aestivum)* is an importance cereal for the economy. It is the world's second most harvested cereal type. In terms of global harvest, it comes behind maize only. For these reasons, wheat can be considered the basic source of food for the whole society.

Cultivation of wheat is not difficult, and it does not require large expenditures compared to other cultivated species like sugar beets, winter oils rape seed or vegetables crop. Wheat as one of the basic cereal types grows on many thousands of hectares. In European Union, it occupies the largest area of all cultivated species. For this reason, wheat cultivation is significant in regenerative agriculture. The role of wheat in crop rotation is very important, because on account of the vast surface area it occupies, it has the greatest impact on soil properties on many farms. In regenerative agriculture, wheat should be grown in this approach to produce the most beneficial effect on biological properties of the soil. At the same time, it needs to be remembered that wheat is a crop rotation filler of some sort. Wheat as cereals is also favorable forecrop for many species. In addition to this crop rotation filler function, wheat provides grain, used to bake bread and produce other cereal products such as flour, etc., which play an important role in human nutrition. Owing to its great importance for human nutrition, ensuring high-quality grain is essential. The combination of these two aspects, i.e. the production of good quality grain and leaving a sufficiently good site, is what typifies regenerative approach to cultivation.

In regenerative agriculture, special attention is paid to soil properties as the soil is the primary factor that affects the size and quality of the yield, not only of wheat.

There are five basic factors that particularly affect the properties of soil. They are called the 5C code (from the English words describing factors affecting soil properties):

Calcium - calcium is of particular importance for regenerative farming, it significantly affects pH, contributes to proper soil structure and is a component necessary for proper plant growth.

Carbon (organic matter in soil) - organic matter in the soil is important, as it increases soil fertility, improves water retention and works as a buffer. However, there are species whose cultivation depletes carbon in soil, potatoes for example. In turn, the cultivation of winter wheat, may increase its content. Regenerative approach activities are then taken that have a particular impact on its increase, e.g. keeping the crop residue on the field (such as cereal straw).

Cover crops – cover crops are not standard practice for winter wheat farming, and they happen only in exceptional cases. It may happen that we have to sow wheat late, for example seeds for that field will be delivered late, which forces us to sow late. In most cases however, the time between forecrop harvest and winter wheat sowing is short, so short that it makes no sense to sow the catch crop. One of the functions of cover crops is that they leave living roots and an adequate amount of organic biomass in the soil, thus providing survival opportunities for soil organisms and improving the quality of soils by positively affecting the resources of organic matter. Therefore, if the time between forecrop harvesting and sowing of the next main crop is relatively short, which is the case with the cultivation of winter wheat, cover crops are not used. However, the wheat itself has a protective role. Sown in autumn, the plant covers the soil during the winter, limiting soil erosion.

Cultivation – soil is not cultivated too intensively in regenerative agriculture and in the case of wheat, we try to minimise cultivation. That is justified for many reasons, because each intensive soil cultivation treatment, such as ploughing for example, disturbs the biological soil balance of the soil, which is our primary focus.

Impact of agricultural activity on the external environment **(Culture)** – in terms of impact on the external environment in wheat cultivation, we work not to adversely affect it. That is achieved for example by limiting the use of plant protection products, or by new plantings and care for the existing mid-field woodlots, which are a natural habitat for beneficial organisms, etc.

5C CODE

NUTRIENT AND SOIL REQUIREMENTS

2.2

Winter wheat has the highest soil requirements of all cereals. Best soils for its cultivation include chernozem, black earth soils, black soils, heavy and medium alluvial soils, loess, etc.

However, with the right agronomical culture and proper field management, wheat can be successfully grown also where soil is of poorer quality. In this case, however, yield instability between individual years should be accounted for as a risk. On farms where regenerative activities are performed, the agronomic soil category may not be as important in wheat cultivation and yield is successfully repetitive even on poorer field sections.

As shown in Table 1, to produce 1 tonne of grain, winter wheat will consume 30 kg N ha^{-1}, 11 kg P2O5 ha^{-1}, 18 kg K2O ha^{-1}, 5 kg CaO ha^{-1}, 3 kg MgO ha^{-1} and 4.5 kg S ha^{-1}. These values are average values for milling wheat. Nitrogen requirements are lower for the cultivation of soft or fodder wheat. Those varieties require as much as 8 kg N·ha^{-1} less, i.e. about 22 kg N·ha^{-1} per one tonne of grain.

Table. 1. Individual macronutrients needed to produce 1t of grain (including by-products) ha -1 (average values)

Nitrogen (N)	Phosphorus (P_2O_5)	Potassium	Calcium (CaO)	Magnesium (MgO)	Sulphur (S)
30 kg	11 kg	18 kg	5 kg	3 kg	4,5 kg

Source: Author's own work

2.3 REGENERATIVE CULTIVATION TECHNOLOGY

LOCATION AND FORECROP

2.3.1

What should be considered in the selection of a site for the cultivation of winter wheat, in addition to its biological properties, is that the field should be properly drained, drainage channels should be cleared, etc. before cultivation.

This will prevent later water ponding, which adversely affects the growth of winter wheat. Land topography is not as important for wheat, because it is not sensitive to frost pools, etc. In the regenerative approach, however, mid-field woodlots should be ensured, along with ponds and watercourses, which are beneficial organisms typically exist and limting wind power, erosion and snow retention.

Photo Inadequate land draining means ponding water, adversely affecting the condition of the crop.

It is very important in regenerative farming, to set up the right crop rotation. Winter wheat, leaving a large amount of residue, has a positive effect on the balance of organic matter in the soil. For this reason, winter wheat is followed by crops such as potato, sugar beet, vegetables, etc., which have a more destructive effect on the soil environment. The best forecrops for winter wheat are non-cereal crops, first of all legumes, but also, winter rapeseed, potatoes (especially "super fresh"), and sugar beets. Wheat shouldn't be cultivated after other. That is because, while wheat monoculture can be profitable, that is to the detriment of biological properties of the soil. In addition, if wheat is grown in succession, fungal diseases are much more likely to occur. In the regenerative approach, we try to use all possible ways to reduce the presence of pathogens.

The regenerative approach to the cultivation of plants, not only winter wheat, means that, in for crop rotation, the field is as long as possible under the living plant cover. The reason is to have living plant roots in the field all the time, which are there to nourish soil microorganisms, whose presence is necessary for the plants to grow properly. In crops where the period from the harvest of the forecrop to the sowing of the next crop is quite long, e.g. in the case of potato cultivation after cereals, a mix of cover crops is sown. On the other hand, winter wheat is cultivated after forecrops, where the period from the harvest of the forecrop to the sowing of the next crop is relatively short, e.g. after beets or late potatoes, wheat is sown practically immediately after the forecrop is harvested. If winter wheat is cultivated after an earlier crop, such as rapeseed or pea. In that case, we sow wheat faster, for example by a week, in order to shorten the time when there are no living roots in the soil . Another aspect is that, in regenerative cultivation, organic fertilization should be done right after the descent of the catch crop.

Stubble after wheat cultivation. There are small holes in the soil made by earthworms.

SELECTION OF VARIETIES

2.3.2

Wheat varieties vary in many respects. The main difference is in the quality group to which a given variety belongs.

There are 4 quality groups: E - elites (only in some countries in European Union), A - bread varieties, B - fodder variety and C – soft (pastry) variety. When selecting varieties, we choose those that meet our quality expectations.

In addition to the grain quality group, another important parameter is winter hardiness of plants. Different varieties of wheat differ in their resistance to overwintering. This is the primary feature that we take into account when choosing a variety. In regenerative cultivation, we try to choose varieties that show relatively high winter hardiness. Plants showing better winter hardiness, apart from the fact that they typically survive winter, show better vigour after winter compared to varieties with worse winter hardiness, especially if temperatures fell below zero. It does happen for plants whose vigour and spring condition are poor that they are more often affected by pathogens.

Another feature to be considered when selecting wheat varieties is disease resistance. The main point of focus here is resistance to leaf diseases such as septoria, rust and powdery mildew. We should opt for varieties that are more resistant to these diseases. Importantly, careful selection of varieties is one of the non-chemical methods of plant protection.

Other factors may be important in selecting a variety only in exceptional circumstances. For example, whether a variety is awned can be important in situations where wheat is grown in fields located close to the forest where wild animals may forage. Awned wheat varieties are apparently not favoured by wild animals.

SOIL CULTIVATION

2.3.3

If we grow winter wheat according to the regenerative approach, the principle to follow is "as little as possible, but as much as necessary".

Clearly, each soil cultivation treatment rather significantly affects air and water conditions in the soil quite intensively. They in turn affect the biological balance in the soil, as soil aeration causes humus to mineralise. In the regenerative approach, we want to have as little adverse impact on these parameters as possible. For winter wheat, we need to bring the soil to the most favourable conditions for the growth of wheat, but also keep in mind that the soil, apart from the crop, is home to beneficial macro and microorganisms that are also important for us.

After the fall of the forecrop, such as winter rape, early potato or pea, we have about one month to sow winter wheat. After the forecrop is harvested, tilling should be shallow and as quickly as possible. If we are going to use organic fertilisers, that is what we do first, followed by shallow tillage. Shallow tillage immediately after the forecrop is harvested has two purposes: first, it reduces the evaporation of water from the soil, and second, it stimulates the germination of weeds and covers the organic fertilizer, if applied. About two weeks after mechanical destruction of weeds, the field should be inspected and if there are a lot of weeds, shallow tilling should be repeated. This is to reduce weed infestation of the soil non-chemically. The next step is pre-sowing. We try to do this without ploughing, although ploughing is an option, for phytosanitary reasons, only where for some reason we need to grow wheat after corn. Typically, we would rotate crops so that to avoid the situation. However, on animal farms, especially cattle farms, it is difficult to rotate crops so that to avoid wheat after corn. In that case we do the plowing because it is necessary. In other cases, after other forecrops, we perform deep cultivation without tilling to about 20-30 cm and sow wheat in the soil so prepared. It is advantageous to use a mobile unit for deep cultivation, which in one pass will cultivate the soil to a certain depth and wheat sowing . If wheat is cultivated after a late forecrop, e.g. sugar beet or potatoes for storage, after organic fertilization, if any, perform deep cultivation and sow wheat. Shallow stubble cultivation is not performed here.

Instead of deep tillage over the entire surface of the field, only strips can be tilled. This method is called strip-till is becoming more and more important as a method of cereal cultivation. Undoubtedly, strip tillage is less resource-consuming compared to deep tillage with a tilling unit. In the case of strip till, only the strip where the seeds are sown is cultivated. This method still requires some agrotechnical studies, but it is likely to be widely used in the future for regenerative farming of winter wheat.

Strip-till cultivator.

SOWING

2.3.4

Sowing is one of the most important action in regenerative farming. After proper preparation of the field, we start sowing seeds.

Before sowing, we set the sowing rate. In regenerative farming, we always calculate the sowing rate based on TSW (thousand seed weight) and the intended plant density. Before sowing, we calculate a certain number of seeds per square meter, convert it into kg·ha^{-1} and attach the seeder. Canopy density is very important in the management of the plantation later. We want the least dense canopy, but dense enough to ensure the desired yield. Table 2 shows the theoretical yield potential of specific crops.

Table 2. Theoretical yield level, taking into account the yield structure at the same level of tillering (TSW of 45 g assumed for the calculations)

Sowing rate [number seeds · m^{-2}]	Number of branches [Number of blades · seed^{-1} · m^{-2}]	Number of spikes [number of ears · m^{-2}]	Number of levels in spike [number]
200	5	1000	8
250	5	1250	8
300	5	1500	8
Number of grains on each level [number]	**Number of grains [No. of grains · m^{-2}]**	**Yield from seeds* [kg · m^{-2}]**	**Yield [t · ha^{-1}]**
4	32000	1,44	14,4
4	40000	1,8	18
4	48000	2,16	21,6

*45g TSW assumed
Source: Own calculations

Table 2 shows that when sowing 200 seeds·m^{-2} and with the degree of tillering equal to 5, the potential yield is 14.4 t·ha^{-1}. This is obviously only theoretical yield that cannot be realistically achieved. The table is only to give the reader an idea of how important it is not to sow the seeds too densely. When sowing 200 seeds·m^{-2} and assuming that the sown wheat has TSW of 45 g, the sowing rate will be equal to 90 kg·ha^{-1}. Too dense fields mean problems in later plantation management. First, the higher the density of the plants, the higher the density of the canopy, the higher its humidity, and the greater the likelihood of fungal diseases. In addition, if the canopy is too dense, individual wheat plants compete for light, water and nutrients, and the denser the canopy, the greater its tendency to lodge.

In determining the sowing rate, the sowing date should obviously be taken into account, too. The later it is, the higher the sowing rate should be. Table 3 shows theoretical sowing rates at specific dates for wheat sowing.

Table 3. Examples of sowing rates taking into account the sowing date of winter wheat and the potential degree of tillering.

Sowing date	Sowing rate [number of seeds · m^{-2}]	Sowing rate [kg · ha^{-2}]*
Early	160 - 180	72 - 81
Average	190 - 220	85 - 99
Late	230 - 260	103 - 117

*TSW of 45 g was used for the calculation
Source: Own calculations

Winter wheat sown at the end of September. In the amount of 180 seeds · m^{-2} (about 90 kg · ha^{-1}). Photo taken in spring - wheat field optimally branched.

As shown above, the sowing rate in kg ha^{-1} is in the range from 72 to 117 kg. This value is consistent with the agricultural practice.

To note, modern farms increasingly often used seeders for precise sowing of seeds. If precision sowing is an option, it should be used for regenerative farming. Variable sowing is based on soil variability, and the highest seed sowing rate is used in the best part of the soil, and the poorer the soil, the less seeds are sown. That is beneficial because of lower yield capacity in poorer soil than in superior soil, and we should use a smaller plant density when the soil potential is smaller. At locations where less seeds are sown, less mineral fertilisation is used.

In addition to the sowing rate, the sowing depth is also an important parameter. Wheat should be sown to a depth of 2 to 4 cm. Deeper sowing means longer emergence and lower initial plant vigour. Too shallow sowing, on the other hand, exposes plants more to low temperatures and greater phytotoxicity of herbicides.

IRRIGATION

2.3.5 Conventional irrigation is of little importance in regenerative winter wheat farming.

That is because the efficiency of irrigation for winter wheat is not too high, and the costs involved are higher than the extra yield. In addition, irrigation significantly affects the moisture content of the canopy, and thus potentially increases the severity of fungal diseases. It is true that, on the one hand, proper hydration of plants improves their condition, but on the other hand, it can cause excessive wetting of the canopy, and thus increase the pressure from the diseases. In practice, irrigation in the cultivation of winter wheat may be justified only in exceptional cases, e.g. if we are dealing with the propagation of a very valuable variety, and it is the only one seed plantation. Irrigation may be considered in this case. It should be performed during the flowering stage. In practice, watering should start after the spike appear, just before flowering and then repeated during the formation of the grains. A dose of 40 mm should be used for both irrigation treatments, i.e. a total of 80 mm. After the irrigation, however an additional canopy protection treatment, such as additional shortening or fungicidal treatment, may be necessary.

In the context of broadly understood water management in wheat cultivation, regenerative farming encourages less water loss from the soil. First of all, ploughing should be abandoned as it will significantly increase the evaporation surface. In effect, water losses are greater from the fields where ploughing was applied.

Treatments performed after harvesting the forecrop, e.g. rapeseed, are also important. Volunteer rapeseed seedlings growing in the field where we are going to grow wheat soon should not be allowed to reach the 3-leaf stage. We destroy volunteers with a shallow mechanical procedure, e.g. using a disc harrow.

Organic matter (carbon) in the soil is also the focus of attention in regenerative water management. Organic matter increases the water holding capacity of the soil. Favourable conditions are also created by retention basins, whose creation is required in regenerative farming. Those basins, next to being a water source that can be used to irrigate other plants, such as potatoes, help surface water to seep up to the surface, which can be seen on adjacent fields. Better access of plant roots to the seeping water has a positive effect on the growth of plants growing next to them - for example, winter wheat.

VARIED FERTILIZATION OF PLANTS AND SOIL

2.3.6 Fertilisation of soil and plants in regenerative farming somewhat differs from conventional cultivation.

The main difference is greater awareness that winter wheat is one of the elements of crop rotation. It acts as a filler, as already mentioned in the chapter on the location and forecrop. In terms of fertilization, wheat in crop rotation consumes the residue of other species in the rotation, as elaborated on below.

Natural fertilisation is also very important for wheat.
Such natural fertilisers can be used for this species as:

- ***chicken manure***
- ***cattle manure***
- ***cattle slurry***
- ***and others of animal origin***

The use of chicken manure is very beneficial from the standpoint of regenerative farming. The manure should obviously be tested for the quantities of the respective nutrients to know what amounts are introduced with fertilization. It can be assumed that one tonne of chicken manure contains about 14 kg of N, 11 kg of P_2O_5, 8 kg of K_2O , 24 kg of CaO and 7 kg of MgO. The quantity used for wheat cultivation is 5 t·ha^{-1}. In addition to enriching the soil with nutrients, chicken manure introduces organic matter that microorganisms feed on, and also contains microelements.
Another useful natural fertilizer is cattle slurry (or whatever slurry is available). Its quantity for regenerative farming is assumed as 20 m^3·ha^{-1}. 1 m^3 of slurry manure contains about 3.4 kg of N, 2 kg of P_2O_5 , 3.7 kg of K_2O , 2.1 kg of CaO and 0.8 kg of MgO.

Cattle manure from cattle farms is a very good natural fertilizer that brings a lot of organic matter into the soil. However, in regenerative farming, it is used for species that are more demanding than wheat, such as potatoes, beets or vegetables. Hence, manure is rarely used for wheat cultivation. However, if for some reason we decide to use manure for wheat, it should be applied in the quantity of about 25 tonnes of fresh manure per hectare.

Natural fertilisation is beneficial for the regenerative farming of wheat, but not all farms have access to it, so it is not a necessary requirement. To note, organic or other natural fertilisers are more and more on sale, and the option should be used, because organic matter is very important in regenerative farming. An interesting type of such a fertiliser is the droppings of insects bred for animal feed. In addition to organic matter, with one tonne of that fertiliser, nutrients are also introduced in the following amounts: 42 kg N, 19 kg P_2O_5, 26 kg K_2O, 7 kg of CaO and 8 kg of MgO. The values are significant in comparison to chicken manure. An additional advantage of this fertilizer is its granular form, so it can be used as a mineral fertiliser, i.e. using an appropriate spreader.

Molasses is also a specific organic fertiliser, used for regenerative wheat farming in the quantity of 15-20l·ha^{-1} together with a liquid UAN or UANS fertilizer.

After natural fertilisation, ingredients brought into the fertiliser balance should be considered. Nitrogen deserves as special note, as the active nitrogen is considered for a particular fertiliser, that is the nitrogen incorporated into the balance. Nitrogen utilization factors for specific groups of organic fertilisers are given in the table below (Table 4).

Table 4. Specific nitrogen utilization rates for the respective groups of organic fertilisers with an example calculation

Type of fertiliser	Nitrogen utilization rate [A]	Fertilizer dose [t • ha^{-1}, m^3 • ha^{-1}] [B]	Total nitrogen content in [kg N·t of org. fer. ·$^{-1}$] [C]	Amount of active nitrogen taking into account the utilization rate [kg N • ha^{-1}] [A • B • C]
Chicken manure	0,40	5	14	28
Cattle slurry	0,50	20	3,4	34
Cattle manure	0,35	25	4,7	41

Source: Own calculations

Mineral fertilization

Precise doses of mineral fertilisers should be applied in regenerative farming. But before fertilisation begins, the quantities of the individual minerals in the soil must be determined. A chemical analysis purpose based on the Mehlich method should be performed to do that.

The results of the composition analysis are available in the form of an abundance map with different amounts of individual components showing in a specific place of the field. That map is used for precision fertilisation. In addition, other tools are used to determine the quantities of fertilization, e.g. satellite images showing how green the canopy is, which are used to determine the doses of N. A crop map of the species preceding winter wheat may also be useful. It can be used to adjust fertilisation.

Regenerative fertilisation for wheat farming is practically limited to nitrogen fertilization, with other types used with the preceding crop. For example, rapeseed can leave nutrients in the crop residues that are enough for wheat, especially in terms of potassium.

Nitrogen fertilization of wheat

As shown in Table 5, wheat needs about 210 kg N·ha^{-1} to produce 7 tons of grain. In regenerative farming, the nitrogen dose is based on the expected yield, with nitrogen introduced with natural fertilization subtracted. Table 5 below shows the fertilisation strategy for two types of wheat sown late and early in autumn.

Table 5. Nitrogen dose for winter wheat, considering the expected yield depending on the sowing date

Winter wheat sowing date	Expected grain yield [t • ha^{-1}]	Wheat nitrogen demand [kg • ha^{-1}] [A]	Nitrogen introduced with chicken manure [kg N • ha^{-1}] *[B]	Mineral nitrogen in the soil [kg N • ha^{-1}] [C]	Nitrogen fertilization demand of wheat [kg • ha^{-1}] [A-B-C]
Early	7	210	28	60	122
Late	5	150	28	60	62

*Data includes nitrogen that is active in fertilisation with chicken manure in the quantity of 5 t·ha^{-1}.
Source: W. Szempiński I inni 2020

Based on the data presented in Table 5, it can be concluded that the yield potential of individual wheats varies. Nitrogen fertilisation doses range from 122 to 62 kg N·ha^{-1}. Having calculated wheat's demand for nitrogen, we proceed to the fertilisation plan. In the two example wheats, the fertilisation strategy will be different. In the first case (early wheat), the dose of 122 kg N will be divided into 3 parts, i.e. 1 of 40 kg N, 2 of 60 kg N and 3 of 22 kg N. The first dose should be used to start the vegetation in the spring as soon as legally permitted, which is often BBCH phase 26-29. One may ask why is it so low? In regenerative farming, we make sure that wheat does not branch too much. That is because when the field is too dense, big problems with maintenance are to be expected, i.e. with shortening and proper protection. Wheat sown early is often very branched in spring, sometimes even too much. Fertilisation in the quantity of 40 kg N is not to stimulate unnecessary additional tillering. The second dose of 60 kg N is applied at BBCH 31 or later, but no later than BBCH 33, because late application of nitrogen may result in the reduction of grains in the spike. To note, 60 kg N is the maximum dose. In regenerative farming, this can be adjusted if the location so requires. For example, in a satellite image based on NDVI, we can see that one part of the canopy shows poorer condition and we know from other sources that the soil is poor in this area. In this case, we adjust the dose down or completely avoid this location in the course of fertilisation. The third dose is applied „on the spike", that is at the time of earing of the wheat. That dose is used only if humidity conditions are favourable.

The beginning of earing. Wheat just after the third dose of nitrogen. fertilization.

The situation is simpler for late-sown winter wheat. The balance shows that we should apply about 60 kg N ha^{-1}. Late wheat is usually poorly branched after winter, so we want to stimulate it to branch, and use all the nitrogen at once in early spring. It is also possible to divide this dose, i.e. 30 kg N·ha^{-1} with a herbicide treatment in autumn, and the rest, i.e. 30 kg N·ha^{-1}, in spring. Wheat fertilisation ends here in this case.

For winter wheat, we usually use nitrate-urea solution with or without sulphur in the first two doses. In the third dose, we use a dry fertilizer - ammonium nitrate or ammonium sulphate.

Potassium fertilization

In regenerative-farming potassium fertilisation, looks like this that potassium is applied in a slightly larger amount for the plant that precedes wheat. In this case, the plant residue of the preceding plant must strictly be left in the field. This fertilization method is used for winter wheat when it is grown after sugar beet, potato or winter rape. If wheat is cultivated after inferior forecrops, e.g. corn (especially when it was grown for silage), potassium fertilization should be performed. Precision spreading is used for potassium, taking into account the expected yield and the potassium content in the soil. Table 6 shows doses of K_2O depending on the abundance of that component in the soil.

The use of pure potassium salt is avoided in regenerative farming, and the preferred fertiliser is potassium sulphate. If we decide to use salt, then, in addition to potassium chloride, it should also contain other compounds. That is because chlorides form soluble forms with calcium in the soil, and so we can lose calcium from the soil by its washout.

Table 6. Fertilization values of K_2O in the cultivation of winter wheat depending on its content in the soil

Assumed wheat grain yield [t · ha^{-1}]	K_2O content in the soil				
	Very low	Low	Average	High	Very high
5	100	80	60	40	20
6	120	100	80	60	40
7	140	120	100	80	60

Source: Own calculations based on W. Szempiński I inni 2020

Phosphorus fertilization

Phosphorus fertilization on farms where natural fertilization is used for wheat can be skipped. Phosphorus can be present in the soil even in large quantities, but unfortunately it is not available to plants. In regenerative farming, however, we are dealing with high biological activity of the soil, which may cause the activation of phosphorus, i.e. the transition of phosphorus into a form available to plants. This is also the case on farms that use natural fertilisers and regenerative farming methods.

In exceptional cases, mineral fertilization with phosphorus can be used, which case precision fertilisation is applied, taking into account the abundance of this component in the soil and the expected yield (Table 7).

Table 7. Doses of P_2O_5 in the cultivation of winter wheat depending on its content in the soil

Assumed wheat grain yield [t · ha^{-1}]	P_2O_5 content in the soil				
	Very low	Low	Average	High	Very high
5	70	60	50	40	30
6	80	70	60	50	40
7	90	80	70	60	50

Fertilisation with sulphur and magnesium

Sulphur fertilisation for regenerative farming should assume 0.25 kg of S for each kilogram of nitrogen. When using natural fertilization, this demand is often contributed alongside. In other cases, mesh fertilization should be considered based on the amount of nitrogen applied. Sulphur can be in the form of potassium sulphate, ammonium sulphate, kieserite, calcium sulphate or elemental sulphur.

Magnesium fertilisation is based on chemical analysis of the soil. If the results indicate a deficiency of this nutrient, fertilisation with kieserite is performed. As with other components, magnesium fertilisation must take into account the expected yield and abundance of this ingredient in the soil.

Fertilization with microelements

Winter wheat requires fertilization with microelements such as Mn in the quantity of about 70 g·ha^{-1}, Zn in the quantity of 60 g·ha^{-1}, 9 g·Cu ha^{-1}. Fertilisation with microelements coincides with plant protection treatments.

PESTS AND DISEASES CONTROL

2.3.7

Prevention is very important in terms of plant protection in regenerative farming of winter wheat.

First, it needs to be ensured that wheat has most favourable conditions for growth. Winter wheat in good condition is much more resistant to infection by diseases and pests

There are four aspects of plant protection treatments in winter wheat farming:

- ***weeds***
- ***diseases***
- ***pests***
- ***lodging***

WEED CONTROL

Prevention is important in weed control for regenerative farming. After the early forecrop is harvested, at least two treatments of shallow soil cultivation should be performed, for example with a disc harrow. This significantly reduces weed infestation in winter wheat. It should be noted freshly sprouted weeds are much more effectively controlled after wheat sowing with the use of herbicides than those that sprouted immediately after harvest and are in a more advanced stage of development. In the regenerative approach to wheat cultivation, we try not to use glyphosate -based plant protection products. Glyphosate, apart from being a total herbicide, which kills all plants in the field, also adversely affects the development of soil microorganisms, disturbing the existing biological balance, and maintaining that balance in the soil is a priority in regenerative farming. Therefore, after the fall of the forecrop, mechanical weed control is performed as far as possible. The only legitimate reason for using glyphosate is the presence of couch grass. This weed is most often found locally and is not present on the entire field. Fighting it should therefore be performed also locally, and not on the entire field. Areas with couch grass are identified using the NDVI map and the treatment is performed only where it is necessary. About 10 l·ha-1 of molasses is added to the glyphosate mixture, intended to nourish soil microorganisms and thus mitigate the adverse effects of glyphosate.

After sowing winter wheat, the ultimate objective is to control monocotyledonous weeds, such as common windgrass, bromes, foxtail and others. In agricultural practice, we generally have two types of winter wheat crops - those sown early after forecrops that quickly leave the field, such as winter rape, peas, early potatoes, and crops that were sown after later forecrops, such as corn, late potatoes or sugar beet. The approach to these two types of crops is different in terms of weed control. For early winter wheats, we perform herbicide treatment on the third leaf (BBCH 13). At the same time, it is important not to exceed this phase, because later we may have a problem with eradicating common windgrass and other monocotyledonous weeds. In the latter case, if winter wheat is sown a little later, we perform the treatment immediately after sowing (BBCH 00). A question then arises, why do we spray at different stages?

In the first case, we are dealing with a situation in which the top layer of the soil can often be dry, and that does not promote a good herbicidal effect. Here, we deliberately wait for the weeds to emerge and then, in addition to the herbicide's effect on the soil, there is also the foliar effect – which is the first reason why we the treatment is delayed. The second reason is that previously sown wheats are often exposed to attacks by pests such as aphids and the third-leaf treatment is a combined weed and aphid control procedure. The third reason is related to the presence of winter oilseed rape crops on the farm. We must be aware that cereal herbicides can adversely affect its development, even if only small residues remain in the sprayer. Even small amounts of cereal herbicides in the sprayer can adversely affect the development of oilseed rape. Herbicide treatments for winter rape are therefore carried out only up to a certain point in the autumn, with rapeseed spraying finishing when the cereals sown first reach the third-leaf stage. In effect, the same sprayer for chemical protection treatments in is not used for these two groups of plants. This is essentially regenerative, as the objective is not to adversely affect the condition of the plants by our field activities.

In the second case, when we seeds are sown later, we no longer wait for the third leaf, but rather perform the herbicide treatment immediately after sowing. The justification here is also related to the care for the condition of the wheat. We must be aware that later sown wheat will be slower to emerge and grow (because temperatures are getting lower). Waiting for the wheat third-leaf phase could therefore mean mean that it will coincide with freezing temperatures. Negative temperature is a stress factor for winter wheat, just as the herbicide treatment, so we try not to apply herbicides when negative temperatures are expected.

Table 8. Examples of active substances useful for autumn application to winter wheat (control of monocotyledonous weeds):

Substancja aktywna	Date of application [BBCH]*	Remarks
Pendimethalin	Most effective in BBCH 00	Can be used at sub-zero temperatures
Diflufenican	In BBCH 03	It also fights dicotyledonous weeds
Flufenacet	No later than BBCH 02	Useful against foxtail grass
Metribuzin	Most effective in BBCH 00	Mainly controls dicotyledonous weeds, auxiliary in common windgrass control
Prosulfocarb	In BBCH 03	It supports the control of monocotyledonous but mainly combats dicotyledonous weeds
Chlorotoluron	No later than BBCH 03	It fights common windgrass well but only until the tillering phase! Some wheat varieties can be highly phytotoxic and the agent cannot be used there

*** works most effectively**
Source: Own data based on product label

For regenerative cultivation of winter wheat, it is important to control weeds as early as in autumn, while spring weed control should not be practiced. This is justified by the fact that wheat in the spring must grow intensively and build the yield. Herbicide treatment, on the other hand, always carries the risk of slowing down the growth of wheat and deterioration of its condition.

In this approach, weeds are eradicated in most cases, and only in exceptional cases and years do we need to perform a corrective treatment, but this is almost always only for dicotyledonous plants. It should be noted that herbicides that control dicotyledonous weeds are not as dangerous to wheat as those that control monocotyledonous weeds. That results from biochemical properties of wheat. Wheat is also a monocotyledonous plant and herbicides that control monocotyledonous weeds also have a significant impact on its physiology and can significantly worsen its vigour and condition.

Foxtail is one of the most dangerous weeds in cereal cultivation. It prefers heavier, wetter soils. The growth and development biology of foxtail is very similar to that of wheat, especially at the beginning of the growing season. Foxtail, on the other hand, blooms and produces seeds a little earlier. If presence of foxtail is identified in a given regenerative-farming field, crop rotation should be set up so that wheat or other cereal species do not occur too often in that field. In such fields, grain should be grown at 5-year intervals. Fighting foxtail is difficult because it becomes resistant to herbicides used in cereals very quickly and when it acquires that resistance, it will be very difficult to fight it. In dicotyledonous crops, such as pea, rape, potato, we can use other herbicides to combat foxtail, which are slightly more effective than those that can be used for winter wheat. In addition, if we cultivate spring species in a field infested with foxtail, we have more time to fight this weed mechanically. In addition, in the regenerative cultivation of spring species, cover crops are sown that are able to effectively compete with foxtail. This again shows how important a holistic approach is to regenerative farming.

Pest control

As already mentioned in the section on cultivation, reduce tillage is usually used for regenerative winter wheat farming. No- till cultivation has many benefits, but it can also produce some hazards in the context of pests. In fields cultivated without ploughing, an increase in the number of rodents can be observed, and there may also be a higher density of pests that are insects, such as noctuid moths (these after ploughed out to the surface during the till and may be eaten by birds).

Protection of the nest of birds of prey. The photo shows the protection of the nest of the Harrier (Circus pygargus) in triticale cultivation as an example of caring for the natural enemies of rodents.

That is why proper crop rotation is so important for regenerative farming of cereals, including wheat. Growing cereals after each other should be avoided, as this is one of the basic non-chemical pest control methods. In addition, mid-field woodlots should also be ensured, as well as other landscape features providing a shelter for predators that feed on pests.

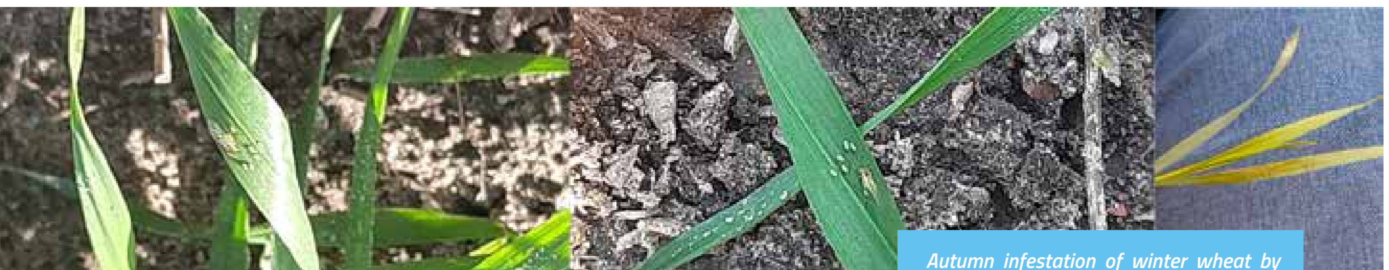
Dangerous pests in cereal cultivation are:

- ***rodents***
- ***soil insect, such as noctuid moths***
- ***aphids***
- ***wheat and grain midge***
- ***cereal leaf beetle***

It is very important for pest control to have as many birds of prey within the plantation, which are able to significantly reduce their population.

Soil pests are very dangerous for cereals. They often occur after certain forecrops - for example, caterpillars of noctuid moths are more often identified in winter wheat after winter oilseed rape. What can we do to limit their presence? First, the field should be inspected after rapeseed and before wheat cultivation, at the stage of mechanical weed control. If there is a significant presence of noctuid moths, ploughing should be considered, or in exceptional cases, wheat cultivation may also be abandoned. In terms of non- chemical methods, apart from ploughing, there is also the option of using predatory nematodes - entomopathogenic species of the genus Steinernema. It is best to apply them at night as spray, because noctuid moths are active at night, and their caterpillars' feeding is also mainly at night. Night nematode spraying ensures that the preparation gets on the caterpillars, and then the nematode will penetrate and kill them from the inside. This treatment is definitely effective, but also quite expensive. The advantage is that the nematodes can control other pests, too. Regenerative farming prefers this control treatment, but if it cannot be used for some reason, a chemical treatment should be considered, which must be performed at night.

Aphids are generally not a big threat to the cultivation of wheat and other cereals. However, there are exceptional situations in which the sucking of cell saps from cereal tissues can also be very dangerous (this is how aphids feed). That may occur when it is very dry and the plants do not have much cell sap. If feeding does not have a significant effect on the condition of the plants or the yield, the pest is not controlled in regenerative farming. Aphids can feed on plants practically throughout the growing season of wheat, but they pose the greatest threat at the beginning of the growing season, that is, in autumn, when winter wheat plants are quite small. Aphids, apart from the fact that they can feed on wheat itself and cause direct damage, which is usually not dangerous, can also be a vector for dangerous viruses. There is no effective treatment against viruses, and infestation of wheat crops by them can cause significant losses in the yield. Infection by viruses is especially dangerous when wheat plants are still young. The later the infection occurs, the less serious the effects. Therefore, aphids should be treated ruthlessly as soon as they appear in the crop. The most effective way to control aphids is to treat wheat seeds with insecticides. Unfortunately, there are currently no approved seed treatments with insecticide for use on winter wheat. Therefore, this insect should be controlled by insecticidal treatment. This pest most often attacks wheat sown early, so one of the insecticides against aphids is added to the herbicide treatment (as described above). It is important in regenerative farming to monitor the presence of aphids on wheat plants. White sticky boards can be used for that purpose.



Autumn infestation of winter wheat by aphid is especially dangerous.

Midges are very dangerous cereal pests. They occur more often on heavy soils and their numbers are greater in humid years. The primary method of controlling this pest is appropriate crop rotation in which wheat should not be grown after cereals. Midge overwinters in crop residues or soil, and so it will occur more often where cereals were grown in previous years. Timing is very important for the control of midges, and we should target adult insects that arrive on the plantation before they lay eggs. The larva of this insect, which bites shoots or grains (depending on the species), is dangerous for wheat. The presence of adult insects on the plantation should be a factor in the decision on control treatments. Sticky boards are used for this purpose, preferably on the side of the field where wheat was grown in previous years, because the insects will most likely come from that direction. The protective treatment is performed after a strong raid of insects is identified.

Another pest found on wheat plantations is the cereal leaf beetle. Generally, control of this pest is typically abandoned in regenerative farming. Even though cereal leaf beetle is present almost every year in wheat fields, it is not usually a pest that can significantly affect the yield. Cereal leaf beetle control is rather treated as an „incidental" treatment - for example, when performing treatments against rust, we can use the relevant insecticide if there is a significant pressure from this insect. The procedure is however not performed only because the beetle is present in the field.

Other pests than those described above may also be present in wheat, but they do not pose a significant threat to its cultivation. Nevertheless, the plantation should always be inspected and an appropriate decision should be made regarding possible treatments where justified. Overall, inspection of the plantation is a must in regenerative farming in terms of plant protection.

Disease control

Dangerous diseases for winter wheat are:

- ***stem base diseases***
- ***septoria***
- ***fusariosis***
- ***powdery mildew of cereals***
- ***rust***

The selection of an appropriate variety, suitably resistant, as mentioned earlier in this study, and crop rotation are important in reducing the presence of diseases in the cultivation of winter wheat.

Among wheat varieties there are many that are resistant to particular diseases. For regenerative farming, those that show high and very high resistance to basic diseases should be preferred. In addition, a properly selected crop rotation is also important for wheat cultivation, and wheat should not be grown after other cereals.

A good example of controlling diseases by properly selected crop rotation is the control of stem base diseases. The fungi that attack the stem base are the species: *Geumannomyces graminis* var. *Tritici* , causing stem base blight. This disease can be limited only by proper crop rotation or chemical treatments of grain based on siltiofam as the active substance. *Pseudocecosporella herpotrichoides* causing brittleness of the stem; *Fusarium* spp. responsible for fusarium disease, stem blight and *Rhizoctonia cerealis* – a species causing sharp eyespot. All those diseases are very dangerous for winter wheat cultivation, and hence the importance of crop rotation. Another very important factor limiting the occurrence of the above diseases is the treatment of seeds with appropriate preparations, very effective in chemical control of stem base blight. The third method of reducing the occurrence of diseases in wheat is chemical treatment, but performed very early in the spring - until BBCH 29, before the shooting phase. The timing is such because cereal plants are still creeping at this time, they do not rise, which ensures best access to the base of the stem and better effect of the treatment. This procedure is also associated with preventive reduction of powdery mildew and shortening. In a regenerative farming, this may be the only chemical treatment to protect wheat crops from diseases. To control stem base diseases preparations based on: prochloraz, triazoles (e.g. tebuconazole), and to a lesser extent also on metraphenone and ciprodinil, are used. The regenerative approach uses a protective treatment with a mixture of different fungicides in smaller doses. It should always be remembered that fungicide treatments also affect the condition of the plants.

Spectoria tiritic, a species of fungus, causes septoria. The selection of the appropriate variety significantly reduces the occurrence of this disease. In regenerative farming, septoria may not be of significant importance and control may not be necessary. The pressure of the fungus causing this disease is greater in wet years. Often, a well-performed treatment against stem base diseases significantly reduces its occurrence. This disease is dangerous in the later stage of wheat vegetation, but good protection of the lower parts of the plants can significantly reduce its occurrence. Preparations based on triazoles or on active substances from the SDHI group are effective against this disease.

Powdery mildew of cereals is a group of diseases that occurs on every plantation, but they are typically not very harmful. In regenerative cultivation of wheat, a single treatment with one of the preventive agents is used to reduce its occurrence. Figure x shows preventive agents containing proqunazid (this agent is very long-acting, but only preventive), metraphenone (shorter preventive action and has a slightly interventional effect). In regenerative cultivation, one of the preventive preparations for powdery mildew is most often added to the first treatment against stem base diseases, and this is most often effective in reducing its occurrence until the end of vegetation. If the pressure of powdery mildew is really high, morpholine agents can be used, but in very small doses, which have a good effect on powdery mildew eradication.

Wheat rust is a disease that tends to occur later in the growing season. Most often, ad hoc interventions are not needed to combat it. Rust is more often controlled in the cultivation of winter rye. In wheat, it most often appears just before harvest, and its pathogenicity in that period is limited. It rarely happens that rust needs to be controlled where it occurs relatively early, before or just after earing. In this case, preparations based on triazoles, strobilurins or preparations from the SDHI group are very effective. For regenerative cultivation, it is better to use preparations based on strobilurins or from the SDHI group to control this disease. Triazoles are not recommended, because when applied at the time of higher temperatures (which takes place at earing) or just after them, they show quite aggressive effects on plants and can negatively affect growth.

Fusariosis is the collective name of diseases caused by fungi of the genus *Fusarium* spp., which, in addition to infesting the stem base, may also infect the spike. This happens rather exceptionally, in years of non-typical weather. The occurrence of this disease is more frequent during very humid weather, e.g. long-lasting dew in the wheat blooming phase. In those years, it may be necessary to apply a chemical treatment against this disease, however, the treatment against spike fusariosis is usually omitted in regenerative cultivation. This is because the treatment window is very short - it is about 24 hours from the infestation. Infestation occurs when wheat blooms. In practice, 24 hours is a very short time, and the effectiveness of the treatment against fusariosis is very limited if the treatment is performed later. This disease is more common in areas where wheat is grown in short rotation. The goal in regenerative farming is to grow wheat infrequently in the same field, which significantly reduces the incidence of this disease.

To sum up wheat protection against diseases in regenerative cultivation, it should be argued that the first treatment, performed until the BBCH 29, i.e. shooting, is the most important. It is absolutely necessary because it protects the field against diseases of the stem base and „cleans the leaves" from any other fungi that may cause diseases at a later stage of wheat vegetation. Leaf diseases such as fusarium, powdery mildew, septoria or rust are most common on subflag or flag leaves. The spores of the mentioned fungi can get to the plantation from two directions: 1. with the wind - then they occur only on the up-

Early infestation by winter wheat rust requires chemical intervention already at the beginning of vegetation. Such behavior will result in later stages.

per part of the canopy on flag and flag leaves , which are well accessible to the process liquid and possible spraying will easily reach the surface of these leaves; 2. „from below" - fungal spores spread from the lower leaves and in this case the situation is more complicated. Because we do not eliminate the source of diseases from the lower parts of the leaves early enough, the threat may occur practically until the harvest of wheat and significantly reduce the effectiveness of treatment on the flag or sub -flag leaf . That is why the first procedure, performed at BBCH 29-33 stage, or even a little earlier, is so important. This procedure necessary and indispensable. It often happens in regenerative cultivation that this first treatment is sufficient until the end of the vegetation. Any other treatments are just a correction of the first treatment. The date of the first fungicidal treatment is usually in the period when the wheat shortening treatment should also be performed.

Treatment against wheat lodging

Lodging of plants occurs most often when winter wheat is in the spike-filling phase. In this period, not much can be done, and so the shortening procedure should be performed much earlier. This treatment is performed at the beginning of the stem shooting, in the BBCH phase 29 to 33. The shortening treatment is combined with the first fungicidal treatment and it decides on the spraying date.

A field of wheat that has been sown early is usually quite well tillered. Sowing density is important in reducing lodging. The date of the shortening treatment is closer to BBCH 30 when the wheat field is strong and tillered. In this case, the treatment should be performed very early, at the very beginning of the stem shooting, i.e. at BBCH 30-31. If the wheat is sown later, the treatment can also be performed later. The only exception is when we want to achieve additional tillering, which is usually the case with very late sowing. Then we also perform this procedure at BBCH 21-29.

Several available preparations based on the following active substances are used to shorten cereals:

chlormequat chloride (CCC) *– preparations based on this active substance are quite effective, but they have one big disadvantage - they are very phytotoxic, and stop the growth of wheat completely outside the main shoot. They also stop the growth of roots, which is not beneficial, because a well-developed root system improves the resistance of plants to drought. This agent is avoided in regenerative farming. It is used only in exceptional cases, e.g. when wheat grows „aggressively" and we can predict that it may fail. However, do not use a dose higher than 500 g CCC·ha^{-1}. Another exception justifying the use of CCC is when we want to do additional tillering. In this case, use a dose of about 50-100 g CCC·ha^{-1}. The tillering is performed in spring, when the plants are in the phase of 2-3 leaves and begin to go into the tillering stage. After shooting, wheat does not tiller any more, so the tillering procedure at this point makes no sense.*

ethyl trinexapac *– this substance is not as aggressive as chlormequat chloride, because the action of this substance is slightly different than CCC and does not have such a negative effect on root growth. Compared to CCC, it is also better at stopping shoot growth once the shooting phase has started (BBCH 33).*

The effectiveness of CCC compared to trinexapac-ethyl is better in the earlier phase, at BBCH 29-30, than in the later phase, like BBCH 33. This is because ethyl trinexapac inhibits shoot elongation growth, but does not inhibit cell division in a plane perpendicular to the surface of the shoot. A clear disadvantage of preparations based on this active substance is that they perform worse on cloudy days.

calcium prohexadione *– this substance can be classified between trinexapac and CCC. Calcium prohexadione is not as aggressive in action as CCC, and at the same time works effectively for shortening. It is worth mentioning that the added value of using preparations based on this agent is additional fertilization of plants with lime, which is very important in regenerative cultivation.*

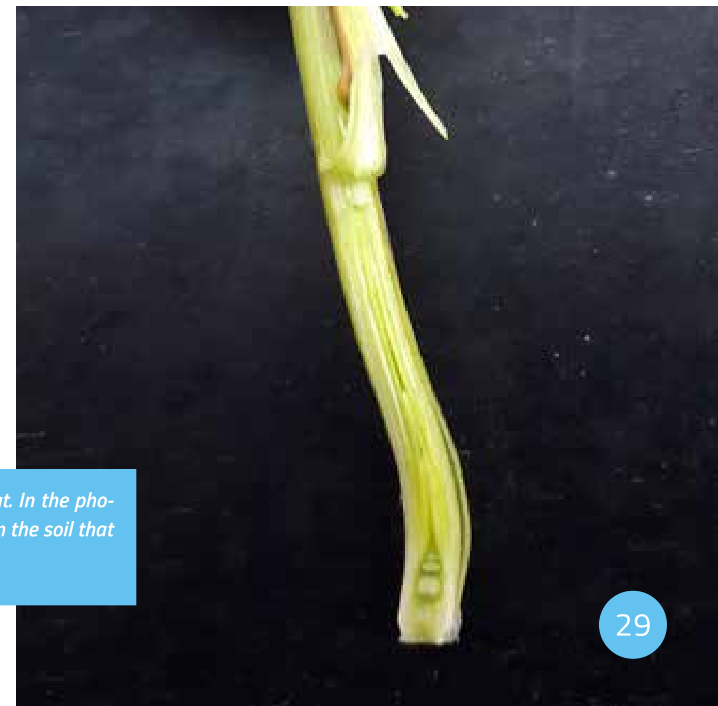
ethephon (ethylene generator) *– ethylene is a plant hormone, often called the "old-age" hormone. For this reason, the use of ethephon -based regulators is possible only when shortening the stem. Ethylene has a very controlling effect on winter wheat, and therefore it is not used for regenerative farming.*

fungicides from the triazole group *are also of some importance in the shortening of plants. However, they are used as a supplement to the basic shortening. Their effect is about 3 times less than trinexapac-ethyl, however, when determining the dose of the growth regulator, the possible use of triazoles in the spray mixture should also be taken into account and the dose of the regulator should be reduced.*

some herbicides are also important in the shortening of plants, especially from the group of growth regulators, such as MCPA, but also sulfonylureas or pinoxaden.

To sum up the protection of winter wheat in regenerative farming, it should be noted that the treatment against weeds is usually carried out in autumn, while in spring a possible correction is applied, but only to dicotyledonous weeds. The control of monocotyledonous weeds still at this stage should be avoided. Monocotyledonous weed preparations have a very adverse effect on wheat.

The dates of spring treatments depend on when we perform the wheat shortening treatment. In regenerative cultivation, we always combine treatments, i.e. shortening with fungicide, insecticide with fungicide. In practice, the first treatment is always performed in the phase from BBCH 25 to BBCH 31, as a protective and shortening treatment. Subsequent treatments depend on the intensity of wheat growth and the weather. If the weather is rather dry, further treatments are usually not performed. If the weather is rather rainy and wheat grows quickly, there is often a need for an additional treatment, including shortening (using only calcium prohexadione or trinexapac-ethyl) in the BBCH phase around 35, in combination with a fungicidal treatment.



Stubble after growing wheat. In the photo you can see small holes in the soil that earthworms have made.

COLLECTION AND STORAGE

2.3.8

Grain harvesting and storage do not differ significantly between regenerative and conventional cultivation.

The only thing is that regenerative farming never uses pre-harvest chemical desiccation with glyphosate or any other such substance. In regenerative cultivation, we wait until the grain reaches the desired moisture content (14-16%) in a natural way, and then proceed with the harvest. It is allowed to collect wetter grain, if necessary, and then dry it in the dryer.

Desiccation is not used for several reasons:

- *glyphosate has a negative effect on soil microorganisms, and can disturb the biological balance in the soil; besides, glyphosate can remain on plants in the form of residues, which is not beneficial as it degrades grain quality*
- *the use of desiccant during harvesting entails purchase costs, moreover, and an additional entry into the field means additional costs and additional exposure of plants to destruction*

View of a winter wheat stubble field where crop residues have been chopped.

For these reasons, this procedure is not performed. When harvesting wheat in the regenerative approach, it is also important that the by-crop stays in the field. Straw is a valuable organic fertilizer and, in addition to organic matter, also leaves nutrients for subsequent plants. In the regenerative approach, we strive to leave the straw in the field. Clearly, if animals are also farmed, it is necessary to collect straw from the field. In this case, straw is always harvested from fields where the succeeding crop is a species that favourably affects the balance of organic matter in the soil. Such crops include, for example, leguminous plants (legumes and small-seed legumes), rapeseed. . Straw must be left on the field as a fertilizer where potatoes or sugar beet are the successive crops.

Yield mapping can be performed during the harvest. The map is important about recognising field variability, on the basis of which optimized decisions on fertilization of the successive plant are later made.

Yield map made with a harvester adapted to its production.

In terms of cereal grain storage, it is important to prepare a suitable storage location. The place where the grain is stored should be properly disinfected. Such treatments are outsourced to a specialized contractor that will perform the treatment with due diligence and care for the environment. Stored grain should have appropriate moisture, not more than 14%.

SOIL PH REGULATION AND THE ROLE OF CALCIUM

2.3.9

Calcium plays an important role in regenerative wheat cultivation. In conventional agriculture, the role of calcium is often limited to pH regulation.

In regenerative cultivation, however, it is recognized that calcium, apart from pH regulation, affects other important aspects of biological life in the soil. Proper pH of the soil can be considered from the point of view of the crop, but also from the point of view of the biological life. Winter wheat has high pH requirements and in order to grow properly, it requires pH ranging from slightly acidic (5.6) to even alkaline (7.5). A value that is optimum for the growth of wheat should be close to neutral - pH 6.5. Winter wheat can grow well in a wide range of soil pH, but it does not tolerate acidic reaction and grows much better on alkaline than acidic soils.

As mentioned earlier, wheat is a filler plant in crop rotation in regenerative farming. Its cultivation is aimed at rebuilding the resources of organic matter after the cultivation of root crops and has a positive effect on the soil structure, which is also related to the presence of calcium ions in the soil, which stabilise its structure. In the regenerative approach, it is also important to keep the pH close to 6.5, although wheat is able to grow well even in more alkaline soils. This is based on the holistic approach to farming, a hallmark of regenerative agriculture. The holistic approach assumes that each crop in the crop rotation should benefit the others. In the case of winter wheat, pH should be kept close to 6.5, as subsequent plants in the crop rotation may react less favourably to higher pH. We should also keep the soil pH in subsequent crops at a similar level, with biological life of the soil in mind. Properly arranged and conducted crop rotation creates a biological balance between the organisms. In the spirit of regenerative agriculture, acting as stewards of the cultivated soil, we do not want to disturb this balance, and strive to maintain it so that it remains more or less constant between individual crops. If the pH value is too low, then liming should be used. The best fertiliser lime is based on chalk or comes from the food industry (e.g. sugar mills). Dolomite limes are not so much recommended, because in addition to calcium, they introduce magnesium into the soil, which can be unfavourable. This is important thinks because in the soil has to be proper ratio of individual components in the soil. If we use dolomite without add calcium we introduce large amounts of magnesium. In this approach magnesium can disturb ratio of individual nutrients in the soil. It is a slower-acting lime compared to chalk or sugar lime. If there is a decrease in soil pH, we want the soil pH to return to the optimum pH range of 6.5 relatively quickly (this is important for biological balance).

What happens if the soil pH is normal or too high? In regenerative agriculture, the role of calcium is not limited to regulating soil pH, as previously mentioned. Calcium is an essential macronutrient and winter wheat needs about 35 kg of CaO·ha-1 to produce 7 tons of grain. This is quite a large demand that the plant covers from soil resources. It may happen that the pH value remains in the range of 6.5 all the time, but this does not mean that the plant does not take up calcium. Therefore, in regenerative agriculture, calcium fertilization is used and attention is paid to regulating the pH of agricultural soil. If the pH of the soil is too low, liming is used, if it is too high, one of the physiologically acidic fertilizers, for example ammonium sulphate or elemental sulphur, can be used to lower its value. If the pH is optimal, and we conclude from the results of the chemical analysis that there is not enough calcium available for plants in the soil, we fertilize the soil with lime. We use calcium sulphate for this, adding calcium nitrate to the spraying.

To sum up, the calcium has the following roles in regenerative cultivation of winter wheat:

- *calcium as an element that can regulate the pH value in the regenerative approach to crops: soil pH should be close to 6.5, as this is the preferred value for the vast majority of cultivated plants. Moreover, constant soil pH will help maintain biological balance in the soil*
- *calcium as an essential nutrient for plants: winter wheat needs about 5 kg of CaO·ha^{-1} to produce 1 tonne of grain, so in the regenerative approach, apart from determining the pH value, we should also ensure that the calcium content is determined to make an informed decision about fertilisation. If the pH value is appropriate, and yet this macroelement is missing in the soil, we fertilize with calcium fertilizers that do not alkalize the soil, such as calcium nitrate or calcium sulphate.*
- *calcium also has a very important role in maintaining the proper structure of the soil: calcium in the soil is a divalent ion, classified as an agent that binds soil particles into aggregates. It has the ability to combine organic particles, organic with mineral ones, and the presence of calcium in the soil is conducive to the development of a favourable aggregate structure of the soil and the maintenance of a stable lumpy structure.*

2.4 SUMMARY OF PRACTICES AND ANALYSIS OF BENEFITS

In conclusion, particular attention is the regenerative farming of winter wheat is paid to:

- selection of location in crop rotation: wheat should be cultivated after non- cereal forecrops, the correct crop rotation means less pressure from diseases and pests and better health of the plants, including their resistance to environmental conditions,

- soil cultivation in the regenerative approach is minimized, cultivation units should be used for deep cultivation or strip till; this approach limits heavy interference with the soil's biological balance and slows down the mineralization of soil organic matter,

- as regards plant protection, all possible non-chemical methods of reducing the occurrence of pathogens should be used, starting from a properly selected crop rotation, appropriate variety, and chemical plant protection treatments should be performed at optimum times,

- natural fertilization should be used, whereas, for mineral fertilization, nitrogen should be used only when we expect it to be absorbed; the condition of the plants should be assessed based on satellite imagery specifying the NDVI and other field data, on the basis of which the dose of fertilizer is adjusted,

- during the harvesting, we try to leave a by-product in the form of shredded straw as far as possible, especially if plants that adversely affect the organic matter in the soil are grown in the crop rotation

The rule in regenerative wheat farming is that it leaves the best possible site for successive plants. We assume that the cultivation of wheat itself has a positive effect on soil properties and, in the regenerative approach, we try to increase its repair capacity relative to the soil environment. This approach has a positive effect on the stability of wheat yield over the years, and improves the site for subsequent crops. It is also important that, as a result of holistic approach, wheat grain from regenerative cultivation is of better quality, is free from pathogens, and has a better chemical composition.

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Winter wheat is an importance cereal for the economy. It is the world's third most harvested cereal type. In terms of global harvest, it comes behind maize and rice only. For these reasons, wheat can be considered the basic source of food for the whole society.

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