Aneta Perzanowska, PhD Eng
Magdalena Wijata, PhD Eng

06

BARLEY
SPRING AND WINTER

CEE REGENERATIVE AGRICULTURE GUIDEBOOK

TERRA NOSTRA FUNDACJA

eit Food

Co-funded by the European Union

CEE REGENERATIVE AGRICULTURE GUIDEBOOK - BARLEY SPRING AND WINTER

Author:
Aneta Perzanowska, PhD Eng
Magdalena Wijata, PhD Eng

Graphic design:
Maciej Wilgosiewicz
Piotr Krukowski
Agencja reklamowa Pixel Star

Publisher:
Fundacja Rozwoju Rolnictwa Terra Nostra
www.fundacjaterranostra.pl

Project Owner:
EIT Food
www.eitfood.eu

Co-funded by the European Union

EIT Food

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

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

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

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

More information at www.eitfood.eu

The Terra Nostra Foundation for Agricultural Development

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

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

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

More information at www.fundacjaterranostra.pl

06

BARLEY

SPRING AND WINTER

CEE REGENERATIVE AGRICULTURE GUIDEBOOK

Poznań 2023

TABLE OF CONTENTS

REGENERATIVE GROWING OF SPRING AND WINTER BARLEY

1

INTRODUCTION TO REGENERATIVE FARMING

Barley is one of the oldest and most widely grown crops and its many advantages can be used in the regenerative approach to barley growing.

Compared to other crops it is a plant which matures and is harvested early, which makes it possible to use barley as a cover crop for undersown crops and to sow various types of catch crops after it as early as July. Barley manages water sparingly, is resistant to droughts and temperature fluctuations, and thanks to its fast development uses well rainwater in the autumn and spring.

Barley grain has many uses, but is mainly used for fodder as a basic ingredient in concentrate mixtures in feeding animals. A significant part of grain yield is used for industrial purposes, mainly for malt production. These diverse directions in the use of barley grain pose different requirements for the grain quality properties which are to a large extent determined by the variety and the applied agricultural technology.

Regenerative barley growing, irrespective of the grain designation, should be characterised by care for soil health and the whole agroecosystem. Particular attention should be paid to optimisation of agricultural technology on sites where barley is grown and to barley itself. The priorities in regenerative management are the protection of soil resources of organic matter, water and nutrients and the biological diversity of soils and the entire agroecosystems, which is a way to achieve satisfactory and stable barley yield in changeable environmental conditions.

2 CLIMATIC, NUTRITIONAL AND SOIL REQUIREMENTS

Barley is grown from the far north and high altitudes to subtropical zone, which shows great adaptability of this species to various environmental conditions

Understanding soil and climatic requirements of barley is crucial in planning regenerative cultivation of this cereal species.

Barley is well adapted to various soil conditions, despite its root system not being as well developed compared to other cereals. Because of this, barley has a lower capacity for absorbing nutrients from the soil that are less readily available, compared to rye or oat, therefore barley grown on good soils, rich in nutrients, with a well-developed humus horizon and balanced pH, yields the highest yield that is stable over the years. On the other hand, barley relatively easily adapts to poorer soil conditions and may produce satisfactory yield also on lighter soils, including soils with a significant sand fraction, provided soil pH is regulated and appropriate agricultural practices are used, in particular treatments improving soil water retention. It should also be remembered that growing barley on poorer sites affects not only yield height, but also grain quality – insufficient soil moisture in the growing season, often affecting lighter soils, contributes to the increase in protein concentration in grains in relation to starch, which poses a problem for growing malting barley. Therefore, malting varieties of barley should be grown on heavier soils, with better water retention capacity compared to lighter soils.

Barley has relatively low water requirements compared to other crops. In order to produce 1 kg of dry mass it uses approximately 350-400 litres of water, while cereals such as wheat or oat manage water less sparingly.

The main root mass of barley is relatively shallow, but individual roots may reach up to 1.5 m under the soil surface, ensuring the survival of plants in less favourable periods. Barley roots develop from the germination (development of rootlets), through the tillering stage (development of secondary roots) until the flowering stage and flower fertilisation. It has been noted that barley produces a larger and deeper root system if soil conditions at the initial stages of growth were less favourable, which may be considered as the species adaptive measure to changeable soil and climatic conditions. With lower soil moisture content and associated limited access to nutrients, barley roots grow deeper in search of water with ions dissolved in it. Although most water is taken up by barley from the soil layer up to 50 cm deep, a well-developed root system may increase the range of water uptake even to the soil layers >100 cm deep, which is of particular importance in the period of critical rainfall shortage. Compared to spring type barley, winter type develops a more extensive and deeper root system, which spreads intensively in the spring. Therefore, in moderate climate of Central Europe winter type barley uses up soil moisture as early as the start of growing season after winter and is not as sensitive to rainfall shortage as spring type barley. Due to a very short growth period of spring barley (110-130 days) even short-term droughts may significantly affect its growth and yield, therefore compared to winter barley it is more unreliable in yield on poorer soils.

TECHNOLOGY OF REGENERATIVE FARMING

3

Site and forecrop

3.1

Inappropriate position of barley in crop rotation on a specific field contributes to a decrease in yield and the need of greater chemicalisation of crops and associated financial and environmental costs incurred on pesticides.

In selecting the site in regenerative barley growing not only should the type of barley (winter or spring) be taken into account, but also the use for the grain. Barley grown for fodder has different requirements as to the site than malting barley grown for processing in the brewing industry. When growing malting barley which requires precise fertilisation with nitrogen, sowing barley after legumes should be avoided as their after-harvest residues are rich in nitrogen (Table 8), which is released into the soil solution in an uncontrolled way. A high protein content in malting barley grain negatively affects the extract efficiency and quality of beer which becomes less clear. Malting barley may be grown after root crops on manure and after vegetables where no intensive nitrogen fertilisation was carried out.

The choice of the site for growing winter barley should first of all take into account the timing of harvesting its forecrop and its nature. The best forecrops for winter barley, which is sown relatively early before winter, are crops harvested early and belonging to dicotyledonous plants (playing a phytosanitary role): in the family of legumes (early varieties of peas and determinate varieties of lupin), Brassicaceae (rapeseed, white mustard and radish grown for seeds), early harvested potatoes or other dicotyledonous crops the harvest timing of which allows for the timely sowing of winter barley. Slightly less favourable forecrops from the point of view of agricultural practice timing are late potatoes and legumes harvested at the end of August. Some hybrid varieties of winter barley show some tolerance for delayed sowing without a decrease in yield and for this reason can be grown even after later forecrops. Good forecrops for spring barley are also dicotyledonous crops harvested late – late root crops (potatoes, sugar beet, vegetables), faba bean, soybean, and other legumes harvested late (for fodder barley), buckwheat grown for seeds, sunflower. Spring barley for silage and grain can also be grown after corn. Spring and winter types of fodder barley can be grown after small seeded legumes. Due to the risk of producing lower quality grain, affected by diseases after cereal forecrops, malting barley varieties should definitely be grown after non-cereal forecrops.

Although both spring and winter barley are less sensitive to being grown following cereal forecrops than wheat, in the regenerative approach growing winter and spring barley after other cereals definitely has to be avoided due to one-sided depletion of soil of nutrients, but mainly due to transmission of diseases and soil fatigue, which may require more intensive chemical protection of the stand. Keeping the share of cereals in the cropping pattern below 50% significantly facilitates the selection of the best forecrops for barley, which are considered to be dicotyledonous plants.

Negative response of barley to being grown after itself and other cereal crops is stronger on poorer soil complexes, compared to better ones. The largest decreases in barley yield (>15%) may occur when barley is grown directly after barley. The best forecrop, both for winter barley and spring barley, among cereal crops is oat due to its phytosanitary function. Oat is considered to be a phytosanitary plant in cereal succession mainly due to the presence of avenacin – a saponin toxic to pathogenic fungi. However, frequent return of oats to the same site may result in proliferation of parasitic nematodes in soil, mainly cereal cyst nematode (cereal crop eelworm, Heterodera avenae), which in extreme cases may lead to a large decrease in cereal yield. Therefore, the oat/barley succession must not be used too often in crop rotation.

Both spring and winter barley are good forecrops for winter rapeseed which is the earliest sown winter crop. Root crops can also be grown after barley, as well as cereals such as oat and cereal mixtures. Barley or wheat should definitely not follow barley.

In case of growing spring barley in the succession: early harvested forecrop – spring barley, in order to avoid leaving the soil uncovered for the autumn and winter season, stubble catch crop of spring species should be introduced between these main crops. In case of growing spring barley after other cereals, a catch crop of dicotyledonous plants will play an important phytosanitary function. Growing stubble catch crops before winter barley is not justified due to a short period between harvesting the catch crop and sowing winter barley.

Stubble catch crops should be sown during the first loosening and mixing post-harvest cultivation. With this approach, the soil does not lose water unproductively and the early timing of stubble catch crop sowing is definitely more important than the precision of cultivation before sowing it. The earlier the stubble catch crop is sown, the greater biomass it produces. Early sowing of catch crop (by the end of July, alternatively by 5th August) is particularly important for legume catch crops, sunflower, millet, and corn. Species such as white mustard, radish, buckwheat, and phacelia are less sensitive to later sowing as catch crops (until mid-August). Stubble catch crop biomass should be left in the field for the winter, or should at most be shallowly mixed into the surface soil layer so that plant residues are present on the field surface or left as plant cover.

Enriching the crop rotation scheme with catch crops is in accordance with the regenerative approach to crop rotation – catch crops protect soil from erosion, bind nutrients, improve the balance of organic matter, sometimes display negative allelopathic properties towards weeds, and have phytosanitary properties. For catch crops sown before barley, mixtures of a few species should definitely be used, instead of sowing only one species and cereal components should be avoided. Also the presence of flowering plants in the catch crop mixture is important, as they provide food for pollinators for which they are a source of benefit. Flowering catch crops are beneficial for the pollinators at the time where most plants in nature have shed their flowers (September-November). They also play a landscaping role (Fig. 1).

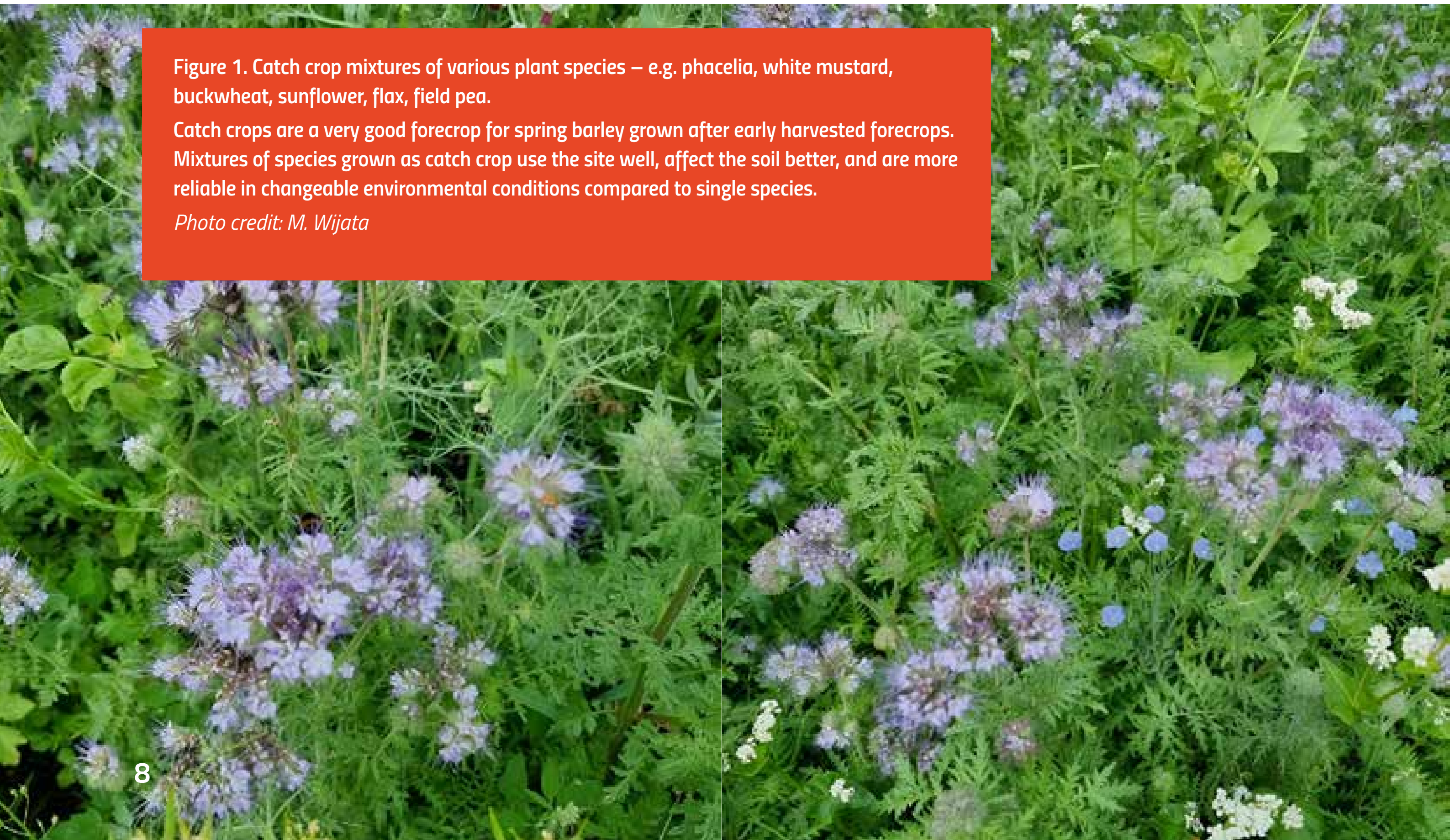
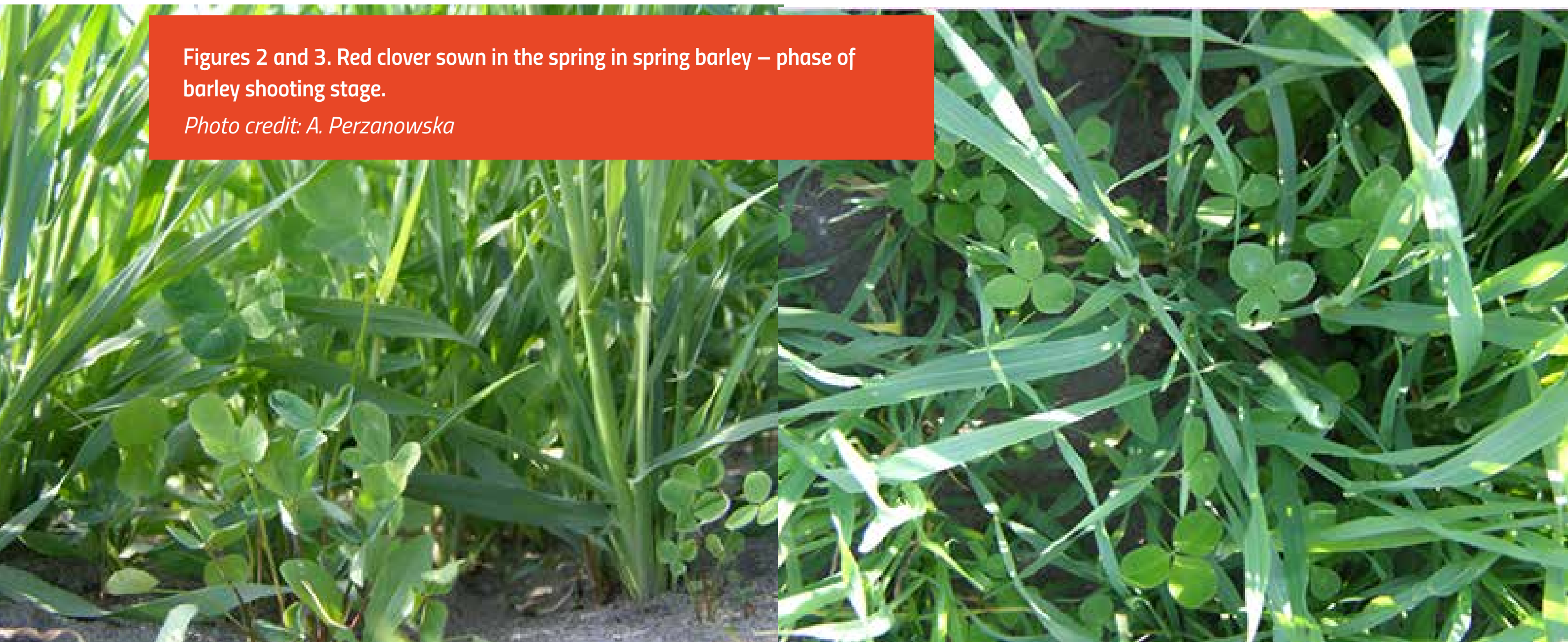


Figure 1. Catch crop mixtures of various plant species – e.g. phacelia, white mustard, buckwheat, sunflower, flax, field pea.
Catch crops are a very good forecrop for spring barley grown after early harvested forecrops. Mixtures of species grown as catch crop use the site well, affect the soil better, and are more reliable in changeable environmental conditions compared to single species.
Photo credit: M. Wijata

Winter barley and spring barley are also good cover plants for undersown crops due to early harvest and a relatively small competition for light. Crops are undersown in the spring in inter-rows of already growing winter barley or in inter-rows of spring barley which had been sown earlier. Barley can be undersown with small seeded papilionaceous plants well as grasses and mixtures of the legumes and grass, which are characterised by a slow early growth and easily become infested with weeds, against which the barley plant should protect. After the barley harvest, the undersown crops can be used in the main crop in successive years (Figures 2-5). Undersown crop may also be a type of catch crop – in this case the biomass of undersown crop developing in barley stubble is used until autumn as pasture or for green manure. Undersown catch crop is not left for another year of full use. It does however enrich short-term crop rotation.



Figures 2 and 3. Red clover sown in the spring in spring barley – phase of barley shooting stage.
Photo credit: A. Perzanowska

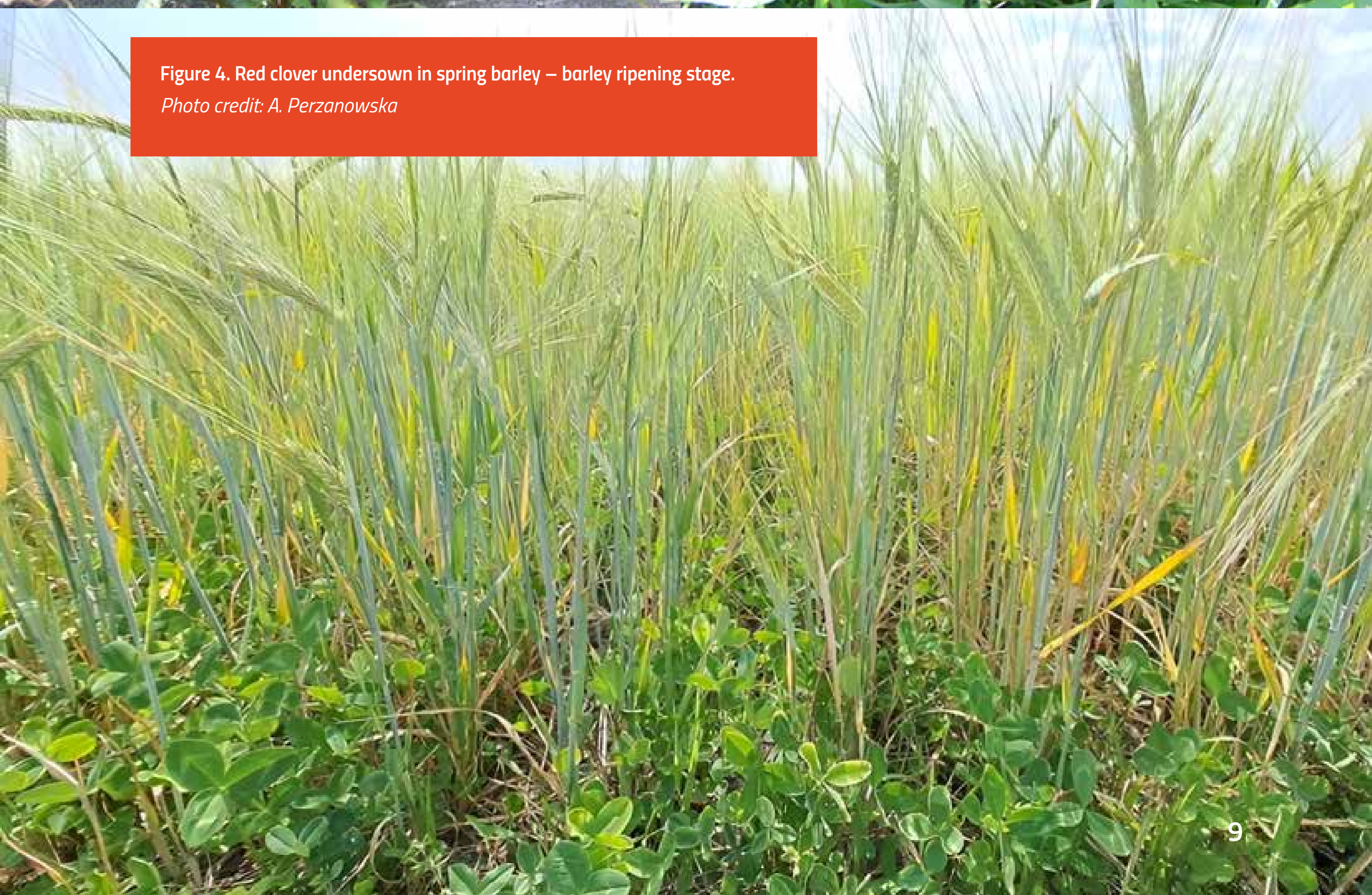


Figure 4. Red clover undersown in spring barley – barley ripening stage.
Photo credit: A. Perzanowska

Figure 5. Undersown red clover in stubble two weeks after cereal harvest – so called stubble-clover.
Photo credit: A. Perzanowska

Each well-planned crop rotation scheme should be divisible into so called crop rotation segments, the combination of which makes it possible to come up with various crop rotation types. In a correctly composed crop rotation scheme, cereals grown as the main crop should account for a maximum of 65%, preferably their share should not exceed 50%. In planning typical crop rotation with a significant cereal share, segments always start with a crop which improves the site, usually a non-cereal crop. Crop rotation segments allowed for cereal growing in the regenerative approach are as follows:

A. non-cereal crop – cereal (50% of cereals)
B. non cereal crop – cereal – cereal/non-cereal crop (maximum 65% of cereals)
C. non-cereal crop – non-cereal crop – cereal – cereal (50% of cereals)

For example 4-year crop rotation for a given field in which cereals account for 50% in the cropping pattern, should be planned as a sequence of crops based on two A segments, that is:

Year 1 – non-cereal crop (first segment), e.g. winter rapeseed + catch crop*
Year 2 – cereal (first segment), e.g. spring cereal + catch crop*
Year 3 – non-cereal crop (second segment), e.g. pea
Year 4 – cereal (second segment), e.g. winter fodder barley
** catch crop mixture without brassica plants due to the presence of rapeseed in crop rotation.*

3.2 Selection of varieties

In the selection of a variety for a specific area, one should be guided by generally available lists of recommended varieties, compiled on the basis of the results of variety experimentation carried out in various countries and regions. The properties of individual barley varieties such as type (fodder or malting), ear build (multi-row or two-row), fertility, resistance to diseases, resistance to lodging, timing of ear formation and ripening, mass of 1000 grains, grain quality, bulk density of grain, grain protein content, and tolerance of soil acidity are important items of information indicating the suitability of a given variety for growing in a specific region, crop rotation conditions, type of soil, and suitability for its purpose. In growing winter barley in temperate climate an important characteristic of a variety is also winter hardiness.

Most winter barley varieties are multi-row varieties grown for fodder, while the number of two-row winter varieties and malting winter varieties is much smaller. Growing winter varieties is recommended for areas with milder climate and longer autumns. Despite recent occurrence of winters with a significantly lower number of days with below-zero temperatures, in climate conditions of Central Europe winter barley varieties with winter hardiness of at least 4 in a 9-point scale should be selected. It should be noted that winter barley varieties with the highest winter hardiness may not survive frost below -20°C if there is no insulating snow cover.

The range of spring barley varieties is wider, most of them two-row malting varieties (Fig. 6), which due to a better quality of grain in an ear compared to multi-row varieties are better suited for malting or for groats production. Among spring barley varieties there is also "naked" barley (with hulless grains).

Figure 6. Two-row barley variety.
Photo credit: A. Perzanowska

In regenerative barley growing the selection of varieties for the site in which they will be grown is crucial. The selection of the variety for soil and climatic conditions may significantly affect the plant vigour, development, and resistance to unfavourable abiotic (e.g. droughts) and biotic (pressure of pathogens and pests) environmental conditions. Particular care must be taken in the selection of a variety in case of recurring problems with viral or fungal diseases on the site – in this case high resistance to diseases may be crucial.

In the regenerative approach to growing crops in modern agriculture, variety rotation on a specific field should also be considered. Increasingly often variety mixtures are used in growing barley for fodder, their advantage being greater resistance to diseases compared to stands comprising only a single variety.

3.3 Soil cultivation

In the regenerative approach to soil cultivation for barley, the following principle should be followed: cultivate as little as possible, but as much as needed. This applies both to cultivation carried out after harvesting the forecrop and the main soil cultivation carried out in order to prepare the field for another crop. This principle shows clearly that intensive tillage typical in particular for a conventional, tillage farming system, should be avoided. One of the main disadvantages of the tillage system is complete disregard for the protective function of post-harvest residues for the topsoil and destroying the natural soil texture, while their appropriate management is the foundation of conservation, regenerative agriculture. Each no-till technology in which more than 30% of the field surface is covered with plant residues is considered to be conservation tillage. Another disadvantage of tillage is the need to carry out this basic cultivation treatment in conditions of optimal moisture, as carrying out tillage with too high or too low soil moisture content results in clumping of furrow slices which requires further energy expenditure to bring the seedbed to appropriate condition. This mistake may be particularly difficult to remedy on heavier soils (Fig. 7). It may delay the preparation of the field and the sowing of crops.

Figure 7. Tillage should be carried out in optimal moisture conditions in order to avoid soil clumping.
Photo credit: A. Perzanowska

The introduction of no-till cultivation should be based on the knowledge and observation of the field, its appropriate preparation, and cultivation treatments should be carried out consciously and for a specific purpose. The most common type of no-till preparation of soil for sowing is whole-surface deep or shallow cultivation. In recent years strip-till has also been more and more commonly used by farmers. The effects of these cultivation systems are presented in figures 8 and 9. In no-till cultivation systems the soil is not overturned, only loosened over the whole surface or only in strips, thanks to which some amount of forecrop residues is still present on the surface of soil. No-till cultivation requires usually the use of various types of aggregates based on a cultivator, equipped with rigid tines, disc section, and a bar roller. Other cultivation tools and machines are also used, which loosen the soil at various depths and mix it without overturning the topsoil and those that spread fertilisers and sow seeds at the same time (strip-till units). Strip-till gives the field surface a unique appearance – between rows of plants there are uncultivated strips covered with post-harvest residues of forecrop. Strip sowing can be carried out into the residues of the main crop or catch crop sown after the main crop. If there is straw left in the field, it should be shredded well and spread evenly on the field surface.

Figure 8. Stubble after strip-till (on the left) and stubble management by whole-surface cultivation using a rigid tine cultivator (on the right).
Photo credit: A. Perzanowska

The most simplified cultivation technique is direct seeding, also called zero-tillage. This system of farming involves elimination of all cultivation treatments, and the only disturbance of soil texture involves making furrows with a special seeder at the time of sowing seeds. Seeds can be sown into the residues of forecrop of the main crop or into the residual biomass of catch crop sown after the main crop. In direct seeding, herbicides are usually used to destroy the catch crop and weed biomass. Weeds and catch crop may also be destroyed mechanically using roller and crimper. Due to complete elimination of tillage, plant residues cover the whole surface of the field (Fig. 10).

Reduced tillage works well for many crops. Cereals are a group of crops which do not respond with a significant decrease in the yield to the elimination of tillage and the introduction of simplifications in cultivation. A decrease in yielding in zero-till systems compared to plough cultivation may often result from deterioration in the main components of yield, in particular ear density per unit of area. This results often from a lower precision of sowing in the presence of plant residues near the surface of soil and, as a consequence, lower number of germinating grains. In order to avoid this, in more challenging sowing conditions, in particular in direct seeding, it is worthwhile to increase slightly the seeding rate and use seeders with structural solutions adapted for this type of cultivation. The introduction of simplifications in farming may also lead to increased weed infestation in the initial years. Therefore, direct seeding should be introduced on fields maintained to high standards, without weeds, with regulated pH. Before the introduction of direct seeding, the problems of soil, i.e. plough pan and subsoil compaction, should also be solved, that is deep loosening using a sub-soiler should be carried out.

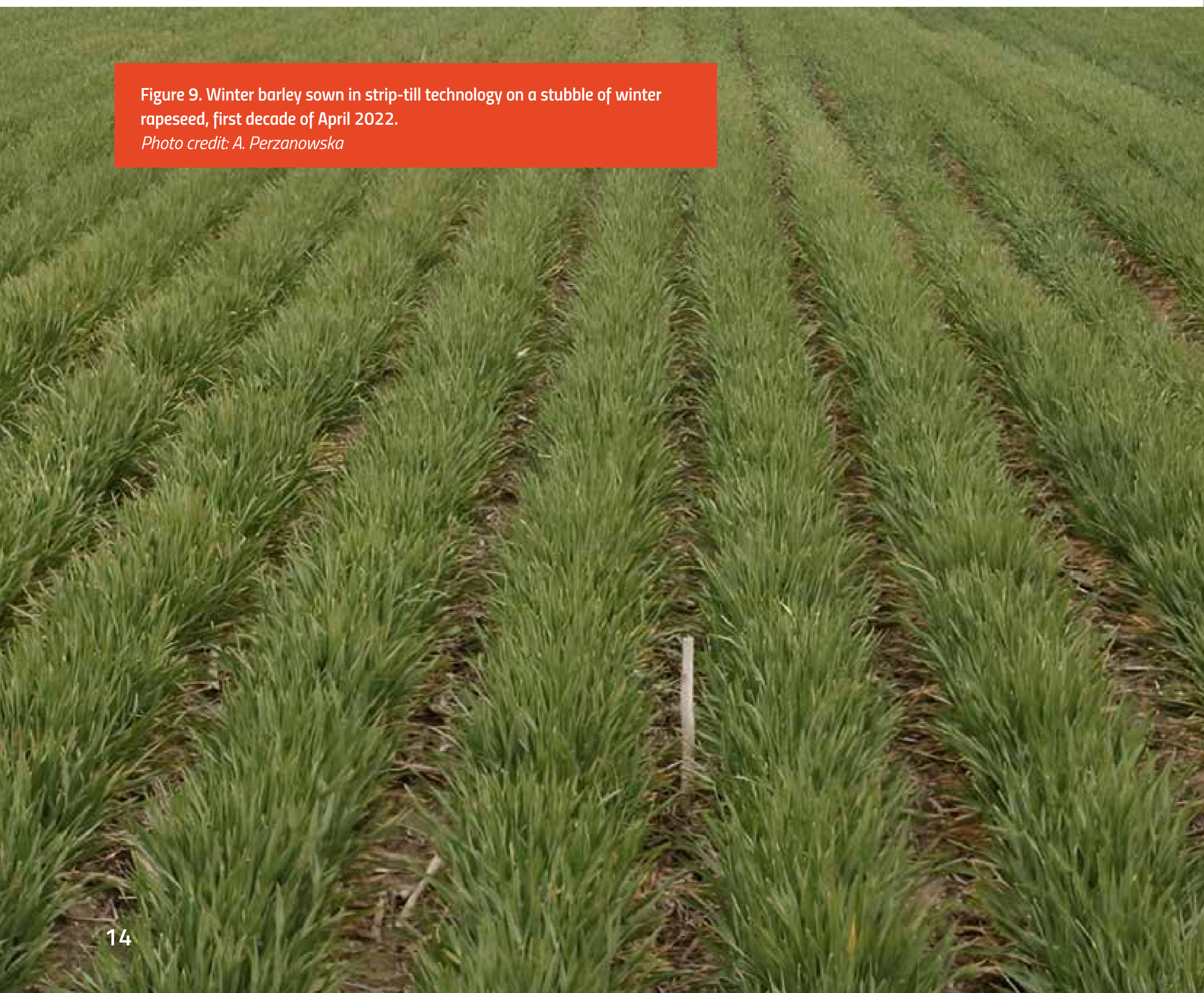


Figure 9. Winter barley sown in strip-till technology on a stubble of winter rapeseed, first decade of April 2022.
Photo credit: A. Perzanowska

Figure 10. Field surface in direct seeding covered with shredded straw at the time of sowing spring cereals.
Photo credit: A. Perzanowska

As the study of Dzienia et al. (2001) showed, barley can be also grown using direct seeding, with winter barley being less sensitive to reduced tillage than spring barley. In field tests the yield of barley on lighter soil (very good and good rye complex) have not decreased significantly in zero-till systems compared to conventional system of farming (Table 1).

Table 1. Yield of winter and spring barley depending on farming systems [t·ha^{-1}]

Crop	Year	Cultivation systems		
		Plough	Zero-tillage	Direct seeding
Winter barley	Average 1995-1998	4,15	3,99	3,93
	%	100,00	96,14	94,70
Spring barley	Average 1994-1998	4,18	3,77	3,89
	%	100,00	90,19	93,06

Source: Dzienia et al., 2001

3.4 Sowing

The quality of the seeds is still underappreciated in practice, although it is a factor which crucially affects the development and, as a result, yielding of crops. Good quality seeds ensure full, fast, and even emergence, which combined with optimisation of the sowing process itself and other agricultural treatments is a way to obtain strong, high-yielding plants, more resistant to fluctuations in soil and climatic conditions or to pests and diseases. Seed material should be healthy and free from contamination, in particular with weed seeds. Grains should be well developed (preferably more than 2.5 mm in diameter) and not damaged by pests.

The timing of sowing, sowing density, and the depth of placing grains should be based on the knowledge of the growth biology of winter and spring barley.

The timing of winter barley sowing varies for different regions and may be modified depending on the weather conditions. However, in average autumn it should fall in the period from early September to early October – the further to the north east the growing region is, the earlier the sowing should be. Seeds should be sown into relatively moist soil, avoiding sowing at the time of soil drought, even if it occurs during the optimal sowing time for a particular region. Winter barley sown on time, produces the main shoot and 2-4 strong lateral shoots with at least four leaves before the winter, and in spring it quickly enters the stage of stem formation and ear formation. In the stage of tillering of barley plants, that is in the autumn, a process invisible to the naked eye takes place – spikelet setting. Then at the end of the tillering stage and the start of stem formation, elements of ear begin to differentiate which in a crucial way affects the future yield. Lateral shoots and spike inceptions developed in the spring are usually weaker than those developed in the autumn, therefore the timing of sowing should ensure that barley develops the majority of strong shoots before the winter. At the same time, too intensive tillering is not entirely beneficial – there is a high probability that with an excessive number of lateral leaves some of them will eventually not produce ears and until the reduction they will unproductively use fertiliser components and water from the site, at the expense of ear-bearing shoots. Therefore, already in the autumn the stand has to be properly maintained, in order to avoid this. Compared to other cereals winter barley is characterised by a relatively low hardiness, which is related to barley's poor hardening capacity. Thus, early on young plants have to be provided with nutrients which play an important role in surviving the winter season.

Spring barley is a long-day plant and requires early sowing, however it is not as sensitive to delay in sowing as oat or spring wheat. The sowing of spring cereals in Poland falls usually in the second decade of March and early April, as soon as severe frost is over. The sowing of spring barley should start at the earliest possible time, as soon as it is possible to drive on the field and soil temperature reaches 3-5°C, though barley can germinate in temperatures of 1-2°C. For a proper development spring barley requires vernalisation (exposure to low temperatures below 10°C) for a period of 1-5 days. In dry spring, in areas with low precipitation, early sowing of barley gains even more importance, all the more so given that young barley is resistant to frost of several degrees, the risk of which in early spring in the Central Europe is high. It should be noted that early sowing is the way to extend the number of days of the growth period of spring barley and, thus, its key stages of growth, in particular the tillering and the development of the root system – both rootlets and secondary roots. Rootlets of spring barley grow quickly even at the temperatures of 1-2°C and as early as in the initial stage of development (the stage of 3-4 leaves) may reach even 60 cm deep into the soil. At the stage of 3-4 leaves, the tillering nodes begin to develop, from which secondary roots grow and shoots develop. The growth of spring barley seedlings at low temperatures leads to faster growth of rootlets and secondary roots in relation to the above-ground parts, which significantly protects the plants against potential, increasingly frequent spring droughts. However, during drought the growth of secondary roots may be impeded. Therefore, barley varieties and plants which develop more rootlets are characterised by a greater resistance to drought at all stages of growth. More rootlets grow from plump grains than from more poorly developed kernels, which additionally confirms the role of the quality of seeds in the success of spring barley growing.

Cereal yield is a product of the number of ears on a unit of area, number of grains in an ear, and mass of one thousand grains. In practice, it is definitely easiest to manage the number of plants per unit of area, that is the sowing density, through appropriate seeding rate or row spacing. Other main components of barley grain yield are more dependent on fertilisation and weather conditions during the growth period. Due to weather conditions which are changeable each year there is no certainty that appropriate to-dressing will actually favourably affect other components of yield – the number of grains in an ear and the mass of one thousand grains which could to some extent compensate for a lower ear density. Adequate sowing density is, therefore, a guarantee of good yields that are stable over the years and is of more significance for two-row varieties compared to multi-row varieties – as multi-row varieties have a greater ability to compensate for a lower ear density with the number of grains in an ear.

Optimal sowing density of winter and spring barley is closely related to the varieties – their tillering capacity and susceptibility to lodging and is recommended by the producers of varieties. Varieties which tiller better are generally sown less densely, while greater density is applied for short-statured varieties, resistant to lodging, and when sowing is delayed for various reasons, as delay in the sowing of both spring and winter barley results in a lower number of tillers. Increased seeding rates can also be applied if sowing takes place in dry autumn or spring due to the risk of poorer emergence. Slightly greater density of plants is recommended when growing varieties with a high yielding potential on good quality soils, while too dense sowing should not be practised on poorer soils. Higher seeding rate is also applied for malting varieties in order to limit the number of tillers of plants and improve grain quality, as grain from lateral shoots is often less plump. At the same time, high seeding rates often encountered in practice should be avoided – too high a stand density leads to a strong competition of plants for water, nutrients, and light, which may lead to a lower yield as a result of a reduction in the number of grains in an ear or lodging and the need to intensify growth regulator application. In addition, excessive stand density lowers its aeration which, in particular in wetter years, may exacerbate the infection of barley with fungal diseases. The number of plants per square metre should be at least 250, that is the seeding rate should ensure at least 250 grains per each square metre. Such a density of grains ensures the density of 500-650 ear-bearing shoots on a square metre.

Selected standards of winter and spring barley sowing are presented in table 2.

Table 2. Selected standards of winter and spring barley sowing

Crop	Time of sowing central Poland		Plant density (million items · ha^{-1})	Example of seeding rate (kg · ha^{-1})	Row spacing (cm)
	Optimal	Acceptable			
Winter barley	10-20 September	until 20 September	2,5-3,5#	130-200* 90 kg or 2 seed units**	9-15
Spring barley	20 March -5 April	until 20 April	2,5-3,5#	110-170* 90 kg or 2 seed units**	9-15

 # two-row varieties are sown more densely *open-pollinated varieties ** hybrid varieties

Source: Journal of Laws 2013, item 616; recommendations of seed manufacturers, ABC wysiewu zbóż IUNG Puławy

The optimal sowing depth for barley is approximately 3 cm, while in less moist soil it can be increased to 4 cm and post-sowing rolling can be used in order to improve the soil-grain contact. Such a treatment improves emergence as it increases the retention of rainwater in the sowing zone and improves upper water movement from deeper soil layers. Barley should not be sown however any deeper, due to the negative effect on emergence, tillering and a greater risk of infection with stem-base diseases. A delay in emergence slows down the progression of plants through successive development stages, which is detrimental both for winter and spring barley and may contribute to a decrease in yield. For this reason in case of a delay of barley sowing for various reasons it is allowed to sow at a more shallow depth of 2 cm in order to speed up emergence. Barley is sown in narrow rows from 9 to 15 cm and, depending on the cultivation system and planned density, these values can be modified.

3.5 Irrigation and water management

Irrigation of farmland should be defined as effective use of available water in order to control the soil moisture and achieve desired response of crops. Soil moisture can be affected directly, actively, by watering (irrigation) of the plantation with set irrigation doses or indirectly, by creating appropriate water and air conditions in soil as a result of the applied agricultural treatments – that is by application of cultivation treatments which reduce loss of water from soil and improve its retention capacity.

If the deficiency of rainfall and soil drought call for irrigating barley, it is crucial to adopt a proper irrigation strategy. Watering barley grown in a field is justified only in the warmer regions of the world, regularly affected by atmospheric and soil droughts and heatwaves. Based on the results of research it was noted that this timing of irrigation had much better results compared to irrigation in the phase of ear formation (preceding the flowering) already in the drought conditions. Early irrigation after sowing has significantly sped up plant emergence and as a consequence accelerated the flowering and ripening, which enabled the plants to go through key phases of barley development before summer heat and drought intensified. It should also be noted that in watering crops the quality of used water is of crucial importance – the presence of excessive amount of dissolved salts, usually sodium chloride, may increase soil salinity and in extreme cases lead to its degradation and deteriorated plant growth as a result of physiological drought.

In the regenerative cereal growing in the temperate climate, including barley growing, irrigation is not recommended. In the regenerative approach, it is imperative to adopt agricultural practices which protect soil water resources and to adopt a strategy of improving soil water retention capacity and water retention of the agricultural landscape as a whole.

Agricultural treatments which improve soil retention capacity and reduce water loss from soil include:

- shallow cultivating measures in the zero-tillage system, limiting unproductive evaporation, which are a part of post-harvest treatments for winter barley and spring treatments for spring crops in case of spring barley (Fig. 11);

- application of the no-till cultivation technology (loosening the whole surface of the field, strip-till) and direct seeding, which protects soil structure and organic matter of soil and ensures that an appropriate amount of plant residues is left near the soil surface which slows down the evaporation;

- mulching soil surface (the whole field or strips in strip-till technology) which protects soil surface and limits evaporation;

- anti-erosion treatments and treatments promoting water infiltration into the soil. Each step to improve infiltration, regardless of the lie of the land, results in more water from precipitation seeping into the soil and feeding the soil water storage, which will be used by crops in the periods between rainfall events. The above mentioned cultivation technique is however particularly useful in growing barley in hilly areas. In this case cultivation across the slope should be introduced, as it significantly improves infiltration of precipitation water and reduces water runoff and water erosion as a result.

- phyto-melioration – i.e. growing in rotation, as the main crop and catch crop, of deep-rooting crops, the roots of which penetrate soil layers well and promote the development of bio-pore network in soil for water transport and the space for deep development of roots of successive plants;

- all 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.

Figure 11. Sharrow stubble cultivation using an aggregate for stubble cultivation immediately after the harvest as an element of post-harvest treatment reduces unproductive evaporation of water from soil and is an element of non-chemical weed control.
Photo credit: A. Perzanowska

In regenerative agriculture supporting soil water retention aims first of all to improve the balance of organic matter in soil and protect natural soil texture. Increasing the organic matter content in soil improves at the same time the soil capacity to retain water (its retention properties). This is linked to the fact that organic matter itself has the capacity to retain significant amount of water on its surface compared to soil mineral particles. It is also important that enriching the stock of soil organic matter leads to an improvement in stability of soil structure and capillary porosity, which usually take place at the same time. Soil texture consisting of stable soil aggregates guarantees the presence of stable network of pores of various sizes – from micropores enabling unobstructed infiltration of water into the soil and access of oxygen to roots and soil organisms, to small capillary pores which have the capacity to retain water against the gravity for longer periods. Thanks to a network of small capillary intra-aggregate pores, the upward water movement from above ground water table, which is usually located at the dept of >100m, to barley radical zone is possible, which is crucial for providing water to plants in the periods between rainfall events. It is very important that the unique,to a large extent biological, soil texture is not damaged by intensive soil cultivation. Intensive tillage interferes with the habitat of soil organisms which play a large role in the structure-making process and mechanically destroys soil aggregates having a protective function for soil organic matter, which can lead to depletion of soil carbon storage and deterioration of structure-forming and retention capacity of soils.

At the time of the climate change and increasingly frequent droughts, it is becoming more and more significant to improve water retention in the agricultural landscape at the micro and macro level.

Improve water retention in the agricultural landscape at the micro and macro level, which can be done, among other things, through:

- treatments limiting water runoff from catchment areas, including fields: this step may be linked to the reconstruction or redevelopment of old drainage systems in order to create drainage and irrigation systems;

- reconstruction/maintenance of natural retention basins in the agricultural landscape: these include waterholes, ponds and various kinds of swamps and peatlands;

- construction of artificial water reservoirs: they can be surface reservoirs of water which may be used in the periods of rainwater deficiency;

- presence of mid-field stands of trees, in particular grown in stripes, which reduce the strength and drying effect of the wind on the surface of the fields.

A separate type of control of water conditions on the site which should be taken into account in regenerative barley growing is appropriate selection of barley varieties for the water conditions of the site. The timing and depth of sowing are also very important, as is liming and balanced fertilisation which significantly improve the vigour of plants, including the development of the root system and resistance of barley to periodic water deficiency in successive development phases. Soil conditions, such as plough pan and subsoil compaction, which hinder deep rooting of barley plants, should also be eliminated.

3.6 Fertilisation of crops and soil

Rational barley fertilisation should be based on the knowledge of nutritional needs of the plant, expected yield, nutritive value of natural, organic and mineral fertilisers used both for barley and for the forecrop of barley and, first of all, knowledge of the amount and quality of nutrients currently found in soil. Table 3 presents average requirement of winter and spring barley for macronutrients: nitrogen (N), phosphorus (P) and potassium (K).

Table 3. The amount of NPK macronutrients necessary to produce 1 tonne of grain (with side crop) · ha^{-1} and approximate fertiliser doses and barley yield (average values).

Crop	Uptake of nutrients per 1 t of yield (kg)			Average fertilisation ($kg \cdot ha^{-1}$)			Average fertilisation ($t \cdot ha^{-1}$)	Primary yield to secondary yield ratio
	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)		
Winter barley	22,3	9,9	18,7	70-120	70-100	90-110	30-60	0,80
Spring barley	21,0	9,6	16,4	60-100 30-60*	70-100 80-120*	80-120 90-120*	30-60 30-50*	0,80

*malting varieties

Source: Authors' own work based on Jadczyszyn, 2013; other information materials

It should be remembered that a plant should be well provided with specific nutrients from the initial stages of development, therefore fertilisation of winter and spring barley should be considered as early as in the year of sowing the forecrop. This rule is justified in particular in case of spring barley which compared to other cereals has a short growth period with a relatively high yield potential at the same time. In case of winter barley it is important to provide young plants with specific nutrients before the winter, so that deficiencies of macronutrients such as potassium, phosphorus, magnesium and sulphur, or micronutrient deficiencies do not impair the development of seedlings and their good overwintering.

Close links between soil nutrient content, soil pH, soil moisture, soil biological life and the availability and uptake of specific ions by a plant indicate clearly that the crucial factors for an appropriate development of plants are adequate soil "nutrition" and pH, taking care of physical and biological quality of soil, and correct proportions between nutrients in soil solution. Therefore, in regenerative agriculture building soil resources of nutrients available to crops is based on a widely-defined building of soil quality and holistic soil management as well as understanding nutritional needs of sown plants and current soil properties on the basis of regular comprehensive soil analyses.

Natural and organic fertilisation

Organic fertilisation has a great potential in building soil fertility and capability, from which the regenerative approach to growing crops also draws. Natural and organic fertilisers, in particular those which contribute significant amounts of organic matter to soil, affect not only the concentration of nutrients in soil, but also many other soil properties that are the foundations of healthy soil. These properties include soil density, structure stability, infiltration capacity, water retention capacity, and biological properties of soil.

The type and form of natural fertilisers affect their nutrient content. Table 4 presents average content of selected nutrients for various types of natural fertilisers. The actual composition of the fertilisers used on a farm may be determined only on the basis of the analysis of its sample in a laboratory.

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

In barley growing, natural fertilisation can be successfully applied for both barley itself and its forecrop (e.g. root crops, rapeseed, corn). It should also be remembered that only part of the nutrients contained in natural fertilisers will be available to plants in the first year after the application of organic fertiliser, and the remaining part will be released in the subsequent years following the application (Table 5).

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 the Journal of Laws 2018 item 1339

In crop rotation schemes with barley, it is important to use manure subjected to the composting process, during which weed seeds and pathogens are neutralised. It is compulsory to mix manure with soil immediately after spreading it on the field and to use soil-applied, natural liquid fertilisers (slurry and liquid manure) avoiding splash application. Such treatments significantly limits the loss of nitrogen from fertilisers (through ammonia emissions) and dispersing it into the environment. In the application of natural fertilisers one should also comply with the guidelines of the document knows as "Nitrate Programme". Nitrogen dispersed into the environment is very reactive and, as it passes through successive biogeochemical pathways, is easily transformed. As a consequence the same nitrogen atom may cause a sequence of adverse effects in the atmosphere (nitrous oxide is a very strong greenhouse gas), in land and water ecosystems (e.g. nitrogen in nitrate and ammonium forms used on arable land) which is described as the nitrogen cascade. Therefore, in the regenerative approach to growing crops, plans of nitrogen fertilisation should be made, the principles of good agricultural practice should be observed and maximum nitrogen doses from all sources for main crop should not be exceeded.

Taking into account the chemical composition of a fertiliser and mineral use efficiency in the first and second year after the application, it is possible to determine the approximate amount of a given nutrient form available for plants, which is released during the transformations of natural fertilisers in soil. Tables 6 and 7 present the calculations for nitrogen from natural and organic fertilisers.

Table 6. Examples of calculation of available nitrogen on the basis of data from tables 4 and 5.

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

Organic fertilisers may be successfully applied on every regenerative farm, however they play a particularly important part on non-livestock farms. So called green manure, that is fresh plant matter introduced into the soil in order to increase its fertility, can be a very valuable source of nutrients in barley growing on various types of farms. Plants for green manure are usually grown as catch crops between two plants of the main crop and may be successfully introduced in crop rotation schemes with barley (see section 3.1). The most valuable plants grown for green manure are legumes and it is worth ensuring that species from this family are present in catch crop mixtures. Due to symbiosis of the legumes with nodule bacteria (Rhizobium) which have the ability to fix atmospheric nitrogen, green matter of these plants is rich in nitrogen, also plant residues of the legumes grown as the main crop may be an important source of nitrogen for the successive crop. For this reason, growing legumes as a forecrop should be taken into consideration in planning nitrogen fertilisation of barley grown after such plants. The amount of available nitrogen left over after growing legumes is presented in table 7.

Table 7. The amount of available nitrogen left over after growing legumes and root crops.

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

Source: the Journal of Laws 2018, item 1339

The data in tables 6 and 7 indicate what the actual saving in using fertiliser nitrogen can be after taking into account its potential amount in soil after the application of natural and organic fertilisers. However, accurate data concerning the amount of mineral nitrogen in soil before the start of barley sowing can be provided by soil analyses.

Other valuable organic fertilisers include by-products of crop production, such as straw, leaves of sugar beet as well as farm compost and digestate. Barley may be fertilised with forecrop straw, e.g. rapeseed or corn straw, and may itself be a source of straw for the successive crop. Table 8 presents chemical composition of barley, corn, and rapeseed straw.

Table 8. Chemical composition of barley, corn and rapeseed straw.

Type of straw	Secondary yield to primary yield ratio	C:N ratio	Content (dry matter %)					Content ($mg \cdot kg^{-1}$ of dry matter)				
			N	P_2O_5	K_2O	CaO	MgO	B	Cu	Mn	Mo	Zn
barley	1,0:1	70-100:1	0,6-1,0	0,25	1,61	0,63	0,20	4,40	4,20	45,0	0,35	24,7
corn	1,2:1	60-70:1	0,8-1,2	0,46	1,25	0,48	0,46	5,40	6,00	55,0	0,44	33,0
rapeseed	2,5:1	40-50:1	0,8-1,2	0,30	2,12	2,18	0,21	9,80	3,18	40,3	0,30	32,5

Source: Authors' own work on the basis of Maćkowiak, 1998 and Grzebisz, 2009

The table shows that, for example, with each tonne of rapeseed straw on average 10 kg of nitrogen, 4.0 kg of phosphorus and 21.2 kg of potassium return to the soil. However, cereal or rapeseed straw is characterised by a wide C:N ratio which may cause a permanent immobilisation of soil mineral nitrogen. Therefore, in fertilisation with straw, nitrogen has to be applied at the same time in order to narrow down the C:N ratio < 33.3:1. 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 – weight of straw ($t \cdot ha^{-1}$)
Nno – current nitrogen content in straw ($kg \cdot t^{-1}$)

For example, calculating a compensating nitrogen dose (Dkn) for corn straw left over after harvest of seeds, containing 10 kg of nitrogen per tonne, yielding 10 $t \cdot ha^{-1}$ is as follows: corn straw yield = 10 $t \cdot ha^{-1} \cdot 1.2$ = 12 $t \cdot ha^{-1}$. Dkn = 12 · (12-10) = 12·2 = 24 $kg \cdot ha^{-1}$. Application of nitrogen in straw fertilisation protects the currently grown crop (e.g. winter barley following rapeseed or corn) against nitrogen hunger caused by excessive retrogradation of soil mineral nitrogen.

Distillery (rye, potato, molasses) slop, sludge, and municipal compost can also be used to fertilise crops, including barley, provided that they meet specific standards and do not adversely affect the soil environment, including soil pH. Plant materials are also used to produce preparations containing humus compounds and biocarbon, which can be used too as soil additives, improving soil quality.

The above information concerning natural and organic fertilisers indicates that they may be an important and inexpensive source of various nutrients in crop production. However, the primary benefit of introducing this type of fertilisers into the soil is the positive effect many of them have on the resources of soil organic matter which plays a huge role for chemical, biological, and physical soil properties.

Table 9 presents indicators of organic matter reproduction from selected natural and organic fertilisers, i.e. possible reproduction of organic matter in soil in kg on the area of 1 hectare per each tonne of fresh mass of applied organic or natural fertiliser. These indicators show clearly that consistent inclusion of organic fertilisation in crop rotation leads to a gradual increase in soil carbon resources, which results in great production and environmental benefits.

Table 9. Reproduction of soil organic matter in kg per 1 tonne of fresh mass of selected natural and organic fertilisers

Type of fertiliser	Dry matter content (%)	Indicator of soil organic matter (SOM) reproduction in kg per 1 tonne of fresh mass of fertiliser
Straw	86	100
Beet leaves, carrot leaves, catch crops	10-20	8-16
Fresh manure	20-30	28-40
Fermented manure	25-35	40-56
Slurry – cattle	4-10	6-12
Slurry - pigs	4-8	4-8

Source: VDLUFA 2014

Mineral fertilisation

The nutrients which are currently in soil have various organic and mineral forms of which only some are available for plants and may be absorbed from the soil solution. Specific soils differ by properties and their capacity to store nutrients and to yield, therefore following the same instruction of mineral fertilisation for growing barley on different soils is bound to be flawed.

In the regenerative approach precise doses of mineral fertilisers are applied based on soil testing. This type of fertilisation should complement organic fertilisation used in crop rotation which is of great importance in regenerative soil management. Historical data and yielding maps of individual fields on the farm are also useful as they provide information on their yielding potential. The current condition of the stand during the growing period may be assessed on the basis of high quality satellite images and these data can be used to plan top-dressing.

Due to its short growth period and fast aging of the root system, spring barley is very sensitive to ionic balance in soil, therefore special consideration should be given not only to the dose of fertilisers, but also their form and soil pH.

Nitrogen fertilisation

Nitrogen fertilisation promotes the growth of crops, but also contributes to the increase of protein content in grain, which is desirable in case of barley grown for fodder. Malting barley requires the application of relatively high doses of potassium and phosphorus and careful nitrogen fertilisation as a way to achieve high yield of grain with a relatively low protein content.

Nitrogen fertilisation of winter barley should be carried out mainly in the spring. However, if nitrogen deficiency is suspected as early as in the autumn and young plants are in poorer condition, it is worthwhile to apply a dose of up to 30 kg of nitrogen in the ammonium form, for example spreading ammonium sulfate. This may be the case when winter barley is sown after a cereal or rapeseed forecrop which leave post-harvest residues with a narrow C:N ratio (Table 8). Application of nitrogen in the nitrate form before winter may adversely affect overwintering of plants. Barley can be also fertilised by foliar application, using even up to 10-15 kg of nitrogen this way. Magnesium sulfate, copper sulfate and microelements can be added to a urea solution. Basic nitrogen fertilisation of winter barley should take place in the spring and it is important to appropriately feed the plants with nitrogen as early as the start of the stem formation stage in the spring. If smaller nitrogen dose (up to 60 kg·ha^{-1}) is applied in the spring, it is usually applied once at the time the growing season is resumed. Higher nitrogen doses are divided into two parts – a larger one is applied at the beginning of the growth period, the second one at the time of stem formation (BBCH – 33). The rule to follow is that the dose of nitrogen should be planned in accordance with the expected yield and the established content of mineralised nitrogen in soil.

In growing spring malting varieties nitrogen fertilisation is usually applied before sowing, in one dose of 30-60 kg·ha^{-1}. Fodder spring barley varieties are fertilised with higher doses of nitrogen, usually between 60 and 110 kg·ha^{-1}. 60% of the dose is applied before sowing and the remaining part from BBCH stage 33 onwards. In later stages barley can be fertilised by foliar application using a urea solution with an addition of magnesium sulfate recommended for the stage, which is practised in growing fodder barley varieties.

When planning fertilisation of barley with mineral nitrogen one should take into account the amount of available nitrogen, coming largely from decomposition of natural and organic fertilisers (Tables 5-9) which significantly affect the amount of mineral nitrogen in soil before the sowing of barley. Making adjustments for mineral nitrogen in soil may significantly lower the level of mineral fertilisation with this element and its dispersion into the environment.

Potassium fertilisation

Potassium and phosphorus positively affect the vigour of both winter and spring barley plants and thus, improve their resistance to diseases and changeable site conditions. Potassium contributes to good water management and adequate density of cell sap before winter which in turn leads to greater resistance to below-zero temperatures. Potassium deficiency in barley slows down its uptake of nitrogen, which impairs the growth of plants and leads to lower yielding.

Regularly applied potassium fertilisers accumulate in soil and have a long-term follow-up effect, therefore in the regenerative approach potassium fertilisation should be planned as early as during the fertilisation of forecrop and the whole crop rotation. As presented in table 10, side crop utilised in the field for fertilisation purposes may be an important source of potassium for a successive crop. Dividing the potassium dose and fertilising both the winter and spring barley in the spring is only justified on lighter soils. Application of mineral fertiliser should be based on the results of soil analysis, determining the amount of available form of this element in soil and the expected barley yield. Average recommended doses of potassium in growing barley based on soil fertility and expected yield are presented in table 10.

In mineral fertilisation of barley with potassium, potassium sulfate should be used, rather than potassium chloride (KCl). Potassium sulfate is an easily soluble type of fertiliser which has less harmful effect on soil organisms and crops compared to the chloride form (KCl). Sulfate also provides soil with sulphur, a very important micronutrient in growing cereal crops.

Table 10. Doses of potassium (K_2O) in kg·ha^{-1} in barley growing depending on the expected yield and soil content of the nutrient

Expected barley grain yield	Soil potassium content			
	Very low	Low	Medium	High
High	85-100	65-85	45-65	35-45
Medium	65-85	50-65	30-45	25-35
Low	50-65	30-50	20-30	15-25

Source: Noworolnik, 2005

The entire potassium fertilisation is applied in the autumn; on poorer soils, where there is a risk of nutrient leaching during the winter, some potassium may be applied in the spring before the start of the growing season.

Phosphorus fertilisation

Phosphorus contributes to good grain plumpness, it is also necessary for a good development of the root system of young plants, which significantly affects their yielding potential and good development in various soil and climate conditions. Phosphorus fertilisation of spring and winter barley should take place before the sowing and for spring barley as early as in the autumn. Only on light soils fertilisation with this nutrient can be partially moved from autumn to early spring.

Phosphorus compounds in soil make up three fractions, of which the most important one from the point of view of plant nutrition is the fraction of water-soluble inorganic phosphorus (P_i) which is present in soil solution and available for plants. Other fractions are soil phosphorus resources in organic and mineral components of the solid phase of soil from which P_i phosphorus is complemented. Organic matter has a great effect on the mobility of P_i phosphorus – the mineralisation process releases available phosphorus from it and it reduces the retention of P_i phosphorus by the solid phase of soil. Secondly, it stimulates microbiological life of soil which also contributes to increased availability of mineral phosphorus for plants. The positive effect of organic matter on the water-soluble P_i fraction available to plants is called a humus forming process and is often the result of organic fertilisation.

Like for potassium, fertilising with mineral phosphorus should be based on the results of soil analysis describing the amount of available form of this nutrient in soil and the expected barley yield (table 11).

Table 11. Phosphorus doses (P_2O_5) in kg·ha^{-1} in growing barley depending on expected yield and soil content of this nutrient

Expected barley grain yield	Soil phosphorus content			
	Very low	Low	Medium	High
High	70-85	50-70	40-50	30-40
Medium	55-70	40-55	30-40	20-30
Low	45-55	30-40	20-30	15-20

Source: Noworolnik, 2005

Sulphur and magnesium fertilisation

Sulphur and magnesium deficiency also slows down the rate of nitrogen uptake by the plants and reduces the effectiveness of nitrogen fertilisation which adversely affects the development of plants, yield and its quality.

Sulphur is an important component of amino acids and lipids taking part in their synthesis and increases plant resistance to environmental stress (temperature fluctuations, droughts, diseases). Mineral nutrients such as phosphorus, iron and nitrogen affect its uptake and functioning in a plant. The main source of soil sulphur is organic matter from organic and natural fertilisers as well as organic residues, including dead biomass or microorganisms taking part in sulfate transformation. Fertilising soil with sulphur is carried out on the basis of all mineral fertilisers in the sulfate form (e.g. magnesium, calcium or potassium sulfates) as well as through the application of elementary sulphur which works more slowly, has an acidifying effect and should be applied to the soil with an appropriately high pH. Important sources of sulphur for crops are also natural and organic fertilisers. The rate of sulphur release from slow-release fertilisers, like elementary sulphur or natural and organic fertilisers, depends to a large extent on the microbiological soil activity.

Sulfate fertilisers, applied to winter and spring barley should be applied to the soil as early as the stage of post-harvest treatment after forecrop and should be well mixed with soil. When growing barley on poorer soils, half of the sulphur should be applied in the spring. Also foliar application of sulphur to barley is possible using a solution of magnesium sulfate.

Magnesium is a component of chlorophyll which plays a crucial role in the process of photosynthesis but also in energetic and enzymatic processes. It works strongly together with phosphorus in promoting the growth of the root system of young plants and seed ripening, as well as affects the effectiveness of phosphorus and nitrogen uptake by plants, therefore regular fertilisation with this micronutrient is important. Sources of magnesium can be slow-release mineral fertilisers, e.g. magnesium carbonate, and natural fertilisers like manure and slurry. In growing barley also fast-release mineral fertilisers such as magnesium sulfate or magnesium potassium sulfate may be used. Fast-release fertilisers have the advantage that with their use the content of available form of magnesium in soil may be adjusted on an on-going basis and the risk resulting from magnesium deficiency for plants can be eliminated. Table 12 presents recommended doses of magnesium in cultivation of barley depending on the expected yield and soil magnesium content.

Magnesium doses (Mg) in kg·ha^{-1} in growing barley depending on expected yield and soil content of this nutrient

Expected barley grain yield	Soil magnesium content			
	Very low	Low	Medium	High
High	55-65	35-55	20-35	10-20
Medium	40-55	20-40	10-20	0-10
Low	30-40	15-30	0-10	0

Source: Noworolnik, 2005

Microelement fertilisation

Due to these important functions, in regenerative growing of barley attention should be paid not only to nutrition of plants with macronutrients, but also prevention of micronutrient deficiency. For example, adequate supply of winter barley with micronutrients as early as in the autumn prevents excessive uptake of nitrates and increases the plant resistance to diseases and low temperatures. This is particularly important in regenerative growing of barley in which chemical protection of the stand should be reduced to a minimum.

The main source of micronutrients for crops which in practice meets the nutritional needs of plants are natural fertilisers regularly used in crop rotation. Natural fertilisers have also a deacidification effect and stimulate microbiological life of soils, which contributes to micronutrient availability. If soil tests show insufficiently low level of soil micronutrients, appropriate natural fertilisers should be used. They should be applied to soil, complemented by foliar application in the form of sulfates or chelates. Foliar application of micronutrients should be carried out in higher temperatures, which increases their effectiveness and speed of their action and makes it possible to use solutions with lower concentrations.

pH regulation and the role of calcium in regenerative barley farming 3.7

Symptoms of calcium deficiency are practically seldom noted in barley plants. What is much more often noted is the effect of factors which limit the supply of calcium and other nutrients to plants caused by a decrease in their availability and deterioration in the development of the root system due to soil acidification, which is associated with deficiencies of alkaline nutrients such as calcium, magnesium or alkaline cations.

Barley is one of the crops particularly sensitive to low soil pH – the optimal pH for its growth is 6.5-7.0. With lower pH barley is very sensitive to the excess of active aluminium and manganese ions which compete with the uptake of such ions as Ca^{2+}, Mg^{2+}, lead to the loss of K^{+} from the roots to the external environment and disturbance in their metabolism.

Protection against weeds, pests, and diseases 3.8

Regenerative farming based on functional biologisation does not entirely eliminate and prohibit the use of synthetic means of production, however, due to their broad spectrum of effect on the environment, crop protection products are treated in functional biologisation as "the necessary evil". The objective of biologisation is reducing the use of chemicals to an absolute, necessary minimum and focusing efforts on prevention and finding causes of problems, instead of reacting to their effects. In pest and disease control various agricultural practices should also be used, such as appropriate selection of forecrop, balanced fertilisation, optimisation and timeliness of agricultural measures. No less important is supporting biodiversity of arable land and the whole agricultural landscape.

Organisms harmful for plants include pathogens, pests and weeds which accompany crops and whose intensified presence may lower the yield of crops. There are four main groups of pathogens attacking crops: fungi, bacteria, viruses, and nematodes. Fungi are the most common plant pathogens. They develop in live or dead organic matter. However, some fungi feeding on dead organic matter when encountering live plants that can be their hosts, go into parasitic mode and cause plant diseases. The course of infection weakens the plants as during their life cycle fungi secrete toxins and enzymes decomposing cell walls and cell structures making up plant tissues. Growing fungi cells form filamentous hypha and mycelia which penetrate and overgrow tissues. At some stage they start producing spores which spread on the site through rain and wind and may give rise to new generations. Usually fungi infect barley leaves, sometimes also ears. Leaf infections weaken the assimilation apparatus and photosynthesis, which as a consequence leads to stumped growth and increased susceptibility of barley to other fungal diseases and adverse environmental conditions. The life cycle of some fungi takes place in soil and they infect also roots, germinating seeds or lower parts of barley stems. The hosts for fungi causing diseases of barley plants are species of crops and weeds in the grass family, but sometimes also dicotyledonous plants. Among nematodes the greatest damage in growing of cereals, including barley, is caused by cereal crop eelworm (*Heterodera avenae*, cereal cyst nematode). This internal sessile parasite lives in soil in the form of cysts and larvae. Invasive larvae hatched from cysts penetrate the roots of host plants and cause deformations of the root system. Affected plants have a weakened root system and stumped growth. Cysts of the nematode may survive in soil for many years and in favourable conditions larvae hatched from them will attack the host plant. Barley can be also attacked by stem and bulb nematode *(Ditylenchus dipsaci)*. A characteristic symptom of damage caused by nematodes is strongly stumped growth of plants and their patchy distribution in the stand.

Barley stand can also be under pest pressure. Apart from direct damage done in the stand during foraging, pests are also vectors of dangerous viral diseases, e.g. barley yellow dwarf virus (BYDV transmitted by aphids). The most common pests of barley and other cereals are aphids and larvae of cereal leaf beetle *(Oulema melanopus)*. Adult cereal leaf beetles forage on cereal plants and monocotyledonous weeds from early spring. In the summer the damage on plants is done mainly by larvae hatched from eggs laid by the insects on leaves. Recent years have seen an increase in their presence in barley crops. Damage of flag leaves may in particular lead to a decrease in the weight of grains from an ear and lowered yield. With a high intensity of foraging of this pest, larvae may damage up to 80% of the assimilation surface of plants, which drastically reduces barley yield. Damaged leaves are also more prone to fungal diseases. Barley plants can also be attacked by larvae of click beetles called wireworms (Elateridae) and Diptera: wheat bulb fly *(Delia coarctata)*, frit fly *(Oscinella frit)*, barley gout fly (*Chlorops pumilionis* Bjk.), and gall midges (Cecidomyiidae). Damage done by wireworms may be intensive when barley crop is introduced after perennials such as grasses or legumes in ground cultivation or after permanent grassland. Wireworms damage roots, larvae of frit fly forage on ripening grains, larvae of wheat bulb fly drill into shoots and damage plants in early spring, while larvae of gout fly damage ears and shank of spring barley (first generation) and young plants of winter barley (second generation). The larvae of gout fly drill tunnels in the shank which may even lead to stoppage of the ear in flag leaf sheath and disturbed ear formation. Aphids can do damage in barley crop if they attack ears between the flowering and the milk-ripe stage. Usually barley is attacked by a bird cherry-oat aphid *(Rhopalosiphum padi)*, English grain aphid *(Sitobion avenae)*, and rose-grain aphid *(Metopolophium dirhodum)*. The risk for a plantation depends on the numbers of the pest. A mass infestation with aphids is particularly dangerous in the stage of barley ear formation. Honey dew produced by aphids is a food for natural aphid predators, but also a great medium for the development of fungi causing sooty mould.

A significant problem in cereal cultivation can be weed infestation of the stand, mainly with monocotyledonous weeds, although weeds in the group of dicotyledonous are also common in cereal cultivation. On farms where winter cereals prevailed in the cropping pattern in the past, monocotyledonous weeds, such as wind-grass, annual bluegrass or couch grass, can become a problem. Where the share of spring cereals is higher an increased pressure of wild oat can be noted. Weeds accompanying barley include dicotyledonous weeds: bedstraw, chickweed, speedwell, deadnettle, the anthemideae, three-coloured violet, corn poppy, white goose-foot, and more. Compared to spring cereals weed control using non-chemical methods in winter cereals can be difficult as it is impossible to carry out an appropriate number of mechanical treatments destroying weeds in a set of post-harvest treatments.

Disease limitation and control

In controlling pathogens in regenerative barley growing a preventative approach is used, closely related to the place of barley in crop rotation. Crop rotation is effective against some plant pests and diseases attacking barley which have a narrow range of hosts and the chemical control of which is ineffective or where active substances used for controlling diseases have been withdrawn from use. An example is take-all disease – a fungal disease of cereal plants caused by fungus from the genus *Gaeumannomyces*. Usually a break in growing barley of one to two years with growing phytosanitary plants in between (dicotyledonous, preferably legumes) may limit the pressure of the pathogen below the threshold of harmfulness. Another example is sharp eyespot disease, also called rhizoctonia of cereals. It is a disease of many cereal plants caused by *Rhizoctonia solani* and *Ceratobasidium* cereale fungi. The function of crop rotation and agricultural measures in limitation of fungal pathogens involves limiting the possibility of soil transmission of inoculum, that is spores of fungi or fragments of mycelium which in favourable conditions may initiate the disease. Post-harvest residues inhabited by fungi are usually the source of inoculum. Therefore, applying crop rotation and intervals in growing host plants leads to significant mineralisation of residues and with no new residues of host plants the population of pathogenic fungi may be significantly reduced.

Crop rotation is also effective in reducing the number of cereal crop eelworm cysts which apart from barley attack also other species in the grass family, including oat, wheat or weeds from this family. In this case cultivation of non-host species of cyst nematode between these crops means that juveniles emerged from cysts die in the absence of a host, reducing the pressure of this nematode and the infestation of the plants.

As described above, the hosts of pathogens causing fungal diseases are also weeds in the grass family and even dicotyledonous weeds. Therefore, effective weed control may also contribute to the reduction in pressure of diseases in a barley stand. It should be remembered, that residues of chemically destroyed weeds and self-sown plants can be paths in transmission of diseases, particularly if the herbicide spraying is carried out directly before sowing barley. Weeds weakened with herbicide spraying are easily colonised by pathogens and if

a weed is a host of fungus causing diseases in barley, there is a high probability of infecting the stand. Therefore, elimination of weeds and self-sown plants should be planned with a good advance before the expected sowing of barley, so that weed residues decompose.
An important part of agricultural treatments related to the intensity of disease spreading in the stand is the density of sowing – excessive density of the stand is conducive to the development of fungal diseases affecting barley. It is also worthwhile to use spatial isolation from other barley stands and cereals affected by these fungi which may be the source of spores.

Cultivation and management of post-harvest residues may also be tools in pest and disease control, including in limiting the pressure of fungi causing diseases of barley plants. Mechanical shredding of post-harvest residues may effectively shred hypha of mycelium, leading to slowing down of the flow of microbiological activity and growth of mycelium, as a result limiting the spread of diseases such as rhizoctonia of cereal. A build-up of plant residues on the surface of soil reduces warming up of the soil and increases its moisture content, which may encourage the proliferation of fungi which they transmit – which is why in cooler regions it is advisable to introduce reduced tillage technologies which move the forecrop residues beyond the seed sowing zone. If we decide to apply mulch from catch crops before growing barley, it is important that plant species in the catch crop mixture have a phytosanitary effect on barley.

Balanced fertilisation combined with care for crucial physical and biological properties of soil are the basis for the development of healthy barley plants. Well-developed, strong plants are characterised by a higher resistance to pathogenic factors. Additionally, in the assessment of barley resistance to diseases, differences between varieties should be taken into account and varieties should be rotated.

If needed, some fungal diseases of barley can be controlled using chemical fungicides, based on specific active substances currently approved for marketing. It should be remembered however, that there are no effective chemical methods to control all pathogens and pests in barley cultivation. Chemical crop protection should be used in justified cases and as a complement to agricultural technology.

Winter barley may be affected by fungal diseases as early as the autumn, therefore increasingly often farmers apply fungicide spraying at the T-0 stage (in the autumn for winter barley at the tillering stage). Each spraying with an active fungicidal substance, including T-0, should be applied when the economic threshold of harmfulness was exceeded and the plantation is at risk. Apart from the application of fungicides in the already growing stand, seed dressing is also used, as it protects barley against diseases such as smut and leaf-strip disease.

Pest reduction and control

In the reduction of pest pressure the timing and density of sowing, cultivation of soil, crop rotation may be of great importance, as well as the diversity of the agricultural landscape and the protection of beneficial organisms (natural enemies of pests).

Early sowing of spring barley and not too early sowing of winter barley in the autumn may to a large extent limit the pressure of frit fly and gout fly. Effective control of wireworms involves tilling the soil a number of times in warm weather, which leads to high mortality of wireworm larvae in loosened and quickly drying soil. In the reduction of pressure from wheat bulb fly the management of stubble is very important as it is related to the life cycle of this insect. Females of wheat bulb fly lay eggs in the summer on open soil or soil lightly covered with vegetation, therefore the stubble should not lie fallow for too long. A good solution for limiting the pressure from wheat bulb fly is the sowing of catch crops soon after the harvest of the main crop in the forecrop – spring barley combination.

In the regenerative approach to crop protection it is crucial to look after beneficial organisms which is linked to the appropriate development of the agricultural landscape. It is important to realise that beneficial organisms rarely have a chance to survive on arable land, therefore biotopes that provide habitat and breeding sites for these organisms should be located in the close vicinity of the fields. Such biotopes include various mid-field stands of trees, unmown roadsides, field boundary strips, bogs and peatlands, meadows and pastures used extensively, idle land etc. It has been noted, for example, that the presence in the close vicinity of fields of areas with early flowering vegetation provides nectar for adult Syrphidae or Chrysopidae insects and the conditions for spring proliferation of aphids which their larvae feed on. Plants flowering in the early spring are necessary to produce several generations of Syrphidae insects in a year and as a consequence their more intensive activity in the nearby fields. An adult female of a Syrphidae insect lays up to 1000 eggs near an aphid colony, from which larvae hatch which feed on these pests – until pupation a single larva can eat even 700 aphids. Also the larvae of Chrysopidae are predators of aphids and other pests – one larva eats even up to 100 aphids and hunts spider mites. Ladybirds and beetles in the Cantharidae family play a similar part in the protection of crops against aphids – adult insects and larvae feed on aphids. Thus, insects visiting fields can effectively prevent damage of the crops caused by aphids, as they naturally control the aphid population. Beetles in the Carabidae family are effective in destroying eggs and larvae of the Diptera which damage barley crops. For this reason, sites should be provided in close proximity to the fields where adult insects find suitable places to overwinter and to feed and reproduce from the early spring months. Also, sparing tillage promotes the existence of beneficial insects in the fields.

Direct vicinity of crops in which aphids are present may increase their pressure on barley – for example sowing winter barley next to unharvested corn plantation may cause the aphids to fly to the stand of emerging barley after the corn is harvested and increase the risk of barley being affected by viral diseases. Therefore, early sowing of winter barley is not recommended.

Chemical control of barley pests should be carried out only is justified cases and when the thresholds of economic harmfulness are exceeded.

Weed limitation and control

Appropriate organisation of crop rotation including catch crops is an important tool for the management of weeds in regenerative crop growing.

In the regenerative management of weed infestation, non-chemical methods are definitely preferred. Important elements of weed control are mechanical methods, that is cultivation in the period after the harvest and in the spring and mechanical care of the stand. For spring barley growing after forecrops harvested early from the field, a complete post-harvest cultivation should be carried out, that is at least 2-3 shallow tillage treatments at intervals using a cultivator, disc harrow or an aggregate for post-harvest cultivation. When sowing barley after early harvested forecrops, shallow cultivation of the stubble should be carried out in the period between the harvest of the forecrop and the sowing of winter barley. The length of intervals between treatments depends on the rate of emergence of weed seedlings and may vary depending on the weather conditions. In the spring, before the sowing of spring barley, shallow tillage should be carried out as early as possible using a harrow, drag or cultivation aggregate. Reduce till cultivation recommended for regenerative growing of cereals is not an inversion cultivation, therefore the emerging weeds sprout from the bank of seeds limited to the topsoil. Therefore, such stimulation of emergence of weeds from seed banks located in this layer of soil significantly reduces the pressure of these weeds in no-till cultivation. Additionally, shallow cultivation protects soil moisture in the post-harvest period and in the spring, destroys pathogens and pests present in post-harvest residues and transmitted through them.

Mechanical weed control using shallow loosening treatments may be carried out also in a growing stand of spring and winter barley. Light harrows with sharp tines and weeder type harrows are used for weeding. The harrowing of spring barley is performed several times: the first time – after the sowing (shallow, 1-1.5 cm deep), the second time – at the stage of coleoptile development (emergence), the next – only after 3-4 leaves are developed. Such an approach to postemergence harrowing is a consequence of the biology of barley growth – in the period before the coleoptile development and the development of 3-4 leaves rootlets of barley are sensitive to mechanical damage. At the stage of a few leaves the tillering nodes are formed and secondary roots start to develop which anchor the seedlings in soil more strongly, thus the seedlings are more resistant to mechanical damage by cultivation. In case of winter barley, spring harrowing is usually only performed twice, 10-12 days apart, with new weed seedings growing in the meantime. Weed control harrowing at this time may also be used to mix nitrogen fertiliser applied in the spring with soil. Spring harrowing also fights mild symptoms of mould. Weed control harrowing of winter barley should not be carried out in the autumn, due to the risk of excessive uncovering of tillering nodes, which may adversely affect overwintering of plants. Each weed control harrowing should be performed carefully and across or diagonally to the rows of sown barley. It is important to carry out the harrowing on a warm, sunny day in the afternoon – in these conditions the plants are more "flexible" and resistant to mechanical deformation, thus the risk of damaging them with harrow tines is lower. Of course, spring harrowing is recommended also when growing spring barley. Apart from the weeding effect, spring postemergence harrowing destroys the soil crust, reduces the loss of moisture, and accelerates warming up of soil.

Mechanical methods are also useful in control of noxious, perennial cereal weed which is couch grass. Effective control of couch grass is particularly important in the fields where introduction of no-till cultivation is planned in subsequent years. The approach to mechanical control of couch grass differs slightly between lighter and heavier soils. On lighter soils, it is important to carry out mechanical weeding in the periods of several days of sunny and warm weather. The first step is skimming with a plough at the depth greater than couch grass rhizomes. Overturned furrow slices are left to dry and then cultivation with a spring-tine cultivator is performed twice crosswise in order to pull the couch grass rhizomes to the surface of the soil. Rhizomes are left to dry and then removed from the field using a cultivator or harrow. This is followed by deep tillage with a skim-coulter in order to cover the residues of couch grass rhizomes with soil. Deep coverage of fragments of rhizomes significantly reduces the emergence of couch grass and its regrowth. On heavier soils, first the couch grass rhizomes have to be cut using a disc harrow (disking the field twice crosswise). Then, wait for the couch grass to emerge, during which time the young plants use up nutrients stored in short fragments of rhizomes. After the field grows green, before the plants manage to store new nutrients in rhizomes, deep tillage should be carried out with a skim-coulter - due to consuming of nutrients from fragments of rhizomes without assimilation of new nutrients, the emergence of couch grass from deeper layers of soils will be significantly reduced.

It is important to remember that in the regenerative approach one should not rely exclusively on chemical weed control. Chemical control should be used in accordance with the code of good agricultural practice, at the right temperature, in suitable weather and in early stages of weed development, as it increases its effectiveness. Chemical weeding should complement other methods of weed control, if needed. In case of winter barley, chemical weeding of the stand should be carried out in the autumn. Spring treatment of plants with active substances may lead to stress and impair their development.

3.9 Plant growth and development regulation

The basis for regulation of plant growth and development is maintaining optimal parameters and timing of sowing and fertilisation. For example, growing fodder barley, both spring and winter barley, sown too densely and on a good site combined with high nitrogen doses may lead to increased susceptibility of the plants to lodging. Also, sowing winter barley too early in warm, extended autumn may cause excessive growth of winter barley plants and their higher susceptibility to fungal diseases and poorer overwintering. In this case, in order to prevent lodging and improve the condition of the plantation, lodging-preventing agents can be applied in the leaf development stage (BBCH 12-14) and in the stem formation stage until the development of the flag leaf (BBCH 30-49). With more intensive barley cultivation, varieties resistant to lodging are also useful, however the bottom line should nevertheless be using optimal agricultural technology and selection of varieties.

Harvest and storage

3.10

Attention to the quality of grain yield and storage is crucial in growing malting barley. The grain for malting purposes should be healthy and without damage. Grain damage may affect seed embryos, which directly affects the ability of grain to germinate. As the key process in malting is germination of grains, grain should be characterised by high germination energy – above 95%.

In order to meet these requirements, the following rules should be adhered to in harvesting and storing grain of malting barley:

- harvest after the stand reaches the dead-ripe stage and grain moisture of 14-15%;

- appropriately adjust the settings of a combine harvester and control them during the harvesting;

- grain which is too moist should be additionally dried at the maximum temperature of 40°C;

- during the storage the grain mass should be regularly aired and checked for presence of store pests which damage germs (e.g. cereal mites).

Grain harvested in the conditions of excessively high moisture, damaged, not properly developed or unripe is not suitable for the brewing industry, and can be only used for fodder or energy-producing purposes.

4 SUMMARY OF TREATMENTS AND ANALYSIS OF BENEFITS

Barley is a cereal species which has many advantages and adjusts well to changeable conditions of the site and can be used for various purposes.

Both spring and winter barley are crops harvested early, which provides good conditions for sowing early winter crops, early sowing of catch crops and the use of undersowing. In the regenerative barley cultivation attention should be paid to the following aspects which combine the production of high yields of good quality and caring for soil health and the whole agricultural ecosystem:

- barley should be ensured an appropriate position in crop rotation which is slightly different for winter and spring barley, for barley grown as fodder and barley for malting purposes. Irrespective of the form and purpose, barley should be grown after non-cereal forecrops which is very important to reduce the pressure of pests and diseases and improve the conditions for plant development, and reduce the need to apply pesticides.

- in crop rotation schemes, where early harvested forecrop is followed by spring barley, multi-species mixtures of stubble catch crops should be grown. Plants grown before barley should have a beneficial phytosanitary effect on it;

- various variants of no-till cultivation should be used. Reduced tillage should be introduced to fields free from a strong pressure of weeds, in particular monocotyledonous weeds (including perennial couch grass) and in the conditions of properly composed crop rotation. No-till cultivation promotes the accumulation of organic matter in soil, protects soil structure, and improves water retention in arable soil;

- elements of landscape which support soil water retention and biodiversity of arable fields should be looked after;

- maintaining optimum timing and parameters of the sowing, including the density of sowing and the depth of seeds. Optimisation of agricultural treatments in this area combined with good quality of seeds promotes the development of strong plants with a well-developed and deep root system which use the site well and are resistant to environmental stress such as moisture deficiency or pressure of pests and weeds;

- rational fertilisation of barley should be based on the understanding of nutritional needs of the plant, expected yield, fertilisation value of natural and organic fertilisers applied for barley and for barley forecrop which improve the balance of organic matter, soil fertility and health. Mineral fertilisation should be used complementarily and be based on regulation of soil pH and the knowledge of amount and quality of nutrients currently in soil (a comprehensive soil analysis) and nutritional needs of barley in specific soil conditions (potential yield level and the plantation condition),

- supporting plant health as well as pest and disease control should primarily be based on non-chemical methods, such as properly composed crop rotation, mechanical treatments, selection of varieties, supporting beneficial organisms by appropriate development of agricultural landscape. Crop protection chemicals should be used in justified cases and their effectiveness should be ensured.

Practical application of the principles of regenerative farming can significantly improve the conditions for crop growth while at the same time decreasing the expenditure incurred for mineral fertilisation or various chemicals for pest and weed control, which has many benefits for the production and the environment. Therefore, regenerative methods can be applied in order to obtain high and good quality yield of winter and spring barley in sustainable agriculture.

Practical application of the principles of regenerative farming can significantly improve the conditions for crop growth while at the same time decreasing the expenditure incurred for mineral fertilisation or various chemicals for pest and weed control, which has many benefits for the production and the environment.

Bibliography:

1. Dz.U. 2013 poz. 616. *Rozporządzenie Ministra Rolnictwa i Rozwoju Wsi z dnia 22 maja 2013 r. w sprawie minimalnej ilości materiału siewnego, jaka powinna być użyta do obsiania lub obsadzenia 1 ha powierzchni gruntów ornych.*

2. Dz.U. 2018 poz. 1339. *Rozporządzenie Rady Ministrów z dnia 5 czerwca 2018 r. w sprawie przyjęcia „Programu działań mających na celu zmniejszenie zanieczyszczenia wód azotanami pochodzącymi ze źródeł rolniczych oraz zapobieganie dalszemu zanieczyszczeniu".*

3. Budzyński W. (2005). *Jęczmień browarny. W: Rynki i technologie produkcji roślin uprawnych: praca zbiorowa.* **Chotkowski J. red. Wyd. Wieś Jutra.**

4. Dziadowiec H. (1993). *Ekologiczna rola próchnicy glebowej. Zeszyty Problemowe Postępów Nauk Rolniczych.* **z. 411, 270-272.**

5. Dzienia S., Szarek P., Koszarska A. (2001). *Uproszczenia w uprawie roli a plonowanie roślin. Nauka-Gospodarce.* **AR w Szczecinie, Szczecin.**

6. Dzienia S., Zimny L., Weber R. (2006). *Najnowsze kierunki w uprawie roli i technice siewu. Fragm. Agron.* **23(2), 227–241**

7. Fotyma M., Mercik S. (1995). *Chemia rolna. Wyd. drugie zmienione.* **Wyd. Naukowe PWN, Warszawa.**

8. Gąsiorowski H. red. (1997). *Jęczmień. Chemia i technologia.* **PWRiL, Poznań.**

9. Grzebisz W. (2009). *Nawozy organiczne. W: Nawożenie roślin uprawnych, Cz. I. Nawozy i systemy nawożenia,* **PWRiL, Poznań.**

10. Grzebisz W. (2009). *Nawozy organiczne. W: Nawożenie roślin uprawnych, Cz. II. Nawozy i systemy nawożenia,* **PWRiL, Poznań.**

11. Häni F., Popow G., Reinhard H., Schwarz A., Tanner K., Vorlet M. (1998). *Ochrona roślin rolniczych w uprawie integrowanej.* **PWRiL, Warszawa.**

12. Hołubowicz-Kliza G. (2010). *Uprawa poplonów. Instrukcja upowszechnieniowa* **166, IUNG-PIB, Puławy.**

13. Hołubowicz-Kliza G. (2023). *ABC wysiewu zbóż – tablice norm wysiewu. Inst. upowsz.* **250, IUNG-PIB, Puławy.**

14. Horoszkiewicz-Janka J., M. Korbas, M. Mrówczyński red. (2017). *Metodyka integrowanej ochrony i produkcji jęczmienia ozimego i jarego dla doradców.* **IOR Poznań.**

15. IOR-PIB. (2010). *Ochrona jęczmienia jarego przed szkodnikami, chorobami i chwastami w gospodarstwach ekologicznych,* **IOR-PIB Poznań.**

16. Jadczyszyn T. (2013). *Dobre praktyki w nawożeniu użytków rolnych.* **Wyd. CDR, Radom.**

17. Jasińska Z., Kotecki A. red. (2003). *Szczegółowa uprawa roślin,* **Wyd. AR Wrocław.**

18. Kaniuczak Z., Bereś P. K., Tekiela A. Krawczyk R., Nijak K. (2010). *Ochrona jęczmienia jarego przed szkodnikami, chorobami i chwastami w gospodarstwach ekologicznych.* **IOR-PIB, Poznań.**

19. Korbas M., Mrówczyński M. red. (2012). *Metodyka integrowanej ochrony jęczmienia ozimego i jarego dla producentów.* **IOR-PIB Poznań.**

20. Kropisz A. (1997). *Nawozy. W: Uprawa roli i nawożenie roślin ogrodniczych.* **Starck J. R. red. PWRiL, Warszawa.**

21. Kuś. J., Martyniuk S. Duer I., Krasowicz S., Smagacz J., Mróz A. (1998). *Agrotechniczne metody ograniczenia ujemnych następstw zwiększonego udziału zbóż w płodozmianie.* **Materiały szkoleniowe 70/98, Puławy.**

22. Maćkowiak Cz. (1998). *Słoma jako nawóz w gospodarstwie bezinwentarzowym.* **Wieś Jutra, 5, 46-48.**

23. Maćkowiak Cz. (1999). *Gnojowica - jej właściwości i zasady stosowania z uwzględnieniem ochrony środowiska.* **Materiały szkoleniowe nr 75/99. IUNG, Puławy.**

24. Maćkowiak Cz., Żebrowski J. (2000). *Skład chemiczny obornika w Polsce. Nawozy i Nawożenie. Rok II,* **4(5), IUNG.**

25. Maćkowiak Cz. (2004). *Zasady stosowania nawozów naturalnych i organicznych w świetle aktualnych regulacji przepisów. W.: Poprawa efektywności wykorzystania składników nawozowych w gospodarstwach rolnych na Mazowszu.* **Rzepiński W. red., Wyd. ODR.**

26. Normatywy Produkcji Rolniczej – Centrum Doradztwa Rolniczego w Brwinowie. https://poznan.cdr.gov.pl/normatywy/.

27. Noworolnik K. (2005). *Jęczmień jary (pastewny). W: Rynki i technologie produkcji roślin uprawnych: praca zbiorowa.* **Chotkowski J. red. Wyd. Wieś Jutra.**

28. Noworolnik K., Leszczyńska D. (2011). *Integrowana uprawa mieszanin odmian jęczmienia ozimego na cele pastewne.* **Inst. upowsz. 190, IUNG-PIB, Puławy.**

29. Pisulewska E. (2005). *Jęczmień ozimy. W: Rynki i technologie produkcji roślin uprawnych: praca zbiorowa.* **Chotkowski J. red. Wyd. Wieś Jutra.**

30. Rayne, N., Aula, L. (2020). *Livestock Manure and the Impacts on Soil Health: A Review. Soil Systems,* **4(4), 64.**

31. Rozbicki J. (1994). Jęczmień. *Uprawa na cele browarne, konsumpcyjne i paszowe.* **MODR Bartoszewice.**

32. Słabński A. (1976). *Jęczmień ozimy i jary.* **PWRiL, Warszawa.**

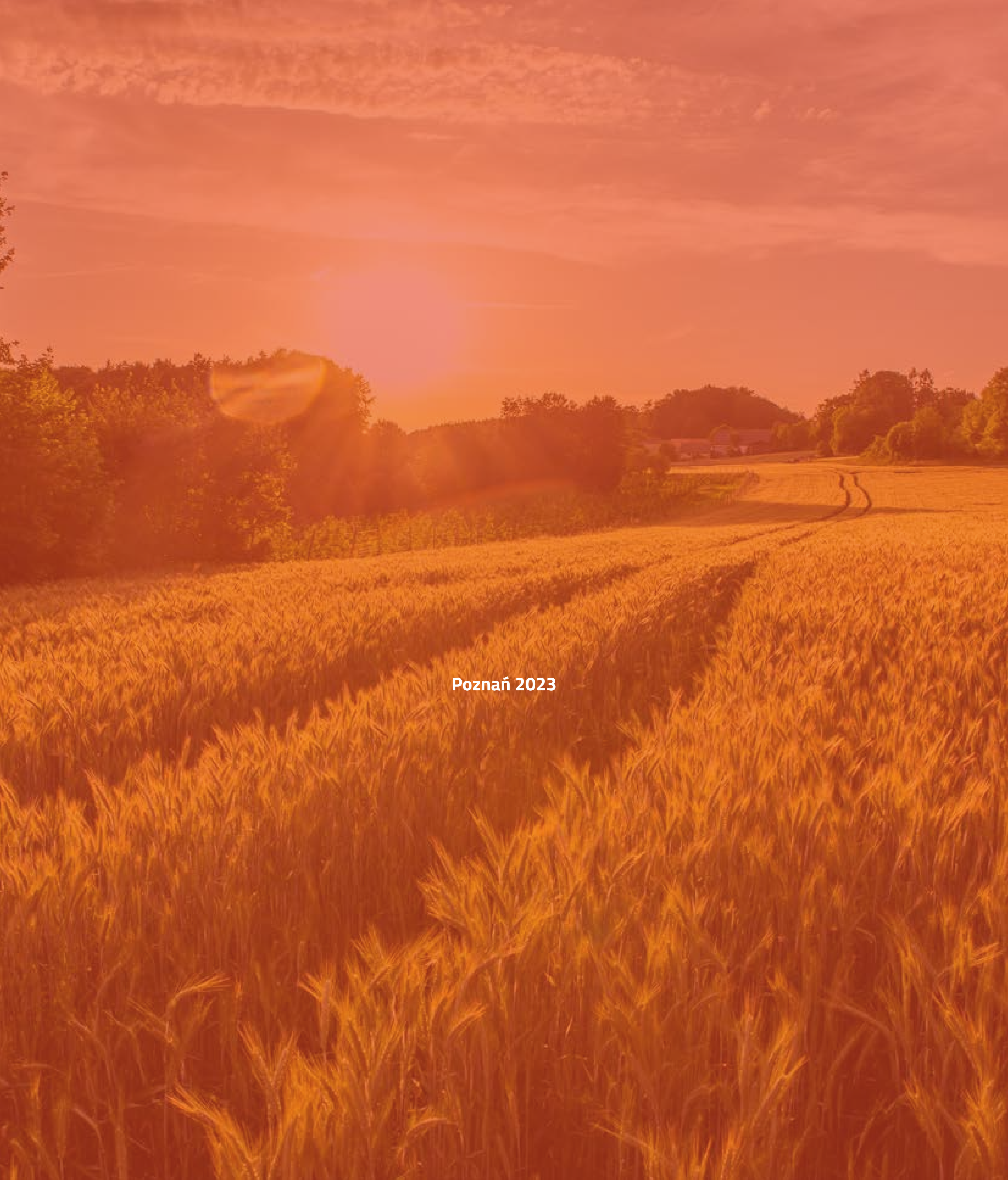
33. Szempliński W., Budzyński W., Bielski W. (2020). *Jęczmień. W: Uprawa roślin. Tom II.* **Red. Kotecki A. Wyd. UP we Wrocławiu.**

34. Ullrich S. E. (2011). *Barley_ Production, Improvement, and Uses (World Agriculture Series),* **Wiley-Blackwell.**

35. VDLUFA. (2014). *Humusbielanzierung. Eine Methode zur Analyse und Bewertung der Humusversorgung von Ackerland.* **Wyd. VDLUFA.**

26. Walczak J. red. (2019). *Wdrażania Dyrektywy NEC oraz konkluzji BAT w zakresie redukcji emisji amoniaku z rolnictwa.* **Fundacja na rzecz Rozwoju Polskiego Rolnictwa. Wyd. Naukowe Scholar.**

27. Yau, S.-K., Nimah, M., Farran, M. (2011). *Early sowing and irrigation to increase barley yields and water use efficiency in Mediterranean conditions.* **Agricultural Water Management, 98(12), 1776–1781.**



Poznań 2023

TERRA NOSTRA FUNDACJA

EIT Food

Co-funded by the European Union