Polish Journal of Agronomy
2019, 39, 16–26

doi: 10.26114/pja.iung.399.2019.39.03

Natural and crop management-related conditions for spring feed barley production

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Abstract. Barley is a cereal of great economic importance, dominating in the cropping patterns of spring cereals. Currently, spring forms are grown primarily for fodder purposes. The correct selection and preparation of a stand for cultivation and the correct timing of crop management practices (sowing, disease management and fertilization adapted to the habitat conditions), as well as the selection of high-yielding and disease-resistant varieties, are vital to secure high crop yields with good quality parameters. Lack of knowledge of the interaction between habitat and crop management factors negatively affects the quantity and quality of barley crop.

Keywords: spring barley, barley cultivation, grain yield, yielding factors

INTRODUCTION

In Poland, cereals represent the most significant group of crop plants (Skarżyńska and Pietrych, 2018). Barley is a basic cereal species of great economic importance. It has been utilised by humans for thousands of years. In Poland, mainly spring barley is grown, the area of which in 2018 was 773 000 ha. This accounted for 80% of its total cultivation and 10% of the cereal crop structure (Central Statistical Office of Poland – GUS, 2019). Currently, spring forms are mainly grown for fodder purposes, for which brewing varieties can also be utilised (Chojnacka et al., 2018). Due to the low content of non-nutrients, barley grain is an excellent feed for all farm animals. Moreover, as a consequence of the relatively high content of palmitic and stearic acids, it improves the palatability and durability of animal products including milk, butter, meat and lard (Leszczyńska and Noworolnik, 2012; Liszewski, 2008; Noworolnik, 2014). Furthermore, due to the higher protein content, straw also exhibits a better feed value than other cereals (with the exception of oats). Production of a high-quality barley grain, characterised by good feed suitability, requires knowledge of interactions between the key natural and crop-management related factors (Noworolnik, 2014).

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HABITAT FACTORS

Based on the analyses of numerous field experiments, it has been established that weather and soil conditions have the greatest impact on the yield of spring barley. In the literature on the subject, the majority of the studies focus on the impact of soil conditions on spring barley yields, while only a few reports demonstrate the impact of weather. Despite its importance, particularly in the aspect of the continuously changing climate, the impact of meteorological conditions is often neglected. Currently, periods without rainfall during vegetation, or periods with precipitation much lower than average, occur more and more frequently (Doroszewski et al., 2012; Eitzinger et al., 2012; Mizak et al., 2011). This is typically accompanied by high temperatures (Ceccarelli and Grando, 1996). Water scarcity is one of the most common environmental stresses, limiting plant growth, development and cropping (Alquadah et al., 2011; Carter et al., 2019; Ceccarelli et al., 2010; Datta et al., 2011; Forster, 2004; Hossain and Uddin, 2011; Khalili et al., 2013). Despite the fact that as a result of a relatively low transpiration coefficient and a high roots suction power spring barley is one of the most resistant cereals to adverse water conditions (Noworolnik, 2008; Noworolnik and Terelak, 2006), research shows that the size of the obtained crops depends on the amount and distribution of rainfall during the growing season (Chmura et al., 2009). Many authors state that the effects of water deficit during barley cultivation depend on the development phase in which it occurred (Chmura et al., 2009; Liszewski, 2008; Pecio, 2002; Rajala et al., 2011). During the germination phase, water shortage reduces emergence, while during the tillering phase, it inhibits the development of the aerial parts and roots, resulting in a reduction in the number of culms, ears and spikelets in the spike (Chmura et al., 2009; Budzyński and Szempliński, 1999). Water deficit during the stem shooting phase reduces the assimilation area and decreases the growth of vegetative organs, which in turn results in a low grain and straw yield. Drought stress during the earing and flowering phases leads to poor ear development, a reduction in the number of grains in the ear and the production of unfertile culms. Kernel development is a period, in which water is necessary to properly fill the grain; therefore, the lack of water during the milk maturity phase is manifested by poor grain formation with a higher content of glumes (Chmura et al., 2009; Budzyński and Szempliński, 1999). Research carried out in various scientific centres considering the impact of drought on the spring barley yields has shown that the quantity of the crop is predominantly influenced by the water shortage during the shooting and earing phase (Al-Ajlouni et al., 2016; Haddadin, 2015; Pecio and Wach, 2015). Trnka et al. (2004) also emphasise that one of the key elements is the content of available water in the soil on the day of sowing. Moreover, a team of scientists demonstrated that a 1% increase in the available water content results in an increase in the yield from 0.54 to 1.01 dt ha^{-1}.

During drought, the soil's ability to store water is crucial for the plant development. Fine-grained deposits are characterised by greater retention capacity (Thompson and Troeh, 1978), because the value of the field water capacity (FWC) increases with increasing content of silt and clay fractions (Hewelke et al., 2013). Due to the poorly developed root system and short vegetation period (about 100 days), spring barley has higher soil requirements than oats, triticale or rye (Noworolnik, 2008). The best yields of spring barley are obtained on loamy and silty soils belonging to the following complexes: very good wheat and good wheat. Based on decades of research (Noworolnik, 2014, 2015a; Noworolnik and Terelak, 2005), it was determined that in very good wheat complex soils, 6% higher spring barley yields were obtained than in good wheat complex soils. In comparison to very good rye complex soils, 10–16% higher yields were achieved, while compared to good rye complex soils, the yields were higher by 19–24%. The biggest difference was noted for poor rye complex soils, in which the yield was 32% lower. In the above studies, it was also established that the response of barley plants to cultivation in specific soil conditions also depended on the cultivar, and the partial compensation for the lower yields obtained in worse soil conditions is the increase of the protein content in the grain (Noworolnik, 2014; Noworolnik and Terelak, 2005).

CROP MANAGEMENT FACTORS

Previous crop

Research conducted by Woźniak (2002) reveals that the best pre-crops for spring barley are pea and potato. The grain yield with such preceding crops was approximately 30% higher than when barley was sown continuously. The group of good preceding crops for spring barley also includes rapeseed, maize and buckwheat. Among cereals, oats and wheat are also acceptable preceding crops; however, barley should not be grown after oat too often, because of the possibility of the parasitic nematodes multiplying in the soil, e.g. *Heterodera avenae, Tylenchorhynchus dubius* and *Pratylenchus negleclus* (Skwiercz and Wolny, 1988). Continuous cultivation of spring barley causes an increase in the plant infestation due to diseases of the base of the stem and roots (Adamiak et al., 2005; Kurowski et al., 2005; Sawinska et al., 2016). This was confirmed by the results of studies carried out by Woźniak (2002), which showed a significant increase in the infection of barley plants grown in monoculture, compared to plants sown after an appropriate preceding crop. The infection rate increased from 2.8% to 13.8% for infections with *Gaeumannomyces graminis* and from 5.4% to 13.4% for infections with *Pseudocercosporella herpotrichoides*. The above studies also determined that two or three consecutive cultivations of barley significantly reduced the number of ears per unit area and the number and weight of grains per ear. Other results based on 47-year observations, presented by Blecharczyk et al. (2005), also show spring barley sensitivity to monoculture. The conducted analyses demonstrate that the grain yield was on average 20% lower than in the case of using a 7-field crop rotation.

Cultivation

Cultivation changes the physical, chemical and biological properties of the soil. At the end of the twentieth century, significant changes regarding the preparation of soil for sowing took place (Giemza-Mikoda et al., 2012). Regardless of the utilised system, cultivation aims to optimise the productivity of the soil by creating optimal conditions for even emergence as well as for plant growth and development (Małecka et al., 2012). Spring barley is sensitive to insufficient soil aeration. Limiting the amount of oxygen inhibits life processes and leads to changes in the plant metabolism (Czyż and Dexter, 2015). Plants grow less and produce fewer lateral roots, resulting in limited productivity of the main shoot, to which the lateral shoots supply nutrients (Pecio, 2002). Properly cultivated soil improves the water-air relations, reduces the amount of weeds and self-seeding of pre-crop plants, causes mixing of crop residues and fertilisers with the soil and increases the biological activity of the soil (Dzienia et al., 2006; Małecka, 2006; Noworolnik, 2014).

Most spring barley plantations are established after preceding crops, which are removed from the field early; therefore, it is necessary to implement post-harvest cultivation. When using traditional cultivation, the first performed operation is the stubble cultivation, the aim of which is to cover the stubble, stop the evaporation of water from the soil, cover the weed seeds and pre-crop grains as well as to level and re-compact the soil. The next stage is harrowing, which should be repeated after each emergence of weeds. If the harvest of the preceding crop was not delayed and the soil is sufficiently moist, catch crops or undersown crops can be used as alternatives to post-harvest cultivation. The last operation, carried out in autumn, is pre-winter ploughing. This step leads to increased porosity of the soil, which in turn results in greater water accumulation and an improved effect of frost on the formation of a lumpy soil structure. Utilising ploughs once every three years (to a depth of 20–25 cm) is sufficient. In the remaining years, it can be replaced by deep soil loosening tools, e.g. a grubber or a subsoiler (Dzienia et al., 2006; Noworolnik, 2014).

In the spring, the first treatment on compact soils should include harrowing or dragging. These treatments reduce the evaporation of water and accelerate soil heating. Prior to sowing, it is recommended to use a tillage aggregate that forms a compacted layer of soil just below the surface. Thanks to this, the seeds are placed at a similar depth and the emergence is even. On light soils, due to the possibility of excessive drying, spring cultivation should be reduced to a minimum, while on heavy soils, the use of active aggregates is preferable. If a cultivator is used, it is recommended to equip the tractor with track eradicators or twin wheels in order to reduce soil compaction (Dzienia et al., 2006; Małecka, 2006; Noworolnik, 2014).

Role of cultivar and seed quality

The contribution of variety to the crop growth is significant; therefore, it is an important element in cereal management. The cultivars differ for their crop production requirements (Noworolnik, 2007b); thus, in order to obtain a high and good quality barley crop, the following factors should be taken into account when choosing the seed material: intended grain use, yielding potential as well as soil and climate conditions (Noworolnik, 2007b; Szczepańska, 2018). In the case of grain intended for fodder, the protein content and amino acid composition are also important (Liszewski, 2008). Scientific studies reveal that native cereal varieties are better adapted to the climate and soil conditions of Poland than the foreign varieties (Noworolnik et al., 2007). The results of experiments carried out as a part of the Post-Registry Variety Experimentation are helpful in deciding what seed material should be used. The aim of the conducted research is to assess the suitability of varieties for cultivation in various climatic and soil conditions of Poland, to verify their characteristics, as well as to make recommendations for cultivation in particular voivodeships. To achieve this objective, lists of recommended varieties are created for a given province (Szczepańska, 2018). The list of agricultural plant varieties, the seed material of which may be produced and marketed in the country, can be found in the national register (www.coboru.pl (a)). Varieties included in the Common Catalogue of Agricultural Plant Species (www.coboru.pl (b)) are also allowed on the market. In recent years, there has been noticeable progress in the breeding of fodder barley. Varieties, which are increasingly better yielding and more resistant to adverse habitat conditions are being developed (Chojnacka et al. 2018; Friedt 2011). In 2019, 56 varieties of fodder spring barley were on the national register list (www.coboru.pl (a)).

Production of varieties increased for many years from non-certified seeds causes a decrease in the quantity, quality and use value of the crop. This happens as a result of genetic changes and overcoming the resistance to biotic stress. Hence, using certified seeds is a way to increase the size and improve the quality of the crops (Oleksiak, 2013; Ziemińska et al., 2015). This was confirmed by the results of a study conducted on a group of about 500 commercial farms. In the fields, where certified material was sown, the obtained spring barley yields were 6.5% higher than the yields from fields, in which non-qualified material was sown. This corresponds to a yield increase of approximately 2.6 dt ha^{-1}. Notably, the value of the obtained yield increase was greater than the costs associated with the purchase of certified seed material (Arseniuk and Oleksiak, 2013). Careful reproduction allows sowing grains for 2-3 years, without a decrease in the yield (www.zdhar.pl). Moreover, the use of certified seeds enables precise sowing processes to be carried out, that are adapted to the considered variety and field. As a result, correct plant density is obtained, the crop emergence is even, the crop development and maturation are balanced and the resistance to pests and diseases is improved (Arseniuk and Oleksiak, 2013).

Sowing date and seeding density

The sowing date is a crop production factor that determines the thermal, humidity and light conditions, in which the phases of plant growth and development take place (Grabiński et al., 2007; Ziemińska and Tkaczuk, 2017). Sowing spring barley should be done as early as possible. However, due to the high sensitivity of this cereal to low temperatures and as a consequence of relatively frequent prolongation of the winter conditions in some regions of the country, it is not always possible (Noworolnik, 2016).

Based on the results of numerous experiments (Gozdowski et al., 2012; McKenzie et al., 2005; Noworolnik 2012, 2013a; Ziemiński and Tkaczuk, 2017), it was determined that delaying the sowing date significantly impact

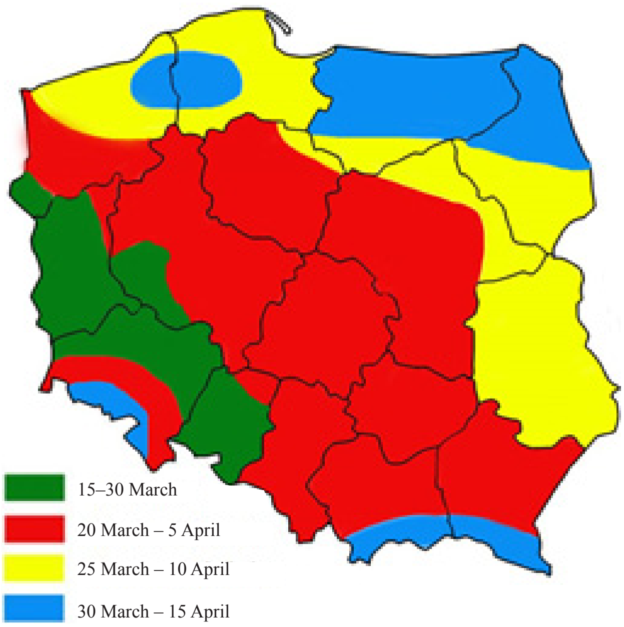

Figure 1. Optimal dates for spring barley sowing (source: www.mojarola.pl).

the spring barley yield. Late sowing is a reason for the reduction in the plant density. This results from the plant loss caused by poorer rooting. In the micro-plot tests carried out at the Institute of Soil Science and Plant Cultivation in Puławy, it was demonstrated that delaying sowing by 10 days led to a decrease in the grain yield of all tested spring barley varieties (Noworolnik, 2013a). In the above studies, it was also observed that delaying the sowing date increased the plant loss from 5–6% to 8–11%. A decrease in the production tillering was also noted, consequently resulting in a smaller number of ears per unit area. Early sowing reduces the negative impact of habitat conditions and allows more effective use of the winter water accumulated in the soil by the plants, which are less affected by pests and diseases. In the above tests, no influence of the sowing date on the number of grains per ear and the mass of 1000 grains was determined. Ziemiński and Tkaczuk (2017) conducted similar studies. They suggest that any delay in the sowing date significantly affects the number of ears per unit area and the mass of 1000 grains. Delaying the sowing date by 20 days (from 2 to 22 April) caused a reduction in the number of ears by 35% and decreased the grain yield by 18% per unit area. Moreover, a reduction in the weight of 1000 grains by 5% was also noted. The study carried out by Noworolnik (2013a) as well as that by Zieliński and Tkaczuk (2017) indicated varieties tolerant to the delay in the sowing date. No significant changes in the yield per unit area were observed; therefore, the described varieties are recommended for cultivation in the late spring seasons (Noworolnik, 2016).

Optimal plant density is an important element of cereal crop production strategy, as it ensures that the plants have a suitable access to light, produce a strong root system and that their stalks do not elongate. As a result, the plants are more resistant to lodging, there is no reduction of the lateral shoots or entire plants, while the nutrients and water in the soil are optimally utilised (Noworolnik, 2003; Noworolnik, 2007b).

Numerous studies (Leszczyńska et al., 2007; Noworolnik, 2015b; McKenzie, 2005) have confirmed that despite the fact that the sowing density is one of the basic factors determining the number of ears per unit area, an increase in seeding rate does not always cause an increase in the grain yield. This is because the response of spring barley to the sowing density depends on the individual characteristics of the variety (Jedel and Helm, 1995; Noworolnik, 2007a, 2015b) as well as on the natural and cultural factors (Noworolnik, 2007a). Studies conducted by Noworolnik (2007a) as well as Jedel and Helm (1995) demonstrate that the lack of a positive reaction of the spring barley varieties to an increased sowing rate (above 400 pieces of grains m^{-2}) is linked to an increased vulnerability to lodging and disease. A dense crop causes the plants to elongate and does not allow free liquid penetration during crop protection treatments (Leszczyńska et al., 2007).

Furthermore, studies often emphasise that the number of plants per unit area is not directly proportional to the number of seeds sown. This happens because excessive planting increases the competition between plants for water, light and nutrients. In this case, the plant loss occurs more frequently, which is confirmed by the studies carried out by Noworolnik (2015b). The results showed that when using a spring barley sowing density of 250 grains per m^2 (depending on the variety), between 0 and 0.5% of plants fell out, while in the case of sowing 450 grains per m^2, 9 to 12% of plants fell out. Excessively scarce sowing is also not beneficial. Even though the plant tillering is better, the stand is airy and healthy and the kernels have a larger mass under such conditions, the appropriate number of ears per unit area is not obtained, which in turn reduces the final crop (Noworolnik, 2007a).

Fertilisation

The main purpose of fertilisation is to provide plants with available forms of nutrients (macro- and microelements). In terms of plant growth, development and yielding, the essential elements, i.e. those without which the plant cannot develop properly, are most important (Kocoń, 2013).

The influence of nitrogen on barley yield has been presented in many papers (Andersson and Holm, 2011; Beatthgen et al., 1995; Noworolnik, 2013b; Noworolnik and Leszczyńska, 2002, 2005; Moreno et al., 2003; Příkopa et al., 2005; Shejbalová et al., 2014). According to these studies, nitrogen affects the growth and development of cereals; however, the degree of this impact depends on the morphological and physiological characteristics of individual varieties. In the studies carried out by Noworolnik and Leszczyńska (2005), it was found that the positive effects of increasing nitrogen fertilisation result from the increase in the number of ears per unit area, which is a consequence of improved tillering. Nitrogen has beneficial effects on the formation of crop structure features, affects the number of ears and the grain yield per ear and increases the levelling of ear sprouts as well as their productivity (Liszewski and Błażewicz, 2016). Nitrogen fertilisation also modifies the chemical composition of the grain, particularly the protein content (Hejcman et al., 2013; Liszewski, 2008). This was confirmed by the results of two pot experiments, which were carried out in the net-protected plant growth facility in Puławy. In the experiments, the reaction of various spring barley varieties to 3 levels of nitrogen fertilization (1, 2 and 3 g N per pot) was investigated. In both experiments, at a dose of 3 g N per pot, the protein yield of the tested varieties was about 2-fold higher than at a dose of 1 g N per pot (Noworolnik, 2013b; Noworolnik and Leszczyńska, 2005). In nitrogen fertilisation, the date of fertilisation is of great importance. Pre-sowing fertilisation determines the ear density. On the other hand, late fertilisation used in the tillering phase or in the beginning of the sprout shooting phase affects the number of grains in the spike and the grain development. Lastly, the utilised fertiliser dose in the heading phase determines the protein content in the grain. Nitrogen is a component, which easily migrates in the soil environment; therefore, it should be considered that excessive use of this element can lead to its excess in the soil, and thus an increased risk of leaching into the groundwater (Liszewski, 2008; Sułek et al., 2007; Noworolnik, 2013).

Both phosphorus and potassium are considered as necessary nutrients of plants from the beginning of vegetation. Phosphorus participates in the process of protein formation, accelerates life processes, causing earlier maturation of plants, reduces the accumulation of harmful forms of nitrogen in the plants and prevents plant lodging (Noworolnik, 2014). The presence of phosphorus is particularly important in the early stages of barley development. Lack of this nutrient during this period results in a decrease in yield, and its subsequent use is ineffective (Sułek and Leszczyńska, 2016). Potassium, on the other hand, determines the growth rate of vegetative plant organs, promotes the uptake of nitrogen, affects the process of photosynthesis, energy metabolism and improves the biological value of proteins as well as plant health (Noworolnik, 2014). Plants sufficiently fed with potassium are also less sensitive to drought stress (Sułek and Leszczyńska, 2016). The results of research carried out by Noworolnik and Terelak (2006) confirm the effects of phosphorus and potassium on the spring barley yield. The above studies determined that the lower the phosphorus and potassium content in the soil, the greater the decrease in the yield.

On the other hand, magnesium determines the amount of grain yield as well as its quality characteristics, i.e. the quantity and quality of the accumulated protein. The positive effects of the magnesium content on the barley grain yield have been confirmed in studies carried out by Noworolnik (2001) as well as by Noworolnik and Terelak (2006). They demonstrated a significant reduction in the spring barley yield with the decreasing content of magnesium in the soil. The protein content in the grain was significantly higher for soils less rich in this element. Higher protein content in the spring barley grain grown in soils with poorer chemical properties is associated with the phenomenon of the negative correlation of the grain yield with the protein content. Since magnesium easily migrates deep into the soil profile, sandy and acidic soils require higher levels of fertilisation with this component (Gaj, 2013). The first reaction of cereals to magnesium deficiency is an incorrectly developed root system. In the next stage, some changes in the aerial plant parts can be observed, which appear in the form of discolouration. High magnesium deficiency leads to the inhibition of the plant growth and development (Tratwal et al., 2017).

The positive influence of sulphur on the spring barley yield was demonstrated in the studies by Barczak and Majcherczak (2008), Eriksen et al. (2001) as well as by Kaczor and Łaszcz-Zakorczmenna (2003). The yield-creating effect of this element is closely related to the plant nitrogen economy. Eriksen et al. (2001) revealed that an appropriate supply of sulphur in barley positively affected the transport of nitrogen accumulated in the leaves to the ears. In conditions of sulphur deficiency, the efficiency of this process was reduced even by half. That means, plants suitably fed with sulphur convert the absorbed nitrogen into the utility yield more effectively (Gaj, 2013). In addition, Kaczor and Łaszcz-Zakorczmenna (2003) demonstrated a considerable impact of an appropriate sulphur supply on the efficiency of potassium fertilisation. Moreover, research conducted by McGrath et al. (1996) indicated that fertilisation with this component gave the best results in the form of an increased yield in conditions of proper supply with nitrogen, phosphorus and potassium. Plants adequately supplied with sulphur also exhibit greater resistance to diseases, pests and drought (Świtkowski and Barczak, 2015).

The optimal pH of spring barley depends on the agronomic category of the soil and ranges from 5.5 for loamy sand (very light soils) to 6.5 for heavy loam (heavy soils) (Leszczyńska and Noworolnik, 2012; www.susza.iung.pulawy.pl). The impact of the soil pH on the spring barley yield has been extensively studied (Noworolnik, 2001, 2006, 2015a; Noworolnik and Terelak, 2006). It has been showed that barley is a plant particularly sensitive to increasing soil acidification. Furthermore, Noworolnik

(2008) suggests that larger yield reductions are the reason for the cultivation of barley in conditions, where the soil pH is in the range of 4-5 rather than 5.2–7.3. Barley grain yields obtained at soil pH above 6.5 were similar to those obtained at pH 5.5 to 6.1. Other studies (Noworolnik, 2006) found that in cultivation conditions, when the soil pH was in the range of 4.8–5.4, there was an approximately 12–14% yield reduction, while in the pH range of 4.2–4.7, an approximately 22–25% decrease was noted in comparison to cultivation in optimal conditions. Excessively acidic pH limits the plant growth and development. At pH below 4.5, free aluminium and manganese ions appear in the soil solution, which damage the root hairs and limit the absorption of water and nutrients (Leszczyńska and Noworolnik, 2012; Czyż et al., 2015). Liming protects plants from harmful effects of phytotoxic substances and reduces the risk of the occurrence of pathogens. It also increases soil bio-activity and affects the formation of a so-called soil lump structure, which helps plants to endure drought periods (Czyż et al., 2015; Igras and Rutkowska, 2012).

Despite the fact that the cereal micronutrient demand is low, microelements carry out important functions in their enzymatic and regulatory processes (Gaj, 2013). Micronutrient deficiency leads to disturbances in the metabolism and increases the susceptibility of plants to adverse environmental conditions (Kocoń, 2010, 2013; Stanisławska-Glubiak and Korzeniowska, 2007), which in turn results in a decrease in yields and deterioration of their biological value (Barczak et al., 2006). In the case of acute deficiency of any of the components, visual symptoms may occur: growth inhibition, chlorosis (yellowing of plants due to the loss of chlorophyll) and necrosis (Kocoń, 2010, 2013; Stanisławska-Glubiak and Korzeniowska, 2007). Copper, zinc and manganese belong to the group of micronutrients, which have the greatest impact on the development, growth and yield of spring cereals. Research conducted by Barczak (2005) demonstrated the positive effect of manganese on the yield of the spring barley grain. In addition, a study conducted by Liszewski and Błażewicz (2015) indicated a significant impact of manganese and copper on the increase of the number of grains in the ear of this cereal compared to objects that were not fertilised with these micronutrients. However, not all researchers obtained the same results. For instance, research conducted by Kozłowska and Liszewski (2012) suggests that the barley grain yield is more influenced by the conditions, in which the vegetation took place than by the application of micronutrient fertilisation.

AGROPHAGES

Agrophages are unwanted organisms (pathogens, pests and weeds), which cause damage to plant cultivation (Hołaj, 2011).

Spring barley exhibits a low ability to suppress weeds; therefore, it is very susceptible to weeding. Although segetal flora is an important element of biodiversity (it occurs in all fields of cultivars, regardless of the soil and climate conditions or the agrotechnics) (Gawrońska-Kulesza et al., 2005), it is not a desirable element in crop stands, as it competes with crop plants for nutrients, water and light (Radzimierski, 2018). The occurrence of undesirable vegetation is one of the main factors limiting the barley yield (Buczek et al., 2007) and is considered as a threat to achieving good quality grain yields (Gawęda et al., 2014; Paczyńska, 2012). Research conducted by Woźniak (2002) showed that the presence of weeds caused growth inhibition, a decrease in the resistance and lodging of plants, a reduction in the density of ears per unit area, a decrease in the number and weight of grains in an ear as well as a reduction in the weight of 1000 grains. Weeds make harvesting more difficult. They contaminate the grain, resulting in reduced yield quality. Undesirable weed activity increases when the economic thresholds of the weed harmfulness are exceeded, i.e. when the weed intensity is so high that it threatens the cultivated plant yield. Research demonstrates that up to 20 weed species occur in cereals (Paczyńska, 2012). The economic harmfulness thresholds of the main weeds found in spring barley are shown in Table 1. Following the rules of crop rotation and proper agrotechnics reduce the number and weight of weeds in a field (Małecka-Jankowiak et al., 2015).

Table 1. Thresholds of economic harmfulness of weeds of spring barley (source: Paczyńska 2012).

Weed species	Threshold (plants per m^2)
Echinochloa crus-galli	5–10
Avena fatua	1–7
Cirsium arvense	2–5
Galium aparine	2–5
Anthemis arvensis	2–5

The health of the plants is one of the key factors affecting the cereal yields. Even though spring barley is characterised by the shortest vegetation period of all basic cereals, fungal diseases cause significant losses in its yields (Sawinska et al., 2016), especially in the years with high rainfall (Adamiak et al., 2005). Susceptibility of barley to diseases is highly dependent on individual varietal characteristics. Thus, when choosing a variety, not only the soil and climate conditions should be considered, but also the resistance to fungal diseases (www.lodr.konskowola.pl). Spring barley is strongly affected by the presence of *Blumeria graminis* (a fungus that causes powdery mildew), especially in the period prior to heading, as leaf infection reduces photosynthesis and increases the intensity of transpiration, and as a result, leads to a decrease in the number and weight of grains. The amount of carbohydrates in the grains decreases, whereas the amount of proteins marginal-

Table 2. Thresholds of economic harmfulness of insect pests of spring barley (source: Mrówczyński et al., 2012).

Pest	Thresholds
Chlorops pumilionis Bjk.	1 egg on stem or 10% of damaged stems
Cereal leaf beetle	1–1.5 of larvae on stem
Aphids	5 aphids per spike
Thrips	10 larvae per spike (the stage of shooting), 40–50 larvae per spike (until the full flowering) or 5–10 mature insects per spike (grain filling)
Gall midge	8 larvae per spike

ly increases (Dąbrowski, 2017). In periods of coolness and humidity, particular attention should be paid to rhynchosporiosis. The pathogen (the fungus *Rhynchosporium commune* casing scald*)* mainly affects the leaf sheaths and bottom leaves, but it also causes the flag leaf and whole ears infection. As a result, the plants die prematurely and yield losses can be as high as 30% (Dąbrowski, 2017). Another disease that is conductive to the development of high humidity is leaf net blotch. The fungus threatens the cultivation of barley at all stages of plant development. Infection occurs mainly on leaves and sheaths, but is also visible on stems and ears. The symptoms are usually noticeable from the stage of stalk shooting. The disease can lead to losses of up to 25%. A further disease that endangers barley plants is fusariosis, which results in deterioration of growth and premature ripening, and, in the case of severe infection, plant lodging and finally plant necrosis. As a consequence of fusariosis, the number of grains in the spike is reduced and as a result of poorly developed grains the weight of 1000 grains is reduced (Dąbrowski, 2017). Fusariosis also generates quality deficiency, consisting in a reduction of feed productivity and accumulation of mycotoxins harmful to animals. Leaf rust of barley inhibits the growth and withering of cereals (Tratwal et al., 2017). Yield losses at increased pathogen intensity can reach 30% (Adamiak et al., 2005). Although barley is less frequently infected by ergot, it is very dangerous. The ergot pathogen parasitizes the pistils of the flowers, and during the ripening period of cereals in infected ears. Instead of grains, there are fungal spores called sclerotia produced. Infected grain is poisonous and can cause serious food poisoning of animals. The ergot reduces grain yield and crop losses can be up to 50%.

Barley plants are a source of food for pests (Mrówczyński et al., 2012) and are therefore threatened by several insects species during the growing season (Kaniuczak et al., 2010). The harmfulness and economic significance of insects varies and fluctuates over the years. Proper crop management measures (soil preparation, sowing date and density, balanced fertilization) contribute in limiting the development of many pests, especially at the level of larval stages and pupae (Mrówczyński et al., 2012). The most important pests threatening the spring barley plant include *Chlorops pumilionis* Bjk. It is a fly, the harmful stage of which is the larvae that feed on the barley's uppermost internode. The larvae slow down or inhibit the growth of the plant, often causing the spike to become arrested in the sheath. The extent of the damage depends on the stage of plant development at which the larvae penetrate into the sheath. The affected uppermost internode is shortened and a furrow caused by the feeding larvae can be seen on it (Kaniuczak et al., 2010). The higher the degree of plant infection, the shorter the stalk, especially the peduncle. The larvae's feeding action reduces the number of grains in the spike and the weight of 1000 grains (Mrówczyński et al., 2012; Paczyńska, 2012). The pests next in importance are cereal leaf beetles (*Oulema* sp.). Both beetles and larvae are the harmful stages. Beetles feed in the leaves the long narrow grooves, while larvae scrape off the upper skin of the leaf and eat the crumb. In favourable weather conditions, larvae feeding may reduce the plant assimilation surface by as much as 50–80%, which, according to the analyses carried out, may result in a decrease in grain yield even by 9 dt ha^{-1}. Feeding of cereal leaf beetle increases the susceptibility of plants to infection by diseases (Kaniuczak et al., 2010). Other pests that endanger the crop of barley are aphids and thrips, which feed on all aboveground parts of plants. Their food source is the sap of the barley plant. Feeding by these insects is particularly dangerous on freshly headed plants as it weakens them and consequently leads to reduction in the number of grains per ear and even the formation of empty ears. In addition, aphids form the so-called honeydew, which is an excellent nutrient for sooty moulds, reducing the assimilation area of the plants. It is estimated that in favourable conditions aphids may cause losses of up to 10 dt ha^{-1} (Kaniuczak et al., 2010). A gall midge is a harmful insect that occurs in a great quantity under conditions conducive to its development. The gall midge lays its eggs on the spikelets of ears after blooming. The harmful stage of this insect is the larvae, which by feeding on grains cause their damage or completedestruction. The result of the infestation by the gall midge is an increased susceptibility to disease, poorly developed grains and unfilled ears (Mrówczyński et al., 2012).

Thresholds for the economic harmfulness of insects to barley are used as an additional measure to assist in making decisions on chemical treatment (Table 2). They are an approximate value and depend on many factors such as: climatic conditions, agrotechnology, cultivars, fertilization (www.cdr.gov.pl).

SUMMARY

Barley is a cereal of great economic importance, dominant in the area under spring-sown cereals. Its cultivation is facilitated by relatively easy production technology, quite low labour intensity and ease of storage and transport. Currently in Poland, mainly spring forms of barley are grown that are used primarily for feed and brewing purposes. The physiological condition of a single plant and the whole field as well as the quantity and quality parameters of the yield are influenced by: properly selected and prepared seedbed, timely seeding, which lengthens the vegetation period and increases the productivity of ears, and selection of the right cultivar, characterized by high yield and health. On-time application of crop production treatments related to plant protection and fertilization also play an important role. However, despite these measures, barley crops are exposed to various types of stress factors, related, among others, to the consequences of climate change. The available data and climatic models reveal that in the next several dozen years, there will be an increase in average air temperature in Poland, which will lengthen the growing season for arable crops, giving on the one hand the possibility to grow new plant species and on the other hand, creating threats to crop (long-term droughts, heat waves, increased pressure from pests and diseases). According to the most likely scenarios, climate change will be significantly perceptible in agricultural production and their effects must be counteracted to ensure stable yields. Plant breeders, biotechnologists, physiologists and biochemists are therefore facing new challenges to find plant varieties with increased drought resistance, high wind tolerance, efficient water and nutrient management and increased resistance to pests and diseases.

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received – 7 October 2019
revised – 17 December 2019
accepted – 30 December 2019

Ministerstwo Nauki i Szkolnictwa Wyższego

„Przetłumaczenie na język angielski wybranych prac zgłoszonych do Polish Journal of Agronomy" – zadanie finansowane w ramach umowy Nr 692/P-DUN/2018 ze środków Ministra Nauki i Szkolnictwa Wyższego przeznaczonych na działalność upowszechniającą naukę