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MAIN INSPECTORATE FOR PLANT HEALTH AND SEED INSPECTION

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# Methodology for the Integrated Production of narrow-leaved, yellow and white lupin (*Lupinus* spp.)

**Approved**
pursuant to Article 57(2)(2) of the Plant Protection Products Act of 8 March 2013
(consolidated text: Journal of Laws [Dziennik Ustaw] 2024, item 630)

**by**
**the Main Inspector of Plant Health and Seed Inspection**

INTEGROWANA PRODUKCJA
URZĘDOWO KONTROLOWANA

Approved by

~~/signed electronically/~~

Warsaw, March 2025

PLANT PROTECTION INSTITUTE — STATE RESEARCH INSTITUTE
ul. Władysława Węgorka 20, 60-318 Poznań

# **Methodology developed as part of task 1.5.**
# ‘Updating and developing Integrated Plant Production methodologies’

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PLANT PROTECTION INSTITUTE — STATE RESEARCH INSTITUTE
ul. Władysława Węgorka 20, 60-318 Poznań
e-mail: upowszechnianie@iorpib.poznan.pl, www.ior.poznan.pl

*Collective paper edited by:*
Dr Roman Krawczyk, Dr Przemysław Strażyński and Prof. Marek Mrówczyński

| *Authors:* | |
|---|---|
| Dr Roman Krawczyk[1] | Dr Kinga Matysiak, Professor at the Institute of Plant Protection – State Research Institute [1] |
| Dr Przemysław Goryński[1] | Prof. Marek Mrówczyński[1] |
| Prof. Danuta Sosnowska[1] | Dr Monika Jaskulska[1] |
| Dr Paweł Bereś[1] | Dr Grzegorz Gorzała[5] |
| Dr Joanna Horoszkiewicz-Janka[1] | Dr Stanisław Stawiński[4] |
| Prof. Marek Korbas[1] | Agnieszka Osiecka[3] |
| Prof. Janusz Podleśny[2] | |
| Dr Roman Krawczyk, Professor at the Institute of Plant Protection — State Research Institute[1] | |

[1] Institute of Plant Protection — State Research Institute, Poznań
[2] Institute of Soil Science and Plant Cultivation — State Research Institute, Puławy
[3] Research Centre for Cultivar Testing, Słupia Wielka
[4] Plant Breeder Smolice, O/Przebędowo
[5] Main Inspectorate of Plant Health and Seed Protection, Warsaw

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## 1. PREFACE

Integrated Plant Production [*Integrowana Produkcja*, IP] is a management system that takes into account the use of technology and biological progress in a sustainable manner in the cultivation, protection and fertilisation of plants while ensuring the safety of the natural environment. The essence of integrated plant production is therefore obtaining crops satisfactory for both producers and consumers, in a way that does not interfere with the protection of the environment and human health. Its strategy is more complicated than that of production using conventional methods. As much as possible, natural biological mechanisms supported by the rational use of plant protection products are used in the integrated plant production process. In modern agricultural production technology, the use of fertilisers and plant protection products is necessary and extremely beneficial, but at times it may also threaten the environment. In integrated plant production, however, special attention is paid to the reduction of the role of chemical plant protection products used to limit pests to a level that does not threaten the crops, fertilisers and other resources needed for plant growth and development to create an environmentally safe system while ensuring high-quality crops free from residues of substances known to be harmful (heavy metals, nitrates, plant protection products).

## 2. LEGAL REGULATIONS APPLICABLE TO INTEGRATED PRODUCTION (IP) AND RULES FOR ITS CERTIFICATION

### 2.1. Integrated pest management as the basis for integrated production (IP)

Integrated plant protection consists of protecting crops against harmful organisms using all available methods, in particular non-chemical methods, in a way that minimises risks to human health, animals and the environment.

Integrated protection consolidates and systematises practical knowledge about organisms harmful to plants (especially about their biology and harmfulness), in order to determine optimal deadlines for taking action to combat these organisms while taking into account naturally occurring beneficial organisms, i.e. predators and parasites of organisms harmful to plants. It also reduces the use of chemical plant protection products to a necessary minimum, thus reducing environmental pressure and protecting the biodiversity of the agricultural environment.

Professional users who use plant protection products are obliged to take into account the requirements of integrated plant protection set out in the Regulation of the Minister for Agriculture and Rural Development of 18 April 2013 on requirements for integrated plant protection (Journal of Laws of 2013, item 505). According to the above-mentioned Regulation, an agricultural producer should use all available measures and methods of protection against pests before applying chemical plant protection in order to reduce the use of pesticides. The provisions of this Regulation put a strong emphasis on, inter alia, the use of crop rotation, suitable varieties, compliance with optimal deadlines, the use of appropriate agrotechnology, fertilisation, and prevention of the spread of harmful organisms. One of the requirements is also the protection of beneficial organisms and the creation of favourable conditions for their occurrence, in particular pollinating insects and natural enemies of harmful organisms. The use of chemical plant protection should be preceded by monitoring activities and supported by appropriate scientific instruments and advice.

**Under the current law, only plant protection products authorised for marketing and use on the basis of authorisations (or parallel trade permits) issued by the Minister for Agriculture and Rural Development may be used for chemical protection of plants.**

The list of plant protection products authorised in Poland is published in the register of plant protection products. Information on the extent of pesticide use in particular crops is placed on the labels. The Ministry of Agriculture and Rural Development makes the register and labels available at https://www.gov.pl/web/rolnictwo/ochrona-roslin.

Information on plant protection products authorised for integrated production is published in the Online Pest Warning System at: https://www.agrofagi.com.pl/143,wykaz-srodkow-ochrony-roslin-dla-integrowanej-produkcji.

**It is the responsibility of each user to read and follow the label before the application of a plant protection product.**

In accordance with the Regulation of the Minister for Agriculture and Rural Development of 31 March 2014 on conditions of use of plant protection products (Journal of Laws 2014, item 516), outdoor pesticides may be applied using:

- ground equipment at a distance of at least 20 m from the apiaries;
- field sprayers at a distance of at least 3 m from the edge of the roadway of public roads, excluding public roads falling within the category of municipal and district roads;
- field sprayers at a distance of at least 1 m from reservoirs and watercourses and non-agricultural areas other than those treated with plant protection products.

**When using plant protection products, the label of the products should be read in detail, as it may contain additional conditions limiting their applicability.**

In accordance with the legislation in force, any use of a plant protection product must be registered. Professional users are obliged to maintain and store for three years documentation containing the name of the plant protection product, the time of use and the dose applied, the area or surface area or unit of weight of the grain and crop or the facilities on which the plant protection product has been applied. The law also requires the method of fulfilling the requirements of integrated plant protection to be indicated in the documentation by providing at least the reason for the treatment with a plant protection product. Filling out the IP Notebook, mandatory under the integrated plant production scheme, fulfils the requirement to keep the above-mentioned documentation for certified crops.

For treatment with plant protection products, equipment intended for that purpose shall be used which, when used for its intended purpose, does not present a risk to human health, animal health or the environment and is technically efficient and calibrated to ensure the correct application of plant protection products. The holders of equipment for the use of plant protection products are obliged to carry out periodic inspections confirming their good technical condition. The first inspection of a new sprayer is conducted no later than five years from the date of its purchase. Tractor and self-propelled field sprayers should be tested at intervals of no more than three years. Manual and backpack sprayers whose tank capacity does not exceed 30 litres are excluded from the testing obligation.

### 2.2. Integrated plant production in legislation

Under this integrated plant production certification scheme, all legal requirements for plant protection products must be respected, with particular regard to the principles of integrated plant protection.

### 2.3. Certification rules

The basic requirement for the possibility of growing crops under the integrated plant production scheme and obtaining an IP certificate is to submit a notification to the entity certifying integrated plant production.

The notification of the intention to use integrated plant production must be made annually by the plant producer concerned to the certification body, **within the time limit laid down in Article 55(2) of the Act of 8 March 2013 on plant protection products**. The integrated plant production scheme is open to all producers. Notification of the intention to participate in the scheme may be submitted on paper by post, electronically, or in person.

Integrated production training is generally available, and those who have acquired the appropriate knowledge through education (confirmed by a post-primary school or higher education) are exempt from the obligation to complete basic training.

Following the notification, the agricultural producer is obliged to cultivate crops according to the method of integrated plant production for the notified plant and to document their actions in the IP Notebook in detail. A model notebook is included in the Regulation of the Minister for Agriculture and Rural Development of 24 June 2013 (consolidated text: 7 November 2023) on documenting activities related to integrated plant production (Journal of Laws of 2023, item 2501).

The certification body inspects growers who follow the principles of integrated plant production. Supervisory actions cover in particular:

- completion of IP training;
- compliance with the production methods approved by the Main Inspector for Plant Health and Seed Inspection;
- fertilisation;
- documentation;
- following hygiene and health principles;

- collection of samples and control of highest tolerable plant protection product residues as well as of nitrate, nitrite and heavy metal levels in plants and plant products.

Tests for maximum permissible residues of plant protection products and levels of nitrates, nitrites and heavy metals in plants are carried out on plants or plant products from no less than 20 % of plant producers entered in the register of producers kept by the certifying entity, with priority being given to tests carried out for plant producers suspected of failing to comply with the requirements of integrated plant production. The tests are carried out in laboratories accredited to the relevant extent pursuant to the provisions of the Act on the Conformity Assessment System of 30 August 2002 or the provisions of Regulation No 765/2008.

A certificate issued at the request of the producer attests that integrated plant production principles are followed. The producer obtains the certification if they have complied with the following requirements:

- they have completed an integrated production plant training and hold a corresponding training certificate, subject to Article 64(4),(5),(7) and (8) of the Act on plant protection products;
- they produce and protect plants in line with the detailed methodology approved by the Main Inspector available on the website administered by the Main Inspectorate for Plant Health and Seed Inspection;
- they use fertilisation based on the actual plant nutritional needs determined on the basis of, in particular, the analysis of the soil and plants;
- they correctly document the activities related to integrated plant production;
- follows hygienic and sanitary rules in plant production, particularly those defined in methodologies;
- in plant and plant product samples collected for testing, no maximum permissible residues of plant protection products and levels of nitrates, nitrites and heavy metals have been exceeded;
- they adhere to requirements concerning plant protection against harmful organisms, particularly those specified in methodologies, during plant production.

Integrated plant production certificates are issued for a period necessary for the plant product to be disposed of, but for no longer than 12 months.

A plant producer granted a certificate attesting that they follow the integrated plant production principles may use the Integrated Plant Production mark to distinguish the plants for which the certificate has been issued. The model of the mark is made available by the Main Inspector on the website administered by the Main Inspectorate for Plant Health and Seed Inspection.

## 3. CLIMATE AND SOIL REQUIREMENTS AND SITE SELECTION

### 3.1. Climate

White lupin was its least grown species, but in recent years there has been an increased interest in its cultivation, which has been reflected in the increase in the area of cultivation. This species, apart from the late varieties of soybean, has the longest growing period (130–150 days) of all the legumes grown in Poland. The most favourable conditions for the growth and development of white lupin occur in the southern and central part of Poland. The cultivation of this species has not yet been recommended in the northern and north-eastern areas of our country or in the foothills. However, changing weather conditions and the associated significant warming of the climate increase the possibility of growing later ripening plants also in these areas.

Narrow-leaved and yellow lupins have a much shorter growing period (Descriptive list of agricultural plant varieties, RCFCT [Research Centre for Cultivar Testing], 2024), so their cultivation is possible in almost all parts of the country except in the foothills and the littoral. The North-East region is also considered to be less suitable for cultivation.

The thermal requirements of lupin are moderate; it germinates already at 3–4 °C, and seedlings can withstand frosts up to −8 °C. In the phase of several leaves, lupin plants are more resistant to low temperatures than in the cotyledon phase. However, too low temperatures persisting for a long period of time after sowing seeds cause uneven emergences (Podleśny and Podleśna 2010a) and reduce the vigour of the seedlings, which increases the susceptibility to diseases of the plants grown from them.

Of the lupin species grown in our country, the white lupin has the highest water requirements. Hydrating the soil up to 70% of the field water capacity (fwc) during the flowering and pod setting phase has a positive effect on the yield of this species. The optimum amount of precipitation during the growing season is about 400 mm for narrow-leaved lupin and about 300–350 mm for yellow lupin. Due to the high mass of 1000 seeds, lupin requires a significant amount of water during germination and plant growth. The amount of water taken during the imbibition of the seeds is between 150 % and 170 % by weight of the seeds. The second critical period for lupin is the flowering and formation of pods. Water scarcity in that phase causes flowers and pods to fall, which consequently leads to a low stocking density of the pods on the plant and a significant reduction in seed yields (Podleśny and Podleśna 2009a; 2011). On the other hand, too much rainfall after the sowing can seal the topsoil and make it more difficult for plants to emerge. Abundant and long-lasting precipitation during seed ripening can cause adverse phenomena in the cultivated field, i.e. plant lodging, and in particular increased seed infestation by pathogens, which often leads to an extension of the growing period and an increase in qualitative and quantitative yield losses.

Lupin has moderate thermal requirements (Podleśny and Podleśna 2010b). Optimal thermal conditions for the growth and development of lupin plants are in the range of 12–18 °C. Too high temperatures during the plant growing period, especially during flowering and pod formation, adversely affect the yield of lupin (Podleśny and Podleśna 2012).

### 3.2. Soil

Soil requirements of the three lupin species grown in our climatic zone are very diverse (Szukała et al. 1997). The cultivation of white lupin is recommended on class IIIa to IVa soils of the agricultural suitability categories: wheat, defective; rye, very good; and rye, good, having a slightly acidic pH in the range of 5.6–6.0. It can also be grown on better soils, located in undulating areas with a large moisture variability, where horse beans and peas cultivation may be unreliable. On acidic soils, a high concentration of aluminium ions limits root growth and the development of rhizobacteria. This species does not tolerate wetland, basin, and very weak soils.

The soil requirements of narrow-leaved lupin are much lower. In this respect, it occupies an intermediate position between yellow lupin and white lupin. Cultivation of this species is recommended on magnesium-rich class IVa and IVb soils of categories: rye, very good (4); and rye, good (5), with a pH close to neutral.

Yellow lupin has the lowest soil requirements, therefore, class IVb, V and VI soils of agricultural suitability categories: rye, good (5); rye, weak (6); rye, weakest (7), are indicated as suitable for cultivation of this species (Dzienia and Szwejkowski 1988). However, yellow lupin yields best on class V soils part of the ‘rye, good’ category (Prusiński 1997). The optimum pH value for this species varies between 5 and 6. It should be emphasized that yellow lupin is one of the few species of agricultural plants requiring an acidic pH and does not tolerate neutral, alkaline or freshly limed soils. On calcium-rich soils, it suffers from chlorosis, a disease associated with a lack of readily available iron, manganese, zinc and copper. The lighter the soil, the smaller its buffer capacity and the more harmful the liming.

All lupin species show poor growth and development on highly clayey, concise and wet soils. Under these conditions, the roots have insufficient air access for proper growth and formation of root nodules, resulting in a poor supply of nitrogen to the plants.

### 3.3. Precursor crop

It is important to ensure that the site intended for lupin cultivation is weed-free and maintained in good soil condition. The most suitable precursor crop for lupin cultivation is cereals in the second or third year after manure. The straw after harvesting cereals should be ploughed or thoroughly mixed with the soil. Inappropriate preparation of the field before the sowing of lupin can deteriorate plant emergence and increase the infestation of seedlings by pathogens (higher fungal diseases pressure).

**In the cultivation of lupin as part of a certified integrated production, a minimum of 4 years of interval in the cultivation of lupin on the same site must be ensured.**

Lupin cannot be grown in succession more often than every 4–6 years. On lighter soils the interval in lupin cultivation should be 5–6 years, while on better soils, cultivation may be carried out every 4–5 years. White lupin is less sensitive to frequent cultivation after itself than narrow-leaved and yellow lupins. Lupin must also not be grown after other Fabaceae plants. More frequent cultivation of lupins in succession leads to unilateral depletion of nutrients (the phenomenon of soil exhaustion), the multiplication of bacteriophages destroying rhizobacteria and the increase in the occurrence of rot diseases and pests. White lupin, similarly to the other two species of lupin grown in Poland, should not be grown on a site immediately following root crops cultivated on manure. Grown on sites that are too fertile, it produces an excessive mass of vegetative organs at the expense of generative organs, prolongs vegetation, providing low and poor quality seed yield.

Lupin is a highly valued plant in crop rotation. It is an excellent precursor crop, mainly for cereals (Podleśny et al. 2017). Follow-on crops grown after lupin require lower fertilisation doses, mainly with nitrogen. The high importance of lupin as a phytosanitary plant should also be emphasised. For this reason, all lupin species are an important and valuable 'interval crop' in case of frequent successions of cereal crops.

## 4. SELECTION OF LUPIN VARIETIES IN INTEGRATED PRODUCTION

The yield potential of lupin, especially the narrow-leaved and yellow lupin, is limited, but these species are an important element of field rotation where the selection of plants is narrowed down due to a weaker site. Narrow-leaved lupin is a plant that grows well on light soils, and yellow lupin also grows on very light ones. White lupin, on the other hand, has much higher site and water supply requirements, but its cultivation is not very popular. Cultivation of plants on weaker sites, even if such soils are indicated, can be subject to risk. This is due to the need to maintain less fertile soils in good agricultural condition and to use correct agrotechnology, and because the success of cultivation depends on the course of weather conditions more than in the case of fertile site, especially in terms of the distribution of precipitation.

In view of the above, it is of special importance that the habitat conditions determine, as precisely as possible, the choice of the right species and then its variety. An important aspect is the best possible knowledge of the field conditions of the land on which crop production is carried out. It is also important to know which varieties work well on the soils in question, based on your own experience. It is good practice to regularly consult the results of the economic value analysis (WGO) based, for example, on a synthesis of the results of one-year and multi-year varietal experiments or via the 'Variety characteristics' or 'Comparison of varieties' applications available on the RCFCT website (www.coboru.gov.pl).

The varieties of the three lupin species cultivated in Poland are diverse, both in terms of morphological and agricultural-use characteristics. In the process of creative breeding of these species, forms that are thermo-neutral, i.e. tolerant to delayed sowing, have been selected. Wild forms of lupins would naturally contain alkaloids in their seeds in quantities that did not allow their use as animal feed. Hence, one of the most important breeding objectives was the improvement of quality characteristics, including the reduction of the content of these specific substances in aboveground parts of the plant and its seeds. Currently, the vast majority of varieties are fodder forms, with a very low content of alkaloids in seeds, about 0.01–0.02 % of dry matter (DM), allowing their use as feed. The cultivation work on the bitter forms was maintained mainly in the narrow-leaved lupin. The high alkaloid varieties of narrow-leaved lupin (with an alkaloid content of approximately

1.0 % DM) are available to users and are suitable for post-cropping and ploughing. Bitter forms of yellow lupin have not been cultivated in Poland for years. In the course of breeding, the resistance of the varieties to the *Fusarium* pathogens was improved, as the occurrence of infestation on plantations in the midst of the growing period caused the plants to die back. Efforts are still being made to improve the resistance of lupin plants to anthracnose, which currently is the most serious disease of fungal origin for these species.

Lupin varieties vary also according to the type of growth. Within each species, apart from the most popular indeterminate varieties, determinate (epigonal) varieties have been recorded, which mature faster and more evenly, especially when weather conditions are unfavourable. Varieties of this type have reduced lateral shoots, so the vast majority of pods are formed on the main shoot. Therefore, they may bring worse results in areas with repeated periods of drought during the growing season, which significantly reduce the growth of lupin plants.

One of the key trends in the breeding of lupin from the point of view of their economic value is the selection of varieties to improve the level and stability of yields. Good and reliable yielding is one of the main criteria for choosing a variety for cultivation. However, the adverse weather pattern observed in recent years increasingly prevents cultivated lupin from obtaining high yields. On the basis of the results of the PRVTS experiences, in addition to annual syntheses, the RCFCT develops multi-annual lists and publishes them in the Descriptive List of Varieties (DLV). https://coboru.gov.pl/pl/publikacje. Multi-annual average results allow to characterise the economic value of varieties, limiting the importance of the weather course in a given growing season. In addition to the nationwide publications, results are also produced annually based on the experiences performed in individual provinces. They form the basis for the annual compilation of Lists of Recommended Varieties (LRV). Lists created for narrow-leaved and yellow lupin include those varieties that, after at least two years of post-registration testing, yielded the best and most stable crops in the given province. A dozen varieties are recommended each year for narrow-leaved lupin, while just a few for yellow lupin, due to its much more limited data in the National Register (NR). Information on the recommendations can be found at the following links:

https://coboru.gov.pl/pdo/rekomendacja_gat
https://coboru.gov.pl/pdo/rekomendacja_woj

The use of lists of recommended varieties and the appropriate selection of the variety gives farmers greater guarantee for the success of their cultivation, unless the course of the weather characterised by extremely unfavourable developments modifies the suitability of the varieties and affect the results obtained.

The National Register of Lupin Varieties is kept mainly on the basis of the varieties grown in Poland. In recent years, varieties of white lupin were also reported for official testing for the first time in many years and were entered in the NR following official testing (Table 1).

**Table 1.** Number of lupin varieties in the National Register (NR) over the years

| Species | 2004 | 2010 | 2015 | 2020 | Autumn 2024 | |
|---|---|---|---|---|---|---|
| | | | | | total | determinant |
| Narrow-leaved lupin | 10 | 13 | 20 | 31 | 34 | 5 |
| Yellow lupin | 7 | 8 | 8 | 11 | 9 | 0 |
| White lupin | 3 | 2 | 2 | 2 | 4 | 1 |

**The necessary information on lupin varieties that can be grown under the IP scheme is provided on the website of the Research Centre for Cultivar Testing (RCFCT) under the tab 'Selection of varieties for integrated plant production' (https://www.coboru.gov.pl/pdo/ipr).**

## 5. PRE-SOWING TILLAGE AND SOWING

### 5.1. Soil cultivation

Cultivation of the soil under lupin, as in the cultivation of other species of legumes, should aim to destroy as many weeds as possible in the autumn and ensure early sowing of the seeds in spring. Therefore, in the autumn, immediately after the precursor crop is harvested, a ploughing or stubble cultivation should be performed, followed by a harrowing to reduce the weed presence (when no aftercrops have been sown). Winter ploughing should be made to an average depth (20–25 cm), leaving the field in a sharp skid. As it is one of the most energy-intensive crop treatments, the costs associated with its implementation can be significantly reduced by using reversible or pendulum ploughs.

Spring tillage should ensure reduced water losses and adequate field preparation to create good conditions for seed germination and plant emergence. Lupin seeds require a large amount of water for germination, so it is very important to place them on a substrate with good moisture soaking. Levelling should be performed in early spring, and if the soil hasn't been worked for a long time, a cultivator with a string roller or a cultivation unit should also be used. However, the soil should not be worked too deep, because lupin does not tolerate deep sowing. When using a cultivation and sowing unit (active harrows with a top seed drill), seeds can be sown immediately after harrowing, and when the surface of the field after winter is sufficiently level, even without this treatment.

Lupin can be cultivated in a zero-tillage system, but the yield obtained would largely depend on the course of weather. Different soil farming systems do not alter the seed yield, protein yield and energy yield of seed harvest in very wet years and in years with average precipitation. However, in a dry year, direct sowing results in a significant reduction in the above parameters compared to conventional cultivation (Faligowska 2018).

### 5.2. Sowing

For sowing, seed of the certified category, i.e. healthy, undamaged seeds with good germination power, must be used. Seeds intended for sowing should be treated with appropriate fungicide or insecticide and fungicide treatment.

Up-to-date information on recommended plant protection products is given on the website of the Ministry of Agriculture (www.minrol.gov.pl/pol/Informacje-branzowe/Wyszukiwarka-srodkow-ochrony-roslin) or the Plant Protection Institute – National Research Institute (www.ior.poznan.pl).

When the break in the cultivation of lupin in a given field was longer than 4–5 years, the seeds must also be treated with a bacterial vaccine intended for lupins.

It is recommended that the sowing date is as early as possible, as soon as the soil is drained after winter, if possible even in the second half of March. Lupin seeds germinate at a relatively low temperature, and young plants tolerate short-lived frosts well. At early sowing, a natural vernalisation process takes place and a large amount of moisture in the soil creates good conditions for germination and plant emergence. This is especially important in the cultivation of white lupin, the seeds of which need a particularly large amount of water for germination and initial growth. The delay in sowing and the lack of vegetation cause a shift in the phenological phases of lupins (later start of the flowering period) and a disturbance in the proportion between the mass of vegetative and generative organs. The plants are generally higher, produce more vegetative mass, prolong flowering and produce less pods (Podleśny and Podleśna 2010a). A significantly delayed sowing is possible in the case of sowing of so-called thermo-neutral varieties that do not require a vernalisation period and in the cultivation of lupin for green fodder (Podleśny and Podleśna 2009b).

In the cultivation of lupin, it is important to determine the appropriate density of plants per unit of area. If plants are too dense, lodging can occur and too infrequent sowing creates conditions for large weed infestation and strong branching of plants. This affects the prolongation of the growing phase and makes harvesting more difficult. It is recommended to grow white lupin at a density of 60–80 plants/$m^2$, and for narrow-leaved lupins and yellow lupins — determinant varieties: 100–120 plants/$m^2$ and non-determinant varieties: 90–100 plants/$m^2$. Determinant lupin varieties do not produce, or produce strongly reduced lateral shoots. Therefore, the optimum plant density for these types of varieties is greater than for non-determinant closing varieties. In addition, a smaller plant density should be used on better soils and a higher plant density should be used on weaker soils. The possibility of adverse weather conditions (e.g. drought) affecting the emergence and subsequent density of plants in the field should also be taken into account and, for this reason, the sowing standard should be increased by approximately 15 %.

Due to the epigeic mode of germination (the leaves are drawn to the surface of the soil), it is recommended to sow the seeds shallow, i.e. to a depth of 3–4 cm. Too deep sowing hinders and delays the emergence and significantly reduces the vigour of the seedlings. On the other hand, too shallow sowing into a dried up layer of soil also worsens the lupin emergence.

In traditional tillage cultivation, the row spacing should be between 15 and 25 cm. Coulter or disc seed drills should be used. The most commonly used types are cereal tine seed drills or seed drills with seeding apparatus intended for large seeds. In simplified cultivation, disc seed drills or belt sowing seed drills should be used with a row spacing of 30–35 cm. On the other hand, for direct drilling in the stubble, a disc seed drill with an adjustable coulter pressing should be used. Lupin seeds may also be spot-sown with the use of special seed drills intended for this procedure (Podleśny and Bieniaszewski 2012). Such sowing is mainly used in the cultivation of white lupin, because the seeds of this species are flattened, which causes them to be unevenly fed to the seed tubes by tine seed drills.

The seed sowing standard should always be determined according to the following formula:

**sowing (kg/ha) = a x b / c,**

where: a — planned planting density; b — weight of one thousand seeds; c — seed germination capacity

The need for such a calculation of the sowing standard is due to the very large difference in the weight of a thousand seeds between lupin varieties.

## 6. SUSTAINABLE LUPIN FERTILISATION SYSTEM

### Nutritional needs of lupin

Among the lupin species grown in our country, white lupin has the highest nutritional requirements; those of narrow-leaved lupin are slightly lower, and those of yellow lupin — the lowest. In the cultivation of these plants, fertilisation with phosphorus and potassium is needed, since lupins negatively react to their low content in the soil. Potassium is absorbed throughout the growing season, and the greatest demand for this element occurs during the intensive mass gain of vegetative organs, i.e. before flowering and during flowering. This element participates in the regulation of the functioning of the stomata and is responsible for the water management of lupin. It is also necessary for the transport of NO3- ions and assimilates produced in the plant.

High demand for phosphorus occurs in the initial period of plant growth and development. This is due to its participation in the formation of the root system and the production of root nodules, and the presence in high-energetic compounds necessary to conduct metabolic processes in the plant and biological nitrogen fixation.

The average intake of phosphorus and potassium by lupin is about 20.4 kg $P_2O_5$ and 38.5 kg $K_2O$ per 1 tonne of crop, which is higher than that of peas and field beans.

**Fertilisation should be determined based on the nutrient balance analysis carried out through soil tests at least every four years.**

The doses of phosphorus–potassium and magnesium fertilisers should be determined according to the expected yield and soil content of these components (Tables 2–4). To obtain a satisfactory seed yield, lupin usually requires soil with an average content of assimilable phosphorus and potassium.

**Table 2.** Assessment of phosphorus content in mineral soils (mg $P_2O_5$/100 g soil) (materials for determining fertiliser recommendations on arable land, 1989)

| Item | Content class | $P_2O_5$ content |
|---|---|---|
| 1. | V – very low | up to 5.0 |
| 2. | IV — low | 5.1–10.0 |
| 3. | III – medium | 10.1–15.0 |
| 4. | II – high | 15.1–20 |
| 5. | I – very high | over 20.1 |

**Table 3.** Assessment of potassium content in mineral soils (mg $K_2O$/100 g soil) (materials for determining fertiliser recommendations on arable land, 1989)

| Content class | Agronomic category of the soil | | | |
|---|---|---|---|---|
| | very light | light | medium | heavy |
| V – very low | up to 2.5 | up to 5.0 | up to 7.5 | up to 10.0 |
| IV — low | 2.5–7.5 | 5.1–10.0 | 7.6–12.5 | 10.1–15.0 |
| III – medium | 7.6–12.5 | 10.1–15.0 | 12.6–20.0 | 15.1–25.0 |
| II – high | 12.6–17.5 | 15.1–20.0 | 20.1–25.0 | 25.1–30.0 |
| I – very high | over 17.6 | over 20.0 | over 25.1 | over 30.1 |

Lupin also shows considerable nutritional needs in relation to magnesium, which plays an important role in physiological processes related to photosynthesis, the biological reduction of atmospheric nitrogen, and the transport of assimilates from leaves to the roots and ripening seeds. In the cultivation of leguminous crops, magnesium may be applied not only through soil but also through foliar feeding as a 5 % solution of magnesium sulphate heptahydrate. It is recommended to carry out the foliar feeding procedure with magnesium twice, namely at the beginning of the elongation of the stem and at the beginning of the budding phase of the plants.

**Table 4.** Assessment of magnesium content in mineral soils (mg Mg/100 g soil) (materials for determining fertiliser recommendations on arable land, 1989)

| Contents | Agronomic category of the soil | | | |
|---|---|---|---|---|
| | very light | light | medium | heavy |
| Very low | up to 1.0 | up to 2.0 | up to 3.0 | up to 4.0 |
| Low | 1.1–2.0 | 2.1–3.0 | 3.1–5.0 | 4.1–6.0 |
| Medium | 2.1–4.0 | 3.1–5.0 | 5.1–7.0 | 6.1–10.0 |
| High | 4.1-6.0 | 5.1–7.0 | 7.1–9.0 | 10.1–14.0 |
| Very high | from 6.1 | from 7.1 | from 9.1 | from 14.0 |

**Soil pH analysis**

A very important factor influencing the level of lupin yields is the soil pH. However, individual lupin species have different requirements in this respect. White lupin and narrow-leaved lupin should be grown on soils which are slightly acidic or close to neutral with a pH of, respectively 6.0–7.0 and 5.5–7.0 and rich in magnesium.

However, the optimal pH value for yellow lupin varies between 5.0 and 6.0. It should be emphasized that yellow lupin does not tolerate neutral, alkaline or freshly limed soils.

Lupins tolerate acidic soils well, but white and narrow-leaved lupins yield poorly on soil that are too acidic. Therefore, in the cultivation of these species, it is necessary to lime light soils (pH up to 5.0) and medium soils (pH up to 5.5). The needs for liming of arable land are assessed on the basis of the agronomic category of the soil and its pH (Table 5).

**Table 5.** Assessment of the need for liming of mineral soils (materials for determining fertiliser recommendations on arable land, 1989)

| **Liming need class** | **Agronomic category of the soil** | | | |
|---|---|---|---|---|
| | **very light** | **light** | **medium** | **heavy** |
| V — necessary | up to 4.0 | up to 4.5 | up to 5.0 | up to 5.5 |
| IV — needed | 4.1–4.5 | 4.6–5.0 | 5.1–5.5 | 5.6-6.0 |
| III — indicated | 4.6–5.0 | 5.1–5.5 | 5.6-6.0 | 6.1-6.5 |
| II — limited | 5.1–5.5 | 5.6-6.0 | 6.1-6.5 | 6.6-7.0 |
| I — unnecessary | over 5.6 | over 6.0 | over 6.6 | over 7.1 |

The use of calcium before the precursor crops are grown and, in exceptional cases, after the precursor crop has been harvested is recommended in the quantities specified in Table 6. With a low magnesium content in the soil (below 4 mg/100 g soil), approximately 1/3 of the lime doses should be applied in the form of magnesium lime. A carbonate fertiliser ($CaCO_3$, $MgCO_3$) acts more slowly than an oxide fertiliser (CaO, MgO). Carbonate fertilisers can be applied on all soils and oxide fertilisers mainly on soils defined in terms of agronomic category as medium and heavy.

When using calcium fertilisers, attention should be paid to the content of the other ingredients. In addition to the de-acidifying effect, fertilisers containing magnesium also deliver significant amounts of this element over a longer period of time.

**Table 6.** Recommended doses of calcium fertilisers (CaO t/ha); (Podleśny and Brzóska 2006a, 2006b, 2006c)

| **Agricultural suitability categories of the soil** | **Liming requirements** | | | | |
|---|---|---|---|---|---|
| | **necessary** | **needed** | **recommended** | **limited** | **unnecessary** |
| Wheat, very good (1) | 4.5 | 3.0 | 1.7 | 1.0 | 0 |
| Wheat, good (2) | 6.0 | 3.0 | 2.0 | 1.0 | 0 |
| Wheat, defective (3) | 4.5 | 3.0 | 1.7 | 1.0 | 0 |
| Rye, very good (4) | 4.5 | 3.0 | 1.7 | 1.0 | 0 |
| Rye, good (5) | 3.5 | 2.5 | 1.5 | 0.0 | 0 |

If the pH is too low, a liming agent should be used, for example, chalk fertiliser, magnesium-oxide lime or commercially available de-acidifying fertilisers, and mixed with the soil. A very good solution is also the use of granulated lime mixed with the stubble. However, in this case, the effects of liming are noticeable only after a few months due to the slow movement of calcium in the soil.

**Macro- and micronutrient fertilisation**

Only mineral fertilisation with phosphorous and potassium is used in lupin cultivation (Kocoń 2014). These elements are an essential condition for the proper growth and development of plants and enable proper interaction with nodular bacteria. They should be used in their entirety before the seeds are sown, in doses depending on the soil element content (Tables 7 and 8). On heavy and medium soils, fertilizing P and K is best done in autumn for winter tillage, and on lighter soils, where a risk of nutrient leaching exists, in early spring before sowing.

The fertilisation dose should be determined according to the nutrient content of the soil, on the basis of the results of the chemical analysis of the soil and the nutritional needs of the plants. Such analyses should be carried out in the field concerned at least once every 3–4 years. Rational fertilization is a very important activity in integrated plant production. In this system, fertilisation doses should be determined on the basis of the nutrient balance analysis.

**Table 7.** Recommended doses of phosphate fertilisers (kg $P_2O_5$ /ha) depending on the content of $P_2O_5$ in the soil (Podleśny and Brzóska 2006a, 2006b, 2006c)

| Agricultural suitability categories of the soil | Phosphorus content in the soil | | | | |
|---|---|---|---|---|---|
| | very low | low | medium | high | very high |
| Wheat, very good (1) | 50 | 30 | 15 | 15 | 0 |
| Wheat, good (2) | 45 | 30 | 30 | 0 | 0 |
| Wheat, defective (3) | 50 | 35 | 30 | 15 | 0 |
| Rye, very good (4) | 50 | 35 | 30 | 15 | 0 |
| Rye, good (5) | 60 | 40 | 25 | 15 | 0 |

**Table 8.** Recommended doses of potassium fertilisers (kg $K_2O$ /ha) depending on the $K_2O$ content in the soil: (Podleśny J., Brzóska F. 2006a, 2006b, 2006c)

| Agricultural suitability categories of the soil | Potassium content in the soil | | | | |
|---|---|---|---|---|---|
| | very low | low | medium | high | very high |
| Wheat, very good (1) | 65 | 50 | 40 | 30 | 0 |
| Wheat, good (2) | 50 | 40 | 35 | 25 | 0 |
| Wheat, defective (3) | 65 | 50 | 40 | 30 | 0 |
| Rye, very good (4) | 65 | 50 | 40 | 30 | 0 |
| Rye, good (5) | 70 | 70 | 55 | 45 | 20 |

Thanks to the nodular bacteria, lupin has the ability to bind significant amounts of atmospheric nitrogen in the process of biological N reduction, so it is widely believed that nitrogen fertilisation should not be used in its cultivation. Depending on the soil and climatic conditions, lupin binds significant amounts of nitrogen, including yellow lupin that can accumulate from 96 to 140 kg N per hectare and narrow-leaved lupin — 70 kg N per hectare (Wysokiński et al. 2014). A risk exists of delayd ripening of plants and a high infestation of seeds with fungal diseases.

Where a very high P and K content is present in the soil, the recommended doses of these elements should be decreased by 30–40 kg, and at very low levels—increased by 40–60 kg $P_2O_5$ or $K_2O$ per hectare.

In order to achieve a high yield of good quality, leguminous crops also need sulphur (Bartczak et al. 2017, Podleśna 2005), which stems from its necessity for the biological process of nitrogen fixation, photosynthesis and production of whole protein supplemented with sulphur amino acids. For this reason, they belong to the group of plants with a medium demand for this ingredient, i.e. they uptake around 30–40 kg $S/ha^{-1}$.

In lupin cultivation, in addition to fertilising with macroelements, it is important to fertilise with microelements, especially molybdenum (Podleśny 1997) and boron. Molybdenum itself contributes to the management of phosphorus, the transformation of nitrogen compounds and influences plant reproduction (pollen durability). Boron has an effect on the normal growth of generative organs and roots and on flowering and normal development of the vascular tissues. Micronutrient fertilisers may be applied as a soil treatment or through foliar feeding at the start of the budding phase. A dose of 0.04 kg Mo/ha and 0.2 kg B/ha is recommended.

## 7. INTEGRATED PROTECTION AGAINST PESTS

Integrated production of lupin should be carried out using integrated pest management and using technical and biological progress in cultivation and fertilisation with particular regard to human and animal health and environmental protection.

Integrated pest management includes all available actions and methods of plant protection (against weeds, pathogens, pests) with preference given to the use of non-chemical measures and methods that reduce the harmfulness of those organisms, in particular:

- the use of crop rotation, the appropriate date for sowing and plant density;
- the use of appropriate agrotechnology, including the use of mechanical plant protection;
- appropriate measures and methods of plant protection against harmful organisms should be preceded by monitoring of their occurrence and take into account current knowledge on the protection of plants against them;
- use of seed produced and assessed in accordance with seed legislation;
- the application of fertilisation and liming where appropriate;
- the use of hygiene measures (cleaning, disinfection) to prevent the occurrence and spread of harmful organisms;

- protection of beneficial organisms and creating favourable conditions for their occurrence, in particular for pollinators and natural enemies of harmful organisms.

In the framework of integrated plant protection, when carrying out a chemical plant protection treatment, account should be taken of:

- the appropriate selection of plant protection products in such a way as to minimise the negative impact of plant protection treatments on non-target organisms, in particular pollinators and natural enemies of harmful organisms;
- limiting the number of treatments and the quantity of plant protection products used to a necessary minimum;
- preventing the formation of resistance of harmful organisms to plant protection products by appropriate selection and their alternating use.

Plant protection products authorised for use in European Union countries are subject to periodic review in accordance with the latest studies and principles set out by the European Union. Strict requirements in terms of their quality, toxicology and effects on arable crops and the environment are monitored so that they do not pose a risk to the user, the consumer and the environment.

**When planning the use of plant protection products, the current lupin protection programme can be used.**

The list of plant protection products authorised in Poland is published in the register of plant protection products. Information on the extent of pesticide use in particular crops is placed on the labels. The repository of plant protection products can be a helpful tool in the selection of pesticides. Current information on plant protection products use is available on the Ministry of Agriculture and Rural Development website at:
https://www.gov.pl/web/rolnictwo/ochrona-roslin.

The list of plant protection products authorised for IP is available on the Online Pest Signalling Platform at: https://www.agrofagi.com.pl/133,wykaz-srodkow-ochrony-roslin-do-integrowanej-produkcji-w-uprawach-rolniczych.

For the protection against harmful organisms (weeds, pathogens, pests), only products registered and authorised for marketing and use in Poland may be used, and they must be clearly labelled as recommended for use in lupin cultivation.

**The products must be used in a way that ensures that human, animal or environmental health is not endangered.**

It should be borne in mind that the products included in the **list of plant protection products recommended in integrated production** do not present a risk when properly applied in accordance with the approved labelling of the plant protection product.

Compliance with the instructions for use, such as, inter alia, the appropriate choice of the product, the dose, the date of application, the appropriate stages of development of the crop and pests, the appropriate temperature and humidity conditions, and the technical conditions for the performance of the treatment, have a decisive influence on the safety of treatments with plant protection products.

In order to perform laboratory diagnostics (most often carried out to identify pathogens), tests are carried out in laboratories that are appropriately accredited.

### 7.1. WEED INFESTATION CONTROL

Weeds are one of the main agricultural challenges in lupin cultivation and pose one of the major threats of crop loss. As a permanent element of arable fields, weeds utilise habitat conditions efficiently. This is based on their survival strategy, physiological and life cycle processes and adaptability. The associated risk of weed infestation depends on habitat conditions and the dynamics of crop development. The presence of weeds is determined by the so-called 'soil seed bank', i.e. the stock of diaspores (seeds, rhizomes, adventitious roots, tubers, bulbs) accumulated in the soil. The soil seed bank constitutes so-called potential weed infestation (through soil). On the other hand, the seedlings present in the field constitute a current weed infestation. The uncontrolled development of weeds, especially in the early stages of lupin growth, results in a significant decrease in the quantity and quality of seed yields.

The greatest threat to lupin is posed by weeds in the initial period of growth in the so-called critical weed competition period. This is the period from sowing to the BBCH 3 development phase (stem elongation). During this period, the optimal solution is to keep the lupin plantation free of weeds.

#### 7.1.1. The most important weed species

In lupin, the greatest threat is posed by weed species the development of which may continue throughout the lupin growing period. The harmfulness of the most common weeds in lupin crops is shown in Table 9. The peak of their occurrence takes place in spring, from April to May. Lupin prefers early sowing, hence the most common weed species are those of the cryophilic species. Their minimum germination temperature is 2–4 °C. Most commonly, they are dicotyledonous weeds of the following genera: geranium *(Geranium* sp.), cornflower (Centaurea sp.), violet (*Viola* sp.), chickweed (*Stellaria* sp.), goosefoot (*Chenopodium* sp.), poppy (*Papaver* sp.), speedwell (*Veronica* sp.), buckwheat (*Fallopia* sp.), knotgrass (*Polygonum* sp.), shepherd's purse (*Capsella* sp.), pennycress (*Thlaspi* sp.) and Anthemideae weeds (mayweed [*Matricaria* sp.] and locally chamomiles [*Anthemis* sp. or *Chamomila* sp.]). Among monocotyledonous weeds, the most common are couch grass (*Elymus* sp.) and locally also meadow foxtail (*Alopecurus* sp.). Among the species of so-called thermophilic weeds, lupins are most often infested by plants of the following genera: barnyard grass (*Echinochloa* sp.), foxtail (*Setaria* sp.), and among the dicotyledonous weeds: amaranth (*Amaranthus* sp.) and potato weed (*Galinsoga* sp.).

The most dangerous is the emergence of weeds during the initial lupin development period (BBCH 01/31). No control during this period usually results in a severe weed infestation. Competing with lupin plants for water and nutrients, they contribute to a decrease in yield, inter alia, as a result of fewer pods on the plant, fewer seeds in the pod and their lower mass. In extreme cases, plants may form no pods. In addition, in weed infested fields, the risk of developing diseases increases, the occurrence of which also results in a decrease in yield. Some weed species, when not controlled, overgrow lupin crops and their biomass before harvest may be several times higher than the mass of lupin. On a weed-infested plantation, harvesting is hindered, among other things, by clogging the harvester sieves, which reduces the precision of work (increase in crop contamination). This results in losses of seed yield ('losing' of seeds behind the harvester) as well as contamination of the yield (weed seeds, plant fragments). Contamination with weed biomass during the harvest results in an increase in the moisture content of the harvested lupin seeds. Lupin plantations most often are overgrown by weeds of the genera: goosefoot (*Chenopodium* sp.), barnyard grass (*Echinochloa* sp.), cornflower (*Centaurea* sp.), poppy (*Papaver* sp.) and thistle (*Cirsium* sp.).

**Table 9.** Harmfulness of the most common weeds in lupin crops (Krawczyk and Mrówczyński 2012)

| Species | Importance |
|---|---|
| Geranium — *Geranium* sp. | + + |
| Common mugwort — *Artemisia vulgaris* L. | + + |
| Cornflower — *Centaurea cyanus* L. | + + + |
| Cockspur — *Echinochloa crus-galli* (L.) P. Beauv. | + + |
| Common fumitory — *Fumaria officinalis* L. | + |
| Small bugloss — Anchusa arvensis (L.) M. Bieb. | + + |
| Violet — *Viola* sp. | + + |
| Common chickweed — *Stellaria media* (L.) Vill. | + |
| Common stork's-bill — *Erodium cicutarium* (L.) L'Hér. | + |
| Dead-nettle — *Lamium* sp. | + |
| Goosefoot (agg.) — *Chenopodium album* (agg.) | + + + |
| Field poppy — *Papaver rhoeas* L. | + |
| False mayweed — *Matricaria perforata* Mérat | + + + |
| Dandelions — *Sonchus spp*. | + + + |
| Creeping thistle — *Cirsium arvense* (L.) Scop | + + + |
| Couch grass — *Elymus repens* (L.) Gould | + + + |
| Speedwell — *Veronica* spp. | + |
| Catchweed — *Galium aparine* L. | + |
| Common knotgrass — *Polygonum aviculare* L. | + |
| Pale persicaria — *Polygonum lapathifolium* L. | + + |
| Buck-bindweed — *Fallopia convolvulus* (L.) Á. Löve | + + + |
| Field chamomile — *Anthemis arvensis* L. | + + + |
| Chamomile — *Chamomilla recutita* (L.) Rauschert | + |
| Wild rapeseed — *Brassica napus* | + + + |
| Shepherd's purse — *Capsella bursa-pastoris* (L.) Medik | + |
| Field pennycress — *Thlaspi arvense* L. | + |
| Slender meadow foxtail — *Alopecurus myosuroides* Huds. | + |

(+++) very high harmfulness; (++) high harmfulness; (+) low harmfulness or weed of local importance

### 7.1.2. Agronomic methods of weed management

In integrated production, various methods of weed control should be implemented, taking into account preventive measures and direct methods of weed destruction. The main cause of weed infestation is the ‘soil seed bank’, which is why efforts should be made to reduce its abundance through various treatments, in all possible phases.

The strategy to reduce the size of the ‘soil seed bank’ of weeds should be initiated during the post-harvest tillage operations. These treatments should in particular target species of perennial weeds reproduced by underground stolons or rhizomes. Subsequent cultivation treatments that stimulate weed diaspores to germinate, and then combat their seedlings, significantly reduce the number of active seeds in the top layer of the soil.

An important factor limiting weed growth is the uniform emergence of the crop at optimal planting density. Therefore, it is necessary to sow healthy, good-quality seed respecting the recommended agronomic deadlines and sowing density. Optimal planting reduces the risk of secondary weed growth.

In integrated production, treatments should be applied to limit both potential and current weed infestation. The most important activities include:

- appropriate selection of the site, taking into account crop rotation;
- weed control in the post-harvest cultivation of precursor crops based on mechanical or chemical treatments;
- the use of crop treatments as appropriate and in a way that does not lead to soil pulverisation and drying;
- the use of certified seed; adequate seed quality ensures rapid, even emergence and planned plant density when sowing is carried out under optimal conditions (sowing date, sowing depth, soil temperature and moisture, etc.);
- application of sustainable fertilisation;
- application of hygiene measures consisting of regular cleaning of machinery and equipment to prevent the spread of weeds.

### 7.1.3. Non-chemical methods of weed control

**Prevention and agronomic methods**

These include: selection of a suitable site for cultivation, appropriate crop rotation to prevent weed compensation, selection of varieties adapted to local soil and climatic conditions, careful soil cultivation, fertilisation based on analyses of the fertilisation needs of the crop and soil nutrient levels to achieve full crop vigour, appropriate sowing dates and plant density, careful maintenance during cultivation, and, as far as possible, preventing weeds from producing seeds.

Certified seed must be used in order to obtain balanced emergence and the optimum stocking density. Seed must be sown respecting the recommended quantities, dates and optimal depth for sowing. It is very important to optimally set the seeding standard, adapted to the requirements of the variety and the site, which effectively reduces the risk of secondary weed infestation.

**Mechanical methods of weed control**

Direct weed control methods involve the control of weeds during the post-harvest tillage operations after harvesting the precursor crop (if no crop is sown). During this period, particular attention should be paid to controlling species of perennial weeds that reproduce by underground stolons or rhizomes, such as couch grass (*E. repens*), dandelions (*Sonchus* sp.), thistles (*Cirsum* sp.), as it is very difficult or impossible to control them during lupin's growing period.

Lupin is characterised by a type of epigeic germination in which the elongating hypocotyl pushes the cotyledon above the soil surface. This is a period of high sensitivity to mechanical damage. Mechanical weeding with a harrow is possible immediately after the sowing (BBCH 01–03) or after the emergence of lupin, from the phase of 3–4 lupin leaves (BBCH 23). Lupin, compared to other crops, such as cereals, is less tolerant in terms of mechanical weeding with the use of harrows (Krawczyk et al. 2020). It is also sensitive to weed infestation and, under certain circumstances, the side effects of post-emergence harrowing can be offset or outweigh the negative effects of weed infestation. During harrowing, care should be taken not to damage or pluck lupin plants. When harrowing, the driving speed (higher speed results in greater intensity) and the type of harrow and its operation settings (whenever possible) should be adapted to the habitat conditions and the development stage of lupin. In order to reduce the side effects of harrowing, the treatment is best carried out in conditions conducive to lower turgidity of the plants. Harrowing is best done in the afternoon, when the top layer of the soil is dry. Weeds in the seedling phase are the most sensitive to harrowing. Harrowing of moist soil has a weaker herbicide effect. Harrowing on an uneven or clodded surface results in an increased damage to the lupin.

Weeding with the use of a weeder requires sowing in a larger row spacing (25–30 cm). The use of a bigger spacing between rows contributes to reduced crop yield due to a lower plant density. In lupin, excessive density of plants in the row is not recommended, as this contributes to an increase in green mass growth at the expense of seed yields and uneven ripening and delay in harvesting.

### 7.1.4. Chemical methods of weed infestation control

The condition for effective action of herbicides is the correct selection of a suitable products and timely execution of the treatment. It should be noted that in the case of a prolonged drought, the herbicidal effect of herbicides applied in the soil (directly after sowing lupin) is weaker.

Only chemical herbicides contained in the '**List of herbicides recommended for integrated production of agricultural crops**' can be used in integrated production. The list of authorised plant protection products for certified integrated production is available in the

Pest Warning System at the following address: (https://www.agrofagi.com.pl/133,wykaz-srodkow-ochrony-roslin-do-integrowanej-produkcji-w-uprawach-rolniczych).

Plant protection products listed in the 'List of Herbicides Recommended for Integrated Production (IP) of Agricultural Plants' have been selected from the '**Register of Plant Protection Products'** (https://www.gov.pl/web/rolnictwo/rejestr-rodkow-ochrony-roslin) on the basis of their harmfulness to humans and warm-blooded animals, in accordance with labels, permits, and decisions of the Ministry of Agriculture and Rural Development and the European Commission.

Information on the extent of pesticide use in particular crops is placed on the labels. The repository of plant protection products can be a helpful tool in the selection of pesticides. Current information on plant protection products use is available on the Ministry of Agriculture and Rural Development website at:https://www.gov.pl/web/rolnictwo/ochrona-roslin.

**Plant rotation after herbicide application**

Herbicides vary in duration of action and biodegradation in soil, which should be taken into account when planning subsequent crops. Each herbicide label contains a section: 'CROP ROTATION', which provides information on the possible cultivation of successive crops. Most herbicides do not pose a risk to follow-on crops, but some herbicides persist longer in the soil and may cause symptoms of phytotoxicity or stunting on following crops.

**Weed resistance to herbicides and methods of limiting it**

The occurrence of herbicide-resistant weed biotypes is becoming a serious problem, which is why proper monitoring is crucial in terms of preventing weed resistance to herbicides.

One of the factors contributing to the development of weed resistance to herbicides is improper weed control based only on a widespread use of herbicides, without taking into account other methods, in particular agronomic ones.

The risk of weed resistance to herbicides increases when herbicides with the same mechanism of action are used cyclically. In order to counteract the risk of weed resistance to herbicides, it is necessary, among other things, to use herbicides with a different mechanism of action or at least from different chemical groups alternately. For this purpose, classification according to the mechanism of action of the active substance based on the HRAC classification (*Herbicide Resistance Action Committee*) should be used when selecting the herbicide for the procedure. Individual mechanisms of action of the active substances of herbicides according to this classification are currently assigned numerical codes (formerly, letter codes were commonly used, which can still be found on the labels of plant protection products).

## 7.2. REDUCTION OF DISEASE VECTORS

### 7.2.1. Most important diseases

Lupin is exposed to diseases caused by pathogenic fungi and by other organisms and pathogens. Diseases on the plant can be caused by one or more pathogens at the same time. Seed yield losses in lupin cultivation due to diseases are estimated to be around 10–15 %. However, locally, with an epidemic occurrence of a given pathogen, losses can go up to 90 %. Most often, significant losses in lupin cultivation are caused by lupin fusarium rot, grey spot disease of lupin leaves (lupin leaf canker) and lupin anthracnose, and sometimes by viruses. The first two diseases are the most dangerous in the cultivation of narrow-leaved lupins, while anthracnose causes large economic losses most often in the cultivation of yellow and white lupins (Korbas and Horoszkiewicz-Janka 2012). In addition to these diseases, lupin cultivation may include: brown leaf spotting of lupin, brown stem spotting of lupin (lupin shoot gangrene), black root rot, lupin fusarium rot, powdery mildew of legumes, downy mildew, lupin rust, grey mould, lupin ascochytosis, Sclerotinia sclerotiorum, lupine root rot and seedling blight (Borecki 2017). The degree and severity of infestation of Fabaceae, including lupin, by pathogens depends on many factors, including weather conditions and agronomic treatments (Kurowski et al. 2016). The current threat posed by pathogenic organisms is shown in Table 10. Their importance varies and they are difficult to diagnose, especially when two or more diseases attack a plantation at the same time.

**Table 10.** Economic importance of lupin diseases

| Disease | Pathogen(s) | Importance | | |
|---|---|---|---|---|
| | | yellow lupin | narrow-leaved lupin | white lupin |
| Lupin anthracnose | *Glomerella cingulata* st. kon. *Colletotrichum Lupini* | +++ | ++ | ++ |
| Brown leaf spot of lupin | *Pleiocheta setosa* | ++ | + | ++ |
| Brown stem spot of lupin (lupin shoot gangrene) | *Diaporthe woodi* st. kon. *Phomopsis leptostromiformis* | + | + | + |
| Black root rot | *Chalara elegant* syn. *Thielaviopsis basicola* | + | + | + |
| Fusarium rot of lupin | *Nectria haematococca* var. *brevicona* st. kon. *Fusarium solani*, *Giberella aveancea* st. kon. *Fusarium avenaceum* | +++ | ++ | +++ |
| Powdery mildew of legumes | *Erysiphe trifolii* syn. *Erysiphe martii* | +++ | ++ | +++ |
| Downy mildew | *Peronospora trifoliorum* | + | + | + |

| | | | | |
|---|---|---|---|---|
| Lupin rust | *Uromyces lupinicola* | ++ | + | ++ |
| Grey spotting of lupin leaves (lupin leaf canker) | *Pleospora herbarum* st. kon. *Stemphylium botryosum* | + | +++ | + |
| Grey mould | *Botrytis cinerea* | ++ | ++ | +++ |
| Lupin fusarium wilt | *Fusarium oxysporum* f. sp. *lupini* | ++ | +++ | ++ |
| Fungal rot | *Sclerotinia sclerotiorum* | ++ | ++ | + |
| Sclerotinia sclerotiorum | *Rhizoctonia solani* | + | + | + |
| Seedling blight | different species of fungi (e.g. of the genera: *Fusarium*, *Rhizoctonia*, *Colletotrichum*, *Pythium*) | ++ | ++ | ++ |

(+++) very important disease; (++) important disease; (+) disease of local importance

### 7.2.2. Methods of monitoring disease vectors in lupin cultivation

Weather conditions, especially humidity conditions and the amount and distribution of rainfall during the growing season, temperature and sunshine play a significant role in the severity and timing of disease outbreaks. In the integrated production, it is advisable to know the sources of infection and conditions are conducive to the occurrence of diseases. Thanks to this, it is possible to determine the problematic disease with high accuracy and determine its severity in order to apply a possible threshold of harmfulness. Currently, there are no established damage thresholds for diseases occurring in lupin, so it is recommended to use fungicides according to the instructions on their labels. Table 11 contains information that will facilitate the diagnosis of lupin diseases present during the lupin growth period. This information should be used to precisely determine the date of eradication if a chemical method is needed.

**Table 11**. The most important sources of disease infection and favourable conditions for the development of the pathogens

| Disease | Sources of infection | Favourable conditions for development | |
|---|---|---|---|
| | | **temperature** | **soil and air humidity** |
| Lupin anthracnose | seeds from infected pods, crop residues, conidial spores from the air | 20–25 °C | high air humidity (above 80 %), high precipitation, moist soil |
| Brown leaf spot of lupin | infested seeds, debris of infested plants in the soil, perennial lupin, conidial spores from the air | temperature below 15 °C | high precipitation, high relative humidity of the air |
| Brown stem spot of | post-harvesting residues | above 20 °C | low soil moisture, |

| | | | |
|---|---|---|---|
| lupin (lupin shoot gangrene) | | | periodic drought |
| Black root rot | post-harvesting residues | above 20 °C | low soil moisture, periodic drought |
| Fusarium rot of lupin | agricultural crop residues, clover spores, mycelium in the soil, contaminated seeds | 5–25 °C (wide temperature range) | due to several disease vectors, varying soil conditions, water-deficit soil or wet soil |
| Powdery mildew of legumes | air containing spores, volunteer plants | 17–25 °C | low humidity |
| Downy mildew | seeds, crop residues, weeds | 10–20 °C | high (especially in the early stages of growth) |
| Lupin rust | spores (urediniospores in the air), remnants of infested plants | 15–23 °C | high air humidity |
| Grey spotting of lupin leaves (lupin leaf canker) | residues of infested plants in the soil, seeds, conidial spores formed in clover or lucerne | moist and warm summer, 20–25 °C (optimum 22–24 °C) | heavy rains, periodic droughts |
| Grey mould | seeds, soil, crop residues, volunteer plants, weeds | moist and warm summer, 20–25 °C | rainy weather and damage to plants (e.g. caused by hail) |
| Lupin fusarium wilt | seeds, mycelium in the soil, agricultural crop residues | high temperature (optimum 28 °C) | high air and soil humidity |
| Sclerotinia sclerotiorum | agricultural crop residues, spores in the soil | 20–25 °C | low air and soil humidity |
| Sclerotinia sclerotiorum | sclerotia in the soil, sclerotia contaminating seeds | 15–25 °C | high air and soil humidity |
| Seedling blight | crop residues, mycelium in the soil, seeds | lower temperatures | high soil humidity |

Source: Kryczyński and Weber (2011); Korbas et al. (2015)

In order to effectively prevent the occurrence of diseases, it is important to correctly diagnose them. Table 12 describes the characteristic symptoms of diseases caused by pathogens found in lupin crops. Pathogenic fungi can appear on all parts of lupin and occur from the germination phase, when the radicle emerges from the seeds (BBCH 05) until the end of pod formation (BBCH 79) and even until the seed ripening phase (BBCH 85) – 50 % of mature pods. Depending on the disease, symptoms occur on different parts (organs) of lupin (Table 13).

**Table 12**. Diagnostic features of the most important lupin diseases

| Disease | Diagnostic features |
|---|---|
| Lupin anthracnose | Symptoms of infection may occur on all aboveground parts of the plants; the pathogen first infects young organs of germinating seeds; early infection may cause pre-emergence and post-emergence seedling blight; the disease occurring on older plants follows a secondary infection caused by conidial spores of the fungus, which can spread over considerable distances with wind and rain. The most characteristic symptom of the disease is wilting of the tops of infected plants and twisting of the stems as a result of tissue necrosis; small brownish-salmon stains are visible in one or more spots on the stem; characteristic nests of stunted infected plants can be seen in the field. If the infection occurs later, e.g. at the end of the plant's life, the plant may become infected. If infection occurs later, e.g. at the stage of pod setting or pod formation, the disease symptoms are also visible on the pods. These are round, salmon-coloured spots with a brown border and numerous conidial spores. Under atmospheric conditions favourable to the development of the disease, the fungus penetrates the tissues of the pod and infects the seeds. A heavy infection of the seeds leads to their shrinking, deformation and discolouration. In case of a heavy infection, the pods contain no seeds. |
| Brown leaf spot of lupin | On white lupin, disease symptoms occur on leaves and stems in the form of irregular brown spots; most spots are located near the leaf edges and are approx. 1 cm in diameter. Heavily infected leaves wilt and fall off. The disease symptoms on pods take a form of large, often clustered brown spots, sometimes hollow and covered with a black, velvety bloom. The seeds in the pods are poorly developed, wrinkled and covered with brown spots. The spots on the leaves of the narrow-leaved lupin are brownish-purple in colour and about as big as the width of the leaf; affected leaves turn brown and shrivel. |
| Brown stem spot of lupin (lupin shoot gangrene) | First symptoms in the form of whitish spots, 0.5 mm in diameter, which grow after a few days to a diameter of about 3–4 mm, occur on the lower parts of the stems; on young stems the spots become slightly indented. As the disease develops, the spots elongate and often reach more than half the length of the stem and cover most of its circumference; in the centre of the spots, grey or dark-brown raised areas of about 0,3–2 mm in diameter in the centre of the spots, which are stromatoid fungus bodies containing pycnidia with conidial spores. The fungus then invades the vascular tissues resulting in wilting, dying off and drying of the plants. Young plants that are infected before flowering die most quickly; when older plants are affected, the yield is reduced. |
| Black root rot | Brown-black necroses on the roots. In case of a severe infestation, the entire root system is blackened and the entire circumference of the hypocotyl is black. The plants wither and die. |
| Fusarium rot of lupin | Infected stem turns brown and rots; when the plant is uprooted, the roots remain in the soil. Pink mycelium and conidial spores appear on the lower part |

| | |
|---|---|
| | of the stem at high humidity. |
| Powdery mildew of legumes | White, fluffy, oval clusters of the fungus on the leaves on the upper side of the leaves and sometimes on the stems. |
| Downy mildew | Light green (mosaic) discolouration on the leaves and the cotyledons. Loose structures of the pathogen are observed on the underside of infected plant parts. |
| Lupin rust | In summer, brown spore clusters develop on their own or in groups on the underside of the lupin leaves in circular brown spots. A little later, also on the underside of the leaves, dark-brown spore clusters are produced. A more severe occurrence of rust leads to premature dying off, drying and falling of the leaves. |
| Grey spotting of lupin leaves (lupin leaf canker) | Leaves and pods, sometimes stems, and to some extent seeds and seedlings are affected. Symptoms on the leaves appear in July; starting from the lower leaves, 2–6 mm diameter circular spots appear, at first bright and watery, later turning grey-blue or grey-brown with a darker edge. If 2–3 spots appear on a leaf, the leaf falls off; falling leaves are green but withered; petioles mostly stay on the stem. Spots on stems and pods are round, 1–3 mm in diameter, initially reddish-brown, later turning darker. Stems are brown and bent, and pods are mostly blackened and empty (except for the oldest pods on the main stem). The developed seeds are small and wrinkled. Some plants die off prematurely. Seedlings from infected seeds are dwarfed, bent, with a browned and constricted stem. |
| Grey mould | Brown patches on cotyledons and seedling stems; infested seedlings die off. Brown longitudinal patches, often covered with downy stalks and grey conidial spores on stems, inflorescences, canes. Infested tissues become necrotic, which may cause breakage, wilting and death of the plant. |
| Lupin fusarium wilt | During flowering and pod setting, the plants wither. Brown, mostly longitudinal spots appear on the stems and a mycelium film with spores is visible on the surface during wet weather. In cases of heavy infestation, the plants die off in patches and can easily be pulled out of the soil and do not yield. |
| Sclerotinia sclerotiorum | Infected plants show delayed growth, yellowing, wilting and drying. In narrow-leaved lupins the leaves often turn red and fall off. Young infected plants whose stems have not yet lignified may die off within a very short time. The roots rot and remain in the soil after the plant is uprooted. Rot also spreads to the lower parts of the stems, which show a white film around the circumference of the stem at its base. |
| Fungal rot | Lower stem and upper stem rot with white mycelium appearing in the affected areas, sometimes with a perimeter around the spot and covered by a cotton-like mycelium film. The inside of the stem is filled with cotton-like mycelium in which black, irregularly shaped sclerotia form; mycelium and sclerotia may also be present on the stem surface. Stems break and fracture; leaves dry out and wilt; pods may be affected. |
| Seedling blight | Brown spots on the roots, root collars and stems, over time covering the entire circumference; characteristic narrow spots are formed; a heavy infestation may cause wilting and dying off of the plants. |

Source: Kryczyński and Weber (2011); Korbas et al. (2015)

**Table 13**. Occurrence of symptoms of diseases on individual organs of lupin plants

| Disease | Root | Stem | Leaf | Inflorescence | Pod | Seeds |
|---|---|---|---|---|---|---|
| Lupin anthracnose | | x | x | | x | x |
| Brown leaf spot of lupin | | | x | | | |
| Brown stem spot of lupin (lupin shoot gangrene) | | x | | | | |
| Black root rot | x | | | | | |
| Fusarium rot of lupin | x | | | | | |
| Powdery mildew of legumes | | | x | | | |
| Downy mildew | | | x | | | |
| Lupin rust | | | x | | | |
| Grey spotting of lupin leaves (lupin leaf canker) | | | x | | | |
| Grey mould | | x | x | x | x | x |
| Lupin fusarium wilt | | x | x | | | |
| Sclerotinia sclerotiorum | x | | | | | |
| Fungal rot | | x | | | | |
| Seedling blight | x | x | | | | |

Source: Kryczyński and Weber (2011); Korbas et al. (2015)

In integrated lupin production, it is mandatory to systematically monitor the field in the following developmental phases: two-leaf phase (BBCH 12), shoot development (BBCH 30–35), inflorescence development (BBCH 55–57), flowering (BBCH 65–69), pod development (BBCH 75–79) (Matysiak and Strażyński 2018) to assess the occurrence of diseases.

In determining the dates for treatments with fungicides, the following guidelines for the selected diseases may be helpful. However, it must be taken into account that diseases can develop throughout the growing season of lupin, and health assessments of the plantations should be carried out within the above time limits:

- grey mould — from the beginning of the visible flower bud stage (BBCH 50) to the stage when 50 % of the pods have reached typical length (BBCH 75), inspect the plants diagonally across the plantation for characteristic symptoms caused by the disease;
- powdery mildew of legumes — as soon as the first symptoms appear on the leaves, special attention should be paid at the stage of inflorescence development (BBCH 50) until the stage when 50 % of the pods reach the typical length (BBCH 75), inspecting plants diagonally across the plantation for characteristic symptoms caused by the disease;

- Sclerotinia sclerotiorum — from the visible flower bud stage (BBCH 50) to the stage when 50 % of the pods have reached the typical length (BBCH 75), inspect the lupin plantations diagonally across the plantation for characteristic symptoms caused by the disease;
- fusarium rot of lupin — from the one- to two-leaf stage (BBCH 21) until the end of flowering (BBCH 69), inspect lupin plantations diagonally across the plantation for characteristic symptoms caused by the disease;
- lupin anthracnose — the first inspection should be carried out from the one- to two-leaf stage (BBCH 21); special attention should be paid during the inspections carried out at the stage when the first, single, closed flowers are visible above the leaves (BBCH 55) until the end of the stage when 50 % of pods reach their typical size (BBCH 75) monitoring lupin plantations diagonally across the plantation for characteristic symptoms caused by the disease (Tratwal et al. 2017).

### 7.2.3. Agronomic methods of disease vectors control

**The agronomic method is based on the correct and timely execution of crop planning and management.**

Agronomic activities play a significant role in combating or preventing diseases. They reduce diseases occurring especially in the early stages of lupin development. The following elements of agronomy are important:

- appropriate crop rotation and site selection,
- proper preparation of the soil for sowing,
- rational feeding of plants,
- compliance with the rules of proper fertilisation, timing and density of sowing.

In order to reduce the severity of crop rotation diseases, the cultivation interval indicated in the agronomic section should be maintained. When the break in the cultivation of lupin is too short, an increased incidence of diseases can be expected, especially caused by the fungi of the genus *Fusarium* (causing wilting) and seedling blight. In order to reduce the risk of disease development, sowing seeds within the recommended agronomic deadline is important. Delaying the sowing prolongs the growth period and makes plants more susceptible to disease infestation. Table 14 lists the most important non-chemical methods for reducing field bean diseases.

**Table 14**. The most important agronomic methods for lupin disease control

| Disease | Agronomic methods |
|---|---|
| Lupin anthracnose | certified seed; avoidance of the vicinity of lupins plantations |
| Brown leaf spot of lupin | certified seed; early sowing; correct crop rotation; correct fertilisation (P and K) |
| Brown stem spot of lupin (lupin shoot gangrene) | optimal conditions for development; appropriate crop rotation |
| Black root rot | correct crop rotation; optimal soil conditions |
| Fusarium rot of lupin | at least a 4-year break in cultivation; early sowing; cultivation of resistant varieties |
| Powdery mildew of legumes | deep tillage; correct crop rotation; optimal sowing date; |

| | |
|---|---|
| | sustainable fertilisation; appropriate sowing density |
| Downy mildew | deep tillage, correct crop rotation; optimal sowing date; balanced fertilisation; rational fertilisation with N |
| Lupin rust | early sowing; destruction of crop residues; destruction of weeds |
| Grey spotting of lupin leaves (lupin leaf canker) | early sowing; proper fertilisation; destruction of crop residues; avoiding lupin cultivation in the vicinity of lucerne and clover; careful plant care |
| Grey mould | early sowing; sustainable fertilisation; weed control; harvesting at optimal time |
| Lupin fusarium wilt | appropriate cultivation intervals; early sowing of lupin grown for seeds |
| Sclerotinia sclerotiorum | certified seed; early sowing of lupins for seed; delay in sowing for fodder or ploughing |
| Fungal rot | deep tillage; appropriate crop rotation; sustainable fertilisation; nutrient surplus must be prevented; appropriate sowing density; weed control; spatial isolation from other susceptible crops; removal and destruction of diseased plants during growth period |
| Seedling blight | deep ploughing; appropriate crop rotation, regulation of soil relations; sowing respecting optimal agronomic deadlines; sustainable fertilisation; appropriate sowing density; weed control |

### 7.2.4. Chemical methods of disease vectors control

Currently, the use of chemical methods in the cultivation of lupin is possible through seed treatment and the use of plant spraying during their growth period. Seed of **at least the certified category** which satisfies the production and quality requirements must be used for sowing. It is also recommended to use treated seed for sowing. Fungicides are available for spraying plants during growth, but the scope of diseases to be combated in lupin cultivation is very limited. Therefore, ensuring optimal conditions for lupin emergence and development is recommended, especially in the initial stage of growth, which makes plants less susceptible to infestation by pathogenic fungi.

The use of fungicide treatments during the growing season depends on the severity of the disease. Currently, there are no established damage thresholds for diseases occurring in lupin, so it is recommended to use fungicides according to the instructions on their labels. According to the Guide on large-seed legume protection signalling (Tratwal et al. 2017), the suggested eradication time for selected diseases is as follows:

- powdery mildew of legumes — when about 20 % of plants show the first symptoms of the disease;
- lupin anthracnose — the first symptoms of the disease on leaves, stems or pods indicate the need for the treatment.

Plant protection products should be used in accordance with the current list of products recommended for lupin cultivation in integrated production.

Messages from the Online Pest Warning System (www.agrofagi.com.pl) may be helpful. Use instructions on the label should be read before application.

The list of plant protection products authorised in Poland is published in the register of plant protection products. Information on the extent of pesticide use in particular crops is placed on the labels. The repository of plant protection products can be a helpful tool in the selection of pesticides. Current information on plant protection products use is available on the Ministry of Agriculture and Rural Development website at: https://www.gov.pl/web/rolnictwo/ochrona-roslin.

The list of plant protection products authorised for IP is available on the Online Pest Signalling Platform at: https://www.agrofagi.com.pl/143,wykaz-srodkow-ochrony-roslin-dla-integrowanej-produkcji.html.

## 7.3. REDUCTION OF LOSSES CAUSED BY PESTS

### 7.3.1. Most important pests

The development of integrated rules for the protection of lupin against pests, taking into account environmental aspects, is particularly important due to the large number of species damaging this group of plants. The extent of their harmfulness depends primarily on the weather conditions, the developmental stage and condition of the plant, as well as the method of cultivation. The greatest losses due to pest feeding can occur on seed plantations, with heavy infestation and plant damage leading to the liquidation of plantations or disqualification of seed material.

The growing threat from pests is mainly caused by the gradual increase in the area of cultivation of legumes (Fabaceae). Simplifications of cultivation as a manifestation of production intensification, improper crop rotation, or insufficient spatial isolation also have a negative impact. Another possible problem is the incorrect monitoring of the most important pest species, their identification, determination of harmfulness thresholds, and timing for optimal control. The most important lupin pests include: weeviles, aphids, root flies, pea moth, lygus, thrips, butterfly caterpillars, slugs and soil pests – cutworms, grubs and wireworms (Hołubowicz-Kliza et al. 2018; Mrówczyński et al. 2017; Strażyński and Mrówczyński 2016; 2019; Tratwal et al. 2017; Krawczyk et al. 2020) (Tables 15 and 16).

**Table. 15** Economic importance of lupin pests

| Pest | Current | Forecast |
|---|---|---|
| Aphids | +++ | +++ |
| Sitona weevils | +++ | +++ |
| Thrips | + | ++ |
| Root flies | ++ | +++ |
| Caterpillars | + | ++ |
| Lygus bugs | ++ | ++ |
| Pea moth | + | ++ |
| Soil pests | +++ | +++ |

| | | |
|---|---|---|
| Gastropods | ++ | +++ |

(+++) very important pest, (++) important pest, (+) locally important pest

**Tabela 16**. Characteristics of damage caused by lupin pests

| Pests | Characteristics of damage |
|---|---|
| Lupin weevil Pea leaf weevil<br>Sitona crinitus<br>Sitona griseus and others | Beetles feed on leaf blades by gnawing characteristic notches on their edges (so-called notched feeding damage). The greatest losses occur in spring (up to the 6-leaf stage), especially when warm and dry weather favours the development of insects on young seedlings. In later phases, more serious damage occurs as a result of the reduction of the assimilation surface of plants and the risk of secondary infestations by pathogens. Larvae feed in the root zone on root nodules, limiting the fixation of atmospheric nitrogen. |
| Black bean aphid<br>Aphids of lucerne, locusts and peas | Adult insects and larvae of aphids are harmful. Aphids inhabit younger, apical fragments of plants. As a result of aphids' feeding, the growth of plants is inhibited. Inhabited plant fragments may become deformed, wither, and dry out. Spores or other factors causing secondary fungal and bacterial infections may enter the feeding sites of aphids through damaged tissues. Aphids can transmit viruses as so-called vectors. |
| Thrips | In the case of a severe infestation by the pest, small, necrotic spots are visible on the damaged leaves (white on flowers, silvery on young pods); eventually these organs wither and fall, and the pods become stunted. The harm caused by thrips is the greater, the younger the plants that are attacked. |
| Pea moth | The caterpillars bite their way inside the pods, where they feed on the outer layer of seeds. The seeds are irregularly bitten off, surrounded by faeces and yarn. |
| Turnip maggot<br>Root fly | The larvae bit their way inside the seeds or feed on sprouts and young cotyledons. Early infested plants do not germinate or develop well, and their cotyledons are irregularly bitten and blackened. Bean seed fly is common, sometimes in high intensity, especially on damper, freshly ploughed soils, or after fertilisation with manure. |
| Grubs<br>Cutworms<br>Wireworms | Larvae damage the underground parts of plants. They can eat imbibed seeds, seedling roots, or gnaw on the stems of young plants at their base. Mass foraging of the larvae is manifested by patchy losses in sowing (so-called bald spots), mainly at the edges of plantations. |
| Caterpillars damage the leaves | Butterfly caterpillars feed on leaves and, in cases of mass infestation, can lead to partial defoliation of plants. |
| Lygus bugs | Both adult and larval stages of the lygus bugs are harmful. They suck the sap from the tissues of the leaves, causing their deformities and frequently leading to secondary infestations by the pathogens. |

### 7.3.2. Pest monitoring methods

Monitoring for the presence of pests in a plantation is a very important part of integrated plant protection. Continuous observation facilitates the assessment of the current situation in the field and, if necessary, allows for a quick response. Therefore, it is necessary to systematically monitor the occurrence of pests from the time of emergence to maturation, at least once a week, using appropriate methods. The basic element underpinning a properly set date for pest control is the monitoring of pest flights and number. Monitoring is carried out primarily on the basis of visual inspection or, in the case of soil pests, soil sieving. Other methods are also useful, such as sweep-netting or sticky boards. The basic method of plantation inspection is visual inspection (tour). Depending on the shape of the field, it should include the edge of the plantation and two diagonals. Depending on the pest species, the average number of pests per 1 m2 or 100 randomly selected plants should be checked. Such observations should be carried out in several places on the plantation. A useful method is sweep-netting. This is an easy and quick way to make an initial assessment of the species composition and number of insects on a plantation. This method of monitoring, when applied correctly, provides preliminary information not only about pests, but also about other insects, including the beneficial ones, present on the plantation in a relatively short time. However, it should be remembered that this method is not precise and in the event of a detected threat, more detailed inspection of the plantation should be carried out. For the purpose of initial inspection, 25 strokes should be made with a sweep net from the edge of the plantation, moving inward. Sweep-netting should always be carried out in the place most vulnerable to pest infestation, for example from last year's location of the crop concerned. Observations on the occurrence of soil pests consist of sieving the soil at several sites from holes measuring 25 × 25 cm and 30 cm deep. It is crucial for proper pest risk assessment to know the basics of the morphology and biology of a given pest species, e.g. the time of potential occurrence on the crop. Monitoring should be carried out both in order to determine the time of infestation and number of harmful insects on the plantation, as well as after the treatment to check the effectiveness of the control. In case of unsatisfactory effectiveness, the occurrence of resistance or prolonged infestations of harmful insects, such treatment makes it possible to react quickly and, if possible, to repeat the treatment. Due to many factors determining the occurrence of pests, monitoring should be carried out on each plantation. Proper inspection requires knowledge of pest morphology and biology. Regardless of the monitoring method used, the results of observations should be recorded (Tratwal et al. 2017).

Constant monitoring is necessary to determine the optimal treatment timing due to the continuous impact of many environmental factors, and only direct observations enable assessment of the actual threat from pests. Threats can vary depending on climatic conditions, terrain, plant growth stage, natural enemies or even fertilisation level.

Integrated plant protection programmes require considerable knowledge and experience from the farmer, ranging from pest identification to elements of development and habitation to ways of pest reduction and elimination. Information on pest biology, data from previous years on the occurrence of a pest in a given area combined with knowledge of measures to reduce losses can help in selecting the right treatment. The benefits of knowledge of modern methods of plant protection are not only economic. The lack of chemical pest control also translates into a healthier environment.

One of the tools facilitating the implementation of the principles of integrated plant protection is systems supporting the adoption of decisions in plant protection. These systems are helpful in determining the optimal timelines for performing plant protection treatments (in correlation with the plant growth phase, pest biology and weather conditions), and thus make it possible to achieve high efficiency of these treatments while limiting the use of chemical plant protection products to the necessary minimum.

The Online Pest Warning System operated by the Institute of Plant Protection – National Research Institute and partner institutions features, inter alia, the results of monitoring of individual stages of pest growth in selected locations for the needs of short-term forecasting. If the threshold of economic harmfulness is exceeded in individual cases, the system indicates the need to perform treatments. In addition, the system offers instructions that facilitate proper control of plantations and making decisions about the optimal treatment dates. For each pest species, basic information is provided on its morphology, biology and methods of field observation, as well as the value of the thresholds for economic harmfulness. Thresholds of economic harmfulness are the fundamental basis for rational protection. In the case of lupin, specific harmfulness thresholds are developed only for certain pest species. The rules and timelines for their monitoring are set out in Table 17.

**Table 17.** Timelines and priciples for conducting observation of lupin pests

| Pest | Principle and period of observation |
|---|---|
| Sitona weevils | visual inspection of crops for the presence of beetles and damage (serrated leaf edges) —<br>BBCH 10–19 (a pair of shelled leaves — 9 proper leaves) |
| Aphids | presence of aphid colonies on all vegetative organs —<br>growth and flowering<br>(BBCH 30–69) |
| Caterpillars damage the leaves | visual inspection of crops for the presence of caterpillars, yarn and faeces and leaf damage —<br>shoot development until pod maturation<br>(BBCH 21–75) |
| Soil pests | visual inspection of crops for damage to the roots, embryos, cotyledons (characteristic bald patches in sowing) —<br>emergence and leaf development<br>(BBCH 09–15) |
| Lygus bugs | visual inspection of crops for the occurrence of imago and larvae as well as damage to leaves, flowers and pods —<br>shoot development until pod maturation<br>(BBCH 21–75) |

| | |
|---|---|
| Thrips | presence of imago and larvae on all vegetative organs — BBCH 67–79 (first leaf developed — full maturity) |
| Pea moth | presence of butterflies (pheromone traps) and egg deposits — BBCH 67–79 (pod formation) |
| Root flies | presence of flies during emergence — BBCH 10–19 (a pair of shelled leaves — 9 proper leaves) |

### 7.3.3. Agronomic methods of pest control

Preventive actions based primarily on agronomic technics are one of the basics behind integrated lupin protection against pests. Correct agronomics and supplementing of any mineral nutrients improves the condition of the plants, especially in the early growth stages when they are particularly vulnerable to attack from given pest species. Properly carried out protection is intended to encompass a wide range of agronomic methods. The increasingly common use of simplified cultivation methods in connection with climate change creates favourable conditions for the development of pests. Proper observance of basic agronomic recommendations is a key element of the programme of protecting lupin against pests (Table 18).

For lupin, as in other legumes (Fabaceae), it is very important to use correct crop rotation. Many pests overwinter in the top layer of the soil or leftover plant residues. Properly planned crop rotation should include cereals, root and fodder crops. In the case of monocultures, pests have a facilitated access to food after wintering. For the same reason, it is recommended to use spatial isolation from other Fabaceae plants (also those cultivated in the previous year) and other host plants of individual pests, e.g. perennial Fabaceae in the case of pea aphids or lygus bugs. Spatial isolation also helps make certain pests fly over longer distances.

**Table 18.** Agronomic methods for the reduction of lupin pests

| Pest | Protection methods |
|---|---|
| Sitona weevils | crop rotation, shallow tilling, as early sowing as possible, spatial isolation from other Fabaceae (including perennial), post-harvest tillage |
| Aphids | early sowing, balanced fertilisation (particularly with N), spatial isolation from other Fabaceae (including perennial), containment of weeds infestation, post-harvest tillage |
| Lygus bugs | spatial isolation from other Fabaceae (including perennial), containment of weed infestation, post-harvest tillage |
| Pea moth | crop rotation, shallow tilling, discing, possibly early sowing and quick harvesting, post-harvest tillage |
| Root flies | crop rotation, early sowing, increasing the sowing standard, reduction of weed infestation, post-harvest tillage |
| Thrips | crop rotation, spatial isolation from other Fabaceae |
| Soil pests | crop rotation, shallow tilling, discing, weed infestation control, spatial |

| | |
|---|---|
| | isolation from meadows, fallow land and root crops, post-harvest tillage |
| Caterpillars | crop rotation, spatial isolation from other Fabaceae (including perennials), weed control |

Preparation of the place for cultivation, possible addition of minerals and further balanced fertilisation improve the condition of the plants. This is particularly important in the early stages of plant growth when they are extremely sensitive to attack by given pest species. Appropriate measures to reduce the potential damage caused by individual pest species can also be taken at the seed sowing stage. Faster initial vegetation of plants makes it possible to get ahead of the period of greatest danger from all pests, especially those that are dangerous for emerging plants. In addition, faster growth helps stunt the weeds that can constitute a food base for some pests. The plant density is also important. Too dense sowing makes it easier for pests to spread, while sowing too sparsely promotes weed infestation. In addition to competition for water, light and nutrients, weeds are also the food base for some pests, e.g. aphids. The date of harvesting is also very important – too late creates a risk of greater losses, especially qualitative, by insects that can damage the pods.

After harvesting, it is important to perform post-harvest cultivation treatments, aimed at precise fragmentation of crop residues (place of wintering and development of certain pests), controlling weed seeds, including the perennial ones. Post-harvest tillage should be completed with deep autumn ploughing, which serves a phytosanitary role. A thick layer of soil covers the wintering stages of pests, weed seeds and fungal spores. It also brings to the surface pests that are found deeper, exposing them to adverse weather conditions. Simultaneously, soil pests are mechanically destroyed (Tratwal et al. 2017).

### 7.3.4. Chemical methods of pest control

Plant protection products should be used in accordance with the current list of plant protection products recommended for lupin cultivation in integrated production. Messages from the Online Pest Warning System (www.agrofagi.com.pl) may be helpful. Product label should be consulted before its application. The list of plant protection products authorised in Poland is published in the register of plant protection products. Information on the scope of pesticide use in particular crops is contained on the labels. The repository of plant protection products can be a helpful tool in the selection of pesticides. Current information on plant protection products use is available on the Ministry of Agriculture and Rural Development website at: https://www.gov.pl/web/rolnictwo/ochrona-roslin.

The list of plant protection products authorised for IP is available on the Online Pest Signalling Platform at: https://www.agrofagi.com.pl/143,wykaz-srodkow-ochrony-roslin-dla-integrowanej-produkcji.html.

## 8. BIOLOGICAL METHODS APPLICABLE TO THE INTEGRATED PROTECTION AND PRODUCTION OF LUPIN

Biological methods consist of the use of natural biological agents such as: viruses, microorganisms (bacteria, fungi) and macroorganisms (nematodes, parasitic and predatory insects and mites) to reduce the population of pests, pathogens and weeds in plant crops grown outdoors and under covers. It should be emphasised that biological agents do not eradicate harmful organism populations in the same way as chemical pesticides; they only reduce their populations in the long term.

In biological pest control, three main methods are distinguished:

1. introduction, i.e. the permanent establishment in new areas of natural enemies imported from other regions or continents — the classical method;
2. the use of naturally occurring and specially introduced into agricultural and forest areas landscape elements enabling and enhancing the development of populations of beneficial organisms that naturally occur in these environments — the conservation method;
3. periodic colonisation, i.e. the periodic introduction of natural enemies of a given pest on crops on which it does not normally occur or occurs in small quantities — the augmentative method.

In field crops, the use of biopreparations containing parasitic microorganisms is uncommon. First of all, there is little interest from producers in these products, as their efficacy is often much lower compared to the application of chemical plant protection products. Their effectiveness is influenced by weather conditions in the field, which often change. These include: temperature, humidity and insolation. However, it must be remembered that when introduced into the environment these factors persist for a long period.

<u>Reducing the population of pests in lupin with the use of bioinsecticides</u>

The most dangerous lupin pests are: weevils, thrips, turnip maggots, aphids, pea moths, cutworms, white grubs, and wireworms.

Bioinsecticides whose active substance is the insecticidal fungus *Beauveria bassiana* may be used in lupin to control thrips, whiteflies, red spider mites and wireworms, if registered.

When using microorganisms to control lupin pests, <u>it should be remembered that:</u>

- fungal spores are sensitive to high temperatures, low humidity and strong sunlight;
- insecticidal fungi in their first stage of action require temperatures of around 25 °C and high humidity to germinate and enter the insect;
- micro-organisms should be used as soon as a small infestation of plants by pests is observed (at the beginning of its occurrence) and before visible signs of feeding;
- pest caterpillars/larvae do not die until 24–72 hours after eating insecticidal bacteria; during this time, they can feed and look healthy;

- micro-organisms are applied using self-propelled or tractor-mounted field sprayers or manual sprayers. Such treatments should preferably be carried out in the evening or early morning;
- depending on the degree of infestation and climatic conditions, it may be necessary to perform 3–5 application of the agent at intervals of 5–7 days.
- Chemical fungicides must not be used after the use of biological agents containing micro-organisms;
- they are living organisms and have a short shelf life at room temperature, but can be stored in the refrigerator for up to 6 months.

Mechanism of action of insecticidal fungi

The infectious stage of the insecticidal fungus, which is the active substance of the bioinsecticide, consists of spores, which do not have to be ingested by the pest; it is sufficient for them to reach the surface of the host’s body. They sprout and penetrate its interior. The insect dies from paralysis caused by the overgrowth of its body by the developing fungal hyphae. All stages of pest development are vulnerable. The time from infection to the death of the pest is from 3 to 7 days.

Insecticidal fungi, such as *B. bassiana*, are sensitive to low and very high temperatures. The optimal temperature for spore germination is 25 °C. High humidity is required for the penetration of spores into the body of the pest. The use of an insecticidal fungus in the form of a registered biopreparation means that the biological agent introduced into the environment can also act on other pests not listed on the label of the product for a long period of time. Fungus *B. bassiana* is a known biological agent commonly found in soil and may, for example, reduce the different stages of development of pests wintering in soil.

Symptoms of infestation by insecticidal fungi: the body of an infested insect often changes colour. One of the typical symptoms is mummification; the body is hard, and on its surface, in humid conditions, a mycelium of different colours is formed, depending on the species of fungus.

Different insecticidal fungi can be used together because there are no interactions between them.

Gastropods may prove problematic in lupin cultivation. They can be controlled with available biological preparations containing macro-organisms — nematodes — as their active ingredient. Macro-organisms are not subject to registration in Poland. Larvae of an icecticidal nemarode, *Phasmarhabditis hermaphrodita*, penetrate the gastropods’ body through the respiratory canal, infecting it with bacteria and making it stop foraging after 3–5 days. The application of the agent to a moist substrate increases its effectiveness. The preparation is retained in the soil for about 6 weeks. When using nematode preparations, it is necessary to know that the sprayer should have nozzles greater than 0.5 mm, and the pressure of 300 psi should not be exceeded. The preparation contains living organisms — larvae of nematodes, so their use must be carried out especially carefully and according to the label of the product.

Reducing disease vectors in lupin cultivation using biofungicides

The most important diseases in lupin cultivation are: anthracnose, furious rot, grey leaf mould and Sclerotinia sclerotiorum.

A biofungicide containing *Bacillus amyloliquefaciens* bacteria can be used to combat the vectors of Sclerotinia sclerotiorum and grey mould, if it is registered. It is a microbial fungicide in the form of a powder for aqueous suspension intended for preventive use. It is used in the cultivation of white lupin, yellow lupin and narrow-leaved lupin. The product should be applied from the stage when 9 leaves or 9 tendrils to full flowering, when 50 % of the flowers are open (BBCH 19–65).

When using bacteria, the following must be noted:

- they must be used with a self-propelled or tractor field sprayer or a manual backpack sprayer;
- in the fight against the vectors of Sclerotinia sclerotiorum, 10 spraying procedures may be performed with intervals of at least 7 days between treatments;
- fine-drop spraying is recommended;
- they should not be used with chemical fungicides, especially with agents containing copper;
- the product must be stored in a temperature range of 4–25 °C.

Mechanism of action of insecticidal bacteria

The bacterium *B. amyloliquefaciens* interferes with the germination of spores and inhibits the development of pathogen mycelium. The bacterial strain has the ability to produce substances that are antagonistic to disease vectors.

It is important to know that the use of microbiological biopreparations alone is not sufficient. In biological plant protection, an important role is played by the conservation method, which supports biological protection, especially in the protection of field crops.

Conservation biological protection

It consists in human modification of the agricultural landscape in order to create suitable conditions for the action of beneficial organisms present in the environment. The number of beneficial organisms can be increased, inter alia, by sowing melliferous plants in the vicinity of crops, flower strips or leaving natural furrows. Midfield woodlots and bushes play a big role. These sites serve as habitats for those organisms that significantly reduce populations of various pests. The use of different cultivation techniques (e.g. zero tillage) also promotes the development of beneficial soil microorganisms, such as insecticidal and nematocidal fungi (Sosnowska 2018, 2022; Bereś 2024). A very important element is the rational use of selective chemical plant protection products, allowing to reduce their negative effects on beneficial organisms. The decision on the need to perform chemical treatment in the field should be made on the basis of the actual threat of pests to cultivation.

A large role in nature is played by beneficial macro-organisms, i.e. parasitic and predatory insects, mites, and insecticidal nematodes. Under natural conditions, the importance of beneficial ground beetles is growing in integrated plant protection. They are abundant in all agricultural environments, including lupin crops. They are found on the top layer of soil and litter. Due to their large size, high motility and great voraciousness, they are among the most effective beneficial insects, significantly reducing the number of plant pests; among other things, they feed on eggs, pupae and larvae/caterpillars of many species of butterflies, beetles and Hymenoptera. The herbivorous corn ground beetle (*Zabrus tenebrioides*) is an exception in the family of ground beetles, considered to be a pest.

Aphids may be another problem for lupin crops. In natural conditions, aphid populations are reduced by many species of predatory insects, such as ladybirds (Coccinellidae). One larva, throughout its development (approx. 30 days), can eliminate from 100 to 200 aphids. A beetle eats 30–250 aphids a day. This is a lot, but aphids develop very fast. Given that aphid flights usually occur earlier than those of ladybirds and other beneficial insects, it is necessary to decide whether chemical treatment with a plant protection product is needed. If necessary, it should be performed as early as possible, before the flight of natural enemies, or restricted to the edge strips of the plantation, or even for a spot treatment by choosing a selective insecticide. Net-winged insects (Neuroptera) also feed on aphids. Green lacewing larvae eat up to 400 aphids. However, despite enormous aphidicidal effectiveness, the high motility of these insects significantly hinders the ability to control their populations, both natural and artificially introduced into crops. Aphids are also preyed upon by species of soldier beetles (Cantharidae), gall midges (Cecidomiidae), earwigs (Dermaptera), as well as predatory insects such as specialized aphid wasps (Aphidiidae) (Tomalak 2008).

Under favourable conditions (high humidity and temperatures above 20 °C), insecticide fungi belonging to ‘insect destroyers’ (Entomophthoraceae) play a major role. These fungi can cause epizootic diseases, i.e. mass extinction of aphid colonies. The development of insecticidal fungi is promoted by water habitats, strongly humidified habitats, forests, woodlots, rushes and meadows. Forests are more than twice as rich in insecticidal fungi as agro-ecosystems (Tkaczuk et al. 2016). Insecticides can reduce populations of wintering pests in the soil, such as cutworms and sitona weevils. Insecticidal fungal species active in the soil include: *Beauveria bassiana*, *Metarhizium anisopliae* and *Cordyceps fumosorosea*. The effectiveness of these fungi is best at high humidity and a temperature of 25 °C. Insecticidal fungi also act on the surface of the plant. Insects, such as aphids, infested by parasytes can often be found on leaves. Insecticidal bacteria and viruses can also play an important role.

In the environment, not only beneficial insects and micro-organisms play a role in reducing harmful pest populations. It also includes are other animals, such as amphibians, birds or mammals (Wiech 1997). The common toad feeds on a variety of foods, mostly gastropods and insects, often harmful ones. One of the insectivorous mammals is the mole. It is a beneficial animal that feeds on white grubs and other insects found in the soil. The most important example of insectivorous mammals is the hedgehog, which hunts at night, and its food consists in insects, gastropods and other animals. Birds play a useful role in the environment. Therefore, one of the mandatory actions and treatments in integrated lupin production is to create appropriate conditions for the presence of birds of prey, which involves the setting up of resting poles. Birds destroy various pests.

**Predatory birds living near plantations are effective in controlling small mammals (rodents, hares). To enable them to look for prey, resting poles with a height of at least 3 m should be placed along the plantation, in the amount of 1 piece for every 5 ha of lupin plantation submitted for certification under the integrated production scheme.**

The conservation method only serves as a complement to the action of biological agents. The lupin conservation strategy should include a series of actions based on different methods, mainly non-chemical, and the efforts to minimise the use of chemical plant protection products.

Most of the biological agents available do not guarantee better effectiveness compared to chemical agents. This depends on many factors: biotic and abiotic ones. Agricultural producers need to be trained in how such measures work, how to use them, and their relevant advantages and disadvantages. The application of these measures requires a great deal of knowledge. In many cases, an incorrect application is ineffective. The greatest advantage of biological agents is their safety for the environment. They enrich the biodiversity of the agricultural landscape, are safe for the consumer and beneficial organisms, do not require a withdrawal period, and once introduced into the environment, they may persist for a long time and under natural and optimal conditions for their development, they can reduce pest populations without reintroduction. Other benefits of their use: no residues, non-toxicity to entomophages, often specific to concrete groups of organisms (e.g. they only infect aphids), reducing the use of chemical plant protection products and protecting the biodiversity of the environment. There also are drawbacks to their use, such as: sensitivity to environmental conditions (temperature, humidity), having short life in the preparation, the need for precision treatments, slow mechanism of action. This may deter producers from using them.

**Plant protection products, including biological agents, should be used in crops for which they are recommended and the information contained on the labelling of the product should be observed. The basis for their application is the monitoring of harmful species.**

Detailed information on registered plant protection products for lupin protection can be found on the website of the Ministry of Agriculture and Rural Development in the repository of plant protection products:
https://www.gov.pl/web/rolnictwo/wyszukiwarka-srodkow-ochrony-roslin---zastosowanie.
The list of plant protection products for integrated production is available at https://www.agrofagi.com.pl/143,wykaz-srodkow-ochrony-roslin-dla-integrowanej-produkcji.

## 9. PROTECTION OF BEES AND OTHER POLLINATORS

When growing plants, one should be aware that they are not isolated from the outside world. They become an important element of local agrocenosis with its flora and fauna and so they are populated by various micro- and macro-organisms that lived in the site before sowing/planting the crop or populated it during the growing of the cultivated species. Some of the existing flora and fauna can be a factor limiting human activity in growing a given plant by becoming pests, but the vast majority of organisms that appear in the crop are economically neutral, which does not mean that they are worthless. They play a major role in nature as part of complex trophic chains, as well as in the flow of matter and energy cycles in nature. In addition, certain species are considered beneficial in terms of influencing the volume and quality of production, i.e. species pollinating plants or being natural enemies of pests (Tomalak and Sosnowska 2008). Whereas, from an economic point of view, pest risk reduction is important for plant production, it is equally important to take care of the presence of other organisms that support production directly or indirectly. In this case, it is necessary to constantly expand knowledge about the dependencies occurring in nature, including methods of supporting biodiversity, which is crucial for maintaining balance in ecosystems (Krawczyk et al. 2020).

Pollinators, including honeybees, bumble bees, solitary bees and a range of other organisms seeking pollen or nectar may occur on lupin crops. In Europe, the main pollinators are bees (including bumblebees, honeybees and solitary bees), wasps, hoverflies and other flies, butterflies, moths, beetles. Most pollinators are wild species, but some are reared for their economic value (Report for 2020). These organisms can visit the cultivated plant directly, and they can also be attracted by other flowering vegetation in the surrounding area or in the crop itself (e.g. flowering weed species). Another element attracting many insects that play the role of pollinators is the sweet honeydew secreted by aphids and some other true bugs, which covers the leaves. For this reason also, any activities related to plant protection in lupin crops must always take into account the presence of pollinating species (Pruszyński 2008).

Pollinators mostly belong to the bee superfamily, with over 450 species occurring in Poland. The honey bee is only one of them, but at the same time it is a species intentionally introduced into the area of agrocenoses in order to improve the efficiency of pollination of various plants, which has an impact on the volume and quality of yields (Krawczyk and Mrówczyński 2012).

**In order to ensure the development of wild pollinators in agrocenoses, houses for mason bees or mounds for bumble bees or other objects for pollinating insects should be placed within the cultivated area at a number of at least 1 pc per 5 ha of a lupin plantation submitted for certification under the integrated production scheme.**

Although yellow lupin is an optionally cross-pollinated species, which yields even without the presence of organisms that pollinate the flowers, their presence helps with the pollination and thus crop production. A fully self-pollinating species is narrow-leaved lupin, which is pollinated even before the flowers open (Pruszyński et al. 2012; Pruszyński 2016).

In view of the obligation to protect crops in accordance with the principles of integrated plant protection, consideration should be given to the selection of plant protection products in order to minimise the negative impact of plant protection treatments on non-target organisms, in particular pollinators and natural enemies of harmful organisms (Mrówczyński 2013).

When taking measures to protect lupin from pests, one should:

- strictly respect the label for the use of the zoocide in question;
- inform apiary owners of planned plant protection treatments;
- perform protective treatments in the evening, after the end of the flight by pollinators of flowering crops and weeds;
- maintain adequate distances from the apiaries during the procedure;
- keep in mind the toxicity and waiting period;
- prevent the spread of formulated liquid, e.g. by using appropriate anti-drift nozzles;
- ensure rational use of chemical plant protection products registered for use in lupin cultivation and base decisions on the actual threat from pests, which can be monitored by systematic inspections of the crops;
- not to use treatments, if the pest is not present in large numbers and is accompanied by the appearance of beneficial species;
- take into account the possibility of limiting the plant protection area to edge or spot treatment if the pest is not present throughout the plantation;
- protect beneficial species by avoiding the use of broad-spectrum insecticides and replacing them with selective agents (if such insecticides are registered in the crop);
- choose the date of the treatment so that it does not cause high mortality of beneficial insects in the crop;
- based on the results of studies, reduce the dose and adjuvant addition;
- exercise constant awareness that protecting natural enemies of the pests also protects other beneficial species present in the field;
- leave dead furrows and mid-field shelters as a habitat for many species of beneficial insects;
- carefully read the content of the label accompanying each plant protection product and observing the information contained therein (Mrówczyński 2013, Krawczyk et al. 2020, Praczyk and Kierzek 2020).

## 9. PROPER SELECTION OF PLANT PROTECTION TECHNIQUES

### Storage of plant protection products

Plant protection products should be stored:

a) in their original packaging, tightly sealed and clearly labelled and in such a way that they do not come into contact with food, drink or feed;

b) in a manner ensuring that they:

- are not consumed or intended for animal feeding,
- are inaccessible to children,
- there is no risk of:
  - contamination of surface and groundwater within the meaning of the water law,
  - soil contamination due to leakage or seepage of plant protection products into the soil profile,
  - penetration into sewage systems, excluding separate drain-free sewage systems equipped with a leak-proof sewage tank or equipment for their neutralisation.

The labels of plant protection products approved by the Minister for Agriculture and Rural Development contain information on the principles of safe storage.

In accordance with the good practice principles, plant protection products should be stored in separate rooms (outside residential and livestock buildings). These rooms should be clearly marked (e.g.: 'plant protection products') and protected against unauthorised access, i.e. locked.

If poisoning is suspected in connection with contact with a plant protection product, medical advice should be sought immediately and the doctor informed of the method of exposure to the specific chemical in question.

**Requirements for professional users**

Persons or sprayer operators handling plant protection products must be suitably qualified, attested to by a certificate of completion of training in the use of plant protection products or advisory on plant protection products and integrated plant production or another document attesting to their rights to carry out plant protection treatments.

The sprayer operator must be equipped with appropriate protective clothing, as prescribed by the label and the safety data sheet of the plant protection product. The basic equipment of protective clothing includes: a suit, suitable shoes, rubber gloves resistant to plant protection products, glasses and mask to protect the eyes, respiratory system and covering the mouth. Proper work organisation and available technical measures should be used at each stage of the handling of plant protection products, in accordance with the principles of **Good Plant Protection Practice.**

**Devices and equipment for protective treatments**

The sprayer or other equipment used for crop protection must be technically efficient, ensure reliable operation and guarantee the safe use of plant protection products, liquid fertilisers or other agrochemicals. The sprayer must have undergone a technical inspection (with up-to-date certification) and be properly calibrated. The technical efficiency of the equipment is confirmed by the protocol of the inspection carried out and by the control mark issued by an institution authorised to do so (sprayer inspection stations). Testing of new equipment shall be carried out no later than five years after its acquisition and subsequent tests shall be carried out at intervals of no more than three years.

**Equipment used for plant protection treatments must be safe for humans and the environment. In addition, it should guarantee the full effectiveness of protective treatments by ensuring proper action to allow accurate dosing and even distribution of plant protection products on the treated area of the field.**

Before performing the procedure, it is necessary to check the technical condition of the sprayer, in particular the condition of: filters, pumps, lubrication and lubrication points, nozzles, field beam, measuring and control devices, fluid system and agitator. It is also advisable to carry out a preventive rinsing of the sprayer in order to remove mechanical impurities and possible residues after previously performed treatments.

**Calibration (adjustment) of the sprayer**

Periodic adjustment of the sprayer makes it possible to choose the optimal parameters of the treatment. In accordance with good plant protection practice in the adjustment (calibration) process of the sprayer, the type and dimension of the sprayers and the working pressure should be determined, which ensure the application of the assumed dose of liquid per hectare for the specified operating speed of the sprayer.

The adjustment of the sprayer's operating parameters should be performed when changing the type of chemical agent (especially from herbicide to fungicide or insecticide), the dose of the spray liquid, as well as the setting of operating parameters (working pressure, field beam height). The adjustment of the sprayer is carried out each time when replacing important equipment and components of the sprayer (sprayers, pressure gauge, control device, repair of essential elements of the liquid system), as well as when changing the tractor or tyres in the drive wheels. The discharge of the liquid from the nozzles at the specified operating pressure should be checked regularly. When adjusting the sprayer, attention should be paid to the flow capacity of the nozzles and the uniformity (type and size) of the nozzles mounted on the field beam.

An example procedure for calibration of the sprayer is contained in the Code of Good Practice for Plant Protection or other thematic studies in this area.

**Choice of plant protection product and dosage**

**In line with the requirements of integrated pest management, selective measures with low risk to pollinators and beneficial organisms should be chosen.**

**Treatments with plant protection products should be planned in a way that ensures acceptable efficacy with the minimum quantity of plant protection product necessary, taking into account local conditions.**

The dose of the plant protection product should be selected according to the manufacturer's recommendation on the basis of the label, also taking into account the development phase of the plants, their condition and climatic and soil conditions: wind, temperature and humidity of soil and air, type of soil, as well as the content of organic matter in the soil.

The decision to use a plant protection product at a dose lower than recommended on the label must be taken with great care, based on knowledge, experience, observations and professional advice. The use of reduced doses may lead to the development of resistance to active substances of plant protection products in target organisms.

**When using plant protection products, also in split doses, it is necessary to comply with the requirements specified on the product label, i.e.:**

- **time intervals between various treatments;**
- **maximum number of uses per season;**
- **the maximum dose of the plant protection product.**

**Selection of spray liquid volume**

In integrated crop protection systems, the volume of spray (l/ha) should be selected based on available catalogues, training materials and handbooks or other thematic studies. Determination of spray liquid volume should take into account factors such as the type of crop to be sprayed, the development phase of the plants, the density of the crop, the possibility to use different spraying techniques (type of treatment apparatus, type and kind of spraying equipment), as well as the recommendations included in the label of the specific plant protection product.

Contact-action agents require very good coverage of the plants being sprayed and generally require higher volumes of spray than systemic agents. In foliar feeding treatments and when combining the use of several chemicals, it is recommended to use increased volumes of spray liquid. With suitable treatment equipment (e.g. sprayers with auxiliary air stream [(AAS]), the dose can be possibly reduced to 50–100 l/ha which should guarantee sufficient coverage of the treated plants.

**Selection of sprayers**

Spray nozzles have a direct impact on the quality of spraying and thus on the safety and effectiveness of plant protection products. Catalogues and general recommendations concerning their use for the protection of agricultural crops are useful in the selection of suitable sprays for individual plant protection treatments.

The selection of the atomiser for specific protective treatments should be preceded by getting to know its technical characteristics, and above all information about the type, size of the spray slot, and intensity of the liquid discharge.

**Preparation of spray liquid**

The intended volume of the liquid should be prepared immediately before the procedure to avoid undesirable physicochemical reactions. The sprayer agitator must be switched on at all times to protect the mixture from precipitation at the bottom of the tank. Before pouring the product into the tank, it is necessary to read the indications on the label as to the method of preparation of the spray liquid and the possibility of mixing the product with other preparations, adjuvants or fertilisers.

**The measurement of plant protection products and preparation of the spray liquid should be carried out in a way that reduces the risk of contamination of surface water, groundwater and soil and at a distance of no less than 20 m from wells, water intakes, reservoirs and watercourses.**

Sprayer filling:

- the sprayer must be filled on an impermeable and hardened surface (e.g. concrete slab), in a place where it is possible to prevent the spreading of spilled or leaked plant protection products;
- the measured quantity of crop protection product should be poured into the partially filled tank with the agitator switched on or in accordance with the instructions for use of the sprayer;
- empty plant protection product packaging must be rinsed three times, the contents poured into the spray tank, and the packaging preferably returned to the dealer,
- if possible, it is best to fill the sprayer on a special stand with a biologically active substrate;
- when filling the sprayer on permeable ground, a thick plastic foil for collecting spilled or spread preparations should be laid down where the plant protection products are measured and introduced into the sprayer tank,
- spilled or scattered plant protection product and contaminated material must be safely managed using absorbent material (e.g. sawdust);
- contaminated absorbent material must be collected and submitted to a bioremediation site for plant protection products or placed in a sealed, labelled container,
- the container containing the contaminated material should be stored in plant protection product storage until safely managed.

**Combined use of agrochemicals**

In treatments with the use of several agrochemicals, the order of adding ingredients during the preparation of the spray liquid should be observed. A weighed portion of fertiliser (e.g. urea, magnesium sulphate) is poured into the sprayer tank half filled with water with the stirrer on. Further components are added to this solution. It is recommended that they be pre-diluted before pouring into the sprayer tank. Start with an adjuvant that improves compatibility of the components of the mixture, if used. Then plant protection products are added (in the correct order, according to the formulation), followed by water to the desired volume of the sprayer tank.

In multiple-component mixtures with the use of two or more plant protection products, the order of their addition to the liquid should be followed according to the physical characteristics of the formulations. First, add preparations that form a suspension in water, then add agents that form emulsions, and finally, solutions. After adding all the ingredients, replenish the tank with water to the required volume.

Do not use water at a low temperature (taken directly from a deep well) for the treatment. Very hard and contaminated water should not be used. Protective treatments may begin when the spray liquid is properly prepared.

**Treatment conditions**

**Plant protection products should be used in such a way that they do not pose a risk to human health, animal health and the environment, including preventing the spread of plant protection products to areas and facilities not intended for treatment**

Treatments with plant protection products should be carried out in light wind and rain-free weather and moderate temperature and sunshine. Spraying during adverse weather (stronger wind, high temperature and low air humidity) can cause damage to other plants as a result of the spray liquid drifting to areas not to be covered by the treatment, and may cause unintended poisoning of many beneficial species of entomofauna.

Table 19 provides recommendations for optimal and borderline weather conditions during spraying operations. The recommended air temperatures during treatments are conditioned by the type and mechanism of action of the plant protection product applied and such data are included in the label texts. For most preparations, optimal effectiveness is achieved at a temperature of 12–20 °C.

**Plant protection products can be applied outdoors if the wind speed does not exceed 4 m/s.** A slight wind, with a speed of 1 to 2 m/s, is also beneficial due to turbulence and better movement of the sprayed liquid among the sprayed plants. In weather conditions close to the upper (temperature and wind speed) or lower (air humidity) limit values, drift-limiting spray nozzles (e.g. low drift or ejector nozzles) and lower recommended operating pressures should be used for spraying operations.

**Table 19.** Limit and optimal meteorological conditions for plant protection treatments

| Parameter | Limit values (extreme) | Optimal values (most favourable) |
|---|---|---|
| Temperatures | 1–25 °C during the treatment | 12–20 °C during treatment |
| | up to 25°C on the day after treatment | 20°C the day after treatment |
| | not less than 1°C the next night | not less than 1°C the next night |
| Air humidity | 40–95 % | 75–95 % |
| Rainfall | less than 0.1 mm during treatment | no rainfall |
| | less than 2.0 mm within 3–6 hours of the treatment | |
| Wind speed | 0.0– 4.0 m/s | 0.5–1.5 m/s |

Plant protection products should be used in open areas by means of tractor sprayers and self-propelled field or fruit sprayers, if the place of application of these products is remote:

- at least 20 m from the apiaries,
- at least 3 m from the edge of the roadway with the exception of public roads classified in the category of municipal and district roads,

and

- in the case of tractor sprayers and self-propelled orchard sprayers, at least 3 m away from bodies of water and watercourses and from areas not used for agriculture other than those to be treated with plant protection products;
- in the case of tractor sprayers and self-propelled field sprayers, at least 1 m from reservoirs and watercourses and lands not used for agriculture, other than those to be treated with plant protection products.

**It is important to bear in mind the obligation to comply first with the labelling of plant protection products. On many labels, distances (buffer zones) greater than those indicated above are provided from specific sites and facilities after which plant protection products should be used.**

The spraying procedure is performed at a constant movement speed and working pressure, set during sprayer adjustment. Successive runs over the field should be made very precisely to avoid strips being left unsprayed and so that no overlapping of the sprayed liquid occurs in already sprayed areas.

**Post-treatment procedure**

At the end of each treatment cycle, removal of the residual liquid from the sprayer should be carried out by spraying the spray liquid in the field or plantation where the treatment was carried out or on one's own area not used for agricultural purposes, away from drinking water intakes, and sewer wells. The sprayer must be washed thoroughly in the place intended for this purpose.

**The remaining liquid must not be poured into the soil or into the sewage system or poured in any other place that prevents its collection or poses a risk of contamination of the soil and water**.

**Washing and rinsing the tank and the liquid sprayer installation should be carried out at a safe distance (no less than 30 m) from wells, water intakes and reservoirs and watercourses.**

**Procedure for rinsing the tank and liquid system**

- Use the least necessary amount of water for rinsing (2–10 % of the volume of the tank or an amount that dilutes liquid remaining in the tank up to 10 times); it is recommended to rinse the liquid system with a small portion of water three times.
- Turn on the pump and rinse all the elements of the liquid system used during the procedure.
- Spray the rinsings on previously sprayed surface or, if it is not possible, use the residues according to the recommendations on the management of liquid residues.
- The residual liquid drained from the sprayer must be disposed of using technical equipment that ensures biodegradation of the active substances contained in plant protection products. Until neutralisation or disposal, liquid residues may be stored in a sealed, labelled and secured container earmarked for that purpose.

**External sprayer washing**

After the end of the working day, wash all the apparatus from the outside with water, as well as components in contact with chemical agents.

External washing of the sprayer should be carried out at a location that allows the washings to be directed into a closed collection system for contaminated residues or into a neutralisation/remediation system (e.g. Biobed, Phytobac, Vertibac site); if this is not possible, the sprayer should preferably be washed in the field.

Wash the sprayer with a small amount of water, preferably using a high-pressure lance instead of a brush to shorten the time and increase the efficiency of external washing.

Use recommended, biodegradable means to increase washing efficiency.

**Recording of treatments**

Professional users of plant protection products are required to maintain and keep records of their plant protection products for three years. The documentation should contain information on:

- the names of the plant protection product,
- the date of application,
- the dose used,
- the area and crops on which the protective treatment has been carried out,
- reasons for the treatment with a plant protection product.

The law also requires the method of fulfilling the requirements of integrated plant protection to be indicated in the documentation by providing at least the reason for the treatment with a plant protection product. **Filling out the IP Notebook, mandatory under the integrated plant production scheme, fulfils the requirement to keep the above-mentioned documentation for certified crops.**

## 10. HEALTH AND HYGIENE RULES

**Personal hygiene of workers**

Persons working in the harvesting and preparation of crops for sale must:

a) not be infected with or suffer from food-borne diseases;
b) maintain personal cleanliness, obey the rules of hygiene, and in particular often wash hands during work;
c) wear clean clothes and, where necessary, protective clothing;
d) have injuries and abrasions treated with a waterproof dressing.

The producer shall ensure persons involved in harvesting crops and preparing them for sale:

a) unlimited access to washbasins and toilets, cleaning products, paper towels or hand dryers, etc.;
b) have undergone hygiene training.

**Hygiene requirements for crops prepared for sale**

The crop producer should take appropriate measures to ensure:

a) that clean or consumption-class water is used to wash the crops as necessary;
b) the protection of crops during and after harvesting against physical, chemical, and biological pollution.

**Integrated plant production hygiene requirements for packaging, means of transport and places for the preparation of crops for sale**

A producer under the integrated plant production scheme must take appropriate measures to ensure that:

a) cleanliness of rooms (and equipment), means of transport and packages is maintained;
b) farmed and domestic animals have no access to the rooms, vehicles or packaging;
c) harmful organisms (pests and organisms hazardous to humans), that may cause contamination or threat to human health, e.g. mycotoxins, are eliminated;
d) hazardous waste and substances are not stored together with crops prepared for sale.

## 11. PREPARATION FOR HARVESTING, HARVEST, AND POST-HARVEST PROCEDURE

The procedures during the ripening period of lupin plants depend mainly on the course of weather and the degree of weed infestation of the plantation and the uniformity of ripening. In years with a favourable distribution of precipitation and temperatures conducive to even ripening, it is not difficult to carry out harvesting. The harvest period in years with excessive rainfall is associated with the risk of losses in the quantity or quality of seed yield as a result of prolonged growth and uneven ripening (Bieniaszewski et al. 2003; Szukała 2000). Also, limited precipitation, especially in the second half of the growing period, deteriorates seed sowing value parameters (Faligowska and Szukała 2012). Dry and warm weather and plantations not nfested with weeds are the most favourable scenario. In this case, one should only wait until the plants and pods turn brown and the moisture content of the seeds falls below 15 %, and proceed with the harvest of the seeds. A slightly worse situation will occur when the plantation is free of weeds, but due to uneven ripening caused, for example, by soil mosaics, the harvest must be postponed. In the absence of rain, this will be the most appropriate move. Frequent rainfall can cause deterioration of seed quality on the plants that ripen first. In this case, one should decide to proceed to desiccation. The worst scenario is a heavily weeded plantation with plants ripening during very wet weather. In such a situation, a desiccation treatment is necessary. It is, moreover, always indicated in the event of medium and severe weed infestation (unless a severe drought occurs during the ripening period). This is linked to the highly negative effects of weeds on the seed harvesting process itself (sieve blocking, drum clogging, entrapment in the conveyors, difficulties in emptying the tank), as well as the significant increase in moisture of the harvested seeds and the difficult threshing of pods in the case of yellow lupin. The delay in the harvesting of heavily weed-infested plantations caused by frequent rainfall results in a very large reduction in seed germination capacity (by 10–50 %) and a reduction in vigour, as well as the inability to store them longer as storage reserves. The economic reality of the crop indicates that it is not worthwhile to carry out a two-phase harvest as a substitute for desiccation, which, during a period of frequent rainfall, can only worsen the situation.

The seed of leguminous plants is characterised by a greater variety of seeds in a lot than in the case of cereal crops. This is due to greater maternal and fluctuational variability, and genetic factors (Górecki 1983). The maternal variability is related to the different location of the seeds on the plant, the fluctuational variability is due to environmental conditions, and the genetic variability is due to the physiological properties of the seeds. Lupin varieties with traditional growth are distinguished by greater maternal variability. In these varieties, the most valuable seeds in terms of sowing value can be found in the pods of the main shoot, while in varieties with determined growth, the most valuable seeds are those in the lower and middle pods. Varieties of determined growth ripen in a shorter period of time and are less responsive to adverse weather conditions.

Desiccation is carried out only when the plantation ripens unevenly or when it is heavily weed-infested and it should be carried out when most of the pods are slightly brown and the others are yellow. Care should also be taken to ensure that the seed cover is appropriately coloured (BBCH scale 85 – physiologically mature seeds). The period of harvesting from the moment of desiccation usually falls 7–14 days and is strongly dependent on the temperature prevailing in the period after the treatment, unless otherwise indicated in the label of the desiccanting agent's instructions for use. However, depending on the course of the weather, the dose of the preparation used and the occurrence of weeds, this period may be extended up to three weeks.

In the case of narrow-leaved lupin seed plantations, the date of harvest has a significant impact on the parameters of the sowing value, including the vigour of the harvested seeds. Results of the quality tests carried out by Boros et al. on seeds of the narrow-leaved lupin variety (2012) have shown that both accelerated and delayed seed harvesting resulted in a significant reduction in the germination capacity and vigour of the seed (Table 20). However, it should be noted that in the summer, when the weather is dry during and immediately after ripening and the plantation is free of weeds, a delay of harvest of up to three weeks does not significantly affect the germination capacity. The germination capacity of seeds harvested under such conditions has not decreased for up to four years.

Harvesting methods are listed as one of the agricultural practices that influence the biological value of the seeds. According to some authors, a two-stage harvest has a positive effect on the vigour and viability of legume seeds, including narrow-leaved lupin. This is also confirmed by the results of the work of Kurasiak-Popowska and Szukała (2007). The beneficial effect of the two-stage narrow-leaved lupin collection on the biological value of the seeds is a result of the migration of nutrients from the plants to the seeds and their slow drying under natural conditions. However, as mentioned earlier, economic reality shows that it is not profitable to carry out a two-stage harvest. According to Prusiński (2001), in the case of a single-stage harvest, the threshability of the pods, as well as the scale of mechanical damage to the seeds, are influenced by the rotations of the threshing drum, which should be reduced to a minimum. Research by Orzechowski et al. (1987) and Siwiłło and Wrona (1994) showed that the loss of moisture content of the seeds during harvest resulted in an increased damage. The results of the research indicate that proper and timely harvesting largely determines the sowing, reproductive and storage value of narrow-leaved lupin seeds (Table 21).

**Table 20.** Impact of harvest dates on the sowing value parameters of narrow-leaved lupin seeds

| Seed value parameters | Harvest dates | | |
|---|---|---|---|
| | **Accelerated** | **Optimal** | **Delayed** |
| Germination capacity (%) | 83.5 | 93.0 | 43.5 |
| Electrical conductivity test (µS·cm−1·g−1) | 23.2 | 21.10 | 32.36 |
| Seedling growth test (cm) | 12.3 | 14.55 | 9.15 |
| Growth rate test (mg/seedling) | 67.2 | 63.7 | 70.75 |
| Vigour index | 1029.5 | 1353.5 | 395.0 |
| Seedling length (cm) | 28.25 | 32.35 | 21.1 |

**Table 21.** Harvesting technology vs seed value of narrow-leaved lupin seeds

| Seed value parameters | Harvesting technology | | |
|---|---|---|---|
| | **manual** | **experimental harvester** | **combine harvester** |
| Germination capacity (%) | 97.0 | 93.0 | 92.5 |
| Electrical conductivity test (µS·cm−1·g−1) | 18.36 | 21.10 | 15.75 |
| Seedling growth test (cm) | 15.55 | 14.55 | 13.7 |
| Growth rate test (mg/seedling) | 77.6 | 63.7 | 90.5 |
| Vigour index | 1510.5 | 1353.5 | 1267.5 |
| Seedling length (cm) | 33.8 | 32.35 | 31.85 |

Harvesting with a combine harvester is carried out when the plants are completely dry and the moisture content of the seeds drops below 15 %. In the case of feed seeds, it can drop up to 10–12 % without compromising their quality, additionally allowing for a long-term storage. In the case of crops intended for sowing, harvesting seeds that are too dry, below 12 % of moisture content, can cause an increase in damage and even their splitting. Such seeds are characterised by a reduced germination capacity and a large number of abnormally germinating ones. It is safest to thresh plantations when the moisture content of lupin seeds is between 13 and 14.5 %.

The daily profile harvest time depends on the species. Yellow lupin, due to the difficult to thresh pods, should be collected in the afternoon hours, in dry, sunny weather. The collection of narrow-leaved lupin is much easier and it can be threshed throughout the day, just like cereals. The differences between these species stemming from the level of difficulty to thresh the pods (very easy in narrow-leaved lupin and very difficult in yellow lupin) also affect the way the harvester's working units are set up. The yellow lupin should be threshed at drum speeds of between 550 and 700 rotations per minute and at the minimum gap between the drum and the threshing floor. Once the seed harvest has begun, it must be checked whether no unthreshed pods are left behind the harvester at the husk discharge point. In the case of seed plantations, a dilemma arises with regard to the fact that an increase in drum rotations often causes severe damage to the seeds, while low rotations generate unthreshed pods. Sometimes the harvest must be postponed for a period of time until the pods lose their elasticity and begin to open more easily. However, such a decision in the event of humid weather may compromise the quality of the seeds. The opposite should be done for the threshing of narrow-leaved lupin, setting the maximum working gap between the drum and the floor, and the rotation of the drum in the range of 450–600 rotations per minute. Attention should also be paid to the setting of the conveyor; it should not be placed too far in front of the harvesting unit to avoid the shaking down of the pods (yellow lupin) or their self-opening (narrow-leaved lupin). When harvesting lupin seeds for sowing, the principle should be applied that threshing is always done with the lowest drum rotation and the maximum gap between the drum and the threshing floor.

The moisture content of the harvested seeds must always be determined to ensure that it does not exceed 15 %. If the harvested lupin seeds are contaminated with moist weed seeds, particularly of white goosefoot, they need to be cleaned as soon as possible so that their humidity does not rise above 15 %. When using hygrometers with simpler electronic design, it should be taken into account that the moisture measurement of freshly harvested seeds is 1.5–3 % lower than the actual humidity (since they only measure surface moisture). The measurement should be repeated the next day, when the internal moisture penetrates to the surface of the seed. Electronic hygrometers with advanced technological solutions show the actual moisture content of freshly harvested seeds.

When storing seeds, the number of transport operations with high-speed bucket lifts and the discharge of seeds on hard metal surfaces from high heights should be limited. Avoid or limit the use of any auger conveyors. During storage, seeds should not be stored on concrete, uninsulated floors, because in such conditions, after a longer storage period, humidity increases above 15 %. This results in a deterioration of the seed parameters and a strong infestation by fungi. Such seeds are not suitable either for feed or for sowing purposes.

Before ploughing, lupin straw should be shredded appropriately (e.g. with a disc harrow).

## 12. DEVELOPMENTAL STAGES OF LUPIN BASED ON THE BBCH SCALE

The precise determination of the development phase of cultivated plants constitutes an important step in plant production. Observing the successive developmental phases of a plant has been becoming particularly important in plant protection. The correct assessment of the growth and development phases of the plant not only allows to achieve a higher effectiveness of the plant protection products used, but also, in many cases, prevents damage to plants. It should be borne in mind that both too early and too late application of plant protection products can have a negative impact on yield.

To meet the expectations of all those involved in plant production, be it scientifically or practically, at the end of the 1990s, the universal BBCH scale was developed, thanks to which it is possible to easily and accurately determine the development phase of a cultivated plant.

Its universality means that the numerical codes assigned to each growth and development stage are the same for each crop species and, in the absence of a specific stage, they are simply omitted. The main (basic) phases of growth and development are described using numbers from 0 to 9. However, to determine the exact date of the treatment or the date of its effectiveness assessment, it is not sufficient to determine only the main stages of plant growth. In order to characterise a given phase more precisely, it is necessary to add a second digit.

Particular phases can occur at the same time within one plant or within one plantation. When lupin plants on a particular field reach stages of a particular phase, e.g. the two-leaf phase (BBCH 21) and the four-leaf phase (BBCH 23), the description of the plants within the same phase should be separated by a dash [–]. The presence on plantations of plants in the two-leaf and four-leaf phase should be described as follows: BBCH 21–23. When plants are in different development phases, the different phases should be separated by a slash [/]. For example, when in the final phase of lupin flowering (BBCH 69) plants formed their first pods (BBCH 71), the situation on the plantation is represented as BBCH 69/71.

**Main growth stage 0: Germination**

**01** Dry seed
**03** Seed imbibition complete
**05** Radicle emerges from seed coat
**07** Hypocotyl is half as long as the seed
**09** Hypocotyl is twice as long as the seed

**Main growth stage 1: Emergence**

**11** Cotyledons break through the soil surface
**15** Cotyledons completely unfolded

**Main growth stage 2: Rosette formation**

**21** 1st and 2nd leaf unfolded
**23** 3rd and 4th leaf unfolded
**25** 5th leaf unfolded
**29** Rosette formation completed (1st internode elongated to more than 1 cm)

**Main growth stage 3: Stem elongation** *[1]

**31** Beginning of stem elongation
**32** The leaves at the base begin to separate
**35** Completely separated leafs
**36** Formation of side shoots

**Main growth stage 5: Inflorescence development**

**53** Flower buds visible at the top of the shoot *(1 cm)*
**57** First petals visible

**Main growth stage 6: Flowering**

**61** Beginning of flowering**,** first flowers open

**63** Around 75 % of flowers open

**65** The first flowers lose their characteristic colour

**69** End of flowering phase: all flowers have bloomed

**Main growth stage 7: Development of fruit (pod)**

**71** First pods visible *(longer than 2 cm)*

**73** 75 % of pods visible

**77** The first pods have reached their full size *(seeds clearly visible*, *pods are light green)*

**79** Approximately 75 % of pods have reached their typical length

**Main growth stage 8: Ripening**

**81** Green maturity phase *(green cotyledons)*

**83** The first pods turn brown

**85** Browning of approx. 75 % of the pods, seed cover coloured to the right colour (seeds white or well-developed in form)

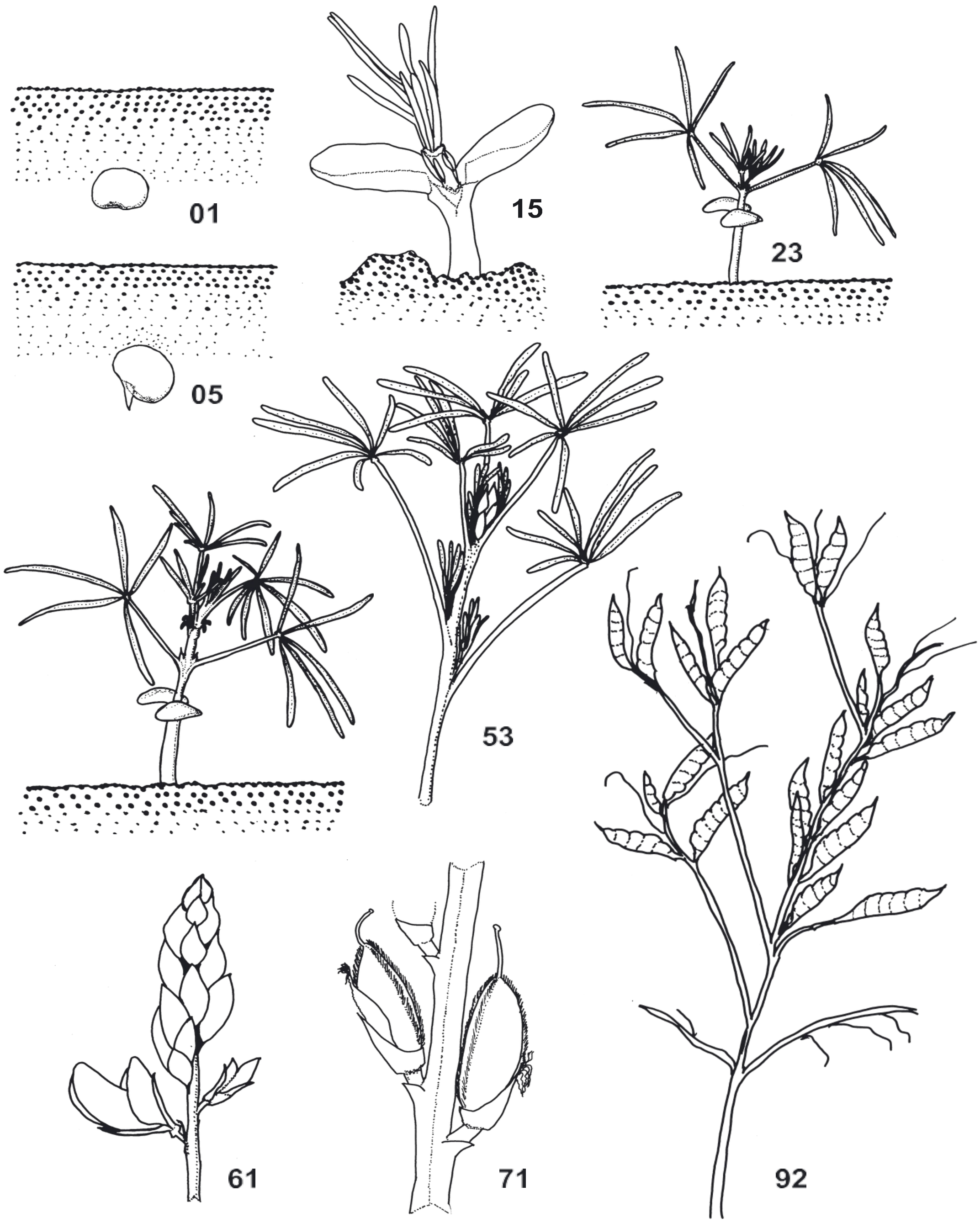
**87** Yellow maturity phase, all brown pods (yellow cotyledons, seed cover can be *crushed between fingers)*

**89** Hard seeds *(it is not possible to crush the seed cover)*

**Main growth stage 9: Senescence**

**92** Full maturity, shoot axes have dried

[*1] – stem elongation may take place before the development of the 6th leaf


01
15
23
05
53
92
61
71

## 13. RULES FOR KEEPING RECORDS IN INTEGRATED PRODUCTION

The cultivation of plants under the integrated plant production system is inextricably linked to the keeping or possession of various types of documentation by the agricultural producer. The IP Notebook is one of the most important of such documents. Model notebooks are included in the Annex to Regulation of the Minister for Agriculture and Rural Development of 24 June 2013 on documenting activities related to integrated plant production (consolidated text Journal of Laws 2023, item 2501). The record-keeping rules will change on 1 January 2026 as a result of the application of the Implementing Regulation (EU) 2023/564.

Other documents that a integrated plant producer must possess or may have to deal with during the certification process include:

- the methodology of integrated plant production;
- the notification of accession to integrated plant production;
- the certificate of the registration number;
- programme or conditions for certification of integrated plant production;
- the price list for the certification of integrated plant production;
- the contract between the agricultural producer and the certification body;
- rules for dealing with appeals and complaints;
- information on GDPR;
- lists of plant protection products for IP;
- inspection reports;
- checklists;
- results of tests carried out on residues of plant protection products and levels of nitrates, nitrites and heavy metals in agricultural crops;
- soil and leaf test results;
- certificates of completion of training;
- reports or proof of purchase attesting to the technical functioning of the equipment for applying plant protection products;
- purchase invoices for, among others, plant protection products and fertilisers;
- application for a certificate;
- IP certification.

The certification process begins with the completion and submission, within the statutory deadline, of the integrated plant production application by the producer to the certification body. A model application may be obtained from the certification body or downloaded from its website.

The application form should be completed with information such as:

- the name, surname and address and place of residence or the name, address and registered office of the plant producer;
- the PESEL (personal identification) number, if one has been assigned to them.

The application must also include the date and signature of the applicant. The application shall be accompanied by information on the species and varieties of plants to be grown under the IP system and the location and area of their cultivation. A copy of the certificate of completion of training in integrated plant production or a copy of the certificate or copies of other documents attesting to the qualification must also be attached to the application.

During cultivation, the agricultural producer is obliged to keep records of activities related to integrated plant production in the IP notebook on an ongoing basis. When applying for certification for more than one plant species, IP Notebooks must be kept individually for each crop.

The Notebook should be filled out according to the following outline.

**Cover —** the plant species and the year of cultivation as well as the number in the plant producers' register should be stated on the cover. Then, own information must be added.

**Inventory of fields/plots/greenhouses/tunnels in the integrated production system:** in the table with the list of fields, record all cultivated varieties submitted for IP certification.

**Field plan with biodiversity-increasing elements —** graphical map of the holding and its immediate surroundings with the proportions of the various elements. The farm plan uses the same markings as those used in the list of fields.

**General information, sprayers, operators —** the year in which production according to the principles of Integrated Plant Production was started is to be recorded. Then, the tables must be filled in. The bullet points should be filled in with appropriate entries and the information confirmed by ticking the relevant boxes (   ). The 'Sprayers' table should be filled in with the required data and the information confirmed by ticking the relevant boxes (□). List all sprayer operators carrying out plant protection treatments in the 'Sprayer operator(s)' table. It is absolutely necessary to indicate that the training in the use of plant protection products is up to date, including the date of completion (or other qualification). In the 'Sprayers' and 'Sprayer operator(s)' tables, all devices and persons performing treatments, including those performed by a service provider, must be listed.

**Purchased plant protection products** — the purchased plant protection products (trade name and quantity) intended to protect the crop for which the Notebook is kept must be recorded in the table.

**Monitoring tools, e.g. colour stickers, pheromone traps** — in this table the used colour sticky boards, pheromone traps, etc. must be recorded with an indication of the pests which these tools were intended to monitor.

**Crop rotation —** the crop rotation table should be filled in with the crop and the code of the field on which it was cultivated. Crop rotations must be reported for the period (number of years) specified in the methodology.

**Seed (…) —** the table is to be filled in by entering information about the purchased material: species, variety, degree of qualification, quantity, and proof of purchase (invoice, official label or marketing operator label).

**Sowing/Planting —** the table should be filled in with the recorded quantity of seed material used in each field. The dates of the activities carried out should also be recorded. For this purpose, tick the relevant boxes (□) to confirm the information on soil testing/assessment for existing pests which would exclude the field from IP cultivation.

**Soil/substrate and plant analysis and fertilisation/fertigation —** soil analysis is a fundamental activity to determine the fertilising needs of the plants. The IP grower must carry out such analyses and record them in the Notebook. Enter the field code, the type or scope of testing and the number and date of the report in the 'Soil and plant analysis' table. All organic fertilisers applied should be recorded in the 'Organic fertilisation (…)' table. If green manures are used, the species or composition of the mixture is indicated in the 'Type of fertiliser' column. In the next table, 'Soil mineral fertilisation and liming', record the date, type and dose of fertilisation and liming applied, and where it was applied. The 'Observations of physiological disorders and foliar fertilisation' table should be used to record observations regarding plant nutritional deficiencies and fertilisers applied. The IP grower must regularly inspect the crops for the occurrence of physiological diseases and record this fact each time. Foliar fertilisation should be correlated with the observations of physiological disorders carried out.

**Control observations and record of plant protection treatments —** the plant protection tables are the basic element of the IP notebook. The first table 'Observations of weather conditions and plant health' is a detailed record of observations, in which we record the data indicated in the heading. In this table, the need for chemical treatment is also indicated. The next two tables are registers of plant protection treatments (agrotechnical, biological and chemical) and are closely correlated with the observation table. When carrying out this type of procedure, it is mandatory to record the name of the plant protection product or the biological or agrotechnical method applied, as well as the date and place of treatment. Table 'Other chemical treatments applied (…)' is a record of all treatments authorised for use on the crop that are not listed in the previous tables e.g. the use of desiccants.

**Harvest —** in this table, record the volume of crop taken from each field.

**Hygiene and health requirements —** record whether people in direct contact with food have access to clean toilets and hand-washing facilities, cleaning products, and paper towels or hand dryers. Also the manner of observing the hygiene and health requirements for IP methodologies should be described.

**Other mandatory requirements for the protection of plants against pests according to the requirements of the method —** a page in the Notebook containing space for IP producer's comments concerning the requirements for pest management set out in the integrated plant production methodologies.

**Information on the cleaning of machinery, devices and equipment used in production, according to the requirements of the integrated production methodology —** notebook page with the IP producer's space for information relating to the cleaning of machinery, devices and equipment used in the production, which is required in the integrated production methodology.

The Notebook also contains space for comments and own notes, and a list of appendices.

It is possible for an agricultural producer to obtain an IP certificate by applying to a certification body. Forms for the relevant applications are available from the certification bodies. Along with the completed application for a certificate attesting to the application of integrated plant production, the plant producer provides the certifying body with a declaration that the cultivation has been carried out in accordance with the requirements of integrated plant production, and information on the species and varieties of plants grown in line with the requirements of integrated plant production, the area of their cultivation and the yield size.

## 14. LIST OF MANDATORY ACTIVITIES AND TREATMENTS IN THE SYSTEM OF INTEGRATED PRODUCTION (IP) OF LUPIN

| **Mandatory requirements** (100 % compliance, i.e. 12 points) | | | |
|---|---|---|---|
| **Item** | **Control points** | **YES/NO** | **Comment** |
| 1. | Use of at least a four-year break in lupin cultivation at the same site (**see Chapter 3.3**). | ☐/☐ | |
| 2. | The selection of varieties recommended by the PRVTS (**see Chapter 4**) | ☐/☐ | |
| 3. | Application of pre-sowing crop treatments according to the methodology (**see Chapter 5.1**). | ☐/☐ | |
| 4. | Use of at least certified class seed with appropriate sowing standard and parameters (**see Chapter 5.2**). | ☐/☐ | |
| 5. | Macro- and micro-nutrient fertilisation based on nutrient balance analysis (**see chapter 6.1).** | ☐/☐ | |
| 6. | The use of agronomic methods in weed control **(see Chapter 7.1.2).** | ☐/☐ | |
| 7. | Systematic inspections, from emergence to the | ☐/☐ | |

| | | | |
|---|---|---|---|
| | beginning of maturation, at least once a week, for diseases such as anthracnose, fusarium rot, powdery mildew, fusarium wilt, grey mould, seedling blight (**see Chapter 7.2.1**). | | |
| 8. | Systematic inspections, from emergence to the beginning of ripening, at least once a week, for the occurrence of pests (such as aphids, sitone weevils, root flies) using appropriate methods (**see Chapters 7.3.1., 7.3.2**). | ☐/☐ | |
| 9. | Performance of at least one pest control treatment with a biological control product, if registered (**see Chapter 8).** | ☐/☐ | |
| 10. | Creating the right conditions for the presence of birds of prey, i.e. setting up resting poles at a frequency of at least 1 piece per 5 ha of plantation (**see Chapter 8).** | ☐/☐ | |
| 11. | Setting up 'houses' for mason bees or bumblebee mounds, or other facilities for pollinating insects in the number of at least 1 per 5 ha (**see Chapter 9).** | ☐/☐ | |
| 12. | Shredding and ploughing of post-harvest residues after harvest (**see chapter 11).** | ☐/☐ | |

**Note:**

**The fulfilment of all the requirements in the list of mandatory actions and treatments under the integrated production scheme must be documented in the integrated plant production Notebook.**

## 14. CHECKLIST FOR AGRICULTURAL CROPS

| **Basic requirements (100% compliance, i.e. 28 points)** | | | |
|---|---|---|---|
| **No.** | **Control points** | **YES/NO** | **Comment** |
| 1. | Does the producer produce and protect the crops according to detailed methodologies approved by the Main Inspector? | ☐/☐ | |
| 2. | Does the producer have up-to-date IP training confirmed by a certificate, subject to Articles 64(4), (5), (7) and (8) of the Plant Protection Products Act? | ☐/☐ | |
| 3. | Does the producer apply plant protection products only from the list of IP-recommended products? | ☐/☐ | |
| 4. | Are all required documents (e.g. methodologies, notebooks) present and kept on the farm? | ☐/☐ | |
| 5. | Is the IP Notebook kept correctly and up to date? | ☐/☐ | |
| 6. | Does the producer systematically conduct control observations of the crops and record them in the | ☐/☐ | |

| Basic requirements (100% compliance, i.e. 28 points) | | | |
|---|---|---|---|
| | notebook? | | |
| 7. | Does the producer deal with empty packaging of crop protection products and products that are expired in accordance with the applicable legal regulations? | ☐/☐ | |
| 8. | Is chemical protection of crops replaced by alternative methods wherever justified? | ☐/☐ | |
| 9. | Is chemical plant protection carried out based on risk thresholds and the alerting of harmful organisms (wherever possible)? | ☐/☐ | |
| 10. | Are plant protection product treatments carried out only by persons holding an up-to-date, as of the date of such treatments, certificate attesting to the completion of training in the scope of the application of plant protection products, advising on plant protection products or integrated plant production, or any other document confirming the permission to apply plant protection products? | ☐/☐ | |
| 11. | Are the applied plant protection products approved for use in the given cultivation - plant? | ☐/☐ | |
| 12. | Is each use of plant protection products recorded in the IP notebook taking into account the reason, date and place of use, the area of the crops, the dosage of the preparation and the amount of the spray liquid per unit area? | ☐/☐ | |
| 13. | Were the plant protection treatments carried out under appropriate conditions (optimal temperature, wind below 4 m/s)? | ☐/☐ | |
| 14. | Is the rotation of the active substances of the crop protection products used for the treatments respected, if possible? | ☐/☐ | |
| 15. | Does the producer limit the number of treatments and the amount of crop protection products used to a necessary minimum? | ☐/☐ | |
| 16. | Does the producer have measuring devices to precisely determine the quantity of the measured plant protection agent? | ☐/☐ | |
| 17. | Are the conditions for safe use of the products respected, as set out on the labels? | ☐/☐ | |
| 18. | Does the producer follow the indications place on the label with regard to environmental precautions, that is, for instance, preserving protection zones and | ☐/☐ | |

| Basic requirements (100% compliance, i.e. 28 points) | | | |
|---|---|---|---|
| | keeping a safe distance from non-agricultural land? | | |
| 19. | Are prevention and withdrawal periods observed? | ☐/☐ | |
| 20. | Are the doses and maximum number of treatments per growing season specified on the label of the plant protection product respected? | ☐/☐ | |
| 21. | Are the sprayers listed in the IP Notebook in good technical condition and are their technical inspection certificates up to date? | ☐/☐ | |
| 22. | Does the producer carry out systematic calibration of the sprayer(s)? | ☐/☐ | |
| 23. | Does the producer have a separate site for filling and cleaning the sprayers? | ☐/☐ | |
| 24. | Does the handling of residues of the operating liquid comply with the indications on plant protection product labels? | ☐/☐ | |
| 25. | Are plant protection products stored in an appropriately marked closed room in such a way as to prevent contamination of the environment? | ☐/☐ | |
| 26. | Are all plant protection products stored only in their original packaging? | ☐/☐ | |
| 27. | Does the IP producer observe hygienic and sanitary principles, especially those specified in the methodologies? | ☐/☐ | |
| 28. | Are appropriate conditions for the development and protection of beneficial organisms ensured? | ☐/☐ | |
| | **Total points** | | |

| **Additional requirements for field agricultural crops** (minimum compliance 50 %, i.e. 7 points) | | | |
|---|---|---|---|
| **Item** | **Control points** | **YES/NO** | **Comment** |
| 1. | Were the plant varieties grown selected for Integrated Plant Production? | ☐/☐ | |
| 2. | Is each box marked according to the entry in the IP notebook? | ☐/☐ | |
| 3. | Did the producer perform all the necessary agronomic procedures in accordance with the IP methodologies? | ☐/☐ | |
| 4. | Are actions taken on the holding to reduce soil erosion? | ☐/☐ | |
| 5. | Have the procedures been conducted using spraying | ☐/☐ | |

| | | | |
|---|---|---|---|
| | devices specified in the IP notebook? | | |
| 6. | Are fertiliser application machines maintained in good working order? | ☐/☐ | |
| 7. | Do fertiliser application machines allow for accurate dose determination? | ☐/☐ | |
| 8. | Is each fertiliser applied recorded with regard to its form, type, date of application, quantity, location and surface? | ☐/☐ | |
| 9. | Are fertilisers stored in a separate and specially designated room in a manner that ensures protection of the environment against contamination? | ☐/☐ | |
| 10. | Does the producer protect empty PPP packaging against unauthorised access? | ☐/☐ | |
| 11. | Does the producer have a dedicated place to collect organic and post-vegetable-sorting residues? | ☐/☐ | |
| 12. | Are there first-aid kits near the workplace? | ☐/☐ | |
| 13. | Are hazardous areas on the farm, e.g. plant protection product storage rooms, clearly marked? | ☐/☐ | |
| 14. | Does the producer use consultancy services? | ☐/☐ | |
| | **Total points** | | |

| **Recommendations** (min. implementation 20%, i.e. 2 points) | | | |
|---|---|---|---|
| **No.** | **Control points** | **YES/NO** | **Comment** |
| 1. | Are soil maps drawn up for the holding? | ☐/☐ | |
| 2. | Are inorganic fertilisers stored in a clean and dry room? | ☐/☐ | |
| 3. | Does the lighting in the room where the plant protection products are stored make it possible to read the information on the packaging of the plant protection products? | ☐/☐ | |
| 4. | Does the producer know how to proceed in the event of spill or scatter of plant protection products and do they have tools to counteract such a threat? | ☐/☐ | |
| 5. | Does the producer restrict access to the keys and the warehouse in which the plant protection products are stored, to persons who have the authority to use them? | ☐/☐ | |
| 6. | Does the producer store on the holding only plant protection products allowed for use with the plant species they cultivate? | ☐/☐ | |

| | | | |
|---|---|---|---|
| 7. | Are wetting agents or adjuvants added to the spray liquid to improve the effectiveness of treatments? | ☐/☐ | |
| 8. | Is the water used to prepare the spray liquid of the correct quality, including the correct pH? | ☐/☐ | |
| 9. | Does the producer deepen their knowledge through Integrated Plant Production meetings, courses or conferences? | ☐/☐ | |
| | **Total points** | | |

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