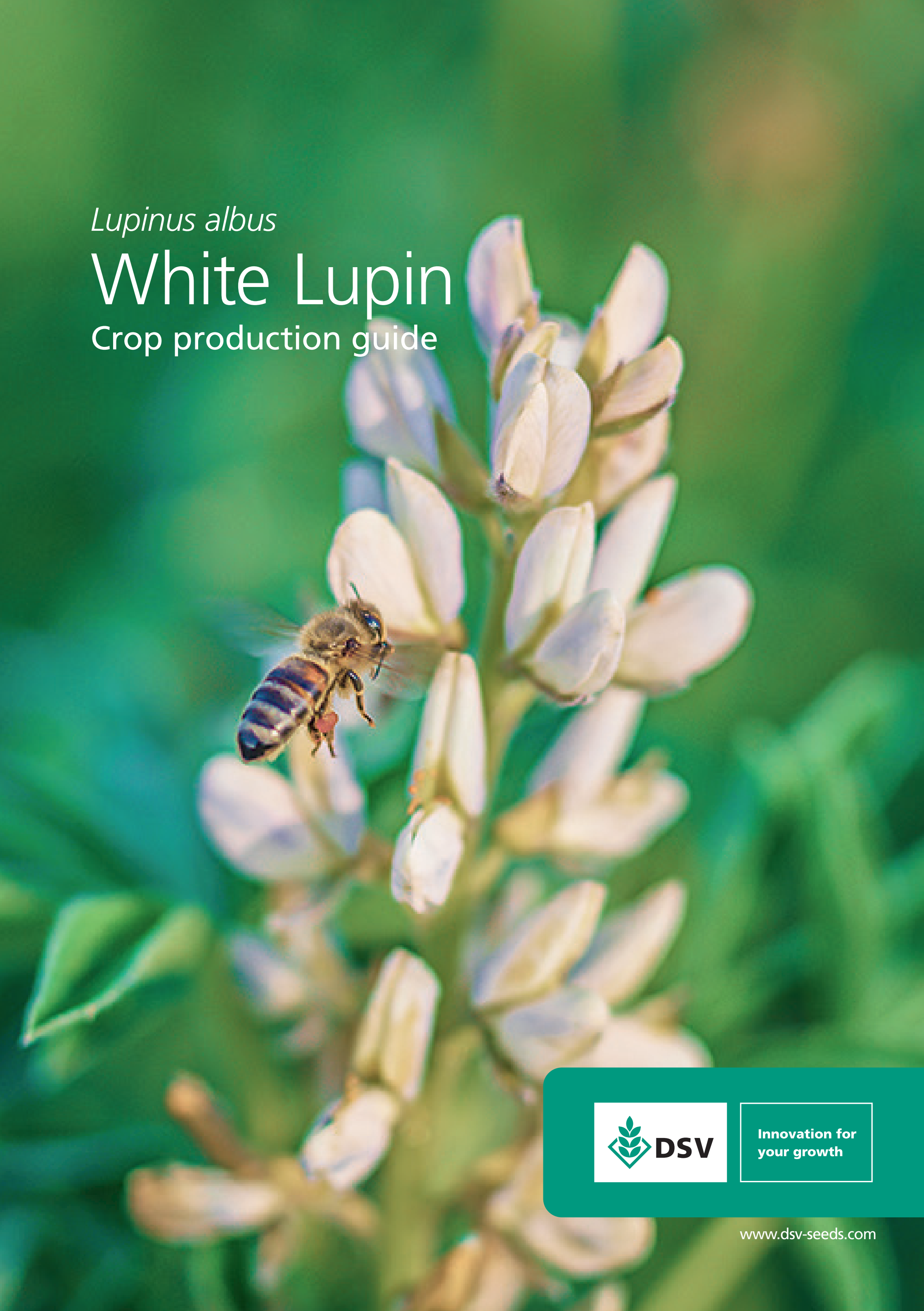


Lupinus albus

White Lupin

Crop production guide

DSV

Innovation for your growth

www.dsv-seeds.com

Deutsche Saatveredelung AG (DSV) is one of the leading mid-sized plant breeders and seed production companies in Germany. The company specialises in the breeding, production and marketing of grasses for animal feed and lawns, oilseed crops, clover, various cover crops, grains, maize and sorghum.

This brochure is a translation from German. Some units used in the original German document may need clarification. The following equivalents apply: 1 tonne = 1.000 kg, 1dt = 100 kg

Contents

Preface

Historically, white lupin played an important role in animal and human nutrition before it almost completely disappeared from European fields in the 1990's. The reason was anthracnose, a fungal disease that is too costly to control.

However in the meantime plant breeders have been able to develop new varieties that are resistant to the disease. These new varieties are tolerant of the fungus. Although they may get infested, the disease will not affect them as seriously as it did in the past. Thanks to this breeding success, growers are again able to include white lupin in their crop rotations. Cropping lupin is indeed a worthwhile strategy. As a grain legume, it has many positive properties that are even more appreciated today. It is grown locally, is rich in high-quality and GMO-free protein, and thus offers a viable alternative to soybean. In addition, by fixing atmospheric nitrogen, loosening the soil and mobilising soil nutrients, lupin is very beneficial to the subsequent crops in the rotation. Therefore, in times of rising input costs white lupin presents a most intriguing option for growers who wish to expand their rotation. It also offers a high yield stability even in hot and dry weather – a characteristic that allows it to adapt to a wide range of different sites and conditions.

This brochure sums up important knowledge on white lupin and how it is cropped (date: March 2022). We would be pleased to see this valuable crop resuming its place in modern rotations.

Yours sincerely Deutsche Saatveredelung AG

1.1 Lupin species

Around 2000 BC, lupin was as popular as grain in Egypt. In Mediterranean countries the crop was first mentioned in scriptures that date back 3000 years. In fact, our ancestors knew very well that lupins contained alkaloids – bitter-tasting and poorly digestible constituents – and therefore they washed the seeds in seawater to make them digestible.This is no longer necessary today, because breeders have been able to breed varieties with lower levels of bitter substances. These varieties are known as sweet lupins.

The generic term "lupin" covers a number of different species. There are three species that are cropped in Central Europe: yellow lupin *(Lupinus luteus)*, white lupin *(Lupinus albus)* and the narrow-leafed lupin, which is known as blue lupin *(Lupinus angustifolius)*. The term "blue lupin" originates from a time when there were only blue-flowered forms of the narrow-leafed lupin. Today, we have a much wider colour spectrum. White lupin is also referred to as broad-leaf lupin, because it has the broadest leaves within the lupin family.

The narrow-leaf lupins have always been the predominant crop, because yellow and white sweet lupins were too susceptible to anthracnose. The three species differ fundamentally in terms of their soil and climate requirements, crop management and harvest quality. In this respect, yellow lupin is very similar to rye, blue lupin to barley and white lupin to wheat.

Botanically speaking, lupin is a legume. Legumes maintain a symbiotic relationship with nodule bacteria and this relationship enables them to fix atmospheric nitrogen and make it available to the entire rotation.

Lupin species and their requirements on soil and climate

	White lupin *Lupinus albus* 	Narrow-leafed lupin *Lupinus angustifolius* 	Yellow lupin *Lupinus luteus* 
Soil type	sL, uL, L, tL, lT, U Highest yields from medium- and better-quality soils (at least sandy loam, preferably loess loam or black soil)	lS, sL, uL Sands, sandy loams; this species is more lime-tolerant than yellow lupin	S, lS Sands and slightly loamy sands with low pH; higher pH levels lead to lime-induced chlorosis (yellowing of the youngest leaves)
pH	5.5–7.3*	5.0–6.8	4.0–6.0
Climate	Suitable for all German climate zones; prefers warmer climates; like narrow-leaf lupin, it is less sensitive to frost than yellow lupin	Suitable for growing in all German climate zones and especially in regions with short vegetation periods; foothills, coastal regions	Temperatures shouldn't be too high during early growth; dry weather during ripening
Yield potential (dt/ha)	20–60	20–45	10–25
Crude protein content at 100 % DM	35–40	30–38	40–44
Vegetation period in days	140–175	120–150	135–150

S = sand | lS = loamy sand | U = silt | sL = sandy loam | L = loam | uL = silty loam | tL = clayey loam
lT = loamy clay

* The most critical parameter is free lime, because high levels of free lime make the site unsuitable for growing lupin

1.2 Breeding lupin

Farmers ceased growing white lupin in the 1990's after the stands were massively infested with the fungal disease anthracnose. In 2001, the German agricultural research institute "Landwirtschaftliche Lehranstalten (LLA) Triesdorf/Mittelfranken" initiated a breeding programme aimed at developing varieties that were tolerant to anthracnose. The goal was come up with a breed that presented a significant improvement to yield and allowed growers to re-introduce white lupin in their rotations.

As a first step, the breeders sourced gene bank material from different parts of the world and tested it for anthracnose tolerance. Then, by crossing suitable strains, they developed a steadily growing gene pool of anthracnose-tolerant breeding material. In 2012, the programme led to a research project which selected anthracnose-tolerant strains and submitted them to a comprehensive trial, the first of its kind.

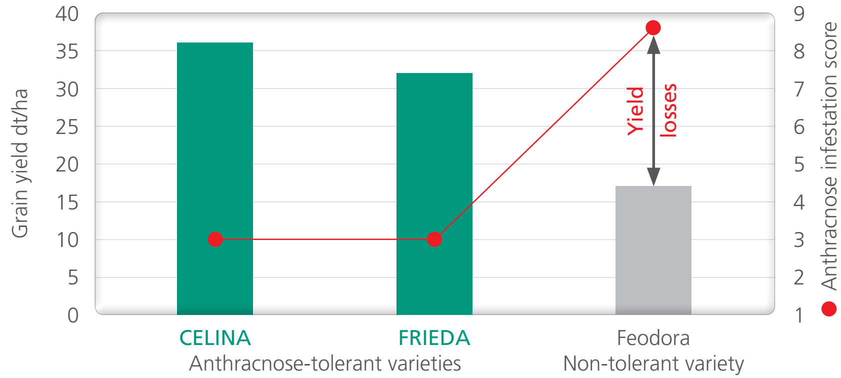
The research activities of the three project partners, Bavarian State Research Center for Agriculture (LfL), LLA Triesdorf and Deutsche Saatveredelung AG (DSV) aimed at registering a variety of candidates at the Federal Plant Variety Office for Value for Cultivation and Use (VCU) testing. 20 lines of white lupin selected by LLA Triesdorf were trialled at six different sites over a period of three years. The focus was on resistance, grain yield and further agronomic parameters. In various weather and field conditions, the breeding lines produced grain yields that were on average 40 % to 60 % higher than those produced by the approved reference varieties, which were susceptible to anthracnose. In addition to that, the breeders documented an improved crop health, both in conventionally and organically farmed trial plots.

In 2019, the Federal Plant Variety Office approved FRIEDA and CELINA as the first anthracnose-tolerant white lupin varieties.

The foremost target in white lupin breeding is to achieve a constant improvement of anthracnose tolerance. Anthracnose tolerance means that the plant may still catch the disease, but to a much lesser extent than the varieties that are susceptible to anthracnose. In anthracnose-tolerant crops the disease spreads more slowly, which translates into a substantial improvement of yield stability. Another priority of the breeding programme is to increase the yield potential and lower the alkaloid content in the plant along with advancing maturity so that harvest can commence between August and mid-September. These aims have been met by FRIEDA and CELINA, which are two of the earliest varieties in our product range (see also page 43).

Further important breeding objectives are higher crude protein levels, better agronomic traits, resistance to other foliar and foot diseases and a lower TGW, hence lower seeding costs.

Tolerance to anthracnose enhances yield security!



Source: International white lupin variety trial 2020, Bavarian State Research Center for Agriculture (LfL); Comparison of DSV varieties CELINA and FRIEDA with the reference variety Feodora on the Hummel site; anthracnose score: Anthracnose-infested green pods, 1 = no infestation, 9 = heavy infestation

The tolerant varieties FRIEDA and CELINA show significantly lower infestation levels than the susceptible reference varieties that do not carry the tolerance.

1.3 Soil fertility

Soil fertility is the foundation of sustainable farming. In organic farming, legumes are indispensable for a fertile soil. Lupins are nitrogen collectors that develop a strong and wide-branching system of roots, which improves the soil texture. Furthermore, lupins are capable of breaking down phosphorus, which is not readily available, thus making it available as a nutrient.

The root system

Lupins form taproots that penetrate the soil as deep as two metres. Their strong and branching roots break up compacted soils as an essential contribution to improving the soil texture. The root channels enable air and water to reach the deeper layers of the soil. As the water in these root channels freezes in winter, it breaks up the soil, thereby loosening it. In addition, the uptake of nutrients from the deeper layers, as well as water absorption and water storage capacity are improved. This allows the plants to absorb the subsoil nutrients before these are washed away.

As a legume, white lupin fixes atmospheric nitrogen in symbiosis with its nodule bacteria *(bradyrhizobium lupini)*, which are known as rhizobia. This process is not only beneficial for white lupin itself but also for the subsequent crops. It is this enormous pre-crop value that allows growers to reduce their nitrogen inputs in the subsequent crop – provided they observe some rules in the rotation.

P mobilisation

Phosphorus is one of the major nutrients for plants. No organism can live without phosphorus – no cell, no plant, no animal. Yet, with the depletion of phosphate reserves around the world, humans need to look at efficient and sustainable ways of using phosphate fertilisers. White lupin employs a special strategy for acquiring phosphate. In low P conditions, it increases its root surface area by forming proteoid roots. These are second-order roots that grow horizontally, forming clusters.

By producing and exuding large amounts of organic acids (mostly citric acid), they lower the pH of the soil solution, which in turn increases the solubility of phosphates significantly. This applies not only to phosphorus but also to iron, manganese and zinc. These proteoid roots are not formed in soils with a sufficient supply of phosphorus.

Diversifying the crop rotation

Leafy crops such as white lupin are suitable for expanding a narrow crop rotation. As a spring crop, it helps diversify rotations that are predominantly winter grains and can break infection chains that are typical for grain (e.g. broken stalks). It can also help suppress weeds that occur in narrow grain rotations (e.g. black grass) and thus help mitigate herbicide resistance issues.

Promoting earthworm populations

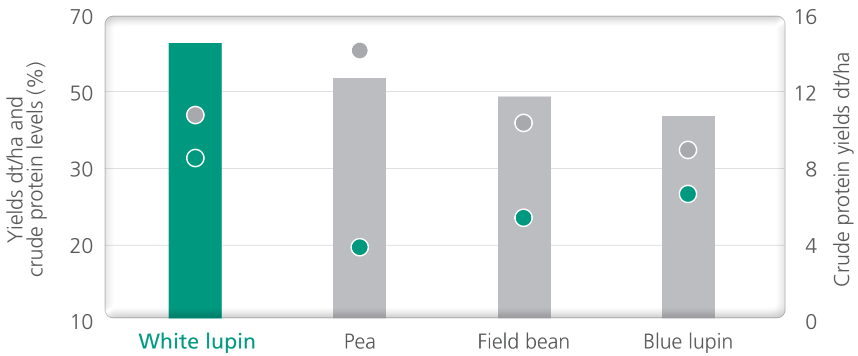
Growing white lupin helps increase the earthworms populations. Earthworms leave their droppings on the surface of the soil and loosen the deeper layers. Increasing earthworm populations leads to a significant improvement of the soil's infiltration capacity, which in turn protects it from erosion due to heavy rainfall. Furthermore, an increased water infiltration capacity means more water is stored in the soil – an important aspect in climate change and with regard to potential heavy rainfall events.

1.4 Comparing lupin with other grain legumes

Growing grain legumes locally is an intriguing option for farmers, because the crop is a good source of protein and a good substitute for imported soya. This paragraph assesses the individual lupin species in terms of yield potential and looks at the advantages of white lupin over soybean, field peas, field beans and blue lupin.

An excellent database for the comparison is the VCU database of the Federal Plant Variety Office (BSA) which includes data across two years. In 2017 and 2018, field pea, field bean, blue and white lupin species were submitted to parallel tests at nine different locations in Germany.

White lupin yielded the highest crude protein levels



Crude protein yields dt/ha, n=8 ● Crude protein content (%) (at 86 % DM), n=8 ● Yields dt/ha, n=9

Source: BSA, VCU Annual Reports 2017 and 2018, orthogonally audited sites; White lupins: Average performance of FRIEDA and CELINA

Yielding an average of 47.3 dt/ha over both trial years, white lupin (varieties FRIEDA and CELINA) performed well, achieving about the same yields as field bean and significantly higher yields than blue lupin. This performance was exceeded only by peas which yielded 60 dt/ha of grains. However, the yield levels achieved in the VCU tests were clearly higher than the typical pea yields. This may be attributed to the choice of the subsequent crop in the trial rotation, which was different from typical rotations; after all, field peas respond more sensitively to a narrow crop rotation than the other species.

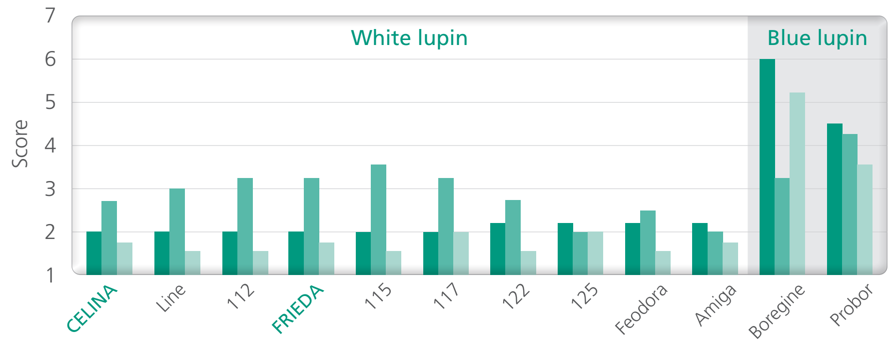
A very intriguing aspect of white lupin is its very high protein content. With a protein content of about 32 % at an 86 % dry matter content, the protein level is significantly higher in white lupin than in field beans and field peas and 4 % higher than in blue lupin. This explains why white lupin delivered by far the highest protein content in the tests, reaching 14.6 dt/ha.

Much better resistance to pod bursting than blue lupin

White lupin requires a slightly better soil quality than blue lupin. It will not grow in the same dry and very light sandy soils in which blue lupin is at home. White lupin also offers a higher yield potential and a higher protein content.

As a major advantage, its pods are much more resistant to bursting than those of blue lupin, which translates into reduced shedding on the combine table. Producing broader pinnate leaves and more branches, white lupin is also more effective at suppressing weeds within the crop. Unlike blue lupin, white lupin also grows on sites with a pH of more than 6.8.

Triesdorf trial results: pods bursting, pods reaching maturity, shedding



Pods bursting Pods reaching maturity Shedding 1 = very few pods bursting

Source: Research project "Evaluating anthracnose-resistant white lupin breeding material *(Lupinus albus L.)* for developing variety candidates"

Project partners: LfL Freising, LLA Triesdorf, Deutsche Saatveredelung AG (DSV), sponsored by BMEL. Time period: 2012-2014; Triesdorf sites 2014

More drought tolerant than field beans and easier to harvest than peas

In the drought years 2018 and 2019, white lupin crops that were growing on more continental climate sites showed a better yield stability and produced higher protein levels than field beans and peas.

White lupin is also less sensitive to soil compaction and foot diseases than peas and has been significantly more aphid resistant than field beans and peas. In fact, common aphid species such as black bean aphids or green pea aphids do not infest lupins. Nano viruses have not been detected in lupins as yet and lab-induced infections with various aphid species have not been successful either. Unlike peas, white lupin is easy to harvest when lodged and grain losses are typically lower than with peas and field beans.

Earlier harvest and better yield stability than soybeans

As the VCU tests for white lupin and soybean are very different, it is not possible to make a direct comparison of their yields. The averaged values from the 2017 and 2018 VCU tests can serve as a reference. In the relatively wet year 2017, soybean and white lupin showed comparable grain yields, but in the drought year 2018 white lupin yielded a surplus of about 11 dt/ha. This means white lupin achieved a higher yield stability in each year; in addition, its average protein content over both years was 4 % higher. Yet, though achieving higher yields in 2018, the average 2-year crude protein yields were on par with soybean.

White lupin matures about three or four weeks earlier than soybean and is harvested earlier. In most areas, while lupin is ready for threshing in mid-August to mid-September, whereas soybean harvests can extend well into October, depending on autumn weather and the maturity group. Lupin can usually be threshed dry, so that the following crops, such as winter barley or winter wheat, can be sown on dates that are typical for the individual regions. Lupins require no special combine headers whereas soybeans should be cut with a draper header to minimise losses.

Soybean is an intriguing option for good soils in warm climates and requires a sufficient water supply from the date of flowering. This applies especially to southern Germany. Lupin, by comparison, is also suitable for less than ideal sites, altitude and northern regions. Here, lupin also benefits from its better tolerance to late frost and cold weather during its early growth period.

Unlike soybean, lupin does not need to be toasted before it can be fed to animals. It is usually sown at an earlier date, hence in wetter soils.

2.1 Crop management

Growing grain legumes is more demanding than growing grain. A critical factor in making white lupin a success is selecting the proper field.

Site conditions

Although lupins can be grown in nearly any type of soil, white lupin is more demanding than blue or yellow lupin. White lupin should not be grown: in 1) very light and sandy soils with a score of less than 25, 2) in dry regions with a low yield potential and 3) at altitudes above 500 m (late harvests in October). Thanks to its deep taproot which enables white lupin to access water in the deeper soil layers, this variety offers an excellent drought tolerance and yield stability. This advantage is, however, of no benefit in extremely shallow soils. In deep and good soils, yields can reach 40 – 60 dt/ha. A major issue is waterlogging, which causes foot diseases and diseases on the emerging plants.

Furthermore, growing white lupin near wooded areas should be avoided, because it is palatable to game and may result in damage. Pigeons, too, can cause serious losses in stands near cities as they feed on lupin from the moment the crop emerges until canopy closure. When the canopy closes the birds lose their landing space and stop feeding on lupin.

White lupin tolerates late frosts down to temperatures of -7 °C, which makes it suitable also for those areas where late frosts are not an exception. Blue and yellow lupins prefer acidic soils yet white lupin also tolerates pHs down to 7.3, contradicting the common opinion that 6.8 is the upper limit. At the same time, the pH should not be lower than 5.5.

In the literature pH is usually used as the only soil parameter, because soils with high lime content usually have high pH levels. Lime in this context is free lime content, i.e. calcium carbonate ($CaCO_3$). This free lime prevents lupins from absorbing the full amount of iron that is required by the nodules for fixing nitrogen, which leads to a nitrogen deficiency in the plant, i.e. yellowish leaves and stunted growth (lime-induced chlorosis). The lime content in the soil can be easily determined by carrying out a hydrochloric acid test using 10 % hydrochloric acid (see page 15). If the level is found to be less than 3 %, the field will be suitable for growing the crop. If the lime content is between 3 % and 10 %, it is recommended to carry out an initial test.

Hydrochloric acid and its effect on the soil	Lime content	Assessment
No reaction	< 0.5 %	No lime present
Crackling	0.5 – 2 %	Slightly calcareous
Clear but brief effervesce	2 – 5 %	Moderately calcareous
Strong effervesce	> 5 %	Highly calcareous

Crop rotation

Lupin is very beneficial for the crop that follows it in the rotation. By developing deep and multiple roots, it produces a good tilth and soil texture. As a legume, the nodule bacteria on its roots fix atmospheric nitrogen, producing up to 40 kg of nitrogen per hectare – to the benefit of the following crop. Traditionally, white lupin is followed by a winter grain in the rotation. White lupin has many beneficial effects on the soil and the following crops. Oilseed rape, sunflowers, potatoes and cabbage are not very suitable for preceding white lupin directly, because they increase the risk of infection with sclerotinia.

To prevent so-called legume fatigue, growers should include breaks in the rotation. Legume fatigue describes a situation in which yields drop because legumes were grown at short intervals. Fatigue can be caused by biotic factors (diseases, pests, bacteria and viruses) or abiotic factors, such as depletion of essential nutrients in the soil due to allelopathy, a poor soil texture or a combination of these factors. The problem is that most pathogens can infest all legume species and multiply on them. Therefore there should be a 5 – 6-year interval between two lupin crops and 2 – 4 years between a crop of lupin and one of peas, field beans, clover or lucerne. However, lupin is less sensitive to foot diseases than peas.

Legume fatigue

In order to diagnose legume fatigue in a field, it is recommended to carry out a disease forecast test. This test helps identify those fields that are either not suitable or less suitable for growing grain legumes. Soil is of course not the only parameter for assessing disease risks and crop growth; weather conditions are equally important.

A differential diagnosis for testing soils for legume fatigue

To test a field for legume fatigue, sample some soil from a representative patch. Then split the sample in two portions. Give one portion a heat treatment and the other no treatment. Then sow white lupin seeds into both samples. If you find growth is much better in the heated rather than in the untreated sample, you will have to anticipate symptoms of biological soil fatigue, such as foot diseases.

Such a test should be carried out three months before seeding.

The following material is required:

- 10 litres of moist soil (a sieved (10 mm) sample from a representative plot)
- 4 fireproof bowls (1 litre) covered with aluminium foil
- 8 pots (1 litre) with saucers
- 40 healthy white lupin seeds
- A pair of scales (0.1 g accuracy)

Evaluation:

Evaluate the samples six weeks after seeding. This may be done earlier if you detect clear disease symptoms on the plants in the control (non-heat treated) bowl. The evaluation consists of a visual inspection but also of weighing the biomass. To do this, cut the shoots at two centimetres from the ground and weigh the fresh mass from each bowl.

If the fresh mass weight from the untreated soil is more than 80 % than the biomass weight obtained from the heat-treated soil, there is presumably no reason to worry about biological soil fatigue.

If the fresh mass weight from the untreated soil is between 20 % and 80 % of the fresh mass weight in the heat-treated sample, there is reason to worry about a biologically induced soil fatigue in wet and cool weather. The lower this weight, the greater will be the risk of legume fatigue when weather conditions get wet and cool. The higher this weight, the greater will be the chance of seeing a good crop performance in good weather conditions.

If the fresh mass weight from the untreated soil is less than 20 % of the fresh mass weight obtained from the heat-treated soil, expect to see severe soil fatigue symptoms – regardless of the weather.

Carrying out the test

1. Ensure the sieved soil is sufficiently moist; add water if necessary. Then mix the soil well and fill four fireproof bowls.

2. Cover the bowls carefully with aluminium foil and place them in the oven. Heat to 70 °C to 100 °C for at least twelve hours.

3. Then mark four flower pots with a "C" (control) and the other four with an "H" (heat treated). Wait approx. 24 hours, then place the cooled and well-mixed soil from the bowls into the pots marked "H". Then place the well-mixed and untreated soil into the four control pots (C).

4. Sow five seeds of white lupin into each pot (C and H). The pots are then placed on the saucers and watered slightly. Keep them in a protected and sufficiently warm place (at least 18 °C) with either natural daylight or light from a plant light. Keep the soil moist during the growth period, and preferably water the pots from the bottom.

Fertiliser application

White lupin does not require **nitrogen** treatment because it can fix atmospheric nitrogen with the help of nodule bacteria (rhizobia). However, one should ensure that all other major nutrients are readily supplied for optimal conditions for the nodule bacteria. High nitrogen inhibits rhizobia development on lupin roots. By comparison, **phosphorus** is an important nutrient, because it supports the supply of energy to the rhizobia. The phosphorus levels are three times higher than in the roots or shoots. A treatment at rates of 10 – 15 kg/ha is required only in soils with a supply of phosphorus at either the A or B level. **Potassium** is important for controlling the plant's water balance and promoting drought tolerance. A potassium deficiency inhibits the development of rhizobia. The application rate should be 40 – 80 kg/ha, especially in light soils. **Magnesium** is an essential component of chlorophyll and is involved in the protein synthesis and in starch transport. Ion antagonism should be taken into account, because excessive levels of cations in the soil solution (H^+, Ca^{2+}, K^+, NH_4^+) inhibit the uptake of MgO. In drought periods, magnesium is not readily available in the soil; the recommended application rate is 10 – 20 kg/ha.

Special attention should be given to **sulphur**, because this is involved in many internal processes in the plant, especially in the symbiotic relationship of the host plant and its rhizobia. A lack of sulphur also inhibits N-fixation (nitrogen fixation). Sulphur requirements are covered by applying potassium sulphate or kieserite, or alternatively elemental sulphur, to the stubble of the previous crop. Applying epsomite is not sufficient to cover crop requirements in sulphur-poor soils.

Another important micronutrient is **boron,** which plays a major role for developing nodule bacteria. The requirement here is about 150 g/ha. Boron is in short supply during drought periods and should be applied shortly before canopy closure. In high yielding crops and/or in drought conditions, additional boron should be added during BBCH 39 – 51. Plants require boron along with calcium and potassium for cell wall formation and for cell division. The micronutrient is also important for various metabolic processes (e.g. carbohydrate metabolism, protein balance, hormone metabolism) and for sugar formation, as well as for the formation of green cells. In addition to giving structure and stability to the cell wall, boron also promotes the formation of pollen tubes during flowering. As a result, boron deficiency often inhibits the generative development, which can result in harvest losses.

Since boron is transported solely by the water transporting tissue (xylem) the supply of nutrients to the target organs will drop when transpiration decreases. Therefore, applying the nutrient to the leaves can be a useful measure. Especially young leaves that have just unfolded show less transpiration than older leaves and are therefore not properly supplied with boron. This is a particular risk in drought periods.

Light green and yellow colourations are symptoms of boron deficiency

Another important micronutrient is **molybdenum,** which helps to metabolise energy. Molybdenum levels are low in light and dry soils and in soils with a pH of less than 5.5. A treatment is recommended in deficient soils when the plants have reached the 6-leaf stage. The micronutrients **cobalt** and **manganese** should also be added if necessary.

Tillage

The crop can be sown into ploughed soil. Ploughing can take place either in autumn or spring when the soil is sufficiently dry. In fields with a healthy soil texture white lupin can also be sown into min-till or direct-drill fields. The seeds are sown into consolidated ground at a depth of 3 – 4 cm, which ensures good seed-to-soil-contact and access to capillary water for easy germination. Herbicides for broad-leaved weeds that are not banned at the time this magazine is written may be applied only during pre-emergence. For the treatment to be sufficiently effective, the seedbed should not be too cloddy.

Sowing conditions and policy

White lupin is sown from mid-March to the end of April. The soil temperatures should be at least 6 °C. The best time for seeding is during extended dry spells. Other favourable conditions are frequent drought periods in the spring where the crops should be planted immediately after the cultivation pass into well-consolidated soil. Once it emerges, the crop is tolerant to late frosts and temperatures of down to about -7 °C, it is more susceptible to freezing during the germination phase. An early sowing date, if conditions permit, enables the plants to form a sufficient number of branches, which ensures high yields and reduces the risk of infestation with soil-borne diseases during emergence. Most diseases that spread during the emergence stage tend to require warmer soils.

If the weather is warm enough, the plants emerge rapidly and show a vigorous early growth and early canopy closure. All these factors combine to reduce the weed pressure. Therefore, seeding should be scheduled to ensure sufficiently moist soils for effective pre-emergent herbicide control. Lupin is more tolerant to late seeding dates than field beans, for example.

The depth should definitely be 3 – 4 cm. An epigaeic germinator, white lupin is not well suited for deep seed placement as this may lead to yield losses.

The optimum seed rate is between 50 and 60 germinable seeds/m². Higher seed rates increase the storage risk and will not boost yield levels. By comparison, in lower-yielding or dry fields (reduced branching), in very heavy soils (poor emergence) or in harrowed fields the rate should be increased by 10 %. The typical seed rate is between 180 – 260 kg/ha, depending on crop TGW and germination capacity. Pneumatic seeders are the best choice or handling the high 350 – 430 g TWG. Growers who use mechanical seeders will verify that the delivery tubes are not blocked and seed delivery is smooth. Row spacings can be identical with those for cereals, which ensures a good crop distribution and effective weed suppression after canopy closure. Wider row spacings are recommended in organic farming and mechanical weed control but should not exceed 35 cm, to that the canopy can close.

Seeds

No doubt, the seed material must be certified. After all, anthracnose *(Colletotrichum lupini)* is the most dreaded lupin disease and is largely transmitted by the seeds. Certified seeds have been tested for anthracnose in the seed certification procedure, which makes them the single most effective measure for preventing anthracnose. **The use of farm-saved seeds is prohibited by law.**

Inoculation with rhizobia

Seeds that are sown after more than 8 – 10 years since the last lupin or serradella crop should be carefully inoculated with a lupin rhizobia agent. This should take place immediately before seeding to ensure a good development of the nodule bacteria. The inoculants are available as liquids or peats. Manufacturer instructions on the proper use must be observed. As the agents lose their efficacy quickly after the inoculation, they should be applied to the seeds immediately before seeding. For the bacteria in the inoculant to stay healthy and active, the agent must not be exposed to sunlight (UV radiation) or heat during storage and mixing. Chlorinated tap water should also not be used for wetting the seeds. Growers should verify the efficacy of the inoculation in June/July by digging up the plants to see whether large numbers of nodules have settled on the roots. Cut the nodules open to check whether they show a healthy orange-red colouration on the inside.

Weed control

Effective weed control is essential both in conventional or organic farming. After all, during an extended early growth, white lupin doesn't compete very well with weeds. Therefore, effective weed control begins with selecting the proper field. Weed burden should be low in general. Maize is a good choice as a preceding crop because it leaves a field that is relatively free of weed. At canopy closure the crop should be free of weeds, which can be achieved either by herbicide or mechanical control in organic farming. Once the canopy is closed, white lupin forms a dense crop that provides effective shading and hence outcompetes weeds.

Chemical weed control

Weed control is essential for securing high yields. The choice of one or a combination of several herbicides is based on the weeds present in the field. A pre-emergence treatment should be carried out immediately after seeding to avoid damage to the seedlings. This is an important aspect, because germination may begin only few days after seeding, depending on conditions and year. Herbicides applied to moist, well-consolidated and fine tilth should effectively kill all weeds, although black bindweed may be a problem at times. Growers in Germany can consult the online database of the Federal Office of Consumer Protection and Food Safety, which lists the products approved for application in white lupin.

Mechanical weed control

Mechanical weed control is either with a harrow or hoe. Shortly after seeding and until shortly before the seedlings emerge, the field should be given two or three "blindfolded" passes. Afterwards and when the weeds are in the filament/cotyledon stage, this practice should be repeated as often as deemed necessary. Growers should avoid harrowing between emergence and the 2 – 4 leaf stage, because during this time the plants break very easily, leading to high losses. For an effective weed control by harrowing, the soil should be loose and the work rate should not be higher than about 2 km/h. Early evening hours are ideal, because at this time of the day the stems are flexible and less prone to damage. Modern harrows have individual tine suspension which reduces the risk of damage.

A very good and certainly more effective implement than the harrow is a mechanical weeder, which in fact is the best choice to deal with high weed pressures. As the air flow through the crop increases, the risk of catching anthracnose decreases.

Harvest and storage

White lupin is usually harvested between mid-August and the first week of September, which means about two or three weeks later than field beans and up to four weeks earlier than soybean. Although the varieties CELINA and FRIEDA are very precocious compared to most other varieties, they tend to form side shoots in wet July/August weather, which will delay harvest significantly.

> Harvesting white lupin is very easy and quick. The stands usually grow to a height of 60 – 80 cm and to more than 1 m during favourable conditions and wet years.

The pods stand upright and the lowest pod crown is usually about 15 – 20 cm from the ground. Unlike soybean with low-hanging pods that should be harvested with a draper header to avoid significant losses, white lupin is less likely to produce losses on the header. This is because the pods are burst-resistant – unlike blue lupin, for example. In addition, the pods ripen quite consistently and even lodged stands can be combined. If lodging occurs before pod formation, the plants usually straighten up again, which is no longer possible after podding when they become too heavy. Full ripeness is reached when the straw has turned brown and the grains rustle in the pods after the umbilical cord has detached from the back seam. Lupin grains are large and make clean samples. The grain moisture should range between 12 % and 16 %. Although grain moisture may be low in dry years, this is not an issue thanks to the low risk of pods bursting, however gentle threshing is very important. This means that drum speeds should be as slow as possible and concave gaps as wide as possible. Axial flow combines seem to be gentler on the grains and produce less crackage.

Choosing the best harvest date may be difficult in wet years when it is difficult to assess maturity. Therefore, harvest may have to start spontaneously to take advantage of a dry spell. The residual moisture will be high in stands that don’t mature uniformly or are exposed to wet weather in late summer.

These batches will require a drying treatment within 24 hours after harvest if moisture levels exceed 24 %. At less than 20 %, the crop can be ventilated with cold air for several days. Ventilating the crop is a must if the temperatures in the store are at risk of rising as a result of weed in the batches. Secondary water absorption (condensation) and high ambient temperatures should also be avoided during storage. Like grain and grain maize, lupin is stored at a residual moisture of less than 14 % to avoid the risk of a massive infestation with yeast or moulds. Due to their high protein content, grain legumes can spoil faster than cereals, for example, especially if the lots contain cracked grains.

A quality assured storage for minimised loss requires rapid and very gentle drying at a maximum temperature of 35 °C. Temperatures above 35 °C should be avoided to prevent quality loss due to heat.

Losing only up to 4 % of their moisture in one drying cycle, legumes don’t dry very well and should therefore receive a second drying cycle after 2 or 3 days during, which the moisture can escape from the heap. The crop should be cooled to 20 °C after the drying cycle. Heavily infested lots that are not cleaned before drying are at risk of spoiling, because the presence of weeds leads to another increase in moisture.

2.2 Pathogens

Fungi

Lupin Wilt *Fusarium spp. / Fusarium oxysporum*

Fusarium fungus is a pathogen that thrives in hot temperatures and causes foot- and wilt diseases in a wide variety of host plants. It requires soil temperatures of more than 15 °C, ideally between 25 °C and 30 °C, and its spores are spread by ground water, wind or infested residues, and invade the plants through the root tips or injuries. The first symptoms of an infestation usually appear during the flowering stage when the plant shows signs of wilting and a typical brown discolouration of the tissue. The root however remains intact. The discolouration is revealed when cutting through the stem. Here, the spores form pinkish/salmon-coloured clusters. Later on, the discolouration will appear, also on the surfaces. An effective measure to reduce the spore potential in the soil is by introducing breaks in the rotation. Another option is to control sitona at a very early stage, because the soil-borne pathogens are transmitted to the plants by the larvae as these feed on them in May.

Pythium spp. – Fungal Soft Rot *Pythium ultimum / Pythium irregulare*

Pythium spp. is a soil-borne pathogen that occurs in lupins and infests mainly the young seedlings. The fungus occurs predominantly in compacted soils and in cold and wet conditions. It is spread by ground water, contaminated biomass and insects. Infestation occurs primarily during germination and early growth and affects the root from the tip to the crown. The stem of an infested plant bends over in its soft and constricted area. Stem areas close to the ground or underground become brown and partly stunded, shrivelled or rotten. Plants that are infested at a later stage show a less vigorous growth, yellowing or withering. Measures for reducing the risk of infestation are long breaks in the rotation and the use of healthy seeds.

Sclerotinia – Stem Rot *Sclerotinia sclerotiorum*

Sclerotinia is active during the emergence stage causing stem rot. This fungal disease infests a wide variety of different host plants (oilseed rape, legumes, sunflower, potatoes). Sclerotia can survive in the soil for up to 15 years. The pathogens germinate in spring and the ascospores are spread by the wind. The infection takes place in branch forks, leaf axils or blossoms when humidity is high. The disease is accelerated by warm temperatures and wet-dry weather, with the fungi forming clusters. Further pathways to infection are through infested crop residues. An initial symptom is stems turning pale, then the shoots and pods above the infested area turn yellow, ripen prematurely and die. If infested at an early stage, the seedlings die during the emergence stage with emerging plants often bending over as their stems become soft. One measure for reducing the sclerotia is the application of spores of the parasitic fungus *Coniothyrium minitans* to the sufficiently wet residues from the infested crop.

Grey Mould *Botrytis cinerea*

Grey mould pathogens are airborne, but sclerotia also survive in stem residues and in the seeds of the host plant. The infestation risk increases in cool and wet weather at temperatures between 10 °C and 15 °C and during extended humid periods. The infestation pressure is particularly high in wind-protected sites with little air circulation through the closed canopy and typically during the months of May and June, i.e. shortly before flowering. That said, there is a constant risk of infestation throughout the entire vegetation period. Grey mould forms white and beige-grey spots and a grey-brownish coat on the leaves and also a coat on the stem. The leaves turn yellow or grey-green and die. Later on, the buds, blossoms and pods turn yellow and die.

Black Root Rot *Thielaviopsis basicola*

Black root rot is caused by a fungus and thrives on many different host plants, including legumes (clover, lupins, lucerne, peas and beans), tobacco, carrots, lettuce and cucumber. Lupins are infected by resting spores that hibernate in the soil, germinate in the spring and actively penetrate the root system of the plants. The first symptoms are thin lesions in the young root. These cause unspecific necroses: the roots shrivel and wither and the pinnate leaves show symptoms of unspecific nutrient deficiency. On older plants, the main root falls apart when it is pulled from the soil; heavily infested plants die. Surviving in the soil for a long period of time, resting spores are not very reliant on the presence of crop residues in the field but they must infest a living plant in order to reproduce.

Preferring neutral and alkaline soils, and also wet soils, black root rot thrives when the crop rotation contains a high number of potential host crops. The fungus is transmitted to other fields by spores clinging to soil particles or insects. A potential infestation can only be detected at an early stage by using a microscopic method. Symptoms showing at a later date may be mistaken for a nutrient deficiency. The typical lesions ("dash symptoms") caused by the pathogen to the plant and the permanent spores to the roots and cotyledons can only be detected with a magnifying glass. One measure for controlling the spore burden in the soil is a longer interval between two lupin crops. Another is to clean implements and machines after using them in an infested field to avoid spreading the disease to uncontaminated fields.

Anthracnose / Brown Leaf Spot *Colletotrichum lupini*

Anthracnose is caused by the fungus *Colletotrichum lupini* and is the most critical lupin disease. White and yellow lupins are particularly vulnerable whereas blue lupin has a certain natural tolerance to the pathogen. The fungus is seed-borne and in the primary infestation phase the pathogen forms clusters of fungi. The secondary infestation takes place as the fungus is transmitted by spray water, droplets or injuries due to harrowing, for example. Humid and warm weather offer perfect conditions for the fungus to develop. In favourable conditions, it can infest entire stands of susceptible varieties and lead to death and a complete loss. All parts of the plant are affected and typical symptoms are brown dips in the leaves, twisted stems and bent leaf stems.

The susceptibility of the plants is controlled by a number of factors: temperatures between 20 °C and 25 °C and a leaf wetness duration of more than 10 hours. The BBCH stage plays an important role, because the plants are most susceptible during the flowering stages (BBCH 60–69) and the pod development stages (BBCH 70–79); but they are also at risk during germination when unspecific wilting symptoms on the leaves or the entire plant can be observed. After an early infection, disease symptoms are usually observed throughout the entire vegetation period, and especially young plants die at some point during the infestation. Dwarfism and deformities are also observed.

As FRIEDA and CELINA have been approved as anthracnose-tolerant varieties, it is now possible to crop white lupin again.

Rhizoctonia *Rhizoctonia solani*

The fungus survives in the soil by forming a compact mass of fungal mycelium *(sclerotia)* on roots and residues. The number of potential host plants is large and includes maize, potato, sugar beet, field bean and soybean. The infested plant will either die during its seedling stage or early growth. Factors that promote an infestation are plant injuries, compacted soil, primary infections with other pathogens and also cool and wet weather. This said, the fungus is also able to infect plants that are not damaged. The initial signs of an early infection are large gaps in the emerging crop. Later infections cause the seedlings to bend over. Typical symptoms are oval and dark brown necroses at the base of the stem. The leaves may also turn pale, because the fungus damages the vascular bundles, which in turn leads to nutritional deficiencies. The use of healthy, e-treated certified seeds contributes to a healthy crop, especially during the first weeks after seeding. Well-timed sowing, optimum seedbed preparation and a good soil texture help accelerate early growth. Growers who rely on mechanical weed control should carefully avoid damaging the plants, because injured plants are easily invaded by soil-borne pathogens.

Options for controlling fungal diseases

In addition to the application of fungicides, there are a number of mechanical control options that can prevent or mitigate infestation with a fungal disease. The first is to use only certified seeds. After all, anthracnose is a seed-borne disease. The second option is to treat the seeds with electrons. This is particularly intriguing for growers in Germany where a number of chemical seed dressings are banned. Seed treatment by electrons is an advanced technology and offers state-of-the-art protection both in terms of the environment and users.

Another option is to have sufficiently long intervals between two lupin crops. As a general rule, stands that are not too dense benefit from a better aeration, which reduces the disease pressure. Crop density is controlled by an appropriate seed rate and row spacing. Growers who rely on mechanical weed control should avoid damaging the crop, especially the roots and the base of the stems, to prevent injuries through which the pathogens invade the plants.

Chemical measures are useful when the first few disease symptoms begin to show. The chemicals applied must be approved.

Pathogens

Insects

Sitona Weevil *Sitona spp.*

Sitona is the main lupin pest and can destroy up to 40 % of the crop's yield potential. Feeding on the leaves, the weevils migrate into the stands during emergence in March and April. Starting from the edge, they eat semi circles into the leaves. This type of damage is typical for the early growth period and may increase to the extent that the entire leaf is eaten all the way to the stem.

However, compared to nodule-eating larvae, foliage-eating weevils are a rather small problem, because the larvae can destroy up to 40% of the nodules and 10 – 40 % of the yield potential. Egg laying begins at an early stage. The females lay up to 1,000 eggs over a period of up to three months. The larvae hatch after about three weeks and feed on the root nodules by hollowing them. This impairs the fixation of atmospheric nitrogen and inhibits growth so that less nitrogen is available for the following crop.

Sitona prefers light soils. Control measures will only be effective, if applied **before** egg laying, i.e. between the cotyledon- and 6-leaf stages. One measure is to promote its predators, such as ground beetles and spiders, by creating, managing and preserving healthy field edge structures.

* Source: Prof. Dr Christine Struck, Rostock University

Lupin Aphid *Macrosiphum albifrons*

The lupin aphid is a relatively large 4 – 5 mm long pest. It has a green colour and a white, waxy coating. Feeding on plant sap, the adult aphids can hibernate at temperatures of -15 °C for two weeks, an ability that allows the adults to reproduce rapidly in spring. A female can release up to 80 larvae in the course of 24 hours. The rapid increase of these sap-sucking insects causes relevant damage to a lupin crop. Infested lupins show a retarded growth and heavily infested young leaves curl up. Another potential hazard by these aphids is the transmission of viruses such as *pea enation mosaic virus* (PEMV). In Germany, there seems to be currently no evidence of a virus that has a significant impact on yield levels. The black bean aphid and the pea aphid also occur in lupin stands, yet they rarely require any control measures.

3.1 Pre-crop value

When grain legumes are added to a rotation it will change the interactions of all the crops within the rotation and their performance. The most significant argument for adding a legume to the rotation is its ability to fix nitrogen and make it available to the following crops. Apart from that, there are many other pre-crop values and beneficial effects for the rotation:

- Fixation of atmospheric nitrogen
- Mobilising soil phosphate
- Diversified rotation
- Humification benefits
- Improved soil texture
- Increased soil life
- Reduced tillage
- Reduction of diseases and pests
- An extra spring crop in the rotation
- Staggered harvest peaks
- Reduced herbicide resistances
- Opportunity of adopting EU agri-environment climate measures

As we assess the productivity of grain legumes, we need to look beyond the subsequent crop and at the crop that follows, and ultimately at the entire rotation. This is necessary, because the monetary gain of a legume crop doesn't appear in the contribution margin of the legume itself but in the margins of the subsequent crops.

Assessing the monetary gain of lupin pre-crop value

From a monetary point of view, the pre-crop value is obtained by reduced direct and labour costs on the one hand, and by increased yields in the subsequent crops on the other. Yet, evaluating the monetary gain is a very complex undertaking, because yields and growing conditions vary and so will N inputs and N savings. The examples and calculations discussed below refer to conventional farming schemes. In organic farming, the pre-crop value of lupin would be higher in the first place. The pre-crop value is generated primarily by the surplus yield of the following crop (surplus yield dt/ha by market price €/ha). Assuming an average production price of 18 € for grain, we would have to credit 126 €/ha to the grain legume when the surplus yield of the subsequent grain crop (wheat or barley) is 7 dt/ha (see table "Surplus yields in the subsequent crop", page 33). It becomes clear that each decitonne of extra yields in the following crop translates into a significant increase in the pre-crop value of legumes – especially in times of very high grain production prices.

But not only does the immediate crop achieve higher yields, the next crop in line can do so, too. In a survey carried out by the University of Applied Sciences Südwestfalen, Germany, farmers reported that they reduced their N rates by an average of 20–30 kg N/ha after a crop of grain legume. Assuming a nitrogen price of 1 €/kg N, this translates into savings of 20–30 €/ha, provided the number of passes does not change. These savings may vary relative to the amount of organic fertiliser being available and applied. The calculation must take into account that input costs vary relative to global crude materials markets and prices, **which are very volatile and change rapidly.**

Surplus yields in the subsequent crop (€/ha)

Surplus yields in the subsequent crop (dt/ha)	Grain production prices (€/dt) 16	18	20	22	24
5	80	90	100	110	120
7	112	126	140	154	168
10	160	180	200	220	240
12	192	216	240	264	288
15	240	270	300	330	360

Another factor is that white lupin improves the tilth, so that farmers may be able to reduce the number of cultivation passes and – depending on site and harvesting conditions – even abandon the plough. This translates into savings of 20 €/ha to 60 €/ha. **In addition, growers must assess for themselves the potential management savings by growing grain legumes.** Depending on the location and the subsequent crop, spraying costs can also be reduced. The following is a simplified calculation of the pre-crop value.

Simplified calculation on the pre-crop value of grain legumes

Pre-crop values	Value (€/ha)
Yield growth in the 1st crop WW/WG (5–15 dt/ha)[1)]	90–270
Surplus yield in the 2nd crop WW/WG (1–3 dt/ha)[1)]	18–54
N savings (5–35 kg/ha N)[2)]	5–35
Reduced tillage costs for subsequent crop seed placement	20–60
Reduced weed pressure; application of less costly chemicals	0–25
Savings from skipping one fungicide treatment	0–45
Total pre-crop value	133–489

[1)] Assuming a grain legume producer price of 18 €/dt [2)] Assuming an N fertiliser price of 1 €/kg

Basic knowledge Cropping Viability Practice

3.2 Value creation

There is the persistent argument that growing lupin creates only little value per hectare, even if its pre-crop value is included in the calculation. The truth is that growers can indeed generate financial gain from growing legumes – for a number of reasons. One is that legume growers in the EU have access to certain funding by applying for Agri-Environment Climate Measures (AECM). Another reason is that white lupin offers a much larger yield potential than blue and yellow lupin. Yet, assessing the viability of grain legumes, we need to look beyond yield levels, because its benefits are neither always measurable nor translate into hard figures. These benefits are discussed in the section "Pre-crop value". Particularly in rotations that are predominantly grain, legumes break disease chains, improve the soil texture, fix significant amounts of nitrogen and make it available to the subsequent crops, plus provide further benefits that lead to surplus yields in the subsequent crops – all of which are not assigned to grain legumes in many profitability calculations. Yet, when assessing the viability of growing grain legumes it is essential to include the pre-crop value in the contribution margin. There are more benefits that are not included in the profitability calculation – such as an increased biodiversity or phytosanitary benefits – which don't translate into immediate monetary gain although they contribute to a more sustainable way of farming.

Setting market prices for lupins is currently difficult. Depending on how the crop is used, the following calculation employs a lupin substitution value that is based on the average long-term wheat price and the average long-term soybean price. Based on the good pre-crop value of lupin, the calculation assumes that the surplus yield of the following crop grows by 10dt/ha. This means that the producer price of wheat or soybean is included in the calculation. From 2010 to 2019, the average price for wheat was 18.05 €/dt and for soybean extraction meal (SES) (44 %) 34.5 €/dt. The aspect of using the crop either on the farm or selling it to another farm deserves special consideration. The value of grain legumes for animal feeds, especially for pigs but also for cattle, is sometimes much higher than the prices the crop achieves on the commodity markets. The feed value is based on the level of digestible protein (nXP) or the metabolizable energy (MJ ME) and praecaecally digestible lysine (pvc lysine), plus a price constellation of wheat and GM soybean meal. This calculation can produce feed value benefits of up to 10 €/dt for white lupin – storage and processing not taken into account. In view of a growing demand for GMO-free animal feeds, the feed value of domestically grown grain legumes should be assessed on the basis of the GMO-free soybean prices. This increases of the feed value of white lupin significantly.

Taking the pre-crop value and the substitution value into account, the contribution margin calculation shows positive margins on all production sites. The fact that the contribution margins vary greatly by location illustrates the value of lupin as an animal feed by animal species although a number of constraints definitely need considering. Many farmers may find white lupin an attractive and competitive option to other main crops. Grain legumes offer a high pre-crop value. They present an excellent addition to mainly winter grain rotations and an effective strategy for managing resistances within the rotation. Grain legume growers can also boost their productivity by forward-looking planning either with regard to selling the crop on the market or to another farm or using it on-farm.

Lupin yields dt/ha		20	30	40	50	60
Exchange price*	€/ha	26.28	26.28	26.28	26.28	26.28
Market performance	€/ha	525.50	788.25	1051.00	1313.75	1576.50
CAP premium	€/ha	by federal state (Germany)				
Min. pre-crop value	€/ha	133	133	133	133	133
Max. pre-crop value	€/ha	489	489	489	489	489
Min. performance		658.50	921.25	1184.00	1446.75	1709.50
Max. performance		1014.50	1277.25	1540.00	1802.75	2065.50
Seeds	€/ha	240	240	240	240	240
Fertiliser	€/ha	80	80	80	80	80
Chemicals	€/ha	45	45	45	45	45
Machine running costs	€/ha	250	250	250	250	250
Miscellaneous	€/ha	35	35	35	35	35
Total running costs	€/ha	650	650	650	650	650
Min. contribution margin		8.50	271.25	534.00	796.75	1059.50
Max. contribution margin		364.50	627.25	890.00	1152.75	1415.50

*In absence of a market price for white lupin, the calculation uses an exchange price (calculated on the basis of digestible lysine and metabolizable energy for pigs using the single-feed formula and assuming a soybean extraction meal price of 34.50 €/dt and a wheat price of 18.05 €/dt)

3.3 Use and sales channels

Human nutrition

White lupin is one of the protein-richest crops. Ancient records show that legumes used to be grown in the Mediterranean countries as many as 3000 years ago when they were appreciated as a valuable food. Being a versatile ingredient in cholesterol-, gluten- and lactose-free foods, white lupin is gaining popularity, also in Germany where supermarkets sell coffee, milk substitutes, ice cream and flour made from lupins. Apart from that, lupin is also used as a protein substitute for meat in vegan and vegetarian diets. As a protein isolate, lupin can be used as an emulsifier in fatty or oily foods such as soups, dressings, mayonnaise, baked goods, bread spreads and sausages.

Containing polyunsaturated fatty acids and many minerals (K, Ca, Mg, Fe), carotenoids, vitamin A, B1 and E, white lupin is also very beneficial from a nutritional point of view. Food made from white lupin has a number of positive effects on the human health. People who suffer from rheumatism benefit from its extremely low purine levels which are known to create uric acid. Consequently, the crop also helps prevent gout and kidney problems. People who suffer from diabetes benefit from the low glycaemic index, which means the carbohydrates are made available very slowly so the blood glucose level increases slowly, too. In addition, white lupin contains a lot of dietary fibre, which leads to less flatulence and to better tolerance than that of other legumes.

Lupins also contain anti-nutritive ingredients, the so-called alkaloids which are known as bitter substances and considered harmful to human health. Breeders have been able to significantly reduce the extremely high alkaloid levels in bitter lupins and develop varieties with much lower levels of bitter substances. These are the so-called sweet lupins. A frequently stated threshold value for human nutrition is 0.02 % of OS (200 mg/kg). The rate may vary depending on the processing received for reducing alkaloids. Seeds with high alkaloid levels must be given a special treatment (debittering) before they can be marketed as a food.

The alkaloid content may vary greatly in lupins and is subject to environmental factors. Farmers who grow lupin for human nutrition must consult their customers to agree on thresholds and requirements and the type of analyses required.

A relative of peanut and soybean, lupin can cause cross-allergies in certain conditions. Depending on national regulations, the presence of lupins or their components in a food has to be listed on the package so that people with allergies or food intolerances can avoid these products.

Animal nutrition

In animal nutrition, white lupin is particularly beneficial for pigs and cattle, but also for poultry, which is attributed to its high protein content and excellent digestibility. It has significantly higher crude protein and crude fat level than field beans and field peas. Crushed or ground, it can be used as an animal feed without receiving any pre- or post-treatment. This makes it much more suitable for on-farm and inter-farm use. The alkaloid threshold for animal nutrition is 0.05 % of the OS (500 mg/kg). This threshold is no problem, because lupin is fed in mixed rather than 100 % lupin rations. For an optimally balanced ration, it is important to observe the recommended prescriptions for white lupin and to carry out an ingredient analysis, including an alkaloid analysis.

The high crude protein content is particularly important. Another advantage of lupin is the fact that it grows in Europe and requires no toasting prior to feeding. The following table shows the essential nutrient levels in white and blue lupin in comparison with soybean extraction meal.

Nutrient levels in lupin and soybean extraction meal

Feed	Crude ash g/kg DM	Crude protein g/kg DM	Crude fat g/kg DM	Crude fibre g/kg DM	Starch g/kg DM	Sugar g/kg DM
White lupin *Lupinus albus*	40	373	88	130	74	73
Blue lupin *Lupinus angustifolius*	37	333	57	163	101	55
Soybean extraction meal	57	510	15	67	69	108

Sources: DLG Kleiner Helfer, 10. Edition 1999

When feeding pigs and poultry, the relatively high content of crude fibre must be taken into account, a high proportion of which consists of non-starch polysaccharides (NSP). Unlike peas and field beans, lupin contains only small amounts of starch. Therefore it cannot replace the usually cheaper cereals in the ration. The low starch levels are beneficial for cattle because they reduce the risk of rumen acidosis. Its sugar and crude fat levels are somewhat higher than those in field beans and peas. Monogastric animals like pigs and poultry require an adequate supply of essential amino acids whereas ruminants are able to synthesise amino acids from non-protein nitrogen (NPN) with the help of rumen microbes. Under the current feeding schemes, the amino acids lysine (especially in poultry) and tryptophan are the main limiting factors for animal performance.

Dairy cows

White lupin makes an excellent feed for dairy cows. Yet for feeding high-dairy-yielding animals supplementing the protected rapeseed extraction meal is recommended to balance the low levels of sulphur-containing amino acids and to reduce the positive ruminal nitrogen balance (RNB) and thereby the nitrogen excretion. An exemplary ration for daily milk yields of 29.7 kg according to NEL and an overview of the key figures of this ration are provided in the following tables.

Example of a dairy ration

Feed	kg WM	kg DM
Maize silage (36 % DM)	24.0	8.6
Grass silage (40 % DM)	16.0	6.4
Barley straw	0.3	0.3
Pressed sugar beet pulp	5.0	1.1
Brewers' grains	5.0	1.1
Dairy feed	1.5	1.3
White lupin	1.5	1.3
Minerals	0.2	0.194
Fodder lime	0.06	0.059
Cattle salt	0.03	0.03
Total	53.6	20.4

Parameter	Rate
NEL	6.8 MJ/kg DM
nXP	157 g/kg DM
Crude protein	156 g/kg DM
Starch	152 g/kg DM
RNB	0 g/kg DM

Pigs

White lupin also makes good pig feed, because it is rich in lysine. A comparison of various grain legumes and their energetic feed values shows that thanks to its higher fat content white lupin offers clear advantages over field beans and forage peas. A drawback however, is that it combines only to a limited extent with maize rations. Their higher crude fibre content makes them especially suitable as a feed for pregnant sows. However, like all native grain legumes it has only low levels of methionine and cystine and therefore must be supplemented by minerals to supply free amino acids to the ration. Alternatively, oilseed rape extraction meal can be used to compensate for the low methionine content.

White lupin is less suitable in organic pig farming, because organic farmers can choose only from a few products that supply the essential methionine and cystine amino acids, one of which is sunflower cake. The amounts used in pig rations range from 5 % for piglets to 20 % for finishing pigs and sows. However, further research is yet to be done here. Up to the time of preparation of this document, there have been no white lupin pig feeding trials in Germany. Most of the advice that is offered by various sources is based on blue lupin calculations and trials. The following tables show an exemplary ration with reduced nitrogen and phosphorus levels for finishing pigs of weights between 65 kg and 90 kg.

Example ration for medium-weight finishing pigs

Feed	DM level (in %)
Barley	40
Wheat	38
Soybean meal	11
White lupin	8
Minerals	3
Total	100

Parameter	Rate
ME Pig	13.05 MJ/kg DM
Crude protein	16.4 %/kg DM
Crude fibre	4.27 %/kg DM
Lysine	1.01 %/kg DM
Methionine & cystine	0.6 %/kg DM

Poultry

White lupin is also suitable as a poultry feed, both for layers and finishers. Here it saves growers considerable amounts of soybean extraction meal, because its crude protein content and amino acid digestibility is almost identical with those of soybean extraction meal. At the same time, it is necessary to supplement white lupin with minerals to make up for its low content of methionine and other sulphurous amino acids. White Lupin can make up to 10 % of layer and broiler diets and up to 25 % of turkey finisher diets.

Aquaculture

White lupin also makes a good fish feed, with lupin meal being suitable for feeding herbivorous as well as carnivorous fish and crustaceans. This way, traditional fish and soybean meal feed can be substituted for by lupin.

Being rich in crude protein and even richer in crude fat than other grain legumes, white lupin is suitable for use in animal feeds; on top of that, it requires no special treatment before it is ready for feeding. As mentioned, it is however necessary to supplement the essential amino acids methionine and cystine to cover animal requirements. Furthermore, it is advised to analyse the individual crop lots as they may vary substantially in nutrient levels.

Thomas Haubold
Manager, DSV Seed Breeding Station Leutewitz

"White lupin is an easy-to-manage crop. Its strong and deep taproot extracts water very efficiently from dry soils. In the drought years 2018 and 2019, the average white lupin yields were 44 dt/ha in our plots. And despite an enormously dry spring, we achieved yields of 35 dt/ha in 2020."

4.1 Varieties

FRIEDA

A protein super food

- High yields and high-quality protein
- Very high yield security thanks to anthracnose tolerance
- Tolerant to summer drought thanks to the deep taproot

CELINA

The protein queen

- TOP yield levels
- High quality-protein yields, preferably used as animal feed
- Local and GMO-free protein source

FRIEDA and CELINA are veritable protein miracles. Unlike soybean, they don't require hot climates and as such they are adapted much better to European climates and grow in many locations. Thanks to their unique anthracnose tolerance, the two white lupins provide a high yield security. The distinctive taproot makes the varieties tolerant to summer droughts. Depending on site conditions, the yield potential is between 20 dt/ha and 55 dt/ha. The average crude protein content is 32 % at 86 % DM. Inoculation with a rhizobium inoculum is recommended.

	Yields		Quality	
Variety	Grain yield	Crude protein yield	Thousand grain mass	Crude protein content
FRIEDA	6	7	7	3
CELINA	7	8	7	3

1 = very low
9 = very high

Source: BSL 2021, excerpt

Selected lupin growth stages and their BBCH codes

BBCH Code Definition

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

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

20 **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)

30 **Formation of side shoots**
31 6th leaf unfolded
33 7th leaf unfolded
35 8th leaf unfolded
37 9th leaf unfolded
38 10th leaf unfolded
39 11 and more leaves unfolded

60 **Inflorescence**
61 First flowers open
63 75 % of flowers open
65 First flowers change colour
69 All flowers withered

70 **Pod development**
71 First pods visible (pods longer than 2 cm)
73 75 % of pods visible
77 First pods have reached full size
(seeds clearly visible, pods are light green, "Moisture visible between the cotyledons")
79 75 % of pods reached full size

80 **Ripening**
81 Green maturity: no moisture visible between green cotyledons
83 First pods are brown
87 Yellow maturity: all pods are brown (seeds can be crushed between fingers, cotyledons are yellow)
89 Maturity: Seeds resist fingernail pressure

90 **Senescence**
92 Complete straw ripeness, shoot axes have dried

Source: https://www.terresinovia.fr/-/les-stades-reperes-du-lupin

White Lupin Brief

Site requirements	• Grows in all German climate regions • More demanding as to soil scores than blue lupin (at least 25 BP) • Grows on sites with pH below 7.3 • Low weed burden required
Sowing date	• At soil temperatures from 6 °C • Depending on the region, from mid-March to the end of April • Ploughing in autumn or spring in sufficiently dry soil • Min-till or direct seeding into well textured soils
Sowing depth	• 3 – 4 cm • Very deep seed depth will reduce yields significantly (epigaeic germination)
Seed rate	• 50 – 60 germinable grains/m² at 12 – 35 cm row spacings
Seed treatment	• Treatment with a rhizobium inoculum for lupins is recommended
Seeds	• **Use only certified seeds: Seed saving is prohibited by law.** This is to prevent the use of anthracnose-infested seeds.
Harvest and storage	• Harvest dates: Usually mid-August to mid-September • Lupin is ready for threshing when grain moisture is 13 – 16 %, (grains rustling in the pods) • Wide concave gap, minimum drum speed
Use	• Animal nutrition: For a balanced and optimum ration, observe the recommendations for white lupin percentages in feed rations and analyse for nutrients including alkaloid levels. • Human nutrition: Seek prior agreement with buyers on require-ments and nutrient levels incl. analyses (contract farming)
Mechanical weed control	• Intensive week control until canopy closure • Hoeing and/or harrowing • 2 – 3 blind harrowing passes before emergence (thread leaf stage of the weeds) • Harrowing at low speeds (approx. 2 km/h) • No harrowing between emergence and first leaf pair
Chemical weed control	• Ask for advice from public and private consultants • Registered herbicides are applied to pre-emergent broad-leafed weed (date: March 2022)

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