SUSTAINABLE SILAGE: PRACTICAL MANUAL FOR FARMERS 2025

Interreg

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Sustainable Silage

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1. Introduction

The current Common Agricultural Policy (CAP) of the European Union is largely focused on environmental protection, increasing biodiversity, nature conservation, and mitigating climate change. In this manual, we will mainly focus on forage production for cattle farmers. We will remind time-tested principles and enhance them with recent insights to ensure forage production that is as environmentally friendly and competitive as possible.

Silage production is a central component of sustainable and efficient livestock farming. Regardless of whether it's a small family farm or a large production unit, a dairy or beef cattle farm, the quality of silage directly affects animal health, productivity, and ultimately the farm's economic performance. This manual is the result of collaboration, bringing together decades of experience, practical knowledge, and science-based comprehension from neighbouring countries with long-standing traditions in forage cultivation and preservation. Researchers and advisors from Finland, Latvia, and Estonia, all familiar with various climate, soil, and farm types, have contributed their expertise.

Cattle farms in the Baltic Sea countries are diverse. For example, the technical solutions of a small family farm differ significantly from those of a large-scale farm. Yet, many principles of forage production apply in both cases. The fermentation process occurs in every silage pile, regardless of its size or the scale of the business. This manual focuses on specific recommendations required for successful forage production.

Modern silage production cannot be considered separately from environmental goals—or more accurately, obligations. Efficient use of resources, minimizing losses, and maintaining forage quality are crucial from both the economic and environmental standpoints. In an era of increasing scrutiny subjected to agriculture's environmental impacts, silage production plays a role in reducing nutrient loss, greenhouse gas emissions, and dependence on purchased feed. This requires attention at every stage of the production chain—from crop selection and mowing time to feed removal and waste management.

The central theme throughout the chapters is close cooperation between researchers, advisors, and practitioners. Many of the practices described are trial-and-error based, and have been over time further developed in the fields. The aim is not only to inform, but also to promote learning and dialogue among farmers, advisors, and scientists.

We hope this manual provides, in addition to practical guidance, a shared understanding of how modern silage management can support the economic viability of the farmer and environmental sustainability at the same time.

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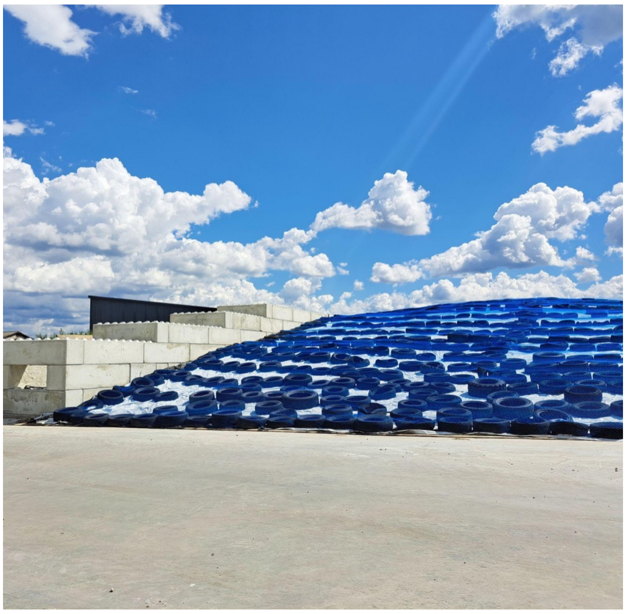
The following project partners have contributed to the manual: The Estonian Chamber of Agriculture and Commerce, the Centre of Estonian Rural Research and Knowledge, the Estonian University of Life Sciences, NGO Farmers Parliament of Latvia, the Latvian University of Life Sciences and Technologies, Pro-Agria Western-Finland and Natural Resources Institute Finland.

2. What is silage?

Author: Ieva Krakopa (Latvia)

Silage is a forage preservation method based on the ensiling process, which reduces pH and preserves nutrients, allowing long-term storage. While typically made from forage crops, silage can also include agricultural by-products and concentrates.

An anaerobic (oxygen-free) environment is crucial throughout the production and storage phases. Plant sugars are the main drivers of successful ensiling. In contrast, excess moisture and high nitrogen levels hinder fermentation. Therefore, good concentrations of sugars are needed and these can be achieved by good wilting, or certain dry matter content, if wilting is not possible.



Silage bunker. Photo by Kristiina Märs

Silage is a more economical conservation method compared to drying. It allows the preservation of a wider range of crops and materials. The most critical challenge in silage production is the maintenance of anaerobic conditions during production, storage and feeding. Proper silage-making improves nutrient availability for animals and reduces the need for additional concentrated feeds, thus being beneficial to a farm's economics as well as the environment.

Common silage crops include grasses, legumes, crop mixtures, whole cereal plants and maize. Additionally, maize cobs, wet grain, sugar beet pulp and wet brewers' grains can be effectively ensiled.

Silage bales. Photo by Ieva Krakopa

Advantages of silage:
» Cost-effective method for preserving forage nutrients
» Often produced locally, reducing the need for transporting feed
» Environmentally beneficial when managed properly

Disadvantages of silage:
» Highly sensitive to oxygen exposure
» Requires investment in packing and covering materials

Silage tunnel. Photo by Ieva Krakopa

Key takeaways

» Silage is an efficient, flexible and cost-effective method for preserving nutrients in forage and by-product materials.
» Success depends on the creation and maintenance of anaerobic conditions, the selection of suitable crops and on achieving the correct dry matter content.
» Proper silage management enhances animal nutrition and supports both environmental and economic goals.

3. Calculating the required amount of silage

Author: Kristiina Märs (Estonia)

The calculation of the required amount of silage should start from considering whether and how long you plan to pasture the animals. For example in Estonia, dairy cows are not usually pastured, young animals are kept in the yard comparatively rarely. On the other hand, meat animals spend 6 months in pastures, depending on the weather, and this must be considered when calculating the amount of silage. It is important to keep some silage in stock, so there is no need to open freshly made silage in June and the fermentation process can be completed as necessary. The recommendation is to keep up to 20% of the required amount of silage as a reserve for dairy herds; for meat animals, the reserve may be slightly smaller. The starch content of corn silage is important for animals. It is important to remember that starch needs to ferment in silage for some time to become digestible in the animal's stomach. Corn silage benefits must be produced so that new season silages can ferment for a minimum of 2 months, preferably for 4 months. If corn silage is very high in solids, it takes even longer (up to 6 months) for the starch to become digestible.

The amount of silage needed to feed the herd depends primarily on the proportion of concentrates in the ration and also on the dry matter content of the silage. In Estonia, the estimate is that the average dairy cow consumes 24-30 kg of dry matter per day. The farmers determine the proportion of how much dry matter do cows get as silage and how much as concentrate. In Estonia, it is estimated that in 365 days, roughage accounts for approximately 60% of the dry matter in a dairy cow's feeding ration (silage, straw and hay). Considering the average weight of a cow is 650 kg and the average feed intake is 3.5% of their body mass, the amount consumed is an average of 23 kg of dry matter per day, of which roughage dry matter could be about 60%. It amounts to 13.8 kg of roughage dry matter per cow per day, of which silage forms about 13.4 kg. This amounts to 4.9 tonnes of silage dry matter per animal per year. It is always reasonable to also consider a certain reserve (approximately 15% of the amount for fermentation loss and about 3% for possible rotten silage). In this case, the annual amount of silage dry matter required per animal is 5.6 tonnes.

Photo by Kristiina Märs

In addition to dairy cows, young stock of different ages must also be considered when calculating the total silage requirement. The amount needed depends significantly on the rearing system and feeding strategy used. Therefore, the recommendation is to estimate silage needs for young stock separately, based on actual feeding plans, rather than using a fixed conversion factor.

The silage requirement for beef cattle varies greatly depending on the breed. The feed consumption need for Scottish Highland cattle is significantly lower than for Charolais. The simplest rule of thumb for beef cattle is that the animal eats 2% of its body weight of dry matter per day. Thus, an animal weighing 500 kg consumes 10 kg of dry matter per day. If the dry matter of the silage forms, for example, 33%, then an animal weighing 500 kg needs to eat 30 kg of silage with such dry matter.

Since most beef cattle farmers use the bale silage production technology, they calculate the required amount of silage in bales.

For example: Aberdeen Angus are pastured (weather permitting) on grasslands from the beginning of May to October. Therefore, 6 months of silage stock is required. Assuming that the dry matter of the silage is about 30-35%, the herd of Aberdeen Angus will consume 10 bales (500 kg/bale) of silage per animal during this period.

When calculating the required amount of silage, we need to take into account possible damage to some silage rolls due to silage film damage caused by birds, and the possibility that storage silos may need to remove the damaged surface layer or edges. In addition, there may occur some dry matter loss during fermentation. Therefore, a loss of about 15% of the quantity is to be considered during silage production.

Photo by Kristiina Märs

Calculation of the field area for silage production

The calculation of the field area required for fodder production very much depends on the soil type, mixture of grasses and fertilization plan. The type of farm – organic or conventional – also plays a role. In organic farms, grasslands are usually not fertilized with mineral fertilizers, and as a result, more land is needed to feed the herd, and it is also the reason why it has a low grass mass yield per hectare.

The type of fodder crops grown as well as the weather play a role here. The summers are increasingly drier and the growth of plants is hindered by the lack of water, which affects the grass the most and their yield can be significantly reduced. Alfalfa is the most abundant and provides a strong yield per hectare. When choosing a seed mixture, you should definitely consider the characteristics of the region and soil pH.

Photo by Kristiina Märs

The general rule is that a dairy farmer needs a maximum of 1 ha of cultured grassland per animal. If corn silage is used in the feed ration, it may be possible to manage with less land per animal under favourable conditions. The average corn silage yield per ha is about 32-35 tonnes (KA >28%).

Table 1. Average yields for the main grassland silage crops

Silage culture	approximate dry matter yield t/ha	Area of cultivated grassland required to produce 1000 t of wilted silage, ha
Red clover (mixed with grasses)	5-7	50
Alfalfa (mixed with grasses)	6-8	45
Italian ryegrass (mixed with other grasses)	6-8	40
Annual ryegrass	7-8	40

Calculation of the field area for corn silage

The green mass yield for corn in Estonia is in the range of 25-60 t/ha. On average, 35 t of corn silage per hectare is stored, and its dry matter content is between 27-30%. A typical feed ration in Estonia contains approximately 50% concentrate and 50% silage, of which corn silage and grass silage make up half. When feed is composed purely of grass silage, 5 t of dry matter per dairy animal per year should be stored, which amounts to 15 t of real silage with a dry matter content of 30-32%. For a dairy animal with offspring, the actual quantity of silage needed is 17 tonnes. When feeding 50% of this as corn silage, the quantity of silage per animal per year should amount to 8.5 tonnes of corn silage and 8.5 tonnes of grass silage, and 10% extra should be added to this.

Key takeaways:

- A dairy animal needs 4.9 tonnes of dry matter silage per year, assuming that the animal weighs an average of 650 kg and that its feed intake is 3.5% of its body weight.
- It is always reasonable to also include a certain reserve (approx. 15% of the amount, of which approx. 3% is for fermentation losses and the rest is for the possible spoilage of the silage). In this case, the annual amount of silage dry matter required per animal should be 5.6 tonnes.
- From an environmental perspective, it is important to prepare the planned amount of silage very carefully and use the technology of wilting in order to reduce the amount of spoiled silage and the impact of its disposal on the environment.

4. Plant species for silage production

Authors: Sirje Tamm, Priit Pechter (Estonia), Anu Ellä (Finland), Iveta Gutmane (Latvia)

Forage production is facing new challenges in the changing climate. Rising temperatures, changing precipitation patterns and increasing drought frequency are all reducing crop yields, which is a growing concern for farmers. Climate directly influences winter-time survival by determining the intensity of environmental impact, such as freezing temperatures and snow coverage, while also indirectly affecting resilience of plants.

In addition to these climatic changes, the diversity of soil properties also influence forage production. Soils vary widely by humus content, moisture maintenance, texture and nutrient levels, and also by the significant presence of peat soils. These variations determine the need for the use of different plant species in pure or mixed sowing to optimize productivity and maintain soil health. To ensure optimal growth and winter survival, it is preferable to choose plant varieties that are local or have been tested under local conditions. These varieties are more likely to adapt to the specific climate, soil type and farming practices of the region, thereby increasing the chances of successful forage production and winter survival.

4.1. Legume forage grasses

In grasslands, forage legumes are the most protein-rich plant group, followed by grasses in terms of nutrients. Forage legumes are highly palatable and provide abundant protein, calcium, phosphorus and essential vitamins for livestock. Perennial forage legumes include cultivated red, Alsike and white clover, alfaalfa, birdsfoot trefoil, and to a lesser extent, galega.

Red clover (*Trifolium pratense L.*)

Red clover sward. Photo by Sirje Tamm

Red clover has a high yield and feeding value for silage; it is a short-term crop, with a typical lifespan of 2-4 years. Red clover performs best on well drained, fertile soils; the best soil pH is 6.0–6.5. Thin loamy soils and floodplain soils with long-term flooding as well as acidic sandy soils and well-decomposed peat soils are not suitable for its cultivation. For better resistance, avoid heavy machinery in wet weather, because these will directly damage the plants by splitting or breaking the plant crowns.

Red clover flower. Photo by Sirje Tamm

Varieties are classified as follows:
By flowering date (early or late) – early varieties will begin flowering in the middle of June and late varieties about 16–17 days later. Early flowering varieties start their growth earlier in the spring, providing approximately 40% of the annual yield from the first cut, with progressively lighter yields in subsequent cuts. The early flowering red clover is somewhat more drought resistant than the late type, because it develops faster in the beginning of growing and uses soil moisture in the spring much better. The late red clover tends to lodge more easily when growing lushly, thus reducing the forage value (due to lower leaves falling off and rotting) and making harvesting more difficult. However, the late red clover varieties are more winter hardy compared to the early red clovers.

By ploidy (diploid or tetraploid) – tetraploid varieties often provide larger plants with larger leaves, stems and flowers. However, tetraploid varieties tend to be more persistent and disease resistant than diploid varieties.

The sowing rate for pure stands is 15 kg/ha.

Alsike clover (*Trifolium hybridum* L.)

Alsike clover sward. Photo by Sirje Tamm

Alsike clover is a short-lived perennial that will last for 2–3 years. Alsike clover does not tolerate droughty locations but can thrive in soils that are completely waterlogged and can withstand spring flooding for up to 6 weeks. Alsike clover will grow better on wetter and more acidic soils than other clovers, including red clover. Aliske clover is one of the few leguminous grasses that survives in a herbage established in the stand on peat soils. It will grow at a lower pH than the other clovers and was formerly used to avoid 'clover sickness', which was caused by red clover being grown too frequently. Alsike clover is resistant to many diseases. Most crop losses of the Alsike clover can be minimized by management practices that maintain a vigorous stand. The regrowth of the Alsike clover is slower than that of the red clover, but this also largely depends on the time of the first harvest. Harvesting the first cut during the flower bud formation phase and cutting slightly higher than usual promotes vigorous growth. Its special feature is that the leaves do not fall or break easily during harvesting, and in addition, the green mass dries faster than the red clover. It is less edible than the red clover (the plants have a bitter taste) and has a lower nutritional value. However, when mixed with other crops, the edibility improves.

The sowing rate for pure stands is 9 kg/ha.

White clover (*Trifolium repens L.*)

White clover sward. Photo by Sirje Tamm

White clover is a perennial legume with a prostrate and stoloniferous growth habit. The common white clover seldom grows tall enough to be harvested purely for silage, but it helps to fill voids in the sward, which would otherwise be filled with weedy species. White clover is an excellent component in crop mixes, because it has a high nutritional value due to the low proportion of structural fibres and its high protein content. White clover has the advantage of retaining high digestibility throughout the season because of its continual renewal of leaves and petioles.

White clover grows well on wet soils and persists far better on these soils than the red clover. It will also perform well on lighter soils, but it should not be sown in deep sands. It does not like very acidic soil, but will grow in soils with a pH of up to 5.6.

White clovers are classified into different groups of small-, medium- and large-leaf types. The small-leaf types of clovers have low productivity. Large-leaf or ladino white clovers are larger leafed and grow more upright, and are thus more productive than other white clover types, but not as persistent as other leaf types of clovers. The medium-leaf types typically reseed more reliably than ladinos, and produce more forage than the small-leaf types.

The sowing rate for pure stands is 12 kg/ha.

Lucerne or alfalfa (*Medicago sativa* Mart.)

Lucerne sward. Photo by Sirje Tamm

Lucerne is a persistent perennial, which will last for 5 or more years. It is a deep-rooting crop, which can sustain dry matter production at times of low rainfall.

The choice of fields is important for lucerne, because it does not tolerate acidic soils. The minimum pH must be 6.0 for root nodulation to take place. Also, it does not tolerate a waterlogged soil, which is commonly the cause of plants dying over winter. Lucerne is characterized by a deep root system (more than 1.5 m), so the recommendation is to avoid growing it in places with a high groundwater level. The insufficient development of the root system affects the wintering and longevity of lucerne plants.

Ice sheeting can have a lethal effect on lucerne stands. Suitable soil types range from clay loam to limestone. The winter resistance of lucerne is one of the most important features for the Baltic and Nordic countries.

Lucerne plant. Photo by Sirje Tamm

The varieties are classified as winter (fall) dormant and non-dormant.

Dormancy is determined by the amount of regrowth produced in the autumn. It is generally measured on a scale 1 to 10, where the rating of 1 means "very winter dormant", expressing no winter growth, and 10 means non-dormant, expressing high winter activity with high regrowth potential. More dormant varieties could survive better in the Nordic-Baltic winter conditions. Growth reduction in the late summer or early autumn, which is triggered by a shorter photoperiod and lower temperatures, is generally recognized as the initial stage of winter hardening in alfalfa. On the other hand, varieties with a high dormancy index provide a higher potential yield. Alfalfa growers will always have to choose between high yield and good winter hardiness. Therefore, farmers are advised to choose local varieties or varieties tested in local conditions.

The sowing rate for pure stands is 20 kg/ha.

Bird´s foot trefoil (*Lotus corniculatus L.*)

Bird's foot trefoil sward. Photo by Sirje Tamm

Bird´s foot trefoil is characterized by good adaptability to different soil and climate conditions, but grows best on a soil with a pH ranging from 6.2 to 6.5 or above. It tolerates wet acidic soil (pH = 4.5) and presents some drought tolerance. It can withstand some soil salinity. It thrives in places, where alfalfa and other forage legumes cannot grow due to soil acidity and moisture content. Bird´s foot trefoil has no tolerance for shade, particularly during the early stages of establishment, and should be sown with slow-growing companion grasses.

Bird´s foot trefoil is a good quality forage crop with a high protein content (15–28% DM). It is high in nutritional value, similarly to *Medicago* spp. and *Trifolium* spp or even higher. Bird´s foot trefoil contains tannins that prevent the cause of bloating in ruminants. The concentration of condensed tannins varies between varieties, particularly in leaves, but increases with maturity and fluctuates between seasons. The condensed tannins in bird´s foot trefoil elicit reductions in CH_4 emissions and urinary N in dairy cattle. It is a bioactive forage legume, which can improve protein utilisation in ruminant livestock. These legumes can also combat parasitic nematodes.

The sowing rate for pure stands is 15 kg/ha.

Galega (*Galega orientalis* Lam)

Galega sward. Photo by Heli Meripõld

Fodder galega (*Galega orientalis* Lam.) is a highly productive, persistent and high-yielding crop, which is rich in nutrients, particularly crude protein. It presents good winter hardiness, but does not tolerate still surface water, high groundwater levels or acidic soils (with a pH value below 6.0); on the other hand, it thrives in poor, rocky and dry soils.

Currently, fodder galega is not affected by any significant fungal, viral or bacterial diseases, nor is it susceptible to insect or nematode pests. To ensure the successful cultivation of galega, its seeds should be inoculated with the specific nodule bacteria *Rhizobium galegae* before sowing. Galega exhibits very slow initial growth in the sowing year. In the harvest year, galega develops early in the spring and grows rapidly, making it vulnerable to late frosts in June.

Unlike other legumes, its leaves do not become brittle or fall off during silage production.

However, it can also present significant challenges, as it has the potential to become invasive. Its introduction should be carefully managed, and ongoing monitoring is essential to mitigate any negative environmental impacts.

The sowing rate for pure stands is 20 kg/ha.

4.2. Grasses

The importance of grasses as forage crop is based on their biological and economic properties: their high tillering capacity, good aftermath growth and high yield potential. Compared to forage legumes, grasses typically present lower protein content, less positive effect on soil fertility, and require substantial nitrogen fertilization when cultivated on mineral soils. Grasses exhibit greater resistance to winter conditions, diseases and adverse growing environments, and generally have a longer lifespan than forage legumes.

Grass species are grouped on the basis of height at which the main biomass is located above ground:

» **Tall grasses**, in which the yield is dominated by long shoots (e.g. timothy, meadow and tall fescue, Italian ryegrass, cocksfoot, reed canary grass and smooth brome).
» **Low grasses**, which form numerous basal leaves. The biomass of low grasses is concentrated near or at the ground level, primarily in the form of basal leaves (e.g., Kentucky bluegrass, red fescue and perennial ryegrass).

4.2.1. Tall grasses

Timothy (*Phleum pretense* L.)

Timothy plant. Photo by Sirje Tamm

Timothy is a sparsely tufted tall grass with good yield potential as a forage crop. It grows well on loamy sand, sandy clay and clay soils with favourable moisture conditions, as well on moderately and well-decomposed peat soils. It also thrives on temporarily waterlogged, medium-depth clay and sandy soils, poorly decomposed peat soils and floodplain soils. Timothy does not persist long on nutrient-poor, acidic or low-water-content soils. It prefers a soil with the pH of 5,5–7,0.

Timothy is usable for 5-6 or more years. Its competitive ability in mixtures is strong in the first few years, and it tolerates companion crops well.

When harvested in time, Timothy presents good palatability and a high nutritional value. Timothy is harvested for silage at the end of the stem elongation phase or during the booting stage. The forage nutritive value decreases rapidly during the period of spring growth, which is typically used for first-cut silage. Timothy does not tolerate frequent cutting, and it is more suited for a two-three cut system. Its regrowth is weak to moderate, depending on precipitation and nitrogen availability. Air temperature and water stress are predicted to increase in the near future, and these could further reduce timothy's regrowth. An air temperature increase of 2 to 3°C could negatively affect the productivity and the nutritional value of timothy (Bertrand et al., 2008). These changes may reduce the advantages of timothy over other forage grass species.

The good winter hardiness of timothy makes it the most suitable grass species in the more Northern areas.

The sowing rate for pure stands is 10 kg/ha.

Meadow fescue (*Festuca pratensis* Huds.)

Meadow fescue is a sparsely tufted tall grass with abundant basal leaves. Its persistence is shorter than that of timothy. It appreciates high soil moisture content, but can be grown successfully on a wide range of soils. On dry soils, as well as on occasionally or permanently waterlogged soils, it only provides a moderate yield. On thin clay soils, sandy soils and poorly decomposed peat soils, the yield is low. It is quite demanding in terms of soil aeration. Temporary high groundwater levels and flooding do not harm it, but still surface water for a prolonged time and a thick ice layer can be damaging. Meadow fescue is quite resistant to spring frosts on marsh meadows.

Its early spring growth yield is good and regrowth consists mainly of leafy shoots, which is ideal for forage use. The regrowth is satisfactory even during drought periods when herbage is provided with sufficient nutrients. In comparison with timothy, the regrowth of meadow fescue is greater, because it tolerates drought better.

Meadow fescue is harvested for silage during the stem elongation or booting stage. Meadow fescue surpasses timothy by palatability and nutritional values, but remains inferior to perennial ryegrasses. In comparison with tall fescue, the meadow fescue presents superior neutral detergent fibre digestibility and it is much more palatable, on the other hand, tall fescue presents slightly better regarding yield.

Meadow fescue's competitive ability in mixtures is modest, but it is a good companion to timothy. Meadow fescue also tends to require less nitrogen than ryegrass.

The sowing rate for pure stands is 25–30 kg/ha.

Tall fescue (*Festuca arundinacea* Schreb.)

Tall fescue is a persistent, long-lived, high yielding and deep-rooted tall grass, which sometimes forms very short underground shoots. It is a highly adaptable species that grows on various mineral and peat soils of different acidity, but it does not tolerate flooding. It is also one of the most drought tolerant species. Tall fescue is a possible alternative to timothy because of its tolerance to recurring drought periods. Tall fescue will even grow fairly well in soils of low fertility, but it is better adapted to fertile conditions.

Tall fescues originally had very tough leaves and were not well consumed by animals. Forage conservation processes have been found to decrease leaf toughness, being highest in pasture, intermediate in hay, and lowest in silage. Breeding activities have led to softer leaves as well as higher yielding varieties with significantly improved palatability and digestibility.

Its regrowth is fast, but after the first cut, it tends not to form new stems, but only provide vegetative growth of broad, shiny and upright leaves.

Tall fescue is typically lower in crude protein than other grasses, except for timothy. However, it is similar in fibre concentration and quality, making it suitable for dairy cow rations. That is why it may be a good fit as a silage crop in a mixed stand with alfalfa.

When growing tall fescue for forage in pure stands, it should be considered that many varieties contain a harmful fungus called endophyte. While endophytes can be enormously beneficial to the plant by making them much more resistant to stresses, they can also be toxic to animals. This fungus makes the plants less palatable and causes stress to animal performance and health. Endophyte-free tall fescue varieties are available.

Endophyte remains in stored forages even after harvest and drying for hay. While the endophyte might not remain viable, it can be detected by an antibody method. The concentration of alkaloids present in these forages are of greater significance than the viability of the endophyte. In silage, alkaloids remain relatively stable and toxic during storage. There is evidence that alkaloid concentrations may decrease during haymaking, especially if the hay is ammoniated. The detection of endophytes in stored forages using microscopy or antibodies is difficult, and its potential toxicity is usually tested by measuring the concentration of ergovaline using HPLC. When using tall fescue in mixtures with a concentration of < 30%, the effect of endophytes and alkaloids in forage is negligible.

The sowing rate for pure stands is 25–30 kg/ha.

Italian ryegrass (*Lolium multiflorum* Lam.)

Italian ryegrass has a bunchy form, with numerous long, narrow, stiff leaves near the base of the plant. Italian ryegrass is quite similar to perennial ryegrass, except it is annual or biennial, depending on climate and/or the length of growing season. It may grow a little taller than perennial ryegrass.

It requires nutrient-rich, moderately moist soils with a neutral pH. It does not tolerate high groundwater levels, acidic soils and it has low drought, cold and frost resistance. Like perennial ryegrass, Italian ryegrass cannot withstand harsh winters. Overwintered Italian ryegrass begins growing early in the spring, and its intensive vegetative growth lasts until late autumn. In mid-summer, the productivity of Italian ryegrass is better than that of most other grass species, including perennial ryegrass. Its regrowth is rapid. Ryegrasses have higher nutrient quality than other grasses of the same maturity. Italian ryegrass provides excellent forage quality, with highly digestible energy, relative forage quality and palatability. It responds to fertilization with a significant increase in yield. If fertilized with nitrogen, its crude protein levels are much higher than many other grass species.

Italian ryegrass can be included in seed mixtures to accelerate the formation of a grass sward and increase the quantity of high-quality forage in the seeding year. In the Baltic countries, it is not recommended to include Italian ryegrass in perennial mixtures in a concentration of more than 30% due to its poor winter hardiness, to avoid rapid sward thinning in the following years.

The sowing rate for pure stands is 30 kg/ha.

Cocksfoot (*Dactylis glomerata* L.)

Cocksfoot is a strongly tufted, deep-rooted, productive long-lived tall perennial grass. It grows well on soils with favourable moisture conditions and temporarily waterlogged soils. On peat soils, the yield is unstable, as cocksfoot is affected by late spring frosts. Cocksfoot does not tolerate freezing, high groundwater levels, still surface water or flooding. It is not frost-resistant in winters with little snow.

Its growth starts very early in the spring, its regrowth after cutting is rapid and consists mostly of leafy palatable shoots. When harvested in time, its palatability and nutritional value are only slightly lower than that of meadow fescue. During droughty summers, cocksfoot´s forage production is greater than that of other forage grasses.

Cocksfoot utilizes nitrogen fertilizers very efficiently, and in soils with sufficient nitrogen reserves, cocksfoot surpasses other species in the sward and becomes dominant. Cocksfoot is shade tolerant and is an ideal companion grass for legumes in mixed permanent grasslands. For silage, it is suitable for mixed sowing with alfalfa (*Medicago sativa* L.) or red clover (*Trifolium pratense* L.).

The sowing rate for pure stands is 20 kg/ha.

Reed canary grass (*Phalaris arundinacea* L)

Reed canary grass plant. Photo by Sirje Tamm

The reed canary grass (*Phalaris arundinacea*) is a rhizomatous forage plant. It thrives well in decomposed peat soils, humus-rich, nutrient-dense mineral soils with moving groundwater, and floodplain soils. It is not well suited for dry, drought-prone, or humus-poor acidic soils. It is a drought-tolerant, frost-resistant, and cold-hardy species. Reed canary grass prefers a soil pH range of 5.5 to 7.5, with an optimal range of around 6.0 to 7.0.

As a typical meadow species, reed canary grass is commonly cultivated in permanent grasslands. Its competitive ability in mixtures is moderate during the first few years. After sowing, it develops relatively slowly, growth starts early in the next spring and it is rapid. When harvested at the optimal time (during the booting stage), reed canary grass has a good palatability and high nutritional value. The yield of regrowth is moderate to large.

Under favorable conditions, reed canary grass tends to outcompete other species, including weeds, and can become dominant in a sward. The nutrient enrichment, particularly through nitrate-nitrogen from agricultural runoff, enhances habitat suitability for *Phalaris arundinacea* and contributes to its increasing dominance. Too low or frequent mowing reduces subsequent yields and the persistence of the plants.

The sowing rate in pure stands is 15 kg/ha.

Smooth bromegrass (*Bromus inermis* L.)

Smooth bromegrass sward. Photo by Sirje Tamm

Smooth bromegrass is a long-lived, creeping tall grass. It is not demanding in terms of soil fertility but is sensitive to soil aeration. Thin, sandy, clayey and poorly decomposed peat soils are poorly suited for its growth. The species is highly resistant to cold, frost, flooding and is also tolerant to drought. Smooth bromegrass grows best in soils with a pH range of 6.0 to 7.5.

In mixtures, the competitiveness of smoot bromegrass is weak during the first few years, but later it becomes dominant in suitable growth conditions. When harvested at the boot or early heading stages, it is a highly palatable and nutritious forage plant. Its regrowth is rapid, even under drought conditions.

The sowing rate in pure stands is 38 kg/ha.

4.2.2. Low grasses

Perennial ryegrass (*Lolium perenne* L.)

Perennial ryegrass is a low-growing tufted low grass with a bunching growth habit. It grows well on humus-rich, lighter-textured mineral soils. It is not suitable for dry clay, peat, sandy or waterlogged floodplain soils. Perennial ryegrass does not tolerate high groundwater levels, acidic soils or companion crops. It has weak drought, cold, and frost resistance, and it does not withstand severe winters. Perennial ryegrass thrives best on fertile soils with a pH between 5.5 and 6.5. For good production, it requires high fertility levels, particularly with nitrogen fertilizers. Perennial ryegrass has very strong tillering ability and rapid regrowth. In drought conditions, perennial ryegrass regrows numerous stems.

Its forage has a very high nutritional value, high sugar content, and good palatability.

Perennial ryegrasses may be either diploid or tetraploid. Generally, the diploid varieties are used in grazing leys. Tetraploid varieties tiller less than diploids, and for this reason, tetraploids should be used more in silage leys. Ryegrass winter hardiness is highly variable among varieties, but typically not very good in the more Northern parts (Finland).

The sowing rate for pure stands is 30 kg/ha.

Kentucky bluegrass (*Poa pratense* L.)

Kentucky bluegrass is a perennial, sod-forming creeping rooted low grass. It thrives in well-drained loams or clay loams rich in humus, particularly those with limestone parent material. It is sensitive to drought, excessive flooding, high water tables and poorly drained soils. However, on fertile soils it demonstrates moderate resistance to frost, freezing, and drought. The optimal soil pH for growth ranges from 5.8 to 8.2. Under favorable growing conditions, the Kentucky bluegrass can become dominant, although its dominance may reduce the overall forage quality of the grassland. In meadows, its yield potential is low to moderate, and its persistence in mixtures is weak during the initial years. The species responds well to nitrogen fertilization and provides rapid regrowth after cutting. The Kentucky bluegrass, although not a typical silage species, is recommended for use like the red fescue, to be included in grass seed mixtures used to establish cultural pastures on peat soils, where it helps to increase the trampling resistance of the sward.

The sowing rate for pure stands is 13 kg/ha.

Red fescue (*Festuca rubra* L.)

Red fescue is a rhizomatous or tufted low grass species. It grows in a variety of soils, but prefers moderately moist sandy loam, silty clay, and temporarily waterlogged floodplain soils. Red fescue is highly resistant to freezing and cold. Red fescue is a relatively slow-growing species that tolerates soils low in fertility, ranging from acidic to slightly alkaline (pH 4.5-7.5). It can be moderately quick to germinate from sowing, but being a relatively slow-growing grass, it develops more slowly compared to ryegrass.

The red fescue's abundant root system, along with the extensively branched underground rhizomes (in stoloniferous subspecies), is primarily located in the upper soil layer. Therefore, it is recommended to be included in grass seed mixtures for establishing cultural pastures on peat soils, where it helps increase the trampling resistance of the sward.

Red fescue starts growth early in the spring, generally slows in growth in mid-summer, and grows vigorously from late summer until freezing. Growth during the summer is dependent on precipitation.

In meadows, red fescue tends to yield relatively poorly. On nutrient-rich soils, it struggles to compete with the Kentucky bluegrass. Due to vigorous tillering, red fescue forms a dense and strong sward that tolerates low, but not frequent, mowing. In older grasslands, it can become dominant. When red fescue constitutes more than 40% of the sward, particularly on peat soils, its palatability significantly decreases, as the basal leaves tend to mold. Compared to Kentucky bluegrass, red fescue has lower palatability and nutritional value, but its regrowth rate is satisfactory. It is often used as a component in seed mixtures, especially in areas with limited suitability for cultivation or in peat soils.

The sowing rate for pure stands is 16 kg/ha.

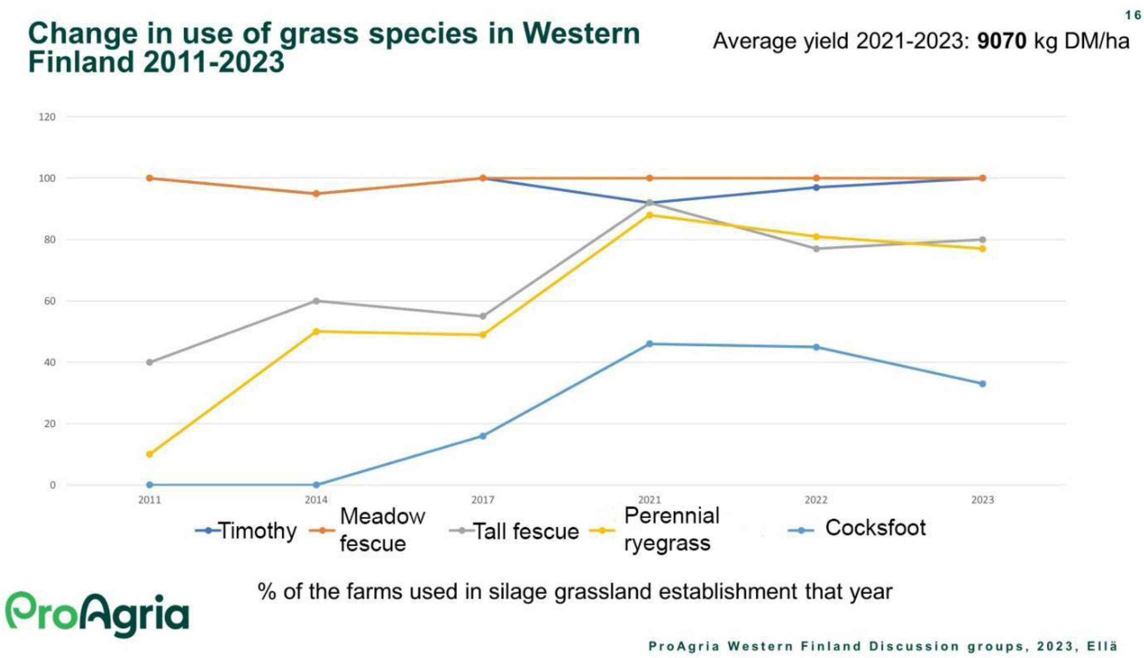
Selecting the appropriate forage grass for specific soil types is crucial for optimizing pasture productivity and sustainability. Table 1 provides an overview of various forage grasses and their preferred soil conditions.

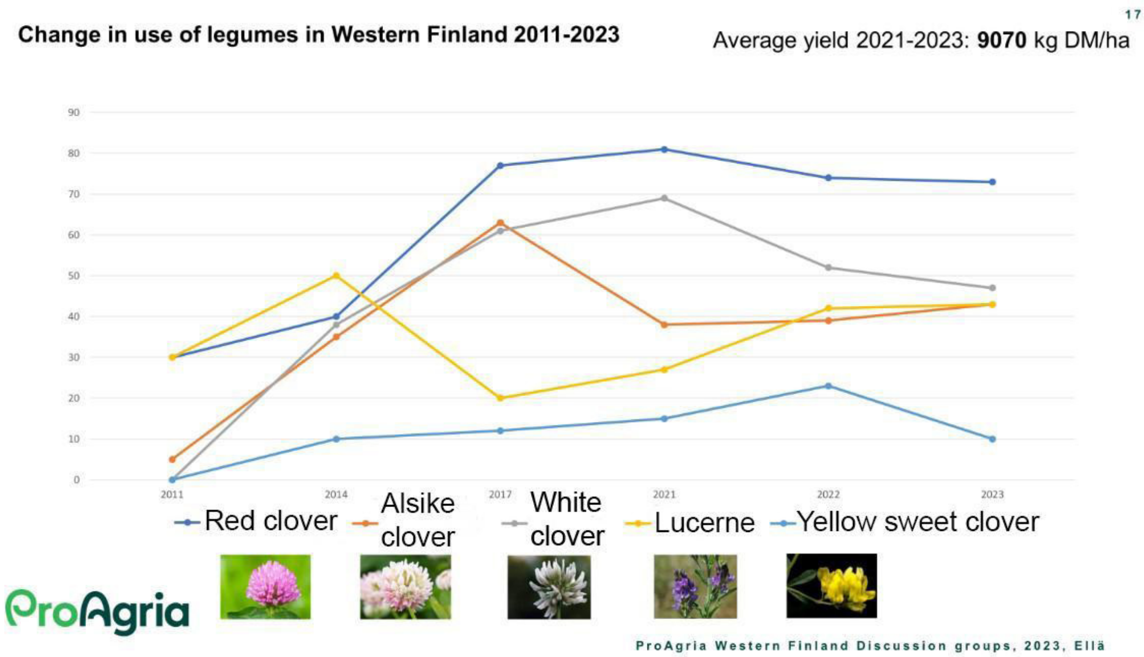
Table 1. Suitability of soil types for different species

Species	Soil pH	Dry sandy soils	Dry gravel loamy soils	Temperate mineral soils	Floodplain	Peat soils
Forage legumes						
Red clover	>5.5	-	××	×××	–	×
Lucerne	>6	××	×××	×××	–	–
Alsike clover	>5.5	××	××	×××	××	××
White clover	>5.5	-	×	×××	××	×
Bird´s foot trefoil	4.5-7.0	××	×××	×××	×	-
Galega	>6	×	×××	×××	-	-
Grasses						
Tall grasses						
Timothy	5.5-7	×	××	×××	×	×××
Meadow fescue	5.0-7	-	-	×××	×	×××
Tall fescue	5.5-6.5	××	××	×××		
Italian ryegrass	>6.5	-	-	×××	-	-
Cocksfoot	5.5-7.5	×××	×××	×××	-	-
Reed canary grass	5.5-7.5	-	-	××	×××	××
Smooth brome	6.0-7.5	x	××	××	××	×××
Low grasses						
Perennial ryegrass	5.5-6.5	-	-	×××	x	
Kentucky bluegrass	5.5-8.2	×	×	×××	××	×××
Red fescue	4.5-7.5	××	×××		×××	

Not suitable; Suitability – × slight; ×× moderate; ××× successful

The next graphs illustrate the changing trends in the use of different forage grass species in silage grassland establishment in Western Finland from 2011 to 2023. Timothy and meadow fescue remain dominant, but tall fescue is gaining ground. Red clover remains the dominant legume, likely due to its high yield and nitrogen-fixing benefits. Increasing interest in alfalfa suggests farmers are exploring more drought-resistant options. Future trends could be influenced by climate resilience, nitrogen efficiency and farmer preferences for durability versus yield potential.





Environmental impact

Forage legumes are widely used to enhance forage yields and quality. Through a symbiotic relationship with specific strains of bacteria, legumes can fix their own nitrogen (N). The bacteria supply nitrogen to the plant, while the plant provides carbon (C) to the bacteria. These bacteria attach to the plant, forming nodules. Compared to grasses, legumes typically have higher crude protein (CP) levels, ranging from 15% to 25%. They can also produce up to 280 kg/ha of nitrogen (N), contributing significantly to soil fertility.

The taproot of legumes has an important role in soil aeration. Legumes typically have deep taproots that penetrate the soil more effectively than plants with shallow root systems. This helps create channels or spaces in the soil, allowing air (and oxygen) to reach deeper layers of the soil that might otherwise become compacted and oxygen-deprived.

That all makes legumes a valuable crop for maintaining soil health.

4.3. Mixtures of species and principles of mixing

When establishing grassland, mixed sowings offer several advantages over single-species sowings:

- » The lifespan of many species is extended.
- » Winter hardiness is improved.
- » The stands remain free of weeds for a longer period.
- » The damage from plant diseases is reduced.
- » It ensures a more stable and higher yield over time.
- » The nutritional value of the forage is higher.

There are several principles to keep in mind to ensure high-quality forage, maximize yields, and balance nutritional content. The selection and proportion of grasses suitable for grassland are determined based on soil type (clay, loam, sandy or limestone), speed of growth and development and regrowth rate etc. The selection and proportioning of species for the mixture prioritize those best suited to the specific soil and moisture conditions. A typical mix for silage can range from 30% to 70% legume content, depending on the desired protein levels and quality of the silage. Higher legume content provides more protein, but may result in lower dry matter yields, while a grass-heavy mix may produce more fibre- and energy-dense silage. Each selected grass and legume in the mixture should have a specific purpose. When choosing mixtures with a high proportion of legumes, it should be taken into account that the ensilaging process will need more attention. A high legume content may result in higher biomass moisture (if the wilting is not done with sufficient quality) and silage effluent afterwards.

Grass species are suited to various environmental conditions differently, but most of these prefer moderately heavy, semi-humid, fertile soils. Legumes are more demanding regarding their growth environment than grasses.

Grasses are categorized based on their growth and development speed (according to the phases of heading and flowering) as follows:

» early-maturing – cocksfoot, galega,
» intermediate-maturing – alsike clover, early type lucerne, red clover, white clover, Italian ryegrass, reed canary grass, smooth bromegrass, Kentucky bluegrass, perennial ryegrass, red fescue,
» late-maturing – bird´s foot trefoil, late type red clover, meadow fescue, tall fescue, timothy.

The growth and development rate of grasses can be regulated by selecting early-maturing and late-maturing varieties to the mixture. The maturing time of each species may of course vary in each country.

It is important to consider that the optimal harvesting period for grass stands with uniform growth rates lasts 3 to 5 days. Legumes tend to establish slower than grasses, so it's important to ensure that grasses don't outcompete legumes, particularly in the early stages. The selected species and varieties in the mixture should provide the highest nutritional yield during this period. Grassland mixtures typically contain 3 to 4 different grass species. The harvesting time is determined on the basis of dominant species. In mixed sowings, forage legumes primarily improve the nutritional value and increase the yield. Legume-to-grass ratio of 60:40 or 70:30 can often help balance early growth with long-term sustainability.

The species of companion grasses for red clover should be selected based on the expected duration of the sward in the crop rotation. For a two-year duration, Italian ryegrass or hybrid ryegrass is recommended. For three or more years, perennial ryegrass or hybrid ryegrass should be used. Tetraploid perennial ryegrass varieties are highly suitable as these generally have a more open growth habit and are less competitive than diploid perennial ryegrass varieties. The grass heading date should be matched with the budding or the beginning of the flowering phase of the red clover to ensure optimal silage quality. White clover can also be included in the seed mix and may become dominant as red clover declines after 3 to 4 years. For silage swards, large-leaf white clover varieties are preferred. One of the key advantages of white clover is its slower decline in nutritional quality during the ageing process compared to grasses.

It has previously been reported that the presence of timothy can improve red clover's persistence. When a winter was unfavourable to legumes, then in the following spring, the red clover population was higher in populations mixed with timothy in comparison with a pure clover population.

The traditional timothy/fescue silage leys in Finland are hardy enough to stand up to harsh winters and deep snow, followed by intense, hot summers, but often lack any 'bottom', leaving lots of bare soil between each plant.

Grass species differ from legumes in their competitiveness. This will influence the grass-to-legume ratio of an established stand. Grasses such as orchard grass and the ryegrasses tend to be more competitive with alfalfa than timothy or meadow fescue. The lucerne and tall fescue mixture also represents a possible alternative – its lower nutritive value is compensated by its slightly greater yield. The Table 2 categorizes species based on soil type and maturity stage, ensuring optimal species selection for various conditions.

Table 2. Grass seed mixtures for different soil types, seeding rate kg ha^{-1} *(Adamovičs A., 2017)*

Species	Mineral soils												Peat soil			
	light soil				medium heavy soil				heavy soil							
	early	early	middle	late	early	early	middle	late	early	early	middle	late	early	early	middle	late
	temp.	perennial			temp.	perennial			temp.	perennial			temp.	perennial		
Red clover (early)	12	3								11	4					
Red clover (late)				3				6	12			5				1
Alsike clover			20										12	6	4	4
White clover																
Alfalfa			10		22					6	7					
Galega						12	8									
Cocksfoot		15				5										
Reed canary grass														10		
Meadow fescue	4		5		6	4	10	3		1	5	3	9		8	6
Tall fescue														6	10	
Smooth bromegrass		7		16		6		4			10	5				
Timothy	2		3	6	2		6	10	8			10	3		4	10
Perennial ryegrass	4				2		3	4	6		3	5				
Red fescue		2		3			3								2	2
Kentucky bluegrass														4		
Total, kg	**22**	**27**	**38**	**28**	**32**	**27**	**30**	**27**	**26**	**18**	**29**	**28**	**24**	**26**	**28**	**23**

Environmental impact

Different grass and legume species vary in their ability to withstand drought, flood or cold temperatures. Mixing species that are appropriate for the local climate and soil conditions ensures a resilient and productive grassland. In addition, legume-grass mixtures reduce the input of N fertilizers and therefore, also reduce greenhouse gas emissions.

Key takeaways

» Select species and varieties that are well-adapted to the local conditions.
» Instead of pure sowing, use mixtures with legumes and grasses.
» Choose species for the grassland seed mixture based on soil characteristics, including acidity (pH), humus content, structure, and moisture regime.
» Incorporating legumes into the feed mix can have both nutritional and economic benefits, leading to better health and higher performance in dairy or beef cattle.
» Well-planned mixtures can enhance persistence, especially under challenging climatic conditions.
» Proper selection and proportioning of legume-grass species for a seed mixture should be based on soil and moisture conditions to optimize forage quality and yield.

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5. Grassland establishment and renewal

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Grassland renewal becomes necessary when yields and crop quality have significantly deteriorated. Usually, the primary cause of declining grass quality is a change in the botanical composition of the sward, specifically, the loss of valuable grasses and the invasion and spread of low-yield, low-nutrition species. Grassland should be renovated when the expected improvement in quality and yield justifies the associated costs.

Grassland renovation is necessary if:
» Less than 50% of the sward consists of high-quality grasses.
» More than 30% of the sward is composed of undesirable herbs and grasses.
» The ground surface is highly uneven.
» The grass cover has been severely damaged by frost or heavy machinery.
» Soil drainage work is essential.

The spread of dandelion (*Taraxacum officinale* Wigg.) and common couch grass (*Elymus repens* (L.) Gould) can lead to rapid deterioration in stand quality.

Grasslands with moderate botanical quality (50–70% high-quality grasses and less than 25% undesirable herbs) can be improved with appropriate technological and management practices. However, this type of improvements may take several years to achieve.

Establishing grasslands through ploughing and new seeding is the fastest and most efficient method, but also the most expensive – especially when renewing old, weed-infested grasslands. Since the existing grass cover is destroyed before seeding, this method allows for the application of organic fertilisers, soil levelling, and the selection of a suitable plant community according to the growing environment and the producer's needs.

When planning to establish a grassland, it is important to understand the **soil** characteristics — including humus content, structure, pH and moisture levels — because these factors will influence what grass species are best suited for the area. Grass species have different environmental preferences, and by matching the right species to the soil you can ensure a healthy growth, good yields and the long-term sustainability of the grassland.

Maximum productivity is achieved when a grassland is established on well-cultivated, weed-free soil. Old, weedy swards usually have to be destroyed. If the renewable grassland contains a significant number of problematic grasses (such as common couch grass, common dewgrass, stinging nettle, and dandelion) or persistent perennial weeds, these should be treated with glyphosate before ploughing.

Organic fertilisers (solid and liquid manure, compost) should be applied before ploughing, liquid manure during spring tillage. The use of organic fertilisers is particularly important when establishing grasslands on humus-poor and eroded soils. The recommended application rate of organic fertilizer is 25–30 t ha^{-1}. Organic fertilizer applied, both before establishment and in subsequent years, stimulates microbiological activity in the grass root zone and enriches the soil with essential nutrients.

Soil tests provide fertilizer and lime recommendations to achieve optimal economic yields. Liming the soil reduces fertilizer costs and boosts yields. Additionally, fertilizer use efficiency improves with a neutral pH. Research shows that forage yields are almost doubled when the same amount of fertiliser is applied to soil at a pH of 6.2, in comparison with acidic soil with a pH of 5.4. Lime fertilizers should be applied in two stages: initially before autumn ploughing and then before spring tillage. This ensures that the lime reaches the seed germination environment. The recommended pulverized oil shale ash rate is 5–6 t ha^{-1}. In Estonia, pulverized oil shale ash is commonly used as a fast-acting lime fertilizer, providing calcium, magnesium, sulphur, potassium, phosphorus and several trace elements (B, Cu, Mn, Mo, Zn, Co).

In acidic soils (pH < 6.0), liming is essential when establishing legumes or legume-rich mixtures, as legumes are particularly sensitive to soil acidity. Lime fertilizer should be applied when the surface soil pH (pHKCl) falls below 6.0 for legumes (although optimal growth is achieved with a pH above 6.2) and below 5.5 for grasses. Peat soils require liming if the pHKCl drops below 5.0.

5.1. Ploughing and soil preparation

Ploughing is a widely used and highly effective method for grassland renewal. However, there is a risk of weed regrowth, making it essential to allow the overturned grass cover sufficient time to decompose. Early autumn ploughing can accelerate decomposition in warm soils, but it also increases the risk of nutrients leaching before plant uptake. Therefore, the timing of ploughing should consider both soil temperature and the risk of autumn rainfall and nutrient loss. On peaty and heavy clay soils, ploughing should be completed by late July to ensure that the old sward decomposes quickly while the soil remains warm.

Proper soil preparation before seeding is essential for creating an ideal environment for germination. Early spring tillage improves conditions for seedling development by enhancing soil structure and moisture retention. Sufficient soil moisture is one of the most critical factors for the rapid and successful establishment of young grass seedlings.

Before seeding, the soil should be well-settled, with only the top 5 cm remaining loose. A key preparatory step is the removal of larger stones after the final soil cultivation to provide optimal conditions for seed establishment. If sowing occurs immediately after cultivation, rolling the soil beforehand is essential to ensure a uniform seeding depth. The optimal seeding depth for grasses ranges from 0.5 to 2.5 cm, depending on seed size and soil texture. The general guideline for seeding depth is about 2.5 times the length of the seed, which helps ensure proper moisture, warmth, and access to oxygen for germination. Based on this rule: perennial ryegrass = 4 mm × 2.5 = 10 mm seeding depth; Kentucky bluegrass is 2 mm long x 2.5 = 5 mm seeding depth. An exception to this rule is fescue. This is a light germinator and needs to be seeded at 5 mm depth. After seeding, it is recommended to roll the field to maintain soil moisture, which ensures better germination conditions and more uniform emergence.

5.2. Seeding dates

Forage grasses should be seeded under moisture and weather conditions that support germination and establishment, with soil moisture being more critical than temperature. In general, perennial forages can be seeded from mid-April to the end of August, depending on the seed mixture composition.

In Estonia, the best seeding periods for mineral soils are early spring and the second half of summer (August). The seeding of lucerne and clover should be completed in the first days of August to ensure successful establishment and winter survival. To survive, most legume seedlings need to develop at least three trifoliate leaves before winter.

In Latvia, the latest recommended sowing time for legumes or legume-containing mixtures is mid-August.

On peat soils, the optimal sowing period is from mid-July to early August. In this case, the new seeding will have fewer weeds, reducing the need for weed control.

5.3. Cover crops

Cover crops can inhibit the growth and development of grasses, which is why grasslands are typically sown without them. Seeding without a cover crop improves the success of ley establishment. However, this method has a drawback – the yield is lower in the first year, producing only 20–40% of the normal yield. While cover crops can provide economic benefits in the establishment year, they also compete with seedlings for moisture, light, and nutrients. This competition can hinder establishment success and often reduce future forage yields. The negative effects of cover crops become more pronounced in dry conditions, potentially leading to establishment failure. Therefore, cover crops are generally not recommended.

In some cases, grasslands are undersown with a cereal cover crop. Early-maturing cereals, typically spring barley, are the most suitable options. A reduced seeding rate of about 30% of the normal cereal seeding rate is recommended and nitrogen fertilization is not recommended, or 35 kg / ha^{-1} (or less). If the cereal crop is harvested for silage, the wax-ripe stage is preferable over the milky stage to avoid loss of soluble carbohydrates and to ensure higher starch content in the silage. Additionally, early removal of the cereal crop as silage extends the autumn growing period for the newly sown forage crop, supporting better establishment and growth.

Latvian farmers often use annual ryegrass (*Lolium multiflorum*) at 12–15 kg/ha as a cover crop for perennial mixtures. This practice allows farmers to harvest silage already in the year of sowing and at the same time, prevent weed establishment.

Red clover (*Trifolium pratense*), alsike clover (*Trifolium hybridum*), timothy (*Phleum pratense*), and meadow fescue (*Festuca pratensis*) are known to tolerate cover crops well. They can establish successfully under a cover crop because they have relatively good shade and competition tolerance. Lucerne (*Medicago sativa*), birds´foot trefoil (*Lotus corniculatus*) and orchard grass (*Dactylis glomerata*) are moderately tolerant of cover crops. While they can establish under cover crops, competing for moisture, light and nutrients can reduce their establishment success. Low grasses (such as perennial ryegrass, Kentucky bluegrass), as well as smooth bromegrass, reed canary grass, and white clover, do not tolerate cover crops well.

5.4. Method of seeding

5.4.1. Row seeding

Special seeders designed for grass seeding should be used as the seeder. The seed spacing should be a maximum of 7.5 cm, and the sowing depth should be 1–2.5 cm for grasses and a maximum of 1.5 cm if the seed mix also contains clovers. This ensures an even sowing depth.

5.4.2. Broadcast seeding

Good results can also be achieved by using a grain seeder when the seeders are removed and the seed is dispersed through the tubes, where it is then mixed with the soil by the roller behind the seeder. Regardless of the seeding method, it is essential that the seeder is equipped with light harrows. Rolling after sowing is crucial for creating a favourable environment for grass seedling development. Rolling should not be performed after rain when the soil is wet. Additionally, it is important to select the appropriate roller weight, e.g. using heavier rollers on peat soils.

In southwestern Finland, surveys show that 53% of the farmers use broadcast seeding as the primary establishment method. 41% seed in lines and the rest implement line seeding in connection with a system that makes the line disappear. In Finland as a whole, line seeding is more common than broadcast seeding.

The establishment style of silage grasslands also varies in Western Finland compared to the whole Finland. The most usual cover crop all over Finland is barley, but oats, wheat and whole crop cereals are more common in western Finland than in Finland as a whole. Whole crop silage makes up 38% in western Finland, but only 23% in the whole of Finland. Green peas compose 9% in western Finland and 13% in Finland as a whole. Establishment without any cover crop is rare in the areas with plenty of clay soil like Varsinais-Suomi in Western Finland, but 15% of the farms in the whole Finland establish grasslands without any cover crops. In western Finland, there are on average 2,2 ways to establish silage grasslands and in the whold of Finland, there are 1,8 ways. This reflects variable soil conditions and farm-specific adaptations in the western region.

5.4.3. Over-seeding of grasslands

Over-seeding is a method for improving grassland productivity and enhancing biodiversity. It is particularly recommended for restoring gaps in grasslands caused by winter damage, such as snow mold. Over-seeding has been successfully used to enhance sparse and species-poor grasslands. The optimal timing for over-seeding depends on the climate, grass species and soil conditions. Its effectiveness relies on maintaining a proper balance of essential nutrients and trace elements in the soil, as well as ensuring a favourable soil structure through appropriate pH levels. The best results have been achieved with the over-seeding of legumes, particularly clovers, which are often underrepresented in grasslands. Clover seeds germinate quickly in moist soils, and their deep root systems contribute to improved soil structure and nutrient availability. For particularly sparse grass cover, companion grasses such as timothy (*Phleum pratense*), meadow fescue (*Festuca pratensis*), and cocksfoot (*Dactylis glomerata*) are commonly used in over-seeding. Among fast-establishing species, Italian ryegrass (*Lolium multiflorum*) and perennial ryegrass (*Lolium perenne*) have been particularly effective in filling gaps within thinning grass swards.

Seed drill"Vredo" for over-seeding used in grassland renewal. Photo by Sirje Tamm

In contrast, over-seeding with slow-growing, low-growing grasses has shown limited success. These species have prolonged germination periods, slow development and are often overgrown by more vigorous species in the sward.

To achieve good over-seeding results, a special more accurate over-seeding technique is recommended.

Direct drill "Underhaug" used for hay seeding in grassland renewal. Photo by Sirje Tamm

Over-seeding is a common practice in Finland, though often challenged by drought and poor establishment results. In Western Finland, 59% of farmers carry out over-seeding in early spring, with less farmers doing so later in spring or summer. In the whole of Finland, 71% of over-seeding occurs in early spring. Most farms over-seed less than 20% of their grasslands annually, while only a few exceed the rate of 40%. These trends are consistent across Finland, although Lapland is also included in the country statistics.

Ryegrass over-seeding with different seeding rates, pre-treatment and seeding times. Photo by Sirje Tamm

Environmental factors:

Implementing no-till or reduced till farming helps protect the soil health, avoid soil erosion and prevent carbon loss.

Key takeaways

» Determine soil pH and nutrient content by means of a soil test and adjust the seed mixture accordingly.
» Moisture is a more critical factor than temperature during seeding.
» Most forage species should not be seeded deeper than 2.5 cm. Small-seeded species should be sown at 0.5 cm or less.
» Avoid heavy fertilization in autumn before over-seeding grassland. Reduce nitrogen application in a timely manner.
» Apply only a light dose of fertilizer around the over-seeding area to minimize competition from existing grass.
» Over-seeding into moist soil is crucial for successful establishment.
» Cover crops compete with forage seedlings for moisture, light and nutrients, reducing establishment success and lowering subsequent forage yields.
» For cover crops, use early maturing cereals.

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6. Grassland maintenance and biological nitrogen fixation

Authors: Sirje Tamm, Priit Pechter (Estonia), Iveta Gutmane (Latvia)

6.1. Seeding year maintenance

Proper management is essential for establishing and maintaining successful, long-lasting grasslands. The first crucial maintenance step for new seedings without a cover crop is weed control by cutting. Weeds compete with cultivated plants for nutrients, light and moisture. Annual weeds commonly spread in new seedings, making it important to cut the stand to approximately 15 cm (above the herbage). At this height, cultivated plants remain unharmed, while weed growth is suppressed, preventing seed maturation and dispersal.

Timely cutting is essential, as delaying the cut can cause the mowed grass to smother cultivated plants and result in bare patches in the grass. However, if weeds aren't a significant problem and the cultivated plants aren't overshadowed, it's more beneficial to harvest the first cut, including weeds, as green biomass.

In some cases, such as with prevalent short-lived broadleaf weeds, herbicide application may be necessary for newly established grasslands. Once legumes are seeded, weed control becomes more challenging due to limited herbicide options. Weeds should be managed in the year prior to seeding for optimal results. To prevent winter damage, it is essential that in the seeding year, the grass stand does not overwinter as unharvested biomass.

6.2. Annual grassland maintenance

Harrowing is a key maintenance practice for grassland management during the utilisation year. It helps repair winter damage, levels mole and rodent hills (which, if left untreated, can contaminate fodder during cutting or harvesting), removes dead plant residues, and improves soil aeration. By loosening the soil surface, harrowing enhances water and nutrient penetration while stimulating grass tillering, leading to a denser and healthier sward. It is important to create these conditions already in the establishment year before grass cultivation.

6.3. Fertilization

Nutrients removed from grasslands with forage yield must be returned to the soil. Fertilization and utilisation intensity must be balanced. Intensive use requires intensive fertilization; otherwise, nutrient depletion can lead to the dominance of less valuable plant species, which may outcompete desirable herbaceous plants.

Fertilization planning must ensure full compliance with the standards and requirements of environmentally sustainable crop production.

Fertilization enhances yield, protein content, and winter resilience in grasslands, but should not rely only on nitrogen. Soil nutrient levels and pH should be assessed beforehand.

Research shows that balanced fertilization based on soil tests is more effective than nitrogen alone. Special attention should be given to nitrogen (N), phosphorus (P), potassium (K), sulfur (S) and magnesium (Mg) to identify deficiencies or marginal levels. The optimal soil pH for grasses and legumes is between 6.0 and 6.5. A low pH limits the absorption of P, Mg, Ca, K and N. Lime fertilizer should be applied to legume grasses if the surface soil pH (0–15 cm) is below 6.0 and to grass species if it is below 5.5.

6.3.1. Nitrogen (N)

Under ideal growing conditions, fast-growing grasses can absorb up to 2.5 kg of nitrogen (N) per hectare per day. However, the effectiveness of the application is diminished when moisture is insufficient to move the nitrogen into the soil and root zone. The amount of nitrogen required for 10 t DM/ha is around 220 kg. Each 1% of clover in the sward can provide approximately 3–4.5 kg of nitrogen per hectare. Therefore, for a plant population with 15% clover, you would need approx. 160 kg N ha. However, the withdrawal can vary wildly according to location, the mixture composition and the intensity of use.

The distribution of nitrogen fertilizer on grasslands is primarily influenced by the number of cuts made per year. The objective is to apply the right amount of nitrogen at optimal times to stimulate healthy growth without causing over-fertilization, which can lead to issues such as excessive vegetative growth or environmental concerns like nitrogen leaching.

Fertilization in early spring is especially critical, as it takes advantage of springtime soil moisture, enabling better nutrient uptake by plant roots. Applying fertilizer early also extends the window for nitrogen and sulphur absorption, enhancing forage yield and quality while reducing the risk of nitrate accumulation in silage.

For systems involving two cuts per year, nitrogen should be divided to support both initial and regrowth phases:

» 50–60% of the total nitrogen in early spring, to stimulate rapid early growth.
» 40–50% after the first cut, to support regrowth for the second harvest.

In a three-cut system (e.g., spring, summer, and autumn), nitrogen should be divided into smaller, well-timed applications:

» 40–50% in early spring.
» 30–40% after the first cut.
» 20–30% after the second cut, to enhance late-season growth and improve winter survival.

For intensive systems with four cuts per year, more frequent and evenly distributed nitrogen applications are necessary:

» 40% in early spring
» 25% after the first cut
» 20% after the second cut
» 15% after the third cut, to strengthen the root system and prepare the grass for overwintering.

This strategic fertilizer distribution ensures that the grass receives adequate nutrition throughout all growth phases, supporting both high forage productivity and the long-term sustainability of the grassland.

To enhance nitrogen efficiency and prevent excessive nitrate nitrogen levels in grass (above 0.2% in dry matter), the nitrogen application per instance on multi-cut grasslands should not exceed 110–120 kg per hectare. Additionally, nitrogen should not be applied in the autumn after the final cut.

Peat soils contain a significantly higher reserve of available nitrogen compared to mineral soils. As a result, grasslands on peat soils require substantially less nitrogen fertilizer, typically ranging from 100 to 130 kg per hectare.

The fertilization of legume-rich grasslands depends on the proportion of legumes in the sward. If legumes make up 30% or more of the forage, high nitrogen fertilizer rates should be avoided. Studies have shown that a small amount of nitrogen, such as 20 kg ha^{-1}, can stimulate plant growth and increase yield. High nitrogen fertilizer rates can reduce the ability of root nodule bacteria to fix atmospheric nitrogen.

Research has shown that nitrogen fertilization of mixed legume-grass forage stands can be challenging, as nitrogen application stimulates grass growth and reduces the longevity of lucerne (legumes). Additionally, lucerne in the stand will absorb some of the applied nitrogen, reducing its ability to fix nitrogen from the air and increasing the cost of nitrogen supply. The yield response of mixed forage stands to nitrogen application depends on factors such as the percentage of legumes in the stand, soil nitrogen level, soil type and forage species. Generally, mixed stands with more than 50% of lucerne show little response to nitrogen fertilization. Yield responses are greatest in stands with a low percentage of lucerne and low soil nitrogen.

6.3.2. Phosphorus (P)

Phosphorus is crucial for forage grasses in the seeding year, and a small amount may also be needed annually, for maintenance fertilization. It supports the development of a strong root system, providing a solid foundation for healthy plant growth and high spring grass yields. In the harvesting year, phosphorus accelerates plant development and boosts grass growth, which is particularly important for older grasslands. However, in early spring, phosphorus in the soil is bound and less accessible to plants due to low soil temperatures.

The phosphorus requirement depends on its content in the soil and is typically applied at 2 to 4 times lower rates than potassium. It is important to note that in acidic soils, the proportion of plant-available phosphorus is low. When applying liquid manure, the P:K ratio is too high (1:5–6), while the optimal ratio is around 1:2.5. Therefore, when using large amounts of liquid manure, additional mineral phosphorus fertilizer should be applied to grasslands.

The following table shows the maximum values for the nutrients P and K in mineral soil and the recommended amounts of nutrients to be added. Maximum values for the content of P and K in mineral soil and the recommended amounts of nutrients in mineral fertilizers for grasslands.

Table 1. The content of P and K in mineral soil and the recommended amounts of nutrients in mineral fertilizers for grasslands*

Content in the soil			Optimal ratio N:P:K	Norm, kg ha^{-1}	
level	Norm, mg kg^{-1}				
	P	K		P	K
legumes grasses grassland					
Low	20–40	50–100	–	29–35	83–100
Medium	41–80	101–200	–	22	62
High	81–120	> 200	–	13–18	38–50
pure grasses grassland (N180 kg ha^{-1})					
Low	20–40	50–100	1 : 0.25 : 0.9	45	160
Medium	41–80	101–200	1 : 0.22 : 0.62	40	110
High	81–120	>200	1 : 0.15 : 0.45	27	80

* By R. Viiralt, 2007, A. Selge, 2012

6.3.3. Potassium (K)

In addition to nitrogen, grasslands also consume large amounts of K. Pre-sowing fertilisation with slurry can increase the K level in the soil, but since K is mobile and leachable, it is important to apply K fertilizer annually. Lucerne, in particular, absorbs significant amounts of K, more than any other nutrient, with its plants containing 2–3% K. Potassium plays several critical roles in plant growth and development, including enhancing winter hardiness and being essential for increasing nitrogen fixation.

It should be noted that one tonne of lucerne dry matter removes 24 kg ha^{-1} K and approximately 3 kg ha^{-1} P. To maintain high lucerne yields, regular phosphorous and potassium replenishment is necessary, especially in soils of low fertility.

Peat soils are very poor in phosphorus and potassium; therefore, grass swards require P 45–55 kg/ha and K 170–200 kg ha^{-1}. If the annual potassium application exceeds 150 kg ha^{-1}, it should be applied in two portions to prevent an excessively high potassium concentration in the first cut (also known as luxury consumption of potassium in grasses).

Additionally, an imbalanced nutrient ratio K:(Ca+Mg) in the grass dry matter (wider than 2.2) can negatively affect animal health.

6.3.4. Sulphur (S)

Sulphur (S) is crucial for forage productivity, particularly in early growth stages. Sulphur deficiencies can limit nitrogen uptake, reducing yield, protein content and crop quality. These deficiencies are common in intensively cropped or leaching-prone soils, especially sandy ones. Sulphur enhances nitrogen uptake, particularly in spring, while magnesium aids in photosynthesis. Both nutrients are vital for increasing yield. Grassland that is used intensively has an annual sulphur requirement of 40–60 kg/ha. Sulphur fertilizing is best done before the plants start to grow in early spring.

6.3.5. Fertilization with liquid organic manure (Slurry)

Slurry is a valuable source of organic matter and micronutrients, reducing the need for commercial fertilizers. It is a practical and cost-effective option for fertilizing grasslands. As a nutrient-rich organic fertilizer, it decreases reliance on expensive mineral fertilizers. Spring fertilization with slurry can significantly boost yields, e.g. Finnish data shows an increase of up to 2,000 kg/ha.

In spring, the optimal time for slurry application is before grass growth begins. Later applications should be injected into the sward to prevent plant contamination, support proper silage fermentation and minimize nitrogen losses due to volatilization. Slurry is also suitable for top-dressing after cutting. To prevent residues from contaminating the next cut and affecting silage quality, it should be applied within five days after mowing, using specialised spreading equipment. The optimal rate after each cut is 25–30 t ha^{-1}.

In Estonia, applying slurry to fields with growing agricultural crops is not allowed from October 1 to April 1. The maximum allowed application is 170 kilograms of nitrogen per hectare per year on arable land.

When determining the application rate per hectare, the key factor is the ammonium nitrogen (NH_4–N) content, as it readily absorbs in plants. In contrast, the remaining nitrogen (organic N) mineralizes slowly and has little immediate effect on yield. Grasslands fertilized with slurry always require supplementation with NPK(S) fertilizers, as nitrogen alone is insufficient. Additionally, plants do not receive enough sulphur (S) from slurry to effectively absorb nitrogen.

Organic fertilizers can also be applied in spring, especially when establishing grasslands on low-humus soils, with a recommended rate of 40–60 t/ha. It is crucial to use well-rotted manure to prevent non-decomposed organic material from contaminating the animal's fodder.

Local legislation requirements should always be considered regarding N and organic fertilization amounts and application dates. These may vary between EU countries.

6.4. Biological Nitrogen Fixation

Forage legumes are important nitrogen fixers in agricultural crop production, in collaboration with nitrogen-fixing bacteria. The most common nitrogen-fixing bacteria in forage legume grasses are Rhizobium species. These bacteria, which are present on the seed, remain active near the young roots. Nitrogen from the air, which diffuses through the upper soil level, is taken up by the root knots of the young plants and is converted from atmospheric nitrogen (N_2) into ammonia (NH_3) through the enzyme nitrogenase. The biological fixation of nitrogen by forage legumes enhances soil fertility and reduces the need for synthetic fertilizers, thereby decreasing the environmental burden of crop production.

Biological nitrogen fixation is influenced by environmental factors, including soil pH, moisture, temperature and nutrient availability. Nitrogen-fixing bacteria generally prefer slightly acidic to neutral soils (pH 6-7). In highly acidic or alkaline soil, nitrogen fixation can be inhibited. Nitrogen fixation is sensitive to extreme temperatures or insufficient moisture. High temperatures can reduce nitrogenase activity, while drought or waterlogged conditions can hinder bacterial activity in the root nodules. Nitrogenase activity generally needs a minimum temperature of approximately 9°C, with an optimum range of 13-26°C and the activity is inhibited above 30°C. It is critical to maintain an adequate supply of P, K and microelements (molybdenum, manganese, etc.) in the soil to maximize the efficiency of biological nitrogen fixation in leguminous plants.

Rhizobia of Lucerne can fix 200-400 kg of nitrogen per hectare per year. Photo by Sirje Tamm

The effectiveness of nitrogen fixation depends on the presence of appropriate nitrogen-fixing bacteria (Rhizobium or related species). Different legume species require specific strains of nitrogen-fixing bacteria (while Rhizobium melilotii nodulate alfalfa, Rhizobium galegae nodulate Galega, Rhizobium leguminosarum biovar trifolii nodulate clover and Mesorhizobium loti bird's-foot trefoil). If these bacteria are not present in sufficient numbers or if the strain is not well-suited to the plant species, nitrogen fixation can be inefficient. Practices such as liming acidic soils, using organic fertilizers and improving soil aeration can promote the development of nitrogen-fixing bacteria on root nodules.

Rhizobia of Galega can fix 100-300 kg of nitrogen per hectare per year. Photo by Sirje Tamm

When establishing a new grassland (where forage legumes have never been cultivated), it is important to inoculate the seeds with a specific strain of nodule bacteria appropriate for the target legume species before sowing.

Nitrogen-fixing bacteria help forage legumes establish more successfully, resulting in higher protein and dry matter yield.

Table 1. Quantities of nitrogen fixed by various legumes (Havlin et al., 2017)

Legume	***Nitrogen fixed (kg ha $^{-1}$/year)***
Red clover	167–188
Lucerne	78–224
Alsike clover	67–170
White clover	129–202
Birdsfoot trefoil	49–168

Environmental impact:

Nitrogen fixation by forage legume grasses has an important role in agriculture and land management, as it improves soil fertility and structure while reducing the need for synthetic fertilizers, thereby supporting sustainable farming practices.

Key takeaways

- Manage weeds in the seeding year through timely cutting to avoid competition and patchiness.
- Annual harrowing stimulates tillering, levels the surface, and improves grass sward density.
- Nitrogen is required for pure grass stands or mixtures with less than 50% of legumes. Apply fertilizer containing nitrogen in early spring and again after each cut, but not later than in the end of August.
- While phosphorus is the most essential in the seeding year, a small amount may also be required annually with the maintenance fertilizer.
- Fertilize annually and generously with potassium, an essential nutrient in maintaining all forage stands.
- Where manure is applied, reduce the rate of fertilization according to the type of manure and the rate of application.
- When older grass swards lose productivity, it is more economical to reseed to a legume or legume–grass mixture than to continue high nitrogen applications.
- Always follow state legislation requirements regarding N and organic fertilization amounts and application dates.
- Legume seeds like lucerne and galega must be inoculated with appropriate Rhizobium bacteria before sowing.
- Biological nitrogen fixation reduces the need for synthetic nitrogen and supports soil fertility.

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7. Establishing of corn for silage

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Corn (Zea Mays L.) is a very important silage crop in the feeding ration of dairy cows in Estonia and Latvia. Corn cultivation is less common in Finland, but thanks to the breeding of earlier varieties, it is also gaining popularity in Southern Finland. Corn originates from Central America and is grown in >160 countries for both grain and silage. The main advantage of corn silage over grass silage is its high yield, high dry matter energy content and moderate starch content, which allows it to replace a significant part of cereal starch in the feeding rations of cows. The facts that corn is easy to ensilage, is harvested in one mowing, is highly edible and grows well even in dry summers when the growth and yield of grasses are modest, are also no less important.

The value of corn silage as feed for dairy cows lies primarily in its starch content. The chemical composition of corn starch also differs from the starch of cereals traditionally grown in our country. Corn contains significantly more amylopectin than barley, wheat or rye. While the starch of traditional feed grains (barley, wheat, oats) is mainly digested in the rumen, about 50% of corn starch is digested in the rumen (depending on the processing of the corn grain), the rest in the small intestine. If the starch digested in the rumen is subjected to microbial fermentation and the cow synthesizes the necessary glucose in the liver from the propionic acid formed during fermentation, then the transient starch is hydrolyzed directly in the small intestine into glucose, which is easily absorbed into the blood and covers the animal's glucose needs in terms of energy much more effectively (up to 42%) than the starch fermenting in the rumen. When feeding high-yielding cows, the fact that passing starch does not ferment in the rumen and reduces the risk of ruminal acidosis (De Boever et al., 1993) makes corn starch particularly valuable.

7.1 Sowing of corn

There are many different varieties of corn and they have different times for maturity, and this is indicated by the variety's FAO number. In Estonia and Finland, the most popular varieties are those with a relatively low FAO number, ranging from 140-170, while in Latvia, varieties with a slightly higher FAO number can also mature for harvesting. The starch content of silage, fiber digestibility, the appearance of corn smut (*Ustilago maydis*), the development of side shoots, etc. largely depend on the variety chosen. Early corn hybrids, which have a higher starch and lower neutral fiber (NDF) content, could have a higher energy content. This would allow dairy cattle to increase production or, by maintaining milk yield, reduce costs at the expense of expensive purchased feeds (Diepersloot et al., 2020). However, the higher NDF content of plants may, in addition to the variety, be due to the incidence of corn smut (*Ustilago maydis*).

Before sowing corn, the field needs to be fertilized with liquid manure at a rate of approximately 35-45 m^3/ha. This is done using either disc harrow or strip-till technology. In addition to organic fertilizer, it is necessary to apply mineral fertilizer before sowing. For this purpose, the recommendation is to perform soil analyses to assess the need for mineral fertilizer. The average fertilizer requirement application should include P at 30 kg/ha and K at 140 kg/ha. Nitrogen is applied together with liquid manure at a total of 95–140 kg/ha, either as a whole or partly later by fertilizing on top or during inter-row cultivation. Phosphorus can also be added later with foliar fertilizers if signs of deficiency appear. The elements provided with foliar fertilizers also help very well against stress caused by frost.

The classic corn seeding rate is 75,000 germinating seeds per hectare. By significantly increasing the seeding rate, the plant density per hectare is higher and there is less sunlight, which causes smaller cobs to develop and the starch content in the silage may be lower. If the seeding rate is lower, the yield per hectare suffers because there are too few plants. The optimal sowing time depends on the soil temperature, which should be at least 8-10 Co at the time of sowing and afterwards. In Estonia, this time usually falls on the second week of May. The sowing depth of corn seeds depends on the soil texture. The usual depth for sowing is 5-6 cm. On fields with lighter soil, which also tend to dry out faster in spring (e.g. peat), the seed can be placed up to 7 cm deep, and on clayier and heavier soils within 3-4 cm. The main pests for corn are insects (aphids, *Chaetocnema mannerheimii*, corn borer, etc.), click beetles, common crane, wild boars and deer. Special detergents are available for corn against click beetles and common cranes. Rolling corn fields after sowing is also becoming increasingly popular in Estonia, which ensures the seed has better contact with soil moisture during dry spring and also helps against birds who do not tend to peck out seeds in rolled fields.

7.2 Corn harvesting

To assess the timeliness of harvesting corn for silage, the maturity of both the corn grain and the plant should be assessed. To do this, break the cob in half, take the grain and squeeze it. If the grain squirts liquid, then you should wait with making silage. This should be repeated with at least 3 cobs, because depending on the corn fertilization background, seeding density and other aspects, the cobs may be at different levels of maturity and the wrong conclusion can be made based on one cob. In addition, the maturity of the plant should be checked. To do this, take the corn plant and break it off at the harvesting height (about 35 cm), then stand it back up and twist it. If a lot of plant juices are released when the stem is twisted, then the dry matter of the silage will probably be lower than recommended. If there is a lot of silage juice, there is a risk that the very small crushed grain pieces will be washed out of the silage with the release of the juices and some of the starch will be lost with the silage effluence. Since the plant juice is located in the lower part of the corn stem, one option is to raise the harvesting height or wait with silage making. The usual harvesting height of corn is 30-40 cm, but in some cases it can be raised to 60 cm. By raising the harvesting height, more corn stalks are left on the field. These stalks have a very low feeding value for animals, and thus, raising the height increases the starch and energy content of the silage. The results of the experiment conducted within the “Sustainable silage” project showed that by raising the harvesting height of corn from 25 cm to 45 cm, the dry matter content of the green mass increased by 9.3%, the starch content by 117 grams per kg of dry matter and the energy content by 0.2 MJ. In the same experiment, the mass of corn stalks that remains on the field when the harvesting height was raised by

20 cm was also weighed, and it was 3.43 t/ha. However, it is not waste material, but instead, it is organic material that is very good food for soil bacteria, as well as an organic fertilizer.

Corn harvesting. Photo by Kristiina Märs

The recommended dry matter content of corn silage is 30-35%. With such dry matter, the length of the chop should be 0.5-1.2 cm. If the green mass of corn is wetter, the length of the chop should be increased to 2 cm. It is important that all corn grains must be crushed very properly. Only a crack in the grain is not enough; the grain must be physically broken into several pieces. The drier the corn silage, the more the grain must be crushed. The starch in the corn grain becomes digestible for the animals by "marination" in silage acids, and in dry silo, where there is already some acidic silage juice, it must have even better access to the interior of the grain as a result of crushing. The starch becoming more digestible is precisely the reason it is important that corn silage is kept closed for at least 2 months before feeding, so that the silage juices can have their effect.

Corn grain. Photo by Kristiina Märs

Table 1. Digestibility of starch in corn silage in the rumen depending on the dry matter content of the silage (Philippeau, Michalet-Doreau, 1999)

Corn silage dry matter content, %	Corn silage starch digestibility *in sacco*
25	83
30	65
36	50
39	50
40	48

Table 2. Digestibility of corn starch in the rumen depending on the time of silage ensiling (Newbold et al. 2006)

Ensiling time in months	Starch digestibility, %	Protein digestibility, %
2	53	39
4	54	36
6	59	34
8	64	43
10	69	47

Allowing corn a longer ensilage period (at least 2 months) is also important in the case of silage containing corn smut. The spores of the fungus only die after sufficient contact with the low pH silage juices. If silage with corn smut is fed too soon, the spores pass through the animal's digestive system and reach the slurry lagoon, from where they are in turn transferred to the field and can remain viable in the soil for up to 3 years, even in fields where corn is not planned to be sown immediately but in subsequent years, thus infecting future fields. The occurrence of corn smut is caused by weather (hot and dry summer), insect attacks, hail/heavy rain damage (damaged leaves provide an entrance for the spores of the fungus) and also the variety of corn. A field trial conducted in Estonia in 2024 found that the occurrence of the fungus was a strongly variety-specific trait (K. Märs et al, 2025).

Corn smut. Photo by Kristiina Märs

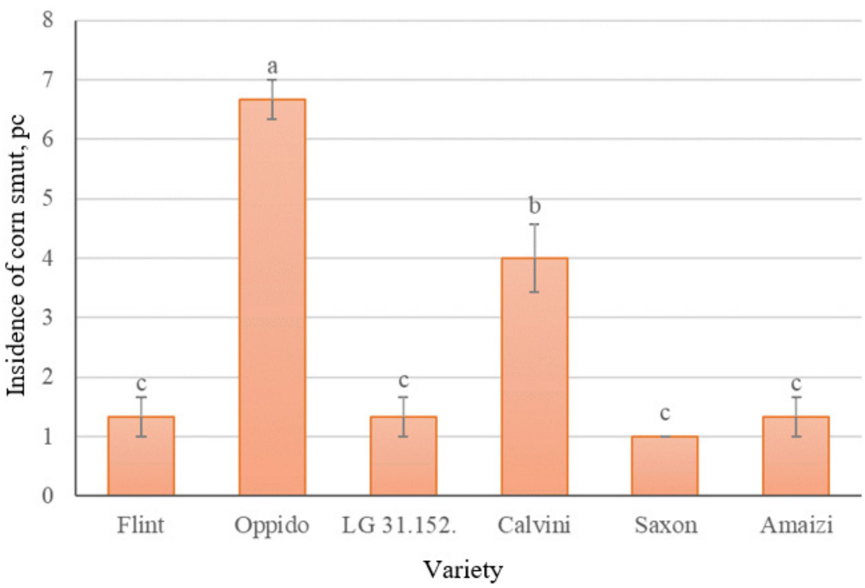


Figure 1. Incidence of corn smut on varieties per 10 plants, pcs. Values marked with different letters on the bars indicate significant differences ($p < 0.05$)

Studies have found that plants infected with corn smut have lower non-structural carbohydrate (NSC) content and dry matter, but higher NDF and acid fiber (ADF) content. This may be due to the lower grain proportion in plants infected with corn smut, which changes the ratio of ears to green parts of the plant in an undesirable direction (Cole et al., 2001). K. Märs et al., 2025 analysis of experimental data showed that the NDF fiber content in green mass of corn is lower in varieties with higher ear weight ($r=-0.83$; $p < 0.05$). From a feeding perspective, increasing attention is paid to the digestibility of NDF fiber, but by choosing a variety with higher ear and grain yield, it is possible to keep NDF fiber in silage lower.

7.3 Making corn silage

Corn should be made into silage before or immediately after the start of night frosts. Frosts break down the plant cells and the spoilage process is more likely to start and the fermentation of corn silage may fail. The longer the corn is left in the field with dead/dried leaves, the greater the risk.

It is recommended to use silage additives for corn silage. In the case of corn silage, heating of the silage in the front after opening can be a problem. In addition to poor management of the silage front, this can be due to a high proportion of yeast. To keep the proportion of yeast under control, it is recommended to choose a silage additive containing a heterofermentative bacterial strain and add it to the silage according to the instructions.

Proper compacting density is critical in making corn silage. If oxygen remains in the corn silage, the ethanol and acetic acid content may increase. In addition, there is a greater risk of heating when opening the silo. All of this affects the feed value of corn silage for animals. Since corn silage is very sensitive to oxygen, it is definitely necessary to use a backing film in addition to the top film when covering the corn silo. Since corn grain is of particular interest to birds, it is advisable to also cover the corn silo with protective nets to prevent damage to the silage caused by birds.

Making corn silage. Photo by Kristiina Märs

Key takeaways:

- From an environmental aspect, it is important to achieve the appropriate dry matter content in corn silage, even in wet autumn conditions. This helps to avoid excessive silage effluent production and the possibility of its leakage into nature.
- We can influence the dry matter content of corn by raising the harvesting height, which in the case of a very wet corn plant could even remain at the height of up to 60 cm.
- After harvesting corn, this gives winter grain sowers an advantage in the spring with fighting birds, because it is inconvenient for birds to land and take off from relatively high harvested corn stalks, and therefore bird damage in such grain fields remains minimal.

8. Minimizing bird and wild boar damage in grasslands and crop fields

Authors: Are Selge (Estonia), Marketta Rinne (Finland)

8.1. Birds

Grasslands and crop fields established for fodder production may be damaged by wildlife. Geese species—such as the Greater White-fronted Goose, Barnacle Goose and Canada Goose—have been the most problematic birds for farmers in the Baltics and Finland in recent years. Other damaging species include cranes, jackdaws, and in coastal areas, seagulls.

Barnacle Geese, in particular, cause damage during their spring and autumn migrations. Large flocks, sometimes in tens of thousands, feed on fields, including grasslands. While they do not significantly affect grassland seedings, they pose a serious threat to corn and other crops, feeding on newly sown seeds and emerging plants. Significant reseeding may be necessary due to losses. The rates could be exceeding 50%.

A policy brief from the Natural Resources Institute Finland (Luke, 2024) outlines strategies to manage damage caused by Barnacle geese. Key recommendations include establishing designated feeding zones and improving deterrence methods.

Geese in the Field. Environmental Board of Estonia, 2024

Key mitigation strategies include:

- Designated decoy fields to draw birds away from production fields.
- Diverse deterrence methods, including visual scare devices, sounds, drones.
- Strengthened cooperation between farmers and environmental authorities.
- European-level coordination on goose migration and stopover management.

Additional bird deterrence measures

- Seed repellents and coatings have shown limited success in deterring birds.
- Visual deterrents such as reflective tape, helium balloons, scarecrows and parked vehicles may help in small fields.
- Deterrence hunting is legally permitted in Estonia under specific regulations. Farmers must report crop type, location and bird species to the Republic of Estonia Environmental Board.

8.2. Wild Boars

The population of wild boars has fluctuated due to African swine fever. Higher numbers of wild boars have resulted in significant damage to grasslands and especially corn fields, where yield losses may reach 20%. The risk is greatest near forested areas.

Wild boar damage in grassland. Photo by Kristiina Märs

Preventive measures

- Cooperation with hunters, including drone-assisted detection and regular culling.
- Electric fencing around small fields (requires maintenance).
- Locating corn fields closer to human settlements and further from forests.
- Applying wildlife repellents or scent barriers.
- Using sound-based deterrents such as propane cannons (volume comparable to rifle shots).
- Frequent field inspections in sensitive periods (e.g. autumn for corn).
- Documenting incidents of damage for pattern detection and rapid response.

Spring wild boar damage in cornfields. Photo by Kristiina Märs

Key takeaways

- Choose deterrent strategies that best suit your specific farm and field situation.
- Alternate deterrent methods to prevent wildlife from adapting.
- Ensure the cost and time invested in deterrence is justified by reduced crop losses.
- Use additional plastic layers or nets for bales and position them near trees to reduce bird landing.
- Protecting silage effectively reduces spoilage and minimizes environmental impact.
- Comply with local wildlife protection laws and ensure humane, ethical treatment.
- Coordinate with neighbors when using noise-based deterrents.
- Maintain cooperation with hunters and local associations to manage wildlife effectively.
- A combination of targeted methods is the most effective way to reduce wildlife damage in agricultural fields.

References:

Policy Brief 1/2024. Hanhipellot ovat toimiva tapa hallita valkoposkihanhien maataloudelle aiheuttamia vahinkoja. https://jukuri.luke.fi/bitstream/handle/10024/554632/Policy_Brief_1_2024.pdf

9. Technologies for harvesting forage for silage

Authors: Kalvi Tamm, Andres Olt, Raivo Vettik, Taavi Võsa (Estonia), Marcia Franco (Finland)

9.1. Introduction to the chapter

The choice of forage harvesting technology, machinery and practices has a significant impact on silage quality, yield and cost as well as the environment. When planning the grass harvesting technology and machinery for the farm, one should consider the requirements for the raw material of grass silage, the area and properties of grasslands, production cost of silage and national environmental standards. The present chapter provides an overview about requirements for grass silage harvesting technology: harvesting technologies, requirements for employees, harvesting operations and equipment, as well as environmental and social aspects of forage harvest for silage.

9.2. Requirements for grass silage harvesting technology

The selection of technologies and practices for harvesting forage should prioritize achieving high yields of high-quality raw material for silage. The quality of the harvested forage is critical for producing superior silage and ensuring its long-term storage stability. High-quality silage, produced in sufficient quantities, contributes significantly to animal welfare and supports the production of high quality milk and meat.

Forage harvesting technology is responsible for evaluating the costs and environmental impacts connected to grassland management. Producing grass biomass involves economic costs and environmental impacts associated with establishing and maintaining grasslands. These resources are wasted when the biomass potential is not fully utilised due to poor management decisions during grass harvest and silage production. The costs and burdens increase with each stage of grass production and silage-making (i.e., harvesting, handling and preservation), so that each successive stage must be approached with even more increased responsibility to maximize efficiency and minimize waste. To ensure cost-effectiveness and environmental sustainability, it is crucial to harvest grass biomass in large quantities and maintain its quality throughout the process.

Forage harvesting equipment has to conform to the requirements or limitations of state legislation related to the harvest or transport of silage raw material. Legislation limits the maximum dimensions, weight and axle load of agricultural and transportation equipment. Registered and actual values are both limited.

When choosing forage harvesting technologies, equipment and practices, one has to consider the requirements for the quality of forage to be ensiled. The quality of the forage for silage must be preserved until it is fully conserved, whether stored in bales, piles or other methods. The choice of harvesting technologies, equipment and practices has an impact on forage yield and properties. Chapter 11 “Fermentation, how to ensure good silage quality” provides an overview of the requirements for the quality of forage to be ensiled.

The choice of forage harvesting technologies, equipment and practices should follow environmental and social criteria. The environmental aspects of grass harvesting are addressed in paragraph 9.14 (Environmental impact of harvesting technologies) and social aspects in paragraph 9.15 (Social impact of forage harvest for silage).

The equipment that is to be used in harvesting technology must be affordable and reasonably easy to maintain and operate. Prior to the start of the silage season, the necessary machinery must be complete, in good condition and adjusted according to specific needs. Malfunctions in the operation of the machinery as well as machine adjustments directly impact the quality of the silage, so it is essential that the skills and knowledge of both machine operators and machine repair and maintenance staff be at a high level. In order to ensure the machinery’s good performance during the harvesting period, it is important to have sufficient infrastructure for repair and maintenance, as well as fast availability of spare parts.

The choice of forage harvesting technologies, equipment and practices must be optimised on the basis of the lowest production cost per ton of good silage.

9.3. Overview of grass forage harvesting technologies

If grass silage is stored in a storage facility (clamp, bunker, tunnel or silo, see Chapter 10. “Silage making technologies in storage”), the operations to get the forage from the field to the storage are:

1) cutting the grass,
2) wilting the forage,
3) swathing the forage,
4) collecting the forage swaths, and
5) transporting the forage from the field to the silage storage.

If the grass silage is stored in round bales, the following operations are involved in the production of this silage:

1) cutting the grass,
2) wilting the forage,
3) swathing the forage,
4) collecting the forages from swathes and compacting to round bales,
5) wrapping the silage bales with plastic film,
6) bundling the silage bales in the field,
7) lifting the silage bales onto a transport vehicle,
8) transporting the silage bales from the field to the animals.

9.4. Requirements for employees connected to the harvesting of grass to be ensiled

The qualification requirements depend on the operations for which the employee is responsible and on the operated equipment. It is important to instruct workers so that they are aware of the quality criteria for the ensiled forage, and of the means of meeting the criteria.

Farm employees play various roles in the process of harvesting grass for silage, e.g the following: silage harvest manager, farm machinery manager, mower operator, tedder operator, windrower operator, loader wagon operator, round bale press operator, bale wrapper operator, loader operator, and transportation vehicle operator.

In a small farm, one person plays many roles, but in a big farm, several people can operate in one role. However, every role requires specific knowledge and skills to fulfil the objectives of this role.

If a machine is multifunctional, e.g. round bale pressing and bale wrapping, then both operations are the responsibility of one person.

The silage harvest manager is responsible for planning the transfer of grass from the grassland to silage storage, taking into account the following:

- the size, relief, surroundings, soil and other properties of the grassland,
- the distance between the grassland and storage; the condition of connecting roads,
- the potential amount and quality of material planned to be harvested (see Chapter 3 "Planning principles in silage production"),
- the storage technology, and the operations of transferring grass form the grassland to storage,
- the quality requirements for forage to be ensiled (see Chapter 11 "Fermentation, how to ensure good silage quality"),
- the properties required for the equipment on every operation of the harvesting process as well as the availability of equipment,
- the need for consumables in each operation (plastic film, silage additives, etc) and how to obtain them,
- the qualification of equipment operators,
- potential risks (connected to weather, employees, equipment, consumables, etc.) and ways to mitigate them fast to ensure a smooth grass harvesting process,
- legislation connected to harvest, equipment and employees,
- the economic, social and environmental aspects of grass harvest for silage.

When organising the harvesting of forage from the grassland, the silage harvest manager must, in addition to following the harvest plan, also ensure that:

- the operators are well supervised so they have a clear understanding of their area of responsibility and the requirements to be met,
- the employees involved in the harvesting are not overburdened,
- the national labour regulations are not violated (observing working hours, among others),
- work safety measures are implemented, and
- the operators monitor the condition of the harvest equipment and maintain it correctly.

The smoothness and cost of the grass harvesting process is highly dependent on the condition of the machinery and the skills of the operators. The farm machinery manager is to ensure that:

- the farm machinery provides required work performance and quality for each grass harvesting operation,
- the farm machinery conforms to current legislation (also relevant traffic legislation),
- the operators are well instructed and trained to operate, adjust and maintain the equipment,
- the farm machinery has guaranteed and reasonably fast technical support in the form of maintenance, repairs and spare parts,
- the farm machinery is provided with consumables (fuels, lubricants, etc.) in sufficient amount and in the required location,
- the machinery meets environmental requirements and is economically optimal.

The harvesting machinery operators should be aware of the quality standards set for the operation they are responsible for, provide possibilities to ensure following the standards and fill the requirements.

It is very important to avoid soil and impurities in forage to be ensiled (Võsa, T).

For this:

- cut high enough (8+ cm, 10+ on micro-hilly / rough land), see also 9.6 "Cutting the grass";
- if tedding, adjust the tines to grip the forage higher above ground, see also 9.7 "Wilting the forage";
- if swathing, the tines must not trail continuously over the ground;
- swaths must not made over soil reels / boundary stones/rocks;
- straight swaths are always more effective for harvesting than those that follow the contour of the field perimeter;
- tines of the collecting wagon should not grab the soil, but instead leave some grass leaves laying at the bottom of the swath;
- minimise driving over growing grass but also over cut forage.

Photo 9.1 Forage is contaminated with soil dust during swathing when swather tines are too close to the ground Photo by Andres Olt.

The machine operator must ensure that the equipment is properly assembled, maintained and adjusted.

The working speed should be optimised to ensure work quality, safety requirements, the working capacity of equipment and its maximum performance.

The choice of the working width overlap must ensure the quality of work (minimise grass left growing after cut, or forage left between swaths after windrowing) but also maximum performance.

Round bale press operators should ensure quality standards of unwrapped round bales. The aim is to produce dense well-shaped bales. The operator should try to ensure that the sward is in full width when entering the mouth of the baler. Well-shaped bales are easier to wrap properly and handle without causing damage. (Beatty, C. 2018)

Bale wrapper operators should ensure following the quality standards of wrapped round bales.

9.5. Preparation of grassland for harvest

The performance and cost of harvest and the quality of silage raw materials is good if the grassland has an even surface, without wheel tracks, dips, stones, molehills, clumps, stumps and other obstacles. The bigger and fixed obstacles, but also hollows or wet locations should be visibly marked, if these are not clearly visible. Non-fixed obstacles, tree leaves, old hay and trash should be removed from the grassland. The drainage system and trenches should be kept in good condition. See also Chapter 6. „Maintaining grasslands for silage production" on how to achieve a grassland with an even surface and minimal obstacles.

These precautions will help to reduce:

- the number of machine breakdowns, and

the time and money needed to repair these,
- wear and tear on machine parts, and the time and money spent on maintenance,
- the proportion of the grass that is left unharvested,
- raw ash in silage,
- damaged grassland surface, and thus, areas that provide low productivity.

Preliminary cutting of grassland edges. This means cutting the edges of the grassland as a separate operation before harvesting - around the edges of pastures, woodland, roads and ditches and around major obstacles. This will help to ensure that later harvesting operations run more smoothly and with fewer disruptions. (eAGFF).

Precautions must be taken to scare animals and birds hidden in the grass away from the working areas of harvesting machinery.

Mowing a meadow is a radical intervention for the animals living in it, whether large or small. Suddenly, there is no food, no protection from predators and no space for development. In addition, the animals are often injured or killed during harvest (eAGFF).

The roe deer is an inhabitant of the semi-open landscape and the edges of the forest. The doe usually gives birth to two fawns in May / June. In the first 2 to 4 weeks after birth, the fawn lies down in tall grass and remains motionless, because it cannot run yet. The doe regularly returns to her fawns to suckle them. Grass harvesting often takes place during this time. Fawns can fall victim to mowing machines during cutting. But young hares, ground-nesting birds and even foxes also run the risk of being caught by the mower (eAGFF).

The following measures can be taken to protect these animals from mowers (eAGFF):
- preliminary cutting of the grassland the evening before: this puts the doe on alert, she takes the fawns out of the field to protect them;
- fawn rescuers / chain garlands attached to the mower. They comb through the next strip to be cut, causing some of the fawns to flee;
- cutting from the inside to the outside or from one side to the other, towards the forest, away from the road - this allows the animals to escape by keeping escape routes open;
- cutting height of at least eight centimetres, preferably 10 to 12 centimetres. This will protect ground nesting birds or hare clutches;
- scare off the animals the evening before using cloth, sacks, foil, construction site warning lights, balloons, etc. (in consultation with local hunters).

While you can recognize big wilds quite easily, small creatures such as lizards, frogs, spiders and insects are easily overlooked. These animals are of great benefit to you as a farmer as they pollinate plants, eat pests, treat dead plant-material, perform many other tasks and contribute to biodiversity. It is therefore worthwhile for you to take care of these animals. Please note the following points (eAGFF):
- cut early in the morning or later in the evening. Many small creatures are most active during the warmest part of the day;
- if possible, leave uncut or alternatively cut verges as retreats. In intensive grasslands, you can make sure that you do not cut all the surrounding areas at the same time, thus providing a substitute for a verge;
- the more intensively the plants in the field are worked, the more the small

creatures are disturbed. The use of cutter bar mowers is the gentlest method. Rotary mowers create a suction effect due to the high blade speeds. The losses are significantly higher compared to blade bar mowers. A conditioner further reduces the chances of survival. So it is recommended to only work as much as is absolutely necessary;
» and cut the plot from the inside to the outside so that animals have an escape route.

9.6. Cutting the grass

The aim of grass cutting (or mowing) is to separate each plant growing in the grassland into two parts:

1. yield part – the part that is cut down, removed from the grassland as forage and used to produce grass silage, and
2. reproduction part – the part that remains growing in the grassland to produce new yield.

For both parts, there are requirements that must be followed when cutting.

If the next cut from the grassland is planned to be harvested in the same or the following year, the reproduction part of forage plants must retain the ability to provide a good yield (see Chapter 6. "Maintaining grasslands for silage production").

For the rapid recovery of a grassland plant's ability to produce good yields, it is important that when cutting,

» the plant stubbles remain large enough to contain sufficient nutrients to provide new leaves for the next cut (Bender 2006, 1, 292);
» the cutting surface of a plant remains minimal, thus reducing water evaporation, nutrient volatilisation and pathogen inlet; and
» the roots of the plants are damaged as little as possible.

The minimum cutting surface of a plant is achieved by the use of sharp cutting blades and sufficient blade speed. The good condition of the cutting blades also helps ensure the uniformity of the cut as well as maintain low fuel consumption, and thus, the blades should be checked regularly and, if necessary, sharpened repeatedly or replaced with new ones. Dull mower blades increase the loss of nutrient-rich foliage in forage, especially when leguminous plants are harvested (Kass et.al., 2021).

Uniform cutting helps to ensure that the yield part is harvested from the grassland in a maximum amount. When poorly cut, valuable yield is left unharvested and when it overgrows, it will contaminate the next cut with low quality material.

The use of blunt blades also increases the risk of the plants being torn out of the ground with the soil and roots, increasing the content of crude ash and the proportion of plant parts with low feed value in silage. The proportion of plants with good regeneration potential in the grassland is thus also reduced.

The mower should be set to cut at the required height above the ground along its full working width and copy the relief of the ground surface as closely as possible.

The quality requirements on the yield part, or forage to be ensiled, are described in Chapter 11. "Fermentation, how to ensure good quality".

Carrying out the cutting

The agrotechnical requirements for cutting grass are as follows (Olt, 2015):

1. cutting should be performed at the right time (for grass silage, see Chapter

11. “Fermentation, how to ensure good quality”)
2. the cutting period must be as short as possible (up to 5 days); it helps to reduce the proportion of overgrown, low quality grass in silage. Some farmers prefer to start cutting a little earlier to avoid overgrowth.
3. Cutting should be performed at the required cutting height, which is to be determined by an agronomist on the basis of grassland surface quality, the condition of plants and the requirements on forage to be ensiled (see Chapter 11. “Fermentation, how to ensure good quality”
4. Cutting must be carried out with a clean cut, i.e. without tearing up the straw and uprooting the soil, and with the smallest possible cutting surface.

Cutting time

The starting date of the harvesting depends on both the forage crop and the weather. Firstly, it should be done at the optimum stage of plant development.

When making grass silage, usually an increase in quantity means a decrease in quality. This is because the more mature and higher-yielding crop will have lower nutritional value from the greater proportion of stems and seed heads. This presents an inevitable compromise in decisions about when to cut grass for silage. The time is best determined on the basis of the class of livestock to be fed and stock performance targets. For maximum yield without significant compromise in quality, most crops are best cut approximately one week before heading. (Germinal. 2025)

The nutritional quality of silage is principally governed by grass silage digestibility (D-value), which starts to fall with the onset of stem formation and heading (by up to 0.5 units/day). Avoid sacrificing quality for quantity by delaying harvest. The cutting date is also critical in terms of the quality of the second and subsequent cuts. To maximise quality, make subsequent cuts at 30–35-day intervals. Grass silage can only be as good as the sward from which it is made. (Udall, E. 2023)

The aim is to produce grass silage with a maximum of 240 g of crude fibre per kg of dry matter. Many years of experience show that the grass is ready for cutting between the 30th (for early field grasses) and 50th day (grasses of the late ripening group) after reaching the corrected grassland temperature of 200 degrees. The height of growth also provides information on the readiness for cutting: at 25 to 40 cm, the grass is considered ready for cutting. (Bonsilage. 2025.)

Very often, the time interval between the first and the second cut is too long, so that silage with a crude fibre content of over 240 g per kg DM is harvested. The sugar content of the plants required for fermentation decreases as the crude fibre content increases. If silage is cut later, it is essential to adjust the cutting length and layer thickness on the silage clamp. (Bonsilage. 2025.)

A late first cut leads to nutrient losses and thus to poorer silage quality. This reduces feed intake and, accordingly, milk yield. Digestibility and valuable crude protein decrease with every percentage increase in crude fibre. (Bonsilage. 2025.)

The grassland temperature calculator is used in Central Europe to determine the date for the start of field work after winter. For this purpose, all positive daily temperature averages are recorded, corrected and totalled from the beginning of the year. If the total exceeds 200 degrees, the sustainable start of vegetation is reached. For adjustments for the month of January, the temperatures are multiplied by a factor of 0.5, for February by

0.75. The full daily value is only applied from March onwards. (Bonsilage. 2025.)

Sugar levels should be above 3% before starting to cut (see Chapter 11. "Fermentation, how to ensure good quality). The time of day for harvesting grasses should be midday, when the sun is at its zenith, because this is when the water-soluble carbohydrates, or sugars, are the highest in plants and the water content is the lowest. (Kass et.al., 2021)

Be sure to wait for the morning dew to recede, as dew evaporates more quickly from unmown plants.

Mowing in the rain should also be avoided, as it is difficult and time-consuming to wilt moisture out of the mown green mass, and it also results in nutrient losses.

In favourable weather conditions, spread-mowing should be preferred as it speeds up the wilting process and eliminates the need for the operation of tedding. If the mower does not allow for this, the machine should be set to mow as wide a swath as it can.

Cutting height

The height of cutting determines the yield of green mass per hectare, but it also affects the quality of the silage. The lower the cutting height, the higher the yield, but also the higher the proportion of fibrous and less digestible straw in the forage. When harvesting grass for silage, the cutting height ranges between 5-10 cm. The cutting height depends mainly on the evenness of the field, but also on the quality of the vegetation. If the grassland surface is uneven, cutting height should be increased to avoid soil contamination in silage. Vegetation should also be checked. If the lower leaves of the plant are dead or contaminated, the mowing height should be increased to avoid unwanted fermentation. Therefore, for the quality of the fermentation, a minimum grass cutting height of 7-8 cm is often recommended. Grass cut in this way do not come into direct contact with the soil, but are supported by the grass stubble, which also accelerates wilting. The choice of the cutting height should also be based on the grass species. For example, leguminous lucerne should not be cut too low, because if the lower shoots and leaf buds are harvested, the plant will not recover for the next cut or will not survive the winter after the third cut.

Tip: For checking purposes, turn the swath partially over once after mowing. If individual stalks are brown at the cutting edge, you should adjust the cutting height upwards. (Bonsilage. 2025.)

Photo 9.2. Cut forage is contaminated with soil. Photo by Andres Olt

Work speed of cutting equipment

If the maximum cutting reach on one blade is 50 mm and the rotation speed of the cutting disc is 3000 rpm (generally for most manufacturers), then the maximum forward speed by cutting can be 18 km/h. This means that if the speed is over 18 km/h, some of the grass isn't cleanly cut and it is getting ripped instead. Unless you get a clean cut, there is a greater risk of contamination in the swath, leading to potential fermentation issues. So 18 km/h is the absolute maximum, and given there will be some yaw and sway in the mower on the back of the tractor, 15-16 km/h is probably a "safer" maximum (Nash, J.).

Even though mowers have the capacity to reach high speeds, adverse field conditions can make operators drive slower. Factors like field roughness, obstructions in the soil and soil moisture should be navigated at a reduced pace. Rough fields can cause damage to the machine, so going slower would be recommended. Obstructions, such as rocks, tile holes or foreign objects can also cause substantial damage to hay mowing machines.

In addition to damaging machinery, operating in wet conditions can cause damage to a field. Tires can drag through the mud and machines are at a risk of being stuck when soil moisture is high. Trying to go faster in these conditions can be even more harmful.

Another thing to consider is high-yielding crops. Dense grass might require mowers to move more slowly. The power capacity of the tractor can also limit mowers in these situations.

Identifying challenges within a field and adjusting speed accordingly will help determine a proper mowing pace. Maximum productivity will only be achieved when a machine is working optimally and producing a quality cut. (Friedrichsen, A, 2025)

Cutting performance

Cutting performance (hectares per hour) needs to be calculated to accommodate the ideal wilting period. In practice, this will be driven by the chopper output. If the plan is to wilt for 24 h, and the chopper is clearing ground at 10 ha/h, it should cut at the pace of 10 ha/h – 24 h ahead of it. If only cut at 8 ha/h, by the time it is picked up, some forage will be too dry, some too wet and some just right. This will lead to greater losses in feed value over the optimum operation. (Nash, J.).

Working out the potential cutting performance (ha/h) of a machine is a more complex process than just taking the spot rate. The spot rate is the working width multiplied by the forward speed. To work out the potential output, you need to consider also additional time losses on:

- Opening up the field
- Turning at headlands
- Finishing the field
- Transition to transport mode and vice versa
- Travel time between work
- Time losses caused by maintenance, repair, unfavourable weather, and operator problems.

The coefficient of work time use efficiency by grass cutting is 0,76-0,88, depending on the length of the field (200-2000 m) (Fortuna, 1985). For example, if theoretical work performance without above-mentioned time losses would be 10 ha/h, then with these time losses at the length of the field 500 m, the coefficient is 0,82 and thus, the cutting performance is 10 ha/h X 0,82 = 8,2 ha/h.

Mowers

Mowers are divided into plain mowers and complex mowers (Bender, A. 2006, 2., 571). Both versions are divided to hanged and semi-trail mowers, and these may be located in a front, side or rear position in relation to the tractor. Plain mowers can be used only for cutting without any additional functionality. Complex mowers have additional functionalities, like conditioning and swathing. Mowers can also be self-propelled, i.e. they can work without a tractor.

Mowers are also divided by cutting device: sickle bar, disc or drum (Machinefinder). Sickle bar mowers use a reciprocating blade to cut grass and often have a reel to fold grass over the knife. Disc mowers use several hubs across the cutting width, and each hub has a small rotating disc with knives. Drum mowers come equipped with two or three large plates known as drums; these ride over the ground while spinning (Machinefinder).

As mowing speed cannot be increased indefinitely, great emphasis has been placed on increasing the working width of mowers. For large areas, mowers up to 9 m wide are used, consisting of two side mowers and one front mower. Mower widths start at 1.2 m but the most common mower widths are 1.4, 2.1, 2.8, 3,.2, 3.6, 4.0 and 4.8 m (Bender, A. 2006, 2., 574).

Advantages and disadvantages of different mower types

Sickle bar mowers (Figure 9.1A), though their design is a bit antiquated, do have a place on a small farm. As the first mechanical hay mowers, they were originally pulled by horses. These mowers work with a reciprocating action, moving triangular blades back and forth between stationary guard fingers. Like a set of barber's clippers, each back and forth action shears off any grass or vegetation that is between the stationary fingers. However, this design tends to make them high maintenance machines.

Sickle bar mowers can be used for cutting hay as well as for other general light mowing duties and can be operated by tractors with as little as 15 horsepower. Sickle bar mowers also cut with relatively little motion, which means less dust in a hay field and less chance of thrown objects like rocks and debris – though this can be a disadvantage since the grass lands in a flat swath and may require a longer drying time.

<u>Advantages of sickle bar mowers</u> (Styron, 2023):

- Requires little horsepower - if a tractor has very low power (10 kW or less), this option will likely be the only choice.
- Lighter weight - if the tractor is very lightweight, or has very little front weight, a sickle bar is your option because it is the lightest in weight. Lighter weight provides possibilities to turn easier and access difficult areas.
- Angled mowing - sickle bars are the only grass mowers designed to work if mowing is performed along ditch banks or ponds. The design of the sickle bar mower gives more options when cutting, i.e., mowing in different angles, in small or tight areas, on banks. If cutting needs to be done on anything else but hay or light material, it is recommended to switch to a hydraulic offset flail mower.
- Less direct motion means less dust/dirt. Disc and drum mowers kick up every chunk of dirt into your future hay. Thus, less motion means a cleaner cut.

The disadvantage of a sickle bar mower (compared to disc or drum mower) is that it wastes energy on (Olt, 2015):

- friction between active and inactive blades;
- overcoming inertia when the sickle bar accelerates after every stop.

Other disadvantages of sickle bar mowers (Goodwin, M. 2023):

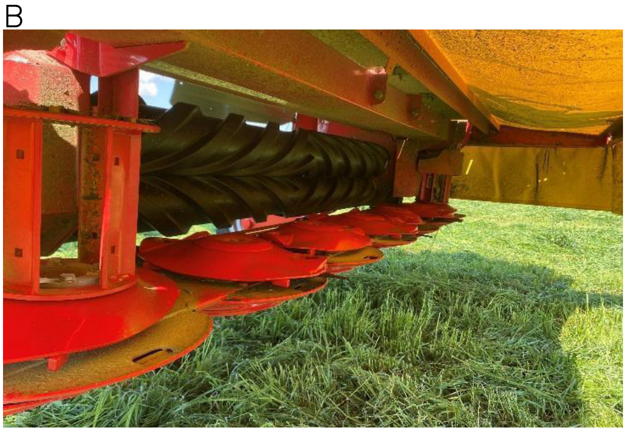
- Slow forward speed – a sickle bar mower can mow a wide swath, but its speed is only about half of that of other types.
- Less robust build – a sickle bar mower has many small, light-weight moving parts that are close to the ground. Hitting an obstruction with a sickle bar mower is more likely to cause catastrophic damage than other types of mowers. A sickle bar mower cannot handle cutting thick material, which is likely to result in quick wear and tear and/or damage.

» Susceptibility to clogging – a sickle bar mower easily becomes clogged when working with very dense, moist, lodged or already cut material. Clogging also becomes a bigger problem when the blades begin to dull.
» Cumbersome blade replacement – when blades become dull, replacing them usually requires special tools and mechanical know-how as well as can be time consuming and expensive.
» Higher repair costs – damage resulting in hitting an unknown obstruction can be expensive to fix. The mower's many small parts must work together in perfect unison. Therefore, if one part becomes damaged, it is likely to result in a cascading, expensive failure.

The mowers with rotating blades do not have such problems.

A

B



C

Figure 9.1.

A. Sickle bar mower (Goodwin, M. 2017a)

B. Disc mower with a rubber-roller conditioner (K. Tamm)

C. Drum mower ((Goodwin, M. 2017b)

Advantages of disc mowers (Figure 9.1B) compared to sickle bar mowers are as follows (Goodwin, M. 2017):
» a disc mower's flexibly fastened cutting blades fold back when they strike undetected objects;
» the blades can be used on either side;
» the cutting blades are easier to change and maintain;
» the mower doesn't clog;
» a higher driving speed when cutting.
» Ease of transition. Hydraulic lift enables transitioning from working to transport and back again without the operator leaving the tractor seat. This is a time-saving feature when mowing several small fields.

Disadvantages of disc mowers are as follows (Goodwin, M. 2017):
» Weight. The problem arises when the tractor has sufficient horsepower and hydraulics, but is lightweight. This can be a safety hazard because of the much heavier cutter bar in comparison with a sickle bar mower. When the mower is in the vertical transport position, it can unexpectedly tip the whole tractor over.
» Repair costs. The problem arises, when it is necessary to frequently mow in places, where the cutter might hit something solid like a boulder, old

fence post, etc. Disc mowers, when damaged, can be extremely expensive to repair.

Typically, a drum mower (Figure 9.1C) is used for hay cutting. A standard drum mower has two counter-rotating drums that are powered by a gearbox above. Each drum is essentially a cylinder of 25-35 cm in diameter and 38-60 cm in length, with a large disc attached to the bottom. Depending on the model, either 3 or 4 free-swinging blades are attached to each of these discs. When in operation, the entire drum/disc/blade assembly rotates. This heavy rotating mass creates a great deal of momentum, which helps power the mower through thick spots in the field.

The lower drum unit is in constant contact with the ground and thus maintains a uniform cutting height for the blades. The drum cutter unit is held at the top on a centre pivot that allows the 2 drums to follow the contour of the ground to maintain a constant cut height even on irregular ground contour.

As a drum mower moves through the field, the drums are rotating toward each other, which causes the cut crop to pass between the drums and be dropped in a windrow behind the mower. This windrowing result has to eventually be spread back out with a tedder or rake in order for the hay to dry properly. (Siromer).

Drum mower's advantages (Siromer):

» Durability. Drum mowers are easily the most rugged of the hay mower types. They rarely sustain damage even from striking an immovable object. This makes them a great choice for contract cutting in unfamiliar fields or for mowing unruly pastures.
» High ground speeds. A drum mower can be run at even higher speeds than a disc mower, and double the speed of a sickle bar.
» Low power consumption. This feature is important particularly for compact tractors of modest horsepower.
» Drum mowers never clog – two large counter-rotating drums create a great deal of inertia for powering through the thickest of hay.
» Easier blade maintenance – a drum mower implements only 4 inexpensive, reversible blades per drum, and these can be easily sharpened or replaced.
» Greater durability – a drum mower is easily the most rugged of all hay mower types, rarely sustaining damage even from striking an immovable object.

Drum mower's disadvantages (Siromer):

» Contour mowing. The drums are very heavy, so it is not recommended to hang the mower out over a downward slope. Drum mowers also do not pivot enough to effectively follow extreme contours like a sickle bar would.
» Weight. A drum mower's heavy weight can be detrimental for tractors with light front ends. Drum mowers are very heavy in comparison with other mower types of the same width. This can make manoeuvrability and transport difficult if the there is not enough weight holding the front wheels of the tractor down.
» Windrowing. Drum mowers windrow the cut crop, it will not dry in the field without being spread out.

9.7. Wilting the forage

The dry matter content of mown grass (or forage) ranges from 15-25%. This depends on the plant species, variety, stage of development, as well as the agrotechnical practices in cultivation and the weather at harvest. As water takes up storage space and does not provide nutrients for the animals, it is not practical to conserve it in silage. In suitable weather conditions, the moisture content can be reduced by wilting.

Wilting increases the dry matter content of the grass and thus the concentration of nutrients. This improves the fermentation of forage. (Kass et.al. 2001).

Forage wilting starts with mowing and can be accelerated by various production techniques. The thinner the swath is after mowing, the more efficient the moisture release.

The wilting of leguminous grasses is particularly difficult in thick swaths, as leguminous plants have a larger leaf area, which prevents water evaporation from the swath. Even if the weather conditions are suitable for wilting and the leaves in the top layer of the swath are already so dry that they are falling off, inside the pile, the green mass is still a 'water bead'. This situation also contributes to the development of undesirable microorganisms on grasses.

Likewise, the younger the plants are harvested, the higher their water content, the denser the swath and the harder it is to wilt. It is therefore preferable to mow broadly. Another argument in favour of mowing broadly is that one of the operations of tedding is then omitted, thus reducing the possibility of contaminating the forage with soil. If the mower does not allow for broad mowing, the widest possible swath should be formed. (Kass et.al. 2001)

Wilting to achieve an optimum silage dry matter of 30-35% (clamp) and 35-40% (bale) should ideally be quick and short, so a maximum of 24-36 hours.(Germinal, 2025). Wilting helps improve sugar levels and reduce silage effluent levels (Kerins, 2021).

» Using a mower-conditioner will increase the speed of wilting and reduce losses of sugar, protein, dry matter of grass silage, also promote faster fermentation and reduce silage effluent levels.
» Leaf pores only remain open for two hours after cutting, and this is when the speed of moisture loss is five times greater than after the pores close – so spread the forage quickly after cutting for silage.
» Spread the forage over all field areas, again to increase the speed of wilting forage.

Crops with high clover content can be wilted for up to 48 hours. In poor weather, try to cut, spread and pick up forage the same day. (Udall, E. 2023)

Conditioners

Conditioners come in three main types: rubber-roller (Fig. 9.3), steel-roller, and tine-rotor (Fig. 9.4). Roller conditioners have two opposing rolls with a raised, interlocking pattern; these crimp the forage between the rollers. Tine-rotor conditioners have an arrangement of steel V-tines on the rotor, which beats the forage against the top of the mower conditioner (Machinefinder).

Mower attachments such as crimpers and splitters encourage wilting and water release from plants. Crimpers are mainly used for the treatment of leguminous grasses and are divided into smooth, grooved, ribbed and profiled. The crimper-mower guides the forage between the rollers, causing mechanical damage to the plant stems and leaves by crimping, bending and folding them.

The impact of rollers on the wilting of grasses is small. Monocot grasses are treated with splitters, the most common of which are the tine-rotor and comb-type splitters. These are used to remove the waxy coating from the plant and to damage the plant by folding it. Splitter-conditioner-mowers should not be used for leguminous grasses, as the leguminous leaf attaches to the stem weakly, which can result in high losses of nutrient-rich leaves during harvesting.

Using a mulcher or spreader will result in fluffier swaths, allowing better air circulation in the swath, thus promoting wilting. The performance of a mower with a crimper or splitter may be lower, but the benefits for wilting compensate for this.

» It is not advisable to use a crimper or conditioner in situations where the weather does not allow wilting.
» Crimping is not advisable and may be detrimental instead of beneficial at a very early stage of development and when making silage from unwilted plant material. It will increase nutrient losses and juice losses and may negatively affect both the fermentation and the physical structure of the silage.

Tine-rotor conditioner (Nash, J. 2.)
There are two elements to a tine conditioner and three modes of action. The cut crop is picked up off the cutter bar and carried over the rotor within a gap between the tines and the hood. This gap and the speed of rotation are adjustable to provide different types of conditioning. The smaller the gap and the higher the rotor speed, the more aggressive the conditioning effect. A tine conditioner scrapes at the plants' waxy surface layers to allow more moisture to escape. This occurs in three ways inside a tine and rotor conditioner.

» Firstly, the action of the tines hitting the grass and lifting it through the machine. The rotor is spinning at 700-1000 rpm, so the tines slice past the forage at a massive speed, causing surface damage to the waxy coat.
» Secondly, the grass touching the hood or canopy is travelling past the stationary metal surface at high speed, so again, these leaves receive some abrasion or scuffing. Some manufacturers put an abrasive surface on the inside of this hood to increase this effect.
» Thirdly, there is a grass to grass effect. The metal of the rotor and tines are travelling at high speed whilst the hood is stationary. The speed that the grass goes through the machine varies depending on where it is in this mat of material. That closest to the rotor is at high speed, that near the hood is at the slowest. This speed difference means the plants are sliding over each other and this causes some of that waxed coat to be destroyed.

Tine-rotor conditioner behind disc mower. Photo by Kalvi Tamm

In trials, engineers found that it's the grass on grass action that's the most effective of the whole process. So, this should be adjusted. In a heavy grass first cut, a lot of material is going through the mower. Closing the conditioner hood down in this type of forage takes a lot of power and fuel. It will probably clog the mower or burn out the belts. So, heavy forage needs the hood fully open. When the forage is lighter, the operator has to close the hood to ensure there is enough resistance through the conditioner to make the most of the grass on grass action.

As the crop matures, the wax gets tougher and harder. In late cut and low D-value forage, the rotor should be at its highest speed as the stemmy material will take a lot of abrasion to break open the surface to allow moisture loss.

If forage with very high D-value is cut, then there won't be very much of it going through the machine. In this case, the grass needs effective conditioning, because the grass will lose lots of feed value whilst waiting in the swath. It should be dried or wilted to the target DM as soon as possible, so the conditioner settings are critical. There is less material in there, so the hood should be closed to get a good speed difference between plants, but at the same time, the crop is delicate, so the rotor should run in its slowest gear.

Plastic tined versus steel tined conditioner:
Plastic tines are gentler for fragile crops such as those with high D-value and those with higher clover content. Steel tines are more aggressive for late cut stemmy crops. Steel lasts longer than plastic in this application.

Rotor speed and size effect on conditioning:
Brochures will list rotor speed options between 600 rpm and 1000 rpm, but the speed of the rotor is not really the critical point, it is the speed of the tine that is important. The actual tip speed of the tine should be calculated for that. Rotor size has a huge effect so much so that the "slower" machine actually can provide a faster tine speed.

Adjusting of conditioner:
The rule of thumb for mostly grass crop, with a typical 2-3 cut system, is to run the conditioner fast, with the hood fully open during the first cut, then close it when the crops are thin. In more detail, the conditioner is to be run as aggressively as possible to start with, then one is to look at the crop. If leaf damage can be seen, one should back off the conditioning, typically by opening the hood. In a leafy crop, the rotor is to be run slower and the hood is to be closed down.

<u>Tedding and swathing (or windrowing)</u> (Kass et.al., 2021)
Tedding:
If weather conditions allow, it is possible to speed up the wilting process by tedding. Tedding involves spreading, mixing or inverting the mown forage laying on ground; it accelerates the evaporation of water from the plants. If the weather is fine, tedding once or twice is sufficient to obtain the desired dry matter content of forage. However, any movement in the field and running over the mown forage with tractor wheels is a potential risk for soil contamination. The more uniform and thinner the layer of forage in the field is when wilting, the less there is a need for tedding. When mowing broadly, there may be no need for tedding in sunny weather, or a single mixing of forage may be sufficient to achieve the desired dry matter content. However, the mown forage must be spread on the field immediately after mowing and then repeatedly turned over with the tedder, if necessary. Therefore, it is preferable to spread the forage evenly over the field, thus reducing the risk of microbial and soil contamination.

Forage tedding (A) and swathing (B). Photo by Andres Olt

Swathing time

- In order to achieve the desired dry matter content of forage, the scattered forage must be swathed immediately before harvesting from the field.
- If the weather is fine but there are problems with the silage production conveyor, the green mass can be swathed earlier to avoid over-wilting.

Swath volume

- The width and depth of the swath should match the capacity of the harvesting machinery.
- A press used for round bale silage production needs a smaller swath than a pick-up harvester.
- In order to utilize the capacity of a high-yielding self-propelling forage harvester, the optimum volume of a swath is made up of several smaller swaths. Tedding and swathing should take place after the morning dew has receded.

When to avoid tedding?

Any mechanised operations with plants will result in losses. Tedding and swathing should not be carried out when the leaves of the plants are already too dry and in danger of falling off. Valuable nutrients can be lost. Particular care should be taken with leguminous grasses.

Excessive tedding in inappropriate weather conditions, and in the hope that the grass might wilt, increases the possibility of soil contamination. Soil contamination can also easily occur in fields with sparse grasses or drought-prone soils. Contamination can cause problems with ensiling by increasing losses during fermentation, leading to butyric fermentation and silage spoilage.

Fermentation is influenced by the intensity of the sun, but also by air temperature, humidity and air velocity.

The duration of wilting depends on these factors and the species on the grassland for silage. The dry matter content of silage should be at least 25%, but preferably between 30 and 40%. It should be taken into account that in order to achieve the target dry matter content in silage, the dry matter content of the forage to be ensiled must be a few percentage points higher. The lower dry matter content of silage compared to the forage is due to the biochemical and microbiological processes during fermentation, where the use of sugars also produces carbon dioxide and water as by-products. The faster the desired dry matter content of the forage to be ensiled is achieved, the better. In good weather conditions, wilting could take up to 24 hours. Rapid and effective wilting intensifies the evaporation of water from the plants, thereby increasing the concentration of sugars, inhibiting the activity of undesirable microorganisms and promoting lactic fermentation.

Wilting for longer than 48 hours has been found to significantly increase the risks of fermentation. The micro-organisms do not wait for the desired dry matter content to be reached, and their activity starts from the moment the crop is cut. Aerobic microbes start to use the sugars present in the plants, their abundance increases and the water soluble carbohydrate content decreases with prolonged wilting. The substrate for anaerobic lactic fermentation is therefore not available. In the case of unsuitable weather conditions, especially in autumn meadows, instead of 'force wilting', it is preferable to conserve the silage with a chemical silage additive.

9.8. Chopping the forage

The chopping of cut grass has a direct impact on the physical structure and quality of silage as well as on the economic aspects of silage production. Chopped grass takes less space per ton in a transportation wagon, so transport efficiency is higher and fuel consumption per transported forage ton is lower (especially for long distances) and the shorter chop is also easier to compact in storage. On the other hand, chopping itself demands additional fuel consumption and reduces harvest performance. All the arguments are probably equally valid, but above all, chopping must serve two main purposes: to support the fermentation process and the digestive physiology of farm animals. (Kass et.al. 2021)

The faster the air is pressed out of the forage the faster the environment in the storage becomes anaerobic and suitable for lactic acid bacteria. Chopping supports the efficiency of compacting silage as well as lactic fermentation. The digestibility of chopped silage is higher in comparison with unchopped forage. In the latter case, the specificities of ruminants' digestive tracts must be taken into account. A forage with too short a chop length lacks roughness (little effective fibre), which reduces rumination and saliva production and, in the case of a concentrate diet, can lead to acidosis. Feeding forage with too long a chop prolongs rumination time and slows down the movement rate of feed particles in the digestive tract. (Kass et.al. 2021)

Chopping may be carried out simultaneously to grass mowing, loading onto a truck or wagon, harvesting with a press collector, loading a wagon or a self-propelled harvester. All the cutting blades of a chopper must be intact, in place and sharp to provide good and economically sound raw material for silage. The chop length must be adjusted to suit the material to be ensiled.

A

B

C

Collecting and chopping of forage for silage by A) loading on a separate wagon with a trailed pickup-chopper (Photo by Andres Olt), B) loading on a self-loading wagon (Photo by Raivo Vettik) or C) pressing with a round bale press (right, bale wrapper is on the left side) (Photo by Andres Olt)

The recommended chop length depends on the silage crop, its stage of development at the time of harvesting and its dry matter content. In exceptional cases, when the plant is at a very early stage of development and the content of cytoskeletal material is low, silage can be made from unchopped green mass. Grasses harvested at the optimum and late stages of development and maize harvested in its entirety must be pre-chopped before ensiling. (Kass et.al. 2021)

The collection and chopping of forage for silage by a self-propelled grass harvester. Photo by Raivo Vettik.

The general principle is that the drier the material, the shorter the chop (Table 1). A shorter chop may make it easier to compact the forage in storage, but it should be borne in mind that, depending on the dry matter content, a short chop may lose its physical structure (roughness) during compacting and become unsuitable for animals.

For this reason, the chop of plant material should be longer at an early stage of development and with a low dry matter content. In this way, the forage is not compacted into a paste and nutrient losses in the form of effluent losses are reduced.

Chopping the plants too short also increases losses from the clamp and can also make the whole clamp really unstable and liable to slippage. Although thankfully this is rare, it is extremely dangerous and can lead to losses of crop and potential pollution incidents. Chopping wet material really short and then compacting too tightly can result in an impervious soggy mat that is unstable and has little feed value. (Nash, J. 3)

The chop of wilted forage may be shorter, as may the forage made of older material. This ensures higher silage density, better fermentation and aerobic stability after opening. When storage is opened, silage is exposed to air-oxygen. In case of properly compacted silage, air cannot penetrate deeper into the silage from the silage front, thus reducing the risk of aerobic deterioration and the self-heating of the silage.

Table 1 Chop lengths by forage type and dry matter content (Kass etal. 2021)

Forage type	DM, %	Chop length, mm
Very wet forage	Below 20	50-80
Non-wilted grass (monocots and legumes) and whole-plant cereal	20-25	25-30
Wilted grass and whole-plant cereal	Above 30	10-25 depending on the plant growth stage and the content of crude fibre
Whole-plant maize	30-35	9-30

When harvesting maize, it is important to note that the maize grain could be cracked or damaged. Lactic and acetic acids produced during silage fermentation help break down the protein prolamin in the vitreous endosperm of the maize grain. The cracked maize grain has better access to silage acids, thereby improving grain digestibility and starch digestibility.

Adjusting the chop length (Nash, J. 3)
There are only two factors that can alter the chop length in a forage harvester, the speed of the feed rolls and the number of knives on the drum. Altering the forward speed of the machine makes absolutely no difference in terms of the length of chop. To reduce the chop length, the driver will need to reduce the speed of the feed rolls feeding the crop to the cutter head. This will reduce the foragers' appetite, however, when drivers are in a hurry, they are always tempted to speed up the feed so they can cover more ground. The only alternative is to fit more knives to the drum at the cutting head.

Some equipment producers have near-infrared (NIR) spectroscopy to perform real time constant crop analysis on a forage harvester. The system can measure the crop yield and dry matter (amongst other things) in real time, and store the data. The NIR sensors on foragers use the dry matter information to make automatic adjustments to chop length.

9.9. Adding silage additives to forage

One way to influence the ensilage process is to use silage additives (or stabilisers). This reduces the risks of silage deterioration during feed preparation, storage and feeding. Silage stabiliser is defined as an additive that promotes lactic acid fermentation and/or inhibits the action of undesirable micro-organisms that have entered the storage with the plant material. As a result, the feed is preserved, the self-heating of silage after opening the silo is prevented, more nutrients are retained and the shelf-life of the feed is extended. (Kass et.al 2021)

A silage additive is added to the forage during harvesting in the field. The dosing unit required for this purpose, together with the nozzles and tank, is mounted on a pick-up wagon, bale press or self-propelling harvester. The positioning of the sprayers on the harvesting machinery should ensure an even distribution of the silage additive in the green mass.

Prior to the start of silage season, the system parts like dosing tank, hose system and nozzles must be thoroughly washed. Parts with obvious biological contamination and doubtful reliability need to be cleaned or replaced with new ones. The dosing accuracy of the unit should be checked and, if necessary, readjusted. The amount of silage additive to be dosed must be in accordance with the additive manufacturer's recommendations and the amount of silage to be harvested. As the nozzles tend to clog, they must be checked daily, preferably repeatedly during the working day, to ensure that they are in good working order. When silage additives are changed, during breaks in silage production between mowings or during other longer breaks in silage production, and at the end of the season, the entire dosing system must be thoroughly washed again to prevent biological contamination.

If acid is used as a silage additive, then acid must always be applied using acid-proof dosing devices. Operators are always to comply with the regulations in safety data sheets (HACCP plan).

9.10. Forage gathering and transport from grassland

Forage for silage is picked up from swaths and transported from grasslands to storage. Various technological possibilities exist for that. Grass forage can be harvested from the field using a self-loading mower, a trailed forage harvester, a self-loading forage wagon, a self-propelled forage harvester or round-bale silage technology. (Kass et.al 2021)

- The self-loading mower harvester operations consist of mowing silage, simultaneously chopping it and loading it onto the transporter.
- The trailed forage harvester and self-propelled forage harvester operations consist of mowing silage or gathering silage from a swath, simultaneously chopping it and loading it onto the transporter.
- The self-loading forage wagon collects forage from a swath, chops and loads it onto the wagon, which then transports and loads it into silage storage.
- A baler used in the production of silage in rolls collects forage from a swath, chops, and then shapes it into rolls by pressing. The bales are wrapped immediately.

The collection of the forage to be harvested from the field, its transport and unloading at the storage site should be carried out quickly to minimise the exposure of the ensiled material to air. The performance of harvesting machinery and its transport capacity must be balanced. For example, if the forage yield is high, or if the distance from the field to the storage is long and there are not enough transport vehicles, there will be disruptions in the forage production process, the performance of the harvesting machinery is not utilized and the cut forage remains in the field for too long. If transported too far, consider storing and ensiling the forage closer to the field, as green fodder stored for long periods in a transporter will quickly deteriorate and become hot. Grassland for silage production could be planned around barns. Care should also be taken that no more forage is transported into storage than can be compacted. Forage harvesting and transport should be organised primarily on the basis of compacting capacity.

Forage must not be contaminated during harvesting and transport, and transporters should not spoil silage already in storage. Oils, lubricants, etc. must not be allowed to enter the forage in the grassland, during transport or during storage. In the field, harvesting and transport equipment running over swaths in the grassland should be avoided. Similarly, dirty tyres must not be driven into the storage area and the area around the storage must be kept clean, otherwise the feed will be contaminated with soil, which may lead to undesired fermentation and silage spoilage. At the end of each workday, harvesting machinery and trailers should be cleaned of any plant material left on the equipment, as this will quickly spoil and contaminate the first forage loads of the following day. Soil, manure, slurry and residues from the previous day's forage on the equipment contain a large number of micro-organisms that cause silage to deteriorate, so their getting into the forage must be avoided at all costs.

Operators are to ensure the forage harvester collects all cut material from the grassland and blows it into the trailer, not back to the ground.

Loose forage and wrapped bales are to be transported to the yard in a safe manner. With bale silage, any torn plastic should be repaired when bales are stacked (Kerins, 2021)

9.11. Making round-bale silage

A round-bale press and a wrapping machine are used to make round-bale silage. The presses can be subdivided into belt presses, roller presses and chain presses (also known as conveyor presses), which in turn can have either fixed or variable chambers. Some presses also have a combination of rollers and belts. (Kass et.al 2021)

The combination of both rollers and belts ensures that bales are perfectly formed and have a dense core. The density across the entire bale makes them resistant to extensive handling and improves the fermentation profile of silage bales. The variable chamber technology means that operations can adjust the size of the produced bale in 5 cm increments, from 90cm up to 150 or 180 cm to enhance baling flexibility (NewHolland).

Belt presses are more suited to produce hay and straw bales.

For silage making, roller or chain type presses should be preferred, as they provide a higher compaction density. Fixed-chamber balers compact forage as the baling chamber fills up, while variable-chamber balers start baling forage into a roll as soon as the core of the roll is formed, after which the roll is tied with net or twine.

The roll is then wrapped with a round-bale wrapper in special plastic film to ensure a hermetic and anaerobic environment for the high-quality ensiling of the forage. There should be at least six layers of film on one silage bale.

There are also round-bale presses on the market, where the baler and the wrapper are combined into a single machine – baler-wrapper. The wrapped bales are stored either at the edge of the field or close to the farm.

Forage is swathed, pressed to round bales and the bales are wrapped by an aggregate. Photo by Raivo Vettik

Balers can be mobile or stationary. Mobile balers are trailed by tractors and pick up forage from a swath while driving. Stationary balers are driven by tractors, but are set standing in one location on the grassland. Forage is transported from the grassland to the baler by a transporter that empties the wagon into a baler's loading hopper. The correct dryness and moisture content of the material is crucial to achieve the highest compression of the material and perfectly compressed bales. In the case of very dry material, water can be added directly to the bale chamber via the water injection unit. Particularly at temperatures above 15 degrees Celsius, the feed can deteriorate in quality due to the high activity of microbacteria. The very high compression during the baling process results in unmatched storage and feed quality. (Göweil, 2025)

9.12. Technologies for harvesting forage: precision and automation

Nowadays, more modern equipment such as tractors, mowers, forage harvesters, balers and other machines have revolutionized forage harvesting, making the harvesting processes more efficient and, consequently, more economically viable. Currently, self-propelled forage harvesters equipped with precision cutting blades and GPS systems are very common. They enable more efficient forage processing, maintaining consistent particle size and nutrient retention.

Emerging innovations in harvesting technology have focused on precision and automation. Sensor-based systems provide real-time data on the dry matter content and crop yield to aid in real-time adjustments to optimize the efficiency and quality of silage production. In this sense, autonomous harvesting machines and robotic tools are reducing labour requirements while improving accuracy.

It can be expected that the adoption of precision and automation technologies has the potential to improve the green biomass harvesting efficiency in the Baltic countries. This can be achieved by proper machinery integration, GPS-guided systems, robotic tools, and sensor-based optimization approaches, which will enable farmers to achieve greater efficiency, sustainability, and more economical structures within the farm.

9.13. Social aspects of forage harvest for silage

Forage harvesting for silage is carried out 3-4 times a year, starting at the end of May in Estonia, at ~30-day intervals, each time for ~10 days. In addition, maize harvesting is performed in the end of September. During these intense periods harvesting impacts the following:

- traffic between grasslands and storages during harvesting - large and heavy harvest machinery and transportation wagons are moving on roads, and these bring some dirt and forage on roads;
- households near grasslands, roads and storages - the work involves low noise, also dust, if the weather is dry and windy.

The following social aspects can also be mentioned:

- diversification of landscape in space and time. The grasslands have different colours (lighter green instead of darker for some weeks after harvest) and patterns (forage swaths and round bales in some days on grasslands) caused by forage harvesting;
- round bales stored on the roadside are used to send messages to society by their plastic film colour, or pictures or texts on the film;
- non-silage people learn forage harvesting technologies, equipment and practices. It is recommended to provide harvesting equipment or silage bales with messages like “Here comes feed for dairy cows”, “Here comes grass for cattle”, “We produce milk”, “We produce beef” etc. It provides an understanding to people of how this work is related to them.

Environmental impact

Harvesting machinery and related technologies, although very beneficial in boosting production levels, are mostly, if not entirely, powered by fossil fuels, which cause increased concentrations of greenhouse gases in the atmosphere. In addition, heavy harvesting machinery passing over the same field multiple times throughout production cycles can cause excessive soil compaction, which reduces aeration and water infiltration into the soil, thus harming overall soil quality. The integration of precision agriculture tools, renewable energy sources and low-impact machinery provides opportunities to mitigate the harmful effects of harvesting technologies on environmental impact.

Minimizing the GHG emissions of forage harvesting

- *Excessive operations when harvesting feed are to be avoided.*
- *Harvesting should be carried out in weather conditions that favour the transport of forage with a low moisture content, thus avoiding unnecessary transport of water.*
- *The equipment should be in good condition and well-adjusted to minimize excessive fuel consumption.*
- *The equipment operators should be trained to find and use optimal work methods and movement routes on the grasslands and roads, so the fuel consumption and exhaust gas emission on harvest operations is minimised.*
- *The operators need to use equipment with high tyre pressure on roads to minimise resistance to movement, thus fuel consumption and exhaust gas emission.*

Minimizing the compaction of grassland soils during harvest
The pores that naturally occur in soil are used for the exchange and transport of water and oxygen through the soil. This function is vital for the root zone of plants. Soil compaction reduces the volume of the pores, so less water and fewer nutrients can be stored in the soil. This affects grass growth negatively. There is a strong correlation between soil compaction and reduced grass growth and yield. (Kuhn 2023)
Soil compaction is a difficult problem to rectify, so prevention is better than cure. Deep tillage to de-compact the soil is often needed to mitigate the effects, but this affects the natural soil structure.
So, it's best to prevent compaction rather than to solve the problems it causes afterwards.

- *This can be done by always working the land in dry conditions. As this is not always possible, it is important to carefully consider which machinery you will be using. Limiting the number of passes and combining work passes – e.g. baling and wrapping – reduces the risk of soil compaction. Transferring newly wrapped bales as much as possible from the wrapping table to the headland limits field traffic when the bales are collected as less movement of heavy machinery – such as bale wagons, telehandlers or loaders – is necessary on the field.*

- *To limit the impact of traffic on the soil, it is important to minimise the weight of the combination and, where possible, reduce tyre pressure. A light machine combined with a trailed implement suitable for the task is the ideal scenario. The basic principle is the lowest possible combined weight per tyre.*
- *The tyre pressure of lightweight combinations can be reduced further once in the field. It is best to consult the pressure table of the tyre manufacturer. Opting for an additional wheel axle allows the tyre pressure to be lowered further. With optimum tyre pressure – preferably below 1 bar – the pressure exerted per cm2 on the soil does not increase when the bale chamber fills with grass or when a bale is on the wrapping table. As the weight increases, the tyre will flatten and therefore distribute the weight over a larger surface. This minimises damage to the grassland.*

If forage transportation equipment moves on the field and roads both, it is recommended to use equipment with variable tyre pressure, so that low pressure is used on the grassland and high pressure on roads.
Minimizing the danger for wildlife during forage harvesting is described in paragraph 9.5 "Preparation of grassland for harvest".

Key takeaways

- Adopting advanced forage harvesting technologies supports long-term sustainability and profitability of animal husbandry.
- Efficient harvesting and the use of harvesting technologies helps ensure the production of high-quality silage.
- Timely harvesting ensures optimal yield and nutrient preservation in forage for silage.
- A smooth and efficient harvesting process is ensured by well-qualified workforce, the good technical condition and proper set-up of the machinery, and the good organisation of work.
- Precision agriculture technologies enhance efficiency and reduce resource waste.
- Employing low-impact machinery, renewable energy, and soil-friendly practices can reduce the environmental footprint of silage production.

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10. Silage sealing and storage technologies

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10.1. Introduction to the chapter

Efficient silage management is crucial not only for maximising feed quality and minimising losses, but also for optimising farm resources and aligning with environmental sustainability. Especially in regions with long storage periods and challenging weather conditions like Northern Europe, the selection of silage storage technologies requires the careful consideration of several factors. These factors include the size and type of farming operations, crop type, climatic conditions, available resources, and adherence to evolving environmental regulations.

In this chapter, we will explore five key silage storage technologies: bale wrapping, tunnel bags, piles, trenches (silage bunkers), and silage towers. Each technology will be analysed in terms of its advantages, disadvantages, operational challenges, and environmental impact. By identifying best practices and practical innovations, farmers can make informed decisions that not only enhance silage quality but also contribute to environmental sustainability and cost-efficiency.

10.2. Background and Context

Northern Europe faces unique challenges in forage preservation due to short harvesting windows and long harsh winters. Ensuring that silage retains its nutritional value while minimising spoilage is essential. This puts enormous pressure on farmers to adopt storage technology that best suits their operational scale, crop type, and environmental conditions.

Environmental regulations have also become increasingly stricter in recent years. Farmers are expected to adopt more sustainable practices, which include reducing plastic waste, managing effluent, and minimising greenhouse gas emissions. These regulations are particularly relevant when choosing a silage storage system, as each technology has its own environmental footprint.

10.3. Silage Sealing and Storage Technologies

10.3.1 Bale Technology

Bale silage, often called "bale silage", "wrapped silage bales" or "round bale silage", is particularly suited for smaller and medium-sized farms. Its flexibility, scalability, and relatively low infrastructure requirements make it a favoured choice. The method involves tightly wrapping individual or multiple bales in plastic to create an anaerobic environment for the forage, thus facilitating fermentation and preservation.

A key advantage of bale silage is its mobility. Farmers can store bales in different locations across fields or under cover and moving them is straightforward by using standard farm machinery. Additionally, the initial investment is manageable, especially for smaller farms, as expensive infrastructure is not necessary.

However, bale silage presents some environmental concerns. It consumes large amounts of plastic, and its disposal poses a significant challenge for farms aiming to reduce waste. Vulnerability to damage from birds and rodents also necessitates constant inspection to maintain the integrity of the plastic wrap, preventing spoilage.

In terms of compaction, bales must be tightly pressed to limit oxygen exposure and support fermentation. Sealing with durable multi-layer plastic is crucial, and regular checks should be made to prevent any breaches that might cause spoilage.

While bale silage allows for easy transportation and precise feeding, where only specific bales can be unwrapped, this technology tends to be labour-intensive. From a resource standpoint, it requires fewer facilities but requires more labour and careful handling. Round bale silages do not usually face problems with heating during feed-out, as they are consumed immediately after opening. Very small farms, such as horse stables with only a few horses, where the consumption of the bale may be extended over several days, present an exception.

Despite high plastic usage (see Chapter 8), bale silage can be adapted for different forage types, though it is not well-suited for high-moisture crops and corn silage. Protecting the bales from external factors, such as wildlife, is critical to avoid damage to the plastic wrap. The golden rules for reducing spoilage include ensuring that wrapping is tight, using high-quality plastic, and maintaining regular inspections.

10.3.2. Tunnel Bag Technology

Tunnel bags, also called “silage bags”, “bag silage”, “silage in plastic tubes” are predominantly used in medium and larger farms. This method involves filling long plastic tubes with silage and sealing them to create an anaerobic environment. Tunnel bags are efficient for storing large amounts of silage while reducing the consumption of plastic in comparison with bale silage, making tunnel bags more environmentally friendly.

A significant advantage of tunnel bags is their ability to store substantial volumes of forage while using less plastic than bale silage. However, the initial cost of specialised bagging equipment can be a hurdle for smaller operations. Once filled, tunnel bags are stationary, so careful consideration is needed when selecting a storage site.

Tunnel bags excel in compaction, as proper packing during the bagging process eliminates oxygen, ensuring high-quality fermentation. Sealing the bag properly is critical, and storage should be done on well-drained surfaces to avoid water damage or effluent issues.

Though transportation of tunnel bags is not feasible once filled, feeding out is efficient and reduces spoilage as the silage is exposed gradually. Tunnel bags require fewer resources in terms of plastic, making them a more sustainable option, but they are still vulnerable to punctures from birds and wildlife.

Recent innovations include more durable oxygen-barrier films, which improve silage fermentation, storage and aerobic stability. However, protective barriers such as nets are necessary to protect the bags from wildlife.

10.3.3. Piles Technology

Silage piles, "silage pits," "silage clamps", "heap silage" are a cost-effective and scalable storage solution for larger farms. This method involves creating a heap of silage, compacting it, and covering it with plastic sheeting weighed down with heavy materials, such as tires or soil, to create an anaerobic environment. This method allows for flexibility in terms of volume and shape, but it requires careful management to prevent spoilage.

The primary advantage of silage piles is their low infrastructure investment, making them accessible for large-scale operations. The scalability of this technology means that farmers can adjust the size of the pile depending on the volume of forage harvested. However, compaction is labour-intensive and requires heavy machinery to ensure that the forage is densely packed, thus reducing the risk of oxygen infiltration, which can lead to spoilage. Sealing is another critical factor: plastic sheets must be weighed down effectively to maintain an anaerobic environment. If sealing is insufficient, oxygen exposure can cause significant losses, especially in the top layers.

From an environmental impact standpoint, silage piles present concerns, especially regarding effluent run-off, which can contaminate surrounding soil and water, if not properly managed. To mitigate this risk, proper drainage systems should be installed. In comparison to bale silage, less plastic is required, but it is still essential to ensure proper sealing to avoid spoilage. Transportation of silage piles is not an option due to their fixed location, but feeding out can be managed in a way that exposes minimal silage to oxygen at a time.

The golden rules for silage piles include maintaining tight compaction, using high-quality plastic for sealing, and ensuring proper drainage. Recent innovations in oxygen-barrier films have improved top-layer sealing, significantly reducing spoilage.

10.3.4. Trenches or Silage Bunkers Technology

Trenches or "silage bunkers", also known as "bunker silos, "drive-over piles" are highly efficient storage systems used in large-scale farming operations. They involve packing silage into ground-level or semi-underground structures, which are then sealed with plastic sheeting.

One of the main advantages of this technology is its ability to store vast quantities of silage while minimising dry matter losses due to the efficient anaerobic environment provided by proper sealing and compaction. Compared to silage piles, silage bunkers generally result in lower spoilage rates due to better oxygen control. However, the initial investment for constructing bunkers can be substantial, making this technology more suitable for larger farms.

Compaction in trenches and bunkers is essential to avoid oxygen pockets, which can spoil the silage. The use of heavy machinery is necessary for the efficient compaction of forage. Sealing involves covering silage with plastic that has to be weighed down to maintain anaerobic conditions. While plastic consumption is lower than in bale silage systems, managing the cover is labour-intensive, and silage remains vulnerable to damage from birds and other external factors.

The environmental impact of silage bunkers is lower in terms of plastic use, but effluent run-off remains a concern. Proper drainage systems (see Chapter 14) are crucial for preventing environmental contamination. Feeding out from silage bunkers is more labour-intensive compared to other methods (see Chapter 13), requiring specialised equipment to remove and distribute the silage. Still, the ability to store large volumes makes it a cost-effective solution for high-volume silage needs.

Innovations in oxygen-barrier films and improved sealing techniques have significantly reduced spoilage rates in silage bunkers, making them even more efficient.

10.3.5. Silage Towers Technology

Silage towers, also called "vertical silos" or "upright silos" provide an effective way of storing large quantities of silage in a compact space. These cylindrical structures are especially beneficial for farms with limited land, as they allow for vertical storage of silage. Silage towers are highly efficient in maintaining high silage quality with minimal dry matter losses, as the vertical design promotes excellent compaction.

The primary advantage of silage towers is their ability to store silage with minimal spoilage thanks to the airtight environment created within the structure. Compaction in silage towers happens naturally due to the weight of the silage pressing down, reducing the need for additional machinery. Sealing involves tightly closing off the top of the tower, ensuring that no oxygen can enter.

As silage towers require little to no plastic for sealing, their environmental impact is lower compared to plastic-based systems. However, the initial investment for constructing and maintaining a tower is high, and specialised equipment is required both for filling and feeding out from the tower.

Silage towers offer excellent protection against spoilage, and their resale value and durability in the long term are significant considerations for farms looking for a long-term solution. They are less flexible when it comes to the variety of forages they can store, being primarily suited for high-moisture crops.

The golden rules for silage towers include ensuring proper compaction and sealing, using specialised equipment for feeding out, and conducting regular inspections of the structure. Innovations in tower design, such as better unloading mechanisms and improved sealing technologies, have reduced labour costs and improved the overall efficiency of silage towers.

Key takeaways

- Each technology, whether it is bale silage, tunnel bags, piles, trenches, or silage towers, comes with its own set of advantages, challenges, and environmental impacts.
- When choosing a storage system, farmers must carefully consider factors like the size of the farm, crop type, available resources, and environmental regulations.
- Innovations, such as oxygen-barrier films and improved sealing techniques, have enhanced the effectiveness of these technologies, helping reduce spoilage and minimise losses.
- The success of each method depends on proper management practices, e.g. tight compaction, sealing, and regular monitoring, to ensure the highest quality silage and minimise the environmental footprint.

10.4. Conclusion

Each silage storage technology offers unique advantages and challenges. Bale silage provides flexibility, but has a high environmental cost due to plastic use. Tunnel bags offer high-quality silage storage, but require significant upfront investment in equipment. Pile silage is cost-effective, but requires careful management to avoid spoilage and environmental contamination. Trenches and silage bunkers are ideal for large-scale operations, but require substantial labour and infrastructure. Silage towers offer the most efficient oxygen control, but are best suited for specialised large-scale operations.

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11. Fermentation - how to ensure good silage quality

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Around the world, ensiling is a growing practice for forage preservation, and ensuring its adequate fermentation process is a crucial step for the success of the production system.

In order to guarantee excellent quality in silage production, operators are to carefully follow the principles of silage making, such as:

11.1. Forage characteristics

The forage plant species and their characteristics related to their chemical composition affect the quality of ensilage. Some of the most important aspects are dry matter (or moisture) and water-soluble carbohydrate (non-structural carbohydrates, also known as sugars) content and buffering capacity.

a. The dry matter content of forage at ensiling affects the rate and extent of fermentation, as water activity affects the microbial viability in the plant biomass. The dry matter content also has a negative correlation with the amount of effluent produced in silage during storage, therefore the higher the dry matter, the lower the amount of effluent lost from silage. According to McDonald et al. (1991), crops ensiled with the dry matter content of 25 - 30% or above will have very little effluent losses.
b. Water soluble carbohydrates are substrates, primarily sugars, that are fermented and converted into lactic acid by lactic acid bacteria. According to EFSA (2018), forages with >3% of water-soluble carbohydrates on fresh matter basis are classified as easy to ensile, while 1.5 to 3.0% are moderately difficult to ensile and concentrations lower than 1.5% of water soluble carbohydrates in fresh matter are defined as difficult to ensile.
c. The buffering capacity of forage is led by chemical compounds called buffers, which resist changes in pH during the fermentation process. This is important because a rapid drop in pH is needed to inhibit undesirable microorganisms and promote the growth of lactic acid bacteria, which are beneficial for silage preservation. Buffering substances, such as proteins and minerals, neutralise some of the acids in the silage, restricting and slowing the decline in pH that provides opportunities for the growth of undesirable bacteria. Additionally, high moisture content (dry matter below 20%) in plant material increases buffering capacity by diluting fermentation acids, slowing the pH reduction, and enhancing the solubility of plant components like organic acids and minerals. In contrast, low moisture content reduces the buffering capacity, leading to a quicker decline in pH. It is worth noting that species greatly affect the buffering capacity of forages. Legumes typically have a greater buffering capacity than grasses, which indicates a greater need for adequate silage management when preserving plant material that is high in legumes.

How to assess the ensilability of forage? Based on the three parameters described above, Pahlow and Weissbach (1999) proposed a fermentation coefficient equation to estimate the ease of ensiling, as follows:

$$\textit{Fermentation coefficient} = \textit{dry matter} + 8 \times \frac{\textit{water soluble carbohydrate}}{\textit{buffering capacity}}$$

Note that the units to be used in this equation are: dry matter, % of fresh matter, water soluble carbohydrates, % of dry matter, buffering capacity, g of lactic acid/100 g of dry matter. Forages with a fermentation coefficient of <35 are classified as difficult to ensile, and consequently require greater handling care to provide silages with high fermentative quality. Forages with a fermentation coefficient between 35 and 45 are considered intermediate, while the ones >45 are easily fermented during ensiling (Table 1).

Table 1. Practical example of crops with difficult (crop 1), intermediate (crop 2) and easy to ensile (crop 3) fermentation coefficients.

Item	Crop 1	Crop 2	Crop 3
Dry matter, % of fresh matter	20	25	30
Water soluble carbohydrates (sugars), % of dry matter	10	12	14
Buffering capacity, g of lactic acid/100 g of dry matter	6.5	6.0	5.5
Fermentation coefficient	**32**	**41**	**50**

These are hypothetical scenarios of the fermentation coefficient varying according to the dry matter and water-soluble carbohydrates content as a function of the buffering capacity when it is 5 (scenario 1) or 7 (scenario 2).

Scenario 1

DM	FC when BC = 5				
33	47	52	57	62	
28	42	47	52	57	
23	37	42	47	52	
18	32	37	42	47	
	9	12	15	18	WSC

Scenario 2

DM	FC when BC = 7				
33	43	47	50	54	
28	38	42	45	49	
23	33	37	40	44	
18	28	32	35	39	
	9	12	15	18	WSC

DM: dry matter, % of fresh matter; FC: fermentation coefficient; BC: buffering capacity, g of lactic acid/100 g of dry matter; WSC: water soluble carbohydrates (sugars), % of dry matter. From red and poor fermentation coefficient to green and high-quality fermentation coefficient.

As shown above, the fermentation coefficient is a very useful parameter for estimating forage ensilability. Its ability to describe the fermentation potential of forages makes it particularly valuable in evaluating their suitability for silage production. However, its limitation comes from the fact that only a few laboratories routinely measure buffering capacity, a key parameter required to calculate the fermentation coefficient.

Given this constraint, an alternative and potentially more convenient approach for assessing forage ensilability is the crude protein to dry matter ratio. This ratio provides a very simple and relatively easy to measure indicator of how easily a forage can undergo the fermentation process required for silage. Based on this method, the crude protein to dry matter ratio can be used to determine how easy or difficult it is to ensile forage:

- A ratio of 0.4 to 0.5 indicates that the forage is easy to ensile.
- A ratio of 0.5 to 0.7 suggests moderate ensilability.
- A ratio of 0.7 to 0.9 means the forage is difficult to ensile.
- A ratio above 0.9 means that the forage is not suitable for ensiling.

This approach provides a practical and widely applicable alternative for the evaluation of forage ensilability, especially in situations where buffering capacity measurements are not feasible. It gives a possibility for a quick and rather rough evaluation of forage material that could support the decision-making processes related to silage production.

11.2. Harvest and ensiling management:

The main objective in harvesting and ensiling a crop is to preserve the quantity and quality of the harvested crop at the time of cutting as much as possible. The qualitative and quantitative proportions in which forage is preserved depends on several factors, such as:

a. The mower's efficiency has a great impact on the success of silage production. It is important to avoid factors that extend the mowing period, such as mowers with dull blades or low-power machinery. In these cases, it may be worthwhile and economical to employ a contractor with suitable machinery.
b. The ideal cutting height depends on the type of forage, yield, potential for regrowth, and therefore, must be investigated in each specific circumstance. Additionally, the smoothness and overall quality of a grassland play a significant role, as uneven terrain or poor-quality swards may necessitate adjustments in cutting height to avoid damage to equipment and ensure uniform regrowth. Cutting the forage too low can slow the regrowth rate, reduce yield and increase the risk of forage contamination with soil and manure. Thus, to achieve efficient forage utilization and maintain the long-term productivity of the grassland, the optimal cutting height must be evaluated on a case-by-case basis, considering both agronomic and environmental factors. However, an ideal cutting height range is recommended, with grasses cut at 7-10 cm, legumes at 8-12 cm, whole-crop cereals at 10-15 cm, and maize silage at 15-20 cm, ensuring a balance between yield, quality, and regrowth potential while minimizing soil contamination and optimizing fermentation.
c. Wilting is the process by which part of the moisture in the mowed forage is evaporated in the field prior to harvesting, thus increasing the dry matter content to the level desired for preservation. Wilting improves the ensilability of forage, because it increases the concentration of sugars and reduces the moisture content as well as inhibits the activity of undesirable microorganisms (e.g. clostridia). Wilting should not exceed a period of 48 hours. The longer the wilting period to reach the target dry matter, the greater the chances of dry matter and quality losses, as well as the risk of rain. Weather conditions (e.g., wind, temperature, risk of rain) directly affect the wilting rate and must

be monitored during the ensiling season. Also, mechanical factors, such as mixing and windrowing, are critical components of the wilting process for silage production. The method of cutting, whether swathed or widespread, significantly affects the rate and uniformity of moisture loss. The use of mowers equipped with conditioners further enhances the wilting process by crushing the forage, thereby increasing the surface area for moisture evaporation. Additionally, tedding plays a key role in facilitating optimal wilting by redistributing forage, ensuring even exposure to sunlight and air. These mechanical practices, when applied correctly, can improve the efficiency of the wilting process, leading to better preservation and quality of silage.

d. The chop length of forage should be dimensioned to meet the requirements for effective fibre in the animal diet and at the same time, the particles should be small enough for good compaction and air exclusion from the silo. For grasses and legumes (e.g., timothy, alfalfa), the ideal length varies between 1 and 3 cm, while for maize and whole-crop cereals silages, the recommendation is between 1 and 2 cm. For very dry forages, a small particle length is recommended (<1.5 cm) to ensure good compaction and adequate density. Good silage compaction is achieved when the forage feels firm under pressure, has minimal air pockets, maintains a uniform structure without visible gaps, presents consistent colour and emits a pleasant acidic smell.

e. Filling, speed and compaction at the silo must be a continuous process throughout silage making. The faster the silo is filled and the more compact it is, the better the results tend to be. Porosity is a function of the density and dry matter concentration of silage, so if the forage is too dry (above 45% dry matter), there will be increased porosity and susceptibility to losses due to deterioration as aerobic microbes have a better chance to remain active. Efficient sealing is critical to ensure the success of silage making and thus minimise losses. Some procedures are essential to guarantee airtight sealing, e.g. sealing the silo immediately after filling and covering with plastic suitable for silages, securing the plastic covers on top the silos with sandbags, tires or other sufficiently heavy material that guarantees compaction, and carrying out adequate maintenance of the plastic while the silo is closed.

11.3. Storage type

A great variety of methods is available ranging from simple and cheap structures to permanent concrete constructions, such as:

a. Bunkers, also known as clamps or trenches, are the most common silos worldwide and consist of walls on two or three sides and silage being covered with plastic. It is usually characterised by long ditches surrounded by concrete walls.

b. Piles, or heaps, are a common method for silage storage, particularly in large-scale operations. This method involves placing compacted forage in a freestanding heap, typically on a concrete or plastic-covered base, to minimize losses from spoilage and effluent runoff. The pile is then covered with plastic sheeting and weighted down to ensure an airtight seal, which is essential for maintaining silage quality and minimizing nutrient losses during storage.

c. Bales, or wrapped bales, are round or rectangular, packed with multiple layers of stretchy polyethylene plastic. This type is quite popular in Europe, where at least 6 to 8 or even more layers of stretchy polyethylene film are recommended, especially in places with warmer climates. Bale plastics are particularly vulnerable to damage from birds and animals, making regular monitoring for holes essential to prevent air infiltration, as this greatly affects the fermentation quality of silage and increases the risk of spoilage.

d. Bag silos can vary in length between 30, 60 and 90 m and require self-propelled or tractor-coupled tubular silage machinery. The goal is to fill the bag to obtain a dense but smooth surface. However, excessive density can lead to an uneven surface. This type of silo produces excellent fermentation because the crop becomes anaerobic quickly, is protected from rain during filling and maintains a seal against exposure to oxygen during storage, but is also susceptible to punctures by birds, animals and hail.

11.4. Silo management

Losses during the storage period are due to fermentation losses and microbial respiration of the oxygen that enters the silo. These fermentation losses (normally 1%-4%) are inevitable and are mainly the result of carbon dioxide production (fermentation of hexoses into acetic acid or ethanol). Minimising the exposure of silage to oxygen minimises respiratory losses, so some factors must be observed, such as:

a. The silo cannot be forgotten during the period in which it remains closed, as it requires plastic maintenance. If the silage is not hermetically sealed, oxygen penetrating the silage during storage is unavoidable. In addition to burying the edges of the plastic and covering the silo appropriately with heavy material, from time to time, it is also necessary to investigate whether there are punctures made by birds or other animals that should immediately be repaired with suitable silo sheet tape. Other factors that affect the integrity of the seal include the following: the plastic cover may not be securely attached to the silage, or there are cracks in the silo walls that allow oxygen to enter. Wind passing over a silo creates a pressure differential between the windward and leeward sides of a silo and this draws air into the silo.

b. Feedout rate is stated as how much silage mass is removed from the silos daily and defines how fast/slow oxygen penetrates/diffuses into the silage. A typical recommendation is that at least 15 cm of silage face should be removed per day. However, it may not be sufficient depending on the characteristics of the silage, as feedout rates are inversely proportional to the average density of the silage. Substantial losses can occur during silo emptying when feedout rates are low, therefore silos must be previously sized according to the amount of silage to be removed from the silo daily.

c. Silo face is the way in which the silage sheet is removed from the silo and must be as uniform and smooth as possible.

11.5. Additives and their dosage

A great range of products to be used in different dosages in silage making have been widely available on the market for decades. Additives are used to improve silage preservation and/or aerobic stability during feedout phase. The effects of these additives on livestock are often more important for the producer to merit their use. Silage additives generally fall into one or more of five categories, based on their effects on silage preservation, which can be: 1. fermentation stimulants; 2. fermentation inhibitors; 3. aerobic spoilage inhibitors; 4. nutrients and 5. absorbents. These products generally have different means of action and can be homofermentative lactic acid bacteria, obligate heterofermentative lactic acid bacteria, combination of inoculants, other non-lactic acid bacteria species inoculants, chemicals (acids and salts) and enzymes (Muck et al., 2018). Some of the positive aspects why additives should be used in silage preparation are to:

a. Inhibit the growth of aerobic microorganisms (especially those associated with aerobic instability, such as lactate-assimilating yeasts, and lack of hygiene, such as *Listeria monocytogenes*).
b. Inhibit the growth of undesirable anaerobic organisms (e.g., enterobacteria and clostridia).
c. Inhibit the activity of plant and microbial proteases and deaminases.
d. Improve the supply of fermentable substrates (i.e., sugars) for lactic acid bacteria.
e. Add beneficial microorganisms to dominate fermentation.
f. Provide or release nutrients to stimulate the growth of beneficial microorganisms.
g. Change ensiling conditions to optimise fermentation (e.g., absorbents).
h. Form beneficial end products that stimulate animal intake and productivity.
i. Improve nutrient and dry matter recovery.

Ensuring good silage quality throughout the ensiling phases:

1. Aerobic phase: it starts when the forage is cut, continues during the wilting period, the sealing of the silo, extending until the oxygen is finally consumed in the silage mass and then anaerobic conditions are achieved within the silo. The duration of this phase affects the composition of forage due to plant enzyme activity, as well as the microbial composition, and consequently, the fermentation quality of the silage. During the aerobic phase, the plant cells are respirating and the enzymes degrade non-structural carbohydrates into carbon dioxide and water, releasing heat. Proteolysis might also take place as proteins are degraded into different forms of soluble non-protein nitrogen. The aerobic phase can continue as long as oxygen is available inside the silo, for instance, when there are holes in the sealing cover.
2. Main fermentation phase: this phase starts when oxygen is fully consumed in the silage mass and anaerobic conditions are reached. During this phase, under suitable conditions, non-structural carbohydrates are converted into organic acids, lowering the silage pH, restricting further detrimental microbial growth, and consequently preserving the silage.
3. Stable phase: when silage reaches a fermentation plateau, very little occurs from this moment on, as long as the silo remains well sealed and airtight. However, if adequate conditions are not maintained, for instance, punctures on the silo cover, silage quality is compromised.
4. Feedout phase: when opening the silo, the silage mass is exposed to air when starting the feedout phase, and then, the dormant aerobic microorganisms are revived. The silage parameters, such as pH, organic acids, ammonia-N and ethanol will dictate the speed of aerobic deterioration. Aerobic spoilage is firstly indicated by heat production. Spoiling microorganisms use silage substrates, such as unfermented non-structural carbohydrates and lactic acid, as substrates when silage is exposed to air, producing carbon dioxide, water and heat, resulting in an increase in temperature and pH, a growth of detrimental microorganisms and silage deterioration. Some fermentation end products, such as acetic and butyric acid, improve the aerobic stability of silage by inhibiting the growth of spoilage organisms, such as yeasts and moulds. Silages with high ammonia-N levels are generally aerobically less stable due to their connection to poor fermentation quality. Elevated ammonia-N is often indicative of clostridial fermentation, which results

in a higher pH and an environment rich in substrates that promote the growth of spoilage organisms, such as yeasts and moulds, once the silage is exposed to air. Ethanol itself is not directly harmful, but its production is often associated with conditions that lead to poor aerobic stability. When silage is exposed to air, the presence of ethanol indicates a high yeast population that can rapidly consume residual sugars and lactic acid, leading to the heating and spoilage of the silage. Poorly fermented silage that lacks residual sugars, lactic acid and other available nutrients can exhibit greater aerobic stability as there are fewer nutrients to support microbial growth, and high concentrations of acetic and butyric acid. In contrast, well-fermented silage, while of higher nutritional quality, may be more prone to aerobic deterioration, because its nutrient-rich composition provides an ideal environment for spoilage organisms when exposed to oxygen.

11.6. How to ensure good silage quality from the cow's perspective

Understanding the chemical and microbial parameters of the silage

1. Silage pH and lactic acid production: silage pH is a measurement of its acidity. Forages with high buffering capacity, for example legumes with high protein and ash contents, tend to have higher pH due to the simple intrinsic characteristics of the plant, and therefore require better management techniques during ensiling. Lactic acid is the most abundant organic acid produced during ensiling and it is formed by lactic acid bacteria causing the fermentation of water-soluble carbohydrates under anaerobic conditions. Lactic acid contributes to lowering the pH of silage, being 10 to 12 times stronger than any of the other major fermentation acids, inhibiting the growth of spoilage microorganisms and preserving the forage (Kung et al., 2018). Under normal feeding conditions, lactic acid is converted into propionic acid in the rumen.
2. Concentration of organic acids/volatile fatty acids: acetic acid is present in silage in the second highest concentration after lactic acid. It is also formed through fermentation by lactic acid bacteria and other microorganisms. Acetic acid in moderate concentrations can be beneficial, as it inhibits yeasts and improves the aerobic stability of silage when exposed to air. When absorbed, it is used as energy or incorporated into milk or body fat. Propionic acid is sometimes undetectable or present in low concentration in well preserved silages. A high concentration of propionic acid is an indicator of poor preservation, although propionic acid per se is not detrimental, e.g., when additives based on propionic acid are used and consequently, propionic acid can be recovered in the final silage. Propionic acid may be present in silage, particularly in silages with higher moisture content or longer fermentation periods. When absorbed, propionic acid is converted into glucose in the cow's liver. Butyric acid should ideally not be detectable in well-fermented silages, as it comes from the metabolic activity of clostridia organisms, which generate losses in the nutritional value of silage, as well as losses of dry matter and poor energy recovery. Thus, butyric acid is a byproduct of fermentation under unfavourable conditions, such as insufficient packing density, excess moisture, or prolonged exposure to air. High levels of butyric acid in silage are undesirable, as they can indicate poor fermentation and result in reduced feed quality and palatability. In the animal

organism, high butyric acid can induce ketosis, and intake and production can be impaired. Butyric acid spores in milk are a serious threat to cheese quality.

3. Ethanol: ethanol is the alcohol most commonly found in silages. High ethanol is associated with a high number of yeasts. The viability of yeast can still be maintained throughout the fermentation process. Silages usually spoil when exposed to air, because some yeasts can assimilate lactic acid under these conditions, increasing dry matter losses and the flavours can transfer to milk. Ethanol is converted to acetic acid or absorbed by the rumen wall and can be converted to milk fat or to be available for body metabolism or growth.
4. Soluble N and ammonia-N: plant and microbial proteolytic processes, mainly through the action of clostridia, lead to changes in nitrogen compounds in silage. Silages with high moisture content have higher concentrations of soluble N and ammonia-N than drier silages and this is due to more extensive overall fermentation. Although high ammonia-N in silage is an indicator of poor fermentation quality and may be linked with reduced voluntary feed intake, it does not represent a major problem when ingested by the animals. When consumed by ruminants, ammonia-N along with energy sources such as volatile fatty acids, is used for microbial protein synthesis in the rumen. These microbial proteins are an essential protein source for the host animal, as they are eventually digested and absorbed in the small intestine. Soluble N and ammonia-N are typically presented as proportions of total N, which makes it possible to compare protein degradation between silages differing in crude protein concentration.
5. Biogenic amines: these are nitrogenous compounds formed in silage by microorganisms during fermentation, decarboxylating amino acids. Examples of biogenic amines are histamine, tyramine, putrescine, cadaverine and phenylethylamine. The presence of biogenic amines in silage is primarily a result of poor fermentation leading to increased pH, and excess protein degradation due to undesirable microbial activity, such as clostridial fermentation. Ruminants consuming silage with high levels of biogenic amines may suffer impaired health and productivity. These compounds may disrupt normal metabolic activities, thereby reducing the feed intake, causing malfunctions of the rumen, and potential toxicity in severe cases. Additionally, biogenic amines can aggravate inflammatory responses or contribute to allergic reactions, further impacting the overall well-being, health and productivity of ruminants. Therefore, proper silage management to reduce the formation of biogenic amines becomes important in maintaining feed quality and animal health.
6. Microbial quality indicators: high yeast and mould counts are indicative of the poor hygienic quality of silages. High yeast numbers are inversely correlated with the aerobic stability of the silage, as well as poor animal performance. Care must be taken when interpreting yeast and mould numbers, because laboratories enumerate the total number of yeasts, but do not differentiate between lactate assimilators and others. Furthermore, yeasts can grow on selective agar during enumeration, but this does not reflect their metabolic capacity in silage. The number of yeasts and moulds can increase markedly from the moment of sampling until their arrival at the laboratory, thus, the number found in laboratory analyses does not always reflect the real value at the time of sampling. Therefore, a silage with a moderate amount of yeast can still

be relatively aerobically stable. Silages that have undergone extensive spoilage may have very low numbers of yeasts and moulds, because these organisms have died due to the lack of substrate. Listeria, bacilli, and ***Clostridium perfringens*** are undesirable microorganisms that can significantly affect silage fermentation and quality. ***Listeria monocytogenes*** is a pathogenic bacterium that thrives in poorly fermented silage with a high pH and insufficient anaerobic conditions, posing a health risk to ruminants and humans. Bacilli, particularly ***Bacillus*** species, are spore-forming bacteria that can survive adverse conditions and, when present, contribute to aerobic instability, leading to spoilage and reduced silage quality. *Clostridium perfringens*, a harmful clostridial species, is involved in undesirable fermentations, producing butyric acid and ammonia-N, which increase pH and promote spoilage. These microorganisms not only degrade the nutritional value of silage but also introduce health risks to livestock, necessitating strict control of the fermentation process to inhibit their growth.

The curious case of the long aerobic stability of poorly preserved silages. Paradoxically, silages that have undergone poor fermentation tend to be more aerobically stable during the feeding phase when the silage mass is exposed to air. This fact is mainly due to the high production of acetic, propionic, butyric acids and ammonia-N, which have antifungal properties, but are undesirable and harmful to the fermentation process and the silage quality as feed. Perhaps the reason why the silage is aerobically stable may be due to its already deteriorated state, as spoiled silage lacks the nutrients present in well-fermented silage that would otherwise serve as substrates for spoilage microorganisms, and thus the silage cannot deteriorate further.

11.7. Silage sampling guidelines for quality analysis

Ideally, silage samples for analysis should be taken as close to feeding time as possible. However, in practice, sampling is often done right after opening the silage storage. In many cases, farmers may want to assess silage quality well in advance to plan the feeding order, especially when multiple silage batches are stored. When evaluating silage quality, it is essential to remember that the fermentation process must be complete before sampling. This typically takes at least six weeks, and sometimes longer. Additionally, every time a sealed silage unit is opened for sampling, air enters the mass, potentially causing spoilage. Therefore, sampling should be done carefully and only when necessary.

Sampling and packing feed for laboratory analysis is a critical task. Since silage is stored in large batches, but only a small portion can be analysed, the sample must be truly representative. A sample can be collected from enclosed storage with a forage probe. If multiple silage batches are being sampled, the probe should be thoroughly cleaned between batches to avoid cross-contamination. Before sampling, the covering material (e.g., nets, sawdust, etc.) must be removed from the plastic film covering the stored silage. If the silage surface shows sign of spoilage, this part must be discarded before collecting the sample. The key to a representative sample is to take multiple sub-samples from different, well-distributed locations across the storage. The more sub-samples taken, the more reliable the overall analysis.

After sampling, close the opening with plastic tape so that neither air nor water can enter the silage sample. The silage should then be covered again with the covering material.

For open storage systems (e.g., bunker silo, clamps, piles), samples must be collected from several different locations in the stored feed face and from at least three depths: 1 m from the surface, in the middle and 1 m above the bottom. For round-bale silage, the samples must be taken from at least five bales per 100 bales. The sample should be taken with a forage probe in the diagonal direction of the bale diameter and subsequently, the opening should be closed with plastic tape.

Silage spoils very quickly, thus the samples must be collected quickly and handled with care. Combine and thoroughly mix the sub-samples, then take a final representative sample weighing about 0.5–1.0 kg. Place it in a plastic bag, expel as much air as possible, seal the bag tightly, and deliver it to the laboratory immediately.

Methods of silage analysis

Farmers can deliver silage samples either in specialized laboratories or by using on-farm analysis tools.

1. Analytical methods can be divided into two main categories:
   a. Wet chemistry methods: these are the most accurate methods and the basis of most of the other methods. The wet chemistry methods are suitable for any type of feeds, the analysis results are accurate, but the analyses are more time-consuming, and the costs are higher.
   b. Express methods: these methods are faster and more affordable, but have limitations. These are feed-type specific, measure fewer parameters, and require individual calibration for each type of feed. While less precise, these are practical for quick assessments on-farm.
2. On-farm dry matter analysis, a subjective evaluation

When laboratory analysis is not immediately available, farmers can rely on simple, on-farm methods to estimate forage dry matter content. These quick evaluations can support immediate decisions about wilting, chopping, or using additives. While not as precise as laboratory results, these tools can still provide valuable insights, especially when timing is critical for making good quality silage. Imagine a hypothetical scenario where a farmer is standing in the field with freshly cut forage and needs to know: "*Is this grass dry enough to chop and ensile, or should I wait?*". These are four possible different ways to help in the decision-making:

a. Farmer's own kitchen as a lab – the microwave method: take a 100-gram sample of chopped forage and place it on a microwave-safe plate. Firstly, weigh the sample and microwave it on medium power for about 1–2 minutes. Remove the sample from the microwave, making sure not to lose any material, weigh it again and repeat the process in short intervals until the weight stops changing. The weight loss represents mostly water, and the difference is the dry matter.
b. The oven method – slow, but accurate and precise: if a farmer has access to a conventional oven, one should dry the sample at about 60°C for 48 hours, or at 105°C for 24 hours. This method is usually more accurate than the microwave method, but it takes longer and is not the best when decisions need to be made urgently. As with the microwave method, the weight loss represents water, and the difference is the dry matter.
c. The compression test – quick, but inaccurate and imprecise: in the complete absence of tools to help make decisions about dry matter content during ensiling, the compression test can be useful. In this case, take a handful of chopped forage, squeeze it firmly for a

few seconds and observe:
- If water drips from your hand, the dry matter content is too low, below 20%.
- If it forms a tight, moist ball without dripping, it is around 25–30%.
- If it clumps loosely, the dry matter content may be around 30–35%.
- If it does not hold its shape and falls apart, the dry matter content is probably above 35%.

d. Near infrared spectrometer (NIR) device: this method provides fast and accurate dry matter readings. The farmer can simply scan the chopped forage and within seconds, see the dry matter value on the screen. While it is a great tool and saves tima, NIR is still expensive.

11.8. Quality criteria of good silage

The quality assessment of silage has three main objectives: to ensure feed safety, support diet formulation using laboratory data and evaluate the success of the silage-making process to improve management practices in subsequent years, if necessary.

Silage quality parameters can be divided into: chemical composition parameters, which are related to forage species and their development phase; hygiene parameters, which are related to the fermentation process; and nutritive value parameters. Chemical composition and hygiene parameters can be measured directly in a laboratory. Nutritive value parameters are calculated based on chemical composition and fermentation parameters. Nutritive value parameters and the principles of their calculation differ from country to country, which is why they can be difficult to compare. It is important that the feed evaluation system and the animal feeding requirements used in diet formulation are calculated on the same basis.

When interpreting and comparing laboratory analyses results, the units the chemical composition of the feed, nutritional value, fermentation parameters, etc. are presented in should be noted as well as whether the results are reported on an as-fed or dry matter basis.

A wide variety of parameters can be determined from silage, which may vary depending on the laboratory. These parameters can be divided into several categories:

1. Ash and minerals: crude ash, macro minerals (Ca, P, K, Na, Mg, Cl, S) and microminerals (Mn, Zn, Fe, Mo, J, Bo, Co, Se).
2. Protein and nitrogen compounds: crude protein, true protein, amino acids, soluble protein, ammonium, nitrates, biogenic amines.
3. Fibre fractions: crude fibre, neutral detergent fibre (NDF), acid detergent fibre (ADF), lignin (ADL), digestible or indigestible neutral detergent fibre.
4. Non-structural carbohydrates: starch, water-soluble carbohydrates (sugars, fructans), pectins.
5. Fermentation products: pH, organic acids (lactic, acetic, propionic, butyric, valeric), ethanol, ammonia nitrogen as % of total nitrogen.
6. Mycotoxins: deoxynivalenol (DON), zearalenone (ZEA), T2-toxin, ochratoxins, etc.
7. Nutritive value indicators: metabolisable energy (ME) and/or net energy for lactation (NEL), metabolizable protein and/or amino acid absorbed in the small intestine (AAT), protein balance in the rumen, organic matter digestibility, D-value, etc.

Table 2 presents the typical composition of well-preserved grass silages in Finland, Estonia, and Latvia. Differences in target silage values across countries stem from variations in forage types, climate, animal production systems, and national feed evaluation models. These differences highlight the importance of using local reference values and aligning analytical interpretations with national guidelines for animal nutrition.

Table 2. Typical composition of well-preserved grass silages.

Parameter	Finland	Estonia	Latvia
Dry matter (DM), %	30 – 40	30 – 40	30 – 40
Crude protein, % in DM	14 – 17	14 - 16	14 - 19
Crude fibre, % in DM		< 26	< 26
Neutral detergent fibre, % in DM	< 52-58	< 46	42 – 52.5
Acid detergent fibre, in DM		< 33	24 - 29
Crude ash, % in DM Maize Grasses Legumes	 – < 8 < 10	 < 5 < 8 < 10	 3.5 - 5 < 8 < 10
Metabolizable energy, MJ/kg in DM	11	> 9.5	
Organic matter digestibility, %	> 68-70*	> 65**	75 - 80***
Ethanol, g/kg in DM	< 10	< 10	< 10
Acetic acid, g/kg in DM Grass Maize	 < 15	 < 20 < 30	 10 - 20 10 - 16
Propionic acid, g/kg in DM	< 1	< 1	<1
Butyric acid, g/kg in DM	< 0.5	< 0.5	< 0.5
Lactic acid, g/kg in DM	< 30-70	30 - 100	30 - 70
pH if DM < 25%	4.0 – 4.2	4.1	4.1
pH if DM 25 - 40%	4.2 – 5.0	4.3	4.3
pH if DM 40 - 55%	5.0 - 5.5	4.7	4.8
Ammonia-N in total N, %	< 4	< 7	<8

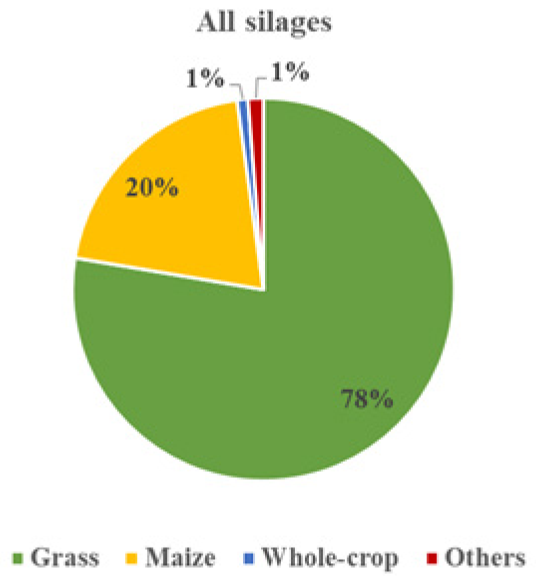
* *In vitro* organic matter digestibility was determined according to Nousiainen et al. (2003) with a correction equation of pepsin-cellulase solubility to *in vivo* digestibility by using data from Finnish *in vivo* digestibility trials (Huhtanen et al., 2006).
** The digestibility of organic matter is calculated based on the organic nutrients (crude protein, crude fibre, crude fat and nitrogen-free extractives) contained in the feed and the corresponding nutrient digestibility coefficients obtained from previous *in vivo* digestibility experiments.
*** NIR method from EUROFINS, based on 48-hour incubation using rumen fluid/buffer solution (39°C), 48-hour incubation using pepsinHCl (39°C), gravimetric detection of the organic matter, standardization product specific using around 10 *in vivo* reference samples.

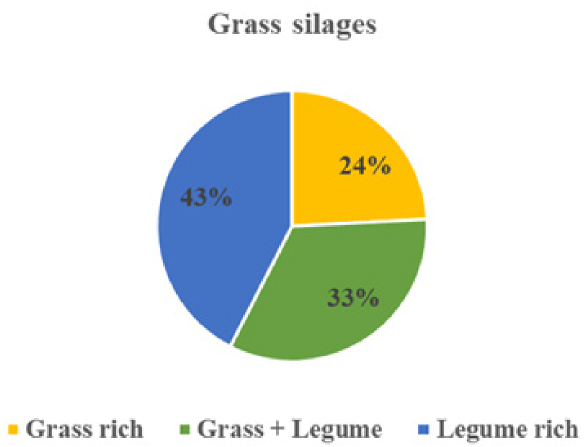
11.9. Farm silage quality in practice – Insights from Estonia

The data of Estonian farmers' silages are derived from silage samples analysed from 2020 to 2024 at the Feed and Metabolism Research Laboratory at the Estonian University of Life Sciences (EMU). The year 2020 has been taken as the reference year to assess changes and trends during the last five years.

Of the silages analysed in 2024, 78% were grass silages, 20% maize silages, and approximately 1% whole-crop cereal silages and 1% other silages (Figure 2). Over the last five years, the number of maize silage samples has increased by 5%, and this has been at the expense of grass silages. Cultivation of maize for silage has increased every year, as more cold-resistant varieties have become available on the market and the weather conditions have been suitable for maize. The year 2024 was the first time in Estonia when some maize fields were harvested for the grain.

In Estonia, grasslands are cultivated for silage production with various graminaceous and leguminous seed mixtures. There are few grasslands with pure crops. Fresh plant material from different grasslands is often stored in large clamp or bunker silos. This means that one storage unit may contain silage of very different botanical composition. To estimate this, the calcium content was taken as the basis for the botanical classification of grass silages. Silages with a calcium content of less than 9 g/kg in dry matter were considered to be dominant in grasses, and legume-rich silages with a calcium content of ≥13 g/kg dry matter (Figure 3). The proportion of legume dominant crops has increased significantly in the last five years and has replaced graminaceous forages. This has mainly come from an increase in lucerne cultivation, as the deeper roots of lucerne allow the harvest of lucerne even in years of drought.

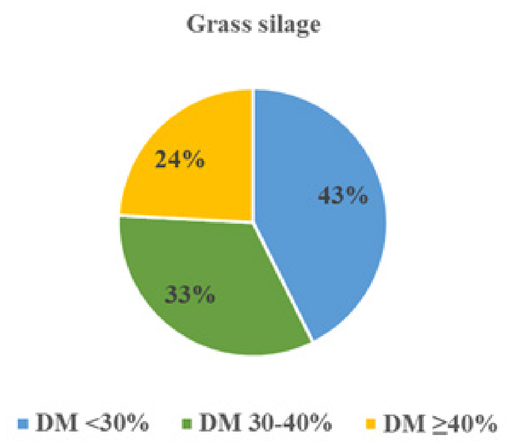


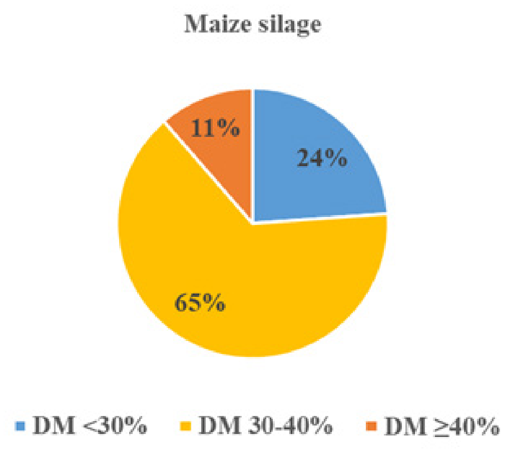


Figures 2 and 3. Botanical composition of analysed silage samples (EMU statistics, 2024).

Among grass silages, 43% had a dry matter content below 30%, with 20% containing less than 25%, while 24% had a dry matter content exceeding 40% (Figure 4). In 2020, 51% of silages had a dry matter content below 30%, and 13% exceeded 40%. Therefore, wilting has become an increasingly common practice to enhance silage fermentation.

In 2024, 24% of maize silages had a dry matter content below 30%, a significant decrease from 71% in 2020 (Figure 5). More than 11% of maize silages in 2024 had a dry matter content over 40%, whereas in previous years, such high values were rare. The recommended dry matter content for maize silage is around 31-35%, yet only 25% of maize silages fell within this optimal range.





Figures 4 and 5. Shares of silages based on dry matter (DM) content (EMU statistics, 2024).

Over the past five years, the dry matter, crude ash, crude protein and calcium contents of grass silages have increased (Table 5). The last three of these parameters indicate an increase in the proportion of legumes in cultivated grasslands. The crude fibre and neutral detergent fibre contents have remained at the same level, at approximately 29% and 50%, respectively. Notably, 74% of silages had crude fibre levels above 27%, which suggests that the harvesting time of plants for silage could be earlier.

Table 5. Median values of silage quality characteristics (EMU statistics, 2024).

	Grass silage		Maize silage	
	2020	**2024**	**2020**	**2024**
Dry matter (DM), %	29.7	31.8	27.0	34.5
Crude protein, % DM	11.9	15.2	8.0	7.5
Crude ash, % DM	8.1	8.8	3.6	3.2
Crude fibre, % DM	29.3	29.4	24.0	20.2
Neutral detergent fibre, % DM	49.4	50.0	49.1	40.0
Starch, g/kg DM	–	–	260	348
Calcium, g/kg DM	9.8	12.1	2.7	2.1
Metabolizable energy, MJ//kg DM	9.1	9.1	10.4	10.9
Metabolizable protein, g/kg DM	73.8	75.3	77.2	76.0
Ethanol, g/kg DM	5.0	2.9	10.0	8.6
Acetic acid, g/kg DM	19.0	17.9	21.0	15.7
Propionic acid, g/kg DM	0.0	0.5	0.0	0.3
Butyric acid, g/kg DM	0.0	0.0	0.0	0.0
Lactic acid, g/kg DM	54.0	46.9	53.0	46.0
Total acids, g/kg DM	83.0	74.7	79.0	64.0
pH	4.4	4.5	3.8	3.8
NH_3-N, %	4.2	4.1	4.0	4.0

The dry matter and starch contents of maize silagea have increased year by year. Over the past five years, the median dry matter of maize silages has increased by 7.5 percentage points. The 2024 analysed maize silage samples' dry matter median was 34.5%. Maize cobs were more mature and consequently, the starch content was higher. In 2020, the starch content of maize silages was 26.0% of dry matter, while in 2024 it was 34.8%. Starch is an important energy source for animals, which is why the 2024 produced maize silages had more metabolizable energy. It must be noted that 2024 was an exceptionally good year for maize growth, and this may not be the case every year.

The fermentation quality parameters were good in Estonian grass and maize silages and the ratios of organic acids also indicate adequate fermentation.

The analysis of the use of silage additives showed that 55% of silages produced in 2024 and analysed in our laboratory were untreated (Figure 6), while 63% of the silages in 2020 were made with a silage additive (biological or chemical). The use of additives has decreased by approximately 18% in the last five years. The reasons for the decrease in the use of silage additives may be different, from the high price of the product, unsatisfactory prior experience or increased awareness of the importance of wilting to better weather conditions during the silage production season.

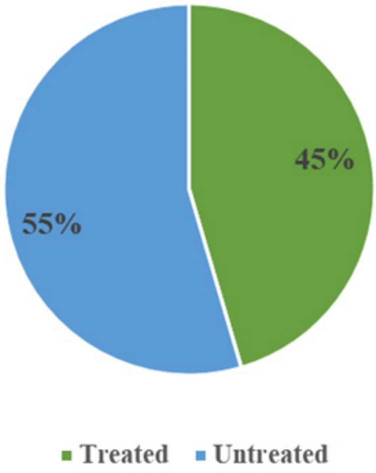


Figure 6. Share of silage samples treated or untreated with additives (EMU statistics, 2024).

Environmental impact

The environmental impact of silage production systems concerns resource use, release of greenhouse gases, and possible runoff of nutrients to water. In the case of ensiling, the carbon footprint involves energy consumption in harvest, wilting, and storage processes, besides methane and nitrous oxide emissions during the fermentative and storage phases. Effluent management becomes important to prevent water contamination through nutrient leaching, if storages are badly managed. Also, the choice of the methods of storage affects the risk of deterioration and wastage, which is crucial to resource efficiency. Proper ensiling techniques will not only minimize the losses but also provide important potential contributions to sustainable livestock systems in optimizing forage quality. Improved sealing materials, application of additives, and the efficient management of silos enhance the level of sustainability through minimal wastage, reduction in the rate of gaseous emission, and the prevention of pollution.

Key takeaways

- Make sure to start with high-quality forage, ideally harvested at the optimal growth stage, typically when the crop is at its peak nutrient content and just before it begins to senesce. Delayed harvesting can lead to decreased quality due to lignification and decreased digestibility. Select crops with high nutrient content and digestibility to ensure valuable feed for livestock.
- Aim for high hygienic quality of the material, such as minimal soil and manure contamination.
- Chop forage into appropriate lengths to optimise compaction and fermentation depending on the type of storage method. Ensure uniform chop length to promote even packing and fermentation throughout the silage mass.
- Aim for an optimal moisture content to support anaerobic fermentation. Excess moisture can lead to seepage and nutrient loss, while insufficient moisture can hinder fermentation and e.g., increase the risk of aerobic deterioration in bunkers.
- Achieve high packing densities to exclude oxygen and promote anaerobic conditions necessary for fermentation. Proper packing minimises the risk of spoilage and mould growth, ensuring efficient fermentation.
- Consider using additives, such as inoculants, organic acids or absorbents, to enhance fermentation and inhibit undesirable microbial growth. Additives can help mitigate risks associated with variable forage quality or unfavourable weather conditions during ensiling, but can only partially compensate for poor silage management techniques.
- Seal silage tightly to exclude air and minimise aerobic deterioration. Use oxygen barrier films or multiple layers of plastic to create an effective seal. Cover silage bunkers or stacks adequately with tires or weighted materials to prevent air ingress.
- Store silage in appropriate structures, such as silos, bunkers or bags, to minimise exposure to environmental factors. Maintain good drainage and ventilation to prevent moisture buildup and mitigate heating. Keep an eye on the storages, e.g., to damages caused by rodents or birds.
- Practise good feedout management to minimise spoilage during storage and feeding. Use proper face management techniques to limit oxygen exposure and preserve silage quality. Feed silage out at a rate consistent with livestock requirements to minimise prolonged exposure to air.
- Before collecting a sample for analysis, it's important to have a clear plan. Silage analysis serves three main purposes: ensure feed safety, formulate accurate and balanced feed rations, and identify any issues or mistakes made during the silage-making process.

Ensuring good silage quality requires attention to detail at every stage of the ensiling process, from crop selection and harvest to storage and feedout practices. Regular monitoring and adaptation to changing conditions are key to maximising feed value and animal performance.

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12. Silage feedout and front face management for quality preservation

Author: Ieva Krakopa (Latvia)

12.1. Animal feeding with silage

Silage can be the sole roughage source for animals or animal groups. This can be so throughout the entire year. Silage may also be used only during the months when fresh pasture is not available. Animals can be fed with one type of silage or often with a mix of two or more silages. Roughages can be fed separately from concentrates or mixed together. In this case, feeding is called total mixed ration (TMR) or partial mixed ration (PMR).

Silage should be stored in anaerobic conditions. It is very vulnerable to secondary fermentation and spoilage as soon as it is exposed to the atmosphere air with oxygen. Therefore, removing it from the bunker / clamp /plastic bag should be done in a way that minimizes the surface's exposure to the air. Feeding baled silage has fewer disadvantages, because in most cases, a whole bale is opened and fed in the same day. Detaching technology and face management are crucial to minimize silage losses, which cause economical losses and harm the environment.

Strategy of feeding:

1. Opened bunker/clamp should be in a size corresponding to the feeding speed (herd size).
2. The speed of feeding needs to be recalculated when it is necessary to feed 2 or more bunkers / clamps / plastic bags at the same time. An example can be provided for grass silage and maize silage.
3. The general rule is that feeding out from a bunker/clamp, from one side to another, should not take longer than 3 days.
4. The face of the bunker / clamp / plastic bag should not be exposed to midday sun and prevailing winds.
5. In cooler weather conditions, silages with higher dry matter, higher sugars and starch should be fed. These are more prone to heating and secondary fermentation. Silages with lower dry matter content should be left for hotter weather.

Good example of removal with a milling cutter. Photo by Ieva Krakopa

Good example of silage removal using a block cutter. Photo by Ieva Krakopa

Good silage removing example- face away from sun. Photo by Ieva Krakopa

Poor example: Removing silage with a bucket causes damage and spoilage. Photo by Ieva Krakopa

Maize silage. Bad face management that leads to aerobic spoilage (heating). Photo by Ieva Krakopa

If a farm is considering growing maize for silage, the advantages and disadvantages described in table should be considered.

Table 1. Feeding one or two silages (grass-legume silage only, grass-legume silage and maize silage in combination).

Grass/legume silage	Grass/legume silage + maize silage
More grain concentrates may be needed for a ration (more own grain can be fed)	Less grain concentrates are needed in a ration
More protein for the ration can be provided from own silage.	More protein supplement in needed
	Special machinery for seeding and harvesting of maize crop (own or contractor service)
One bunker/clamp/plastic bag is opened at a time (planning the size of bunkers in relation to herd size)	Two bunkers/clamps/plastic bags are opened at the same time (planning the size of bunkers in relation to herd size)
Forage and concentrates can be fed separately	The TMR (total mixed ration) or PMR (partial mixed ration) feeding systems are optimal.

Environmental impact

Good management of feedout is the second most important part of the whole process. Huge amounts of nutrients can be lost in the spoiling process. This is caused by heat, CO_2 and water. Thus, resources used for sowing, fertilising, managing and harvesting crops are wasted.

Key takeaways

- Plan your forage feedout according to the consumption of your animals.
- Use appropriate machines to remove silage without invading the open face with oxygen from air, which spoils the next forage before feeding it out.
- Remember that spoiled silage is bad for the environment, your economy and animal health, if it is fed to them.

13. Silage effluent management

Authors: Marketta Rinne (Finland), Kalvi Tamm, Are Selge (Estonia)

13.1. What is silage effluent?

When moist forage biomass is packed into a silo, liquid separates from it and is excreted out of the silo. This liquid is called silage effluent. The effluent contains soluble nutrients from the forage, and presents a loss of feed quantity and its nutritive value.

As part of the Sustainable Silage project, a data set of Finnish and Estonian experimental and practical effluent samples was collected to demonstrate the average composition and extent of variation in silage effluents (Table 1). The most striking result of this exercise was the huge variation in the composition of the effluent samples. This is highlighted by the variation in the DM concentration of the silages, which was 3 g/kg (0.03 %) at the lowest, while the highest observed DM concentration was 153 g/kg (15.3 %). The most obvious reason for the variation is dilution with rainwater in practical farm silos in comparison with the experimental samples, which presented pure effluents. The nutrient content per ton of effluent reflected the water contamination so that nutrient concentrations equalled practically zero in the most diluted samples. An additional factor that may contribute to the low nutrient concentrations in farm samples may be the challenges related to representative sampling. Some sedimentation of dry matter is likely to happen and unless the effluent is carefully mixed prior to sampling, the sample collected may be too diluted.

To demonstrate the effect of the source of samples on the silage effluent composition, the effluent data set was divided into two subsets: The pure experimental samples, and the diluted samples collected from on-farm storages (Table 1). The DM concentration of experimental silages was 89 g/kg (8.9 %), while that of farm silos was only 29 g/kg (2.9 %).

When the nutrient contents are presented on a dry matter (DM) basis, the effect of water dilution can be excluded. This allows us to evaluate the ratios of different nutrients in the effluent. Compared to a typical grass biomass, effluent is enriched in minerals (ash) and nitrogen, which are soluble components and thus end up in the effluent. The water soluble carbohydrate composition varies depending on how much is available in the parent material, and how much of it has been fermented at the time of sampling.

Table 1. Nutrient composition of silage effluent samples from Finland and Estonia

Parameters	Mean	Standard deviation	Minimum	Maximum
Experimental grass effluents from Finland (n=85)				
Dry matter, g/kg fresh matter (FM)	89	25.1	33	153
pH	3.96	0.696	3.21	5.39
Ash, g/kg dry matter (DM)	177	56.1	97	297
Crude protein, g/kg DM	205	67.5	99	332
Water soluble carbohydrates / sugars	132	139.6	3	448
Farm effluents from Estonia (n=8; various plant materials) and from Finland (n=4 grass)				
Dry matter, g/kg FM	29	23.4	2	91
pH	5.51	1.231	4.19	7.80
Ash	529	127.0	273	677
Crude protein, g/kg DM	261	196.4	8	519
Nitrogen, g/kg DM	42	31.4	1	83
Phosphorus, g/kg DM	9	9.2	0	34
Potassium, g/kg DM	57	46.7	0	132
Magnesium, g/kg DM	14	17.4	0	64
Calcium, g/kg DM	45	68.7	0	260
Copper, mg/kg DM	22	30.1	0	81
Manganese, mg/kg DM	125	105.1	1	280
Zinc, mg/kg DM	91	84.9	1	230
Sodium, mg/kg DM	16	23.2	2	56
Boron, mg/kg DM	8	4.7	0	13

13.2. How to prevent effluent formation

During the 1900s, effluent production from silage was very common, as at that time, flail harvesters were used in silage making. With that technology, grass was chopped and picked up fresh for transportation to silos. Towards the end of the 1900s, silage preparation methodology changed quickly. Cutting the grass separately and allowing it to pre-wilt in the field prior to picking up with a precision chopper or self-propelled forage harvester gradually totally replaced flail harvesters and fresh silage.

Wilting is an effective method for preventing effluent production as shown in Figure 1. Generally, none or very little effluent can be expected to be excreted when the grass DM concentration at harvest is above 250 g/kg (McDonald et al. 1991). Other factors also contribute to effluent production so its value is not absolute. Important factors affecting effluent production are the type of silo and the extent of pressure on grass material. The choice of silage additives also affects effluent production. Formic acid based additives cause acid hydrolysis in the cell walls of plants – this releases cell contents and subsequently increases effluent production (Jones & Jones 1995, Ayanfe et al. 2025).

Legumes are inherently more lush than gramineous forage species so the risk of effluent production may be higher when the ensiled material is high in legumes such as clover. Maize silage is typically harvested at a DM concentration of 300 g/kg or above, but in unfavourable conditions, when the crop remains immature at harvest, effluent can be produced even from maize silage.

Another alternative to wilting in preventing effluent formation is to use some other drier material as an absorbent together with the low moisture material to be ensiled. This approach was demonstrated by Hvas et al. (2024) when ensiling sugar beets for cattle feed. They used several feed materials (maize silage, grass/clover silage, grass seed straw, dried beet pulp, fresh beet pulp, dried distillers' grains solubles, wheat bran, rapeseed meal, sunflower meal and maize gluten feed) to increase the DM concentration of fresh beets at around 220 g/kg to above 300 g/kg, and all absorbents successfully eliminated the effluent production.

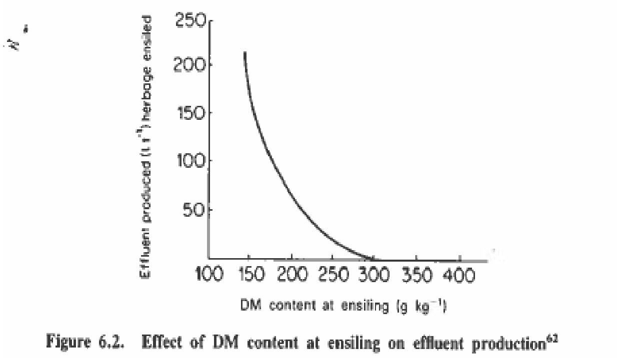


Figure 1. Schematic presentation of how the DM concentration of herbage ensiled affects the effluent production (McDonald et al. 1991).

13.3. The control of effluent is regulated by legislation

Successful wilting requires good weather conditions as wilting is unsuccessful in humid/rainy weather conditions. The increasing variability in weather caused by climate change may complicate forage harvesting and result in cases, where forage needs to be harvested despite too humid conditions. To be prepared for such cases, silo structures are to be planned so that the effluent can be collected and disposed of in a controlled manner. Effluent leaching into the environment is very harmful, as it contains high levels of nutrients, is acidic, and has a high biological oxygen demand, meaning if it drains into water courses, it leads to the depletion of oxygen as well as the subsequent death of fish.

Legislation is in place to prevent the negative environmental effects of effluent leaching.

In Finland, the environmental regulation related to buildings (606/2023) 9§ by Ministry of Agriculture and Forestry states:

Silage storage must be watertight and established so effluent does not escape outside of the storage. The storage must be built so effluent goes into a specific well built for it. There must be a collection well of at least 5 m^3 that is emptied by pumping or through pipes to a watertight storage, slurry tank or urine storage. This is to be included in the building plan.

13.4. How to use effluent in plant production

The minerals captured in effluent can be used for plant nutrition, but as depicted in Table 1, the concentrations of nutrients in the liquid are very low, particularly in farm conditions, where dilution with rainwater has been consistently observed. The dilution may be beneficial, because the soil and plants are not damaged by the effluent, but on the other hand, very high amounts of effluent need to be spread on the field to achieve a proper fertilization effect in the crop production.

At farm level, there are several options for collecting and storing effluent. Often the effluent is directed to a slurry pit and spread on fields mixed with slurry. This way, the nutrients included in the effluent can be circulated back to plant production. In addition, the effluent is diluted with slurry and rainwater, which decreases the risk of effluent damaging the plants and soil.

13.5. How to circulate effluent into animal feed

Effluent contains the same valuable nutrients as the forage material it originates from. The soluble minerals, proteins and carbohydrates have high nutritional value, and effluent can be used as a feed material for ruminants (Randby 1997) or pigs. Specific arrangements are necessary for collecting and distributing it to animals. For cattle, effluent could be added in the total mixed ration mixer. In the liquid feeding system of pigs, effluent could be mixed into the liquid feed. In developing green biorefineries, juice mechanically separated from silage has been used as a feed material for pigs (Keto et al., 2021), and spontaneously excreted effluent is essentially similar material, if it can be hygienically collected and stored for the feeding.

Another option to circulate effluent into the feed is to spread it on top of a silo containing drier batches of forage preserved at the farm. Thus, the nutrients could be circulated into the feed chain. The increased humidity and fermentable substrates (or organic acids, if they have already been fermented) may potentially aid in improving the fermentation quality and the aerobic stability of the drier forage material.

If practically feasible, wet grass material could also be piled on top of a previously made dried silage layer in a silo, and in that case, the effluent excreted from the wet material is absorbed into the drier layer of silage underneath it.

13.6. How to use effluent in green biorefineries

There is increasing interest to use green biomass in novel ways in the so-called green biorefineries (Gaffey et al. 2023). The basic concept of a green biorefinery is that green biomass is mechanically separated into liquid and solid fractions, and these are further developed into various value added products. The spontaneously produced effluent could be used as a source of soluble nutrients, minerals, organic acids etc in a similar manner to liquid produced from fresh or ensiled grass (Rinne 2024).

A lower added value use, but practically feasible, is using the effluent as a feedstock for a biogas digester to produce methane.

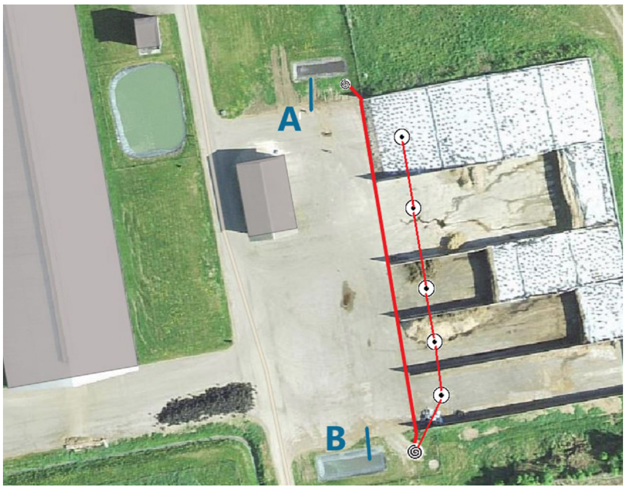
The following photos illustrate the practical aspects of effluent management:

Effluent splashing out from a round bale. Photo by Luke / Kaisa Kuoppala.

Dairy cows offered free access to drinking effluent. Photo by Luke / Marketta Rinne.

The following Estonian case study provides an example of effective effluent and runoff control at farm scale (Hummuli Agro OÜ)

In 2020, the company undertook the following construction works to eliminate the runoff of rainwater from ~1 hectare of farmyard. Feed waste inevitably accumulates on this asphalt area, and it is washed away from the site by rain. In addition to water accumulating from the farmyard, the water flowing down from the silage storage areas also needs to be considered.



Farm silage storage areas and farmyard for feed handling (~10,085 m²).

The red line indicates the collection of potential silage juice (usually happens during the last silage cut, at autumn) through the cross-channel in front of the silage storages and the silage juice collection traps into underground collection containers (with a total capacity of 240 m³) that can be opened from the top and emptied.

The blue line indicates the movement of rainwater primarily into the water collection ponds, with capacities of 60 m³ (A) and 80 m³ (B). These ponds are lined with membranes designed for the construction of slurry lagoons. The membrane joints are welded together and are watertight.

The entire area surrounding the silage storages and the farmyard was levelled to a higher ground to prevent water from overflowing into the environment in case of storage overflow.

The collection containers and ponds are emptied as needed. Contaminated water is pumped out and transported to a nearby slurry storage facility.

Four years of practical experience have proven the effectiveness of this solution.

During this period, there were no leaks into the natural environment. However, pumping the water from the collection ponds and transporting it to the slurry lagoons during rainy periods presents a significant additional task. We believe that this investment has justified itself. In the future, we could consider building stabilization (biotic) ponds (using energy bush) instead of collection ponds.

Key takeaways

- » Silage effluent represents both a nutrient loss and an environmental hazard if not managed properly.
- » Effluent composition varies greatly depending on dry matter content, dilution by rainwater, and sampling technique.
- » Effluent production can be minimised through wilting, crop selection, and proper use of silage additives.
- » Effluent can be utilised in crop fertilisation, animal feeding, and as input for biogas or green biorefineries.
- » All silage storage must include controlled drainage and collection systems to comply with environmental regulations.
- » Practical solutions like those implemented at Hummuli Agro OÜ show that effective infrastructure can eliminate runoff risk.

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14. Sustainable management of agricultural plastic and silage waste

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Waste handling is a crucial part of sustainable silage production. This chapter presents ways the amount of plastic and spoiled silage could be minimized and also recommendations on how to dispose of these items in the most sustainable way possible in Finland, Latvia and Estonia.

14.1 Practices in Finland

It is estimated that in Finland, about 12 000 tonnes of agricultural plastic waste is produced annually, of which 7 000 tonnes is formed of bale wrap films. The vast majority of the plastic material is burnt into energy. It is estimated that in 2021, only about 20% of the agricultural plastic waste was recycled in Finland (2021). The waste management law requires all entrepreneurs (farmers included) to firstly aim at decreasing the use of plastic material and secondly, reusing the plastic material. Decreasing the use of plastics is rarely a possibility at farms, so the main focus should be on how to efficiently recycle the used plastics.

If farmers use plastic to cover and pack a product for their own use (to cover silage bales, for example), they have the responsibility to organize the recycling or waste management of that used plastic product (wrap films, for example). Please read more about the environmental requirements from the guide book: Maatilojen ja puutarhojen muoviopas - Ruokavirasto. There are different options for farmers to organize the waste management of these plastics:

Occasional regional plastic collection campaigns or other regional waste management companies accepting these plastics.

Itä-Suomen murskauskeskus in cooperation with MTK ry Maatalousmuovien kierrätys - MTK (a paid service for farmers)

SuMaKi Oy Suomen Maatalousmuovien Kierrätys Oy (maatalousmuovienkierratys.fi) (free service for farmers From 1st of August 2024 onwards).

SuMaKi is a volunteering producer community that is aiming to increase the recycling of farm plastics. From 1st of August 2024, it has been possible for farmers to get their bale wrap films collected from the farm for free and the plastic material will be recycled. Sumaki reported that 2,3 tonnes of bale plastics were collected and recycled by the end of 2024. The target for 2025 is 4000 tonnes. The collection and recycling of silo cover plastics started on the 1st of April, 2025, and the target for 2025 is to collect 500 tonnes. Farmers need to follow the following guidelines for sorting their bale wrap films: Lajitteluohjeet – Suomen Maatalousmuovien Kierrätys Oy (maatalousmuovienkierratys.fi).

White plastics are collected separately from other colours. Photos by SuMaKi

The recycling of other agricultural plastic packages, like fertilizer bags and other plastic big bags, are the responsibility of the producers of these products. This means that farmers can return these plastic packages to their local recycling units for free. Using formic acid based silage additives is common in Finland. The additives are delivered to the farm in plastic containers in sizes of 30 l, 200l or 1000 l. These containers can also be recycled free of charge (https://www.aiv.fi/tuotteet-ja-palvelut/pakkaustenkierratys#:~:text=Palauta%20k%C3%A4ytetyt%20pakkaukset%20Suomen%20Uusiomuovi,Pakkaukset%20hy%C3%B6dynnet%C3%A4%C3%A4n%20muovin%20jatkojalosteina.)

According to Finland's Ministry of Environment, waste silage is to be stored in a dry manure storage or on a solid surface. This will minimize the risk of nutrient runoff during the storage period. Bale wrap films need to be removed from spoiled silage bales. Spoiled silage can be spread on the fields (using it as a fertilizer), enabling us to get all the nutrients back to use for the next crop. Alternatively, spoiled silage can be delivered to a licensed disposal facility (i.e. biogas plant) or another processing facility to be further processed.

Finland's pilot farmers' tips to minimize the plastic and silage waste at farm level:
» Optimum silo compaction
» Optimum amount of feeding rates of silage
» Silo cover plastic films will be reused as side films at the silo during the silage season.

Agricultural expert's tips for minimizing plastic and silage waste:
» Careful filling and compaction of silo. The side areas are the most critical areas! If the silo is well-compacted and adequate weight material is placed on top of the silo cover, the silage will not spoil on the surface layers either.
» Silage cutter decreases the amount of waste silage.
» Optimum feeding speed.

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Ministry of Environment, 2021, Guidelines for environmental protection in animal husbandry:

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Paalimuovien keräily tiloilta alkanut elokuussa 2024 - KiertoaSuomesta.fi

Maatiloilla syntyy vuosittain 12 000 tonnia jätemuovia – vain pieni osa jopa vuosia varastoidusta muovista päätyy kierrätykseen | Yle

Maatalousmuovijätteen kierrättäminen. Hytonen_Aija. Opinnäytetyö 2024. JAMK.

14.2. Practices in Latvia

The collection of agricultural films is not regulated by the state – it is a private business. Used agricultural packaging can be handed over free of charge to several companies in Latvia. The following types of various films are suitable for recycling, including films from sour hay or silage, roll films, agro-, garden- and other types of films, polypropylene bags or BIG BAGs, plastic cans and barrels.

What should be observed so that farming could be more friendly and valuable to the environment and create less waste:

- In order for the packaging materials to be suitable for recycling, they must be as clean and as dry as possible, without significant admixtures of products, sand, mud, as well as without any waste, including ropes, strings, construction debris, etc. Before handing over the packaging for recycling or planning its storage, it is important to separate it from other types of waste and place it in a dry place to prevent, or at least reduce, the effects of weather conditions.
- In order to make sure the packaging will end up in recycling, and the farm receives all the confirmations about the transfer of packaging for recycling that must be presented to the State Environmental Service, it is best to choose an official waste manager. An official partner will also be able to provide professional advise on the possibilities of recycling the specific packaging.

The farm's agricultural packaging can be delivered free of charge to one of SIA "Eco Baltia vide" waste sorting areas and branches.

- Daugavpils, Dunduru iela 13A (tel. 26028042);
- Madona, Augu iela 29A (tel. 28308600);
- Aizkraukle, Jaunceltnes iela 9 (tel. 28308600);
- Bauska, Īslīces iela 5A (tel. 28308600);
- Liepāja, Ezermalas iela 11 (tel. 22004476).
  Sigulda city "JUMIS" Ltd at the reception area for sorted waste "Zemdegas" (pre-registration)
- Sigulda parish, Zinātnes iela, Peltes (tel. 26112288)

14.3. Practices in Estonia

Agricultural plastic includes products used in farming, such as silage bale wrap, silage cover, plastic tunnels, netting, and plastic twine. It also encompasses other types of plastic used in agriculture or horticulture with similar properties and intended uses. Agricultural plastic is considered a problematic product, and specific requirements apply to its handling, including responsibilities for the producer, importer, and user, which in this case is the farmer.

Agricultural plastic is subject to extended producer responsibility requirements, meaning that the producer (including the importer) is obligated to collect and recycle the agricultural plastic waste generated from their products. The following outlines the obligations for both agricultural plastic producers and users (farmers).

Obligations of Agricultural Plastic Producers (Including Importers)

- The producer must arrange for the collection and recycling of agricultural plastic waste, including ensuring that at least 50% of the waste is processed for recycling. Collection must be organized in a way that makes it as convenient as possible for agricultural plastic users to dispose of their waste.
- The agricultural plastic producer must accept the agricultural plastic waste generated from their products free of charge. The producer must collect waste equivalent to at least the mass of the agricultural plastic they have placed on the market in the previous calendar year.
- Unsorted waste is treated as mixed waste, and the agricultural plastic user is responsible for the handling costs of this.
- The producer must provide information to agricultural plastic users regarding the handling requirements and returning options for agricultural plastic waste.

Obligations of Agricultural Plastic Users (Farmers)

- Agricultural plastic users must collect agricultural plastic waste separately from other waste and avoid mixing it with other types of waste or materials.
- When transporting agricultural plastic waste to a collection point, users must prevent the waste from becoming mixed with or contaminated by other waste or materials.
- Agricultural plastic waste must be sorted by material type before being handed over: silage wrap separately, netting separately, bale wrap separately, twine separately, containers separately, and other plastics separately.

Storing agricultural plastic waste as cleanly and dryly as possible is important to facilitate recycling and reduce plastic waste. Let's consider the removal and collection of silage bale wrap and netting, ensuring the proper handling of agricultural plastic.

The silage bale wrap and netting are to be removed to a waterproof surface, if possible. This prevents contamination and mixing with soil, as well as reduces the risk of silage juices leaching into the ground. Note that, according to the law, stacking silage bales on a field is prohibited. Silage bales can be stacked on a waterproof surface - this is to prevent silage juices from entering the environment.

The aim is to achieve a higher dry matter content, which should be between 35-50%. This reduces the formation of silage juices and makes the feed more digestible for animals.

After removing the wrap from the silage bales, it is to be shaken to remove dirt. Only clean wrap can be recycled. Dirt is relatively easy to remove from clean wrap. If this step is delayed, it becomes very difficult to clean the wrap later, as the dirt will have dried and adhered to the wrap, becoming trapped between layers. If the load contains unclean material, the entire load must be sorted layer by layer. Some of the material may be cleaned by the waste handler, but heavily soiled wrap, especially if it has been stored for a long time, might not be clean enough for recycling and will end up in a landfill.

Returned waste must be free of soil, water, silage residues, stones, and other debris. Plastic contaminated with excessive silage or soil waste cannot be recycled or reused, and the waste handler must sort it separately and direct it to a landfill. While it is not possible to get the wrap completely clean, the amount of contamination should be minimized.

Agricultural plastic waste should be collected separately from other waste. It should not be mixed with tires, other packaging, or trash. The materials are to be immediately sorted by type and collected separately. This saves time and reduces later workload, as the waste will already be in the suitable condition for return. Weather resistance should be considered when collecting. The waste should be stored in a way that keeps it dry, for example, in big bags or under a roof. Collecting in big bags promotes circular economy and allows the reuse, for example, of fertilizer packaging that would otherwise become separate waste.

Properly collected and sorted plastic waste can be recycled, giving used plastic a new life and thereby reducing the amount of waste sent to a landfill, as well as reducing the environmental footprint of agriculture. Remember: the amount of agricultural plastic that can be recycled depends on its cleanliness, storage conditions, and proper handling.

Quick tips for Collecting and Storing Agricultural Plastic Waste

» When removing agricultural plastic:
  - Sort materials immediately by type: silage wrap separately, netting separately, bale wrap separately, twine separately, containers separately, and other plastics separately.
  - Collect the waste immediately in separate categories.
  - If possible, shake silage/bale wrap and other materials to remove excess moisture in order to avoid contamination with soil, silage residues, etc.

» Collect agricultural plastic waste separately from other waste: it should not be mixed with tires, other packaging, or trash.

» Store agricultural plastic waste in a way that keeps it dry: for example, in big bags or under a roof.

Storing agricultural plastic waste. Photos by Kaisa Vahtmäe

The handling of plastic material used in agriculture and the waste generated from it in Estonia is regulated by the Waste Act (https://www.riigiteataja.ee/akt/117032023037). The law obliges the producer of agricultural plastic to return or organize the return and recycling of the agricultural plastic it has marketed. This category includes silage bale film, silage cover film, film tunnel, cover netting and plastic twine. The obligation that remains on the farmer is to ensure that the used and returned plastic materials are clean, i.e. do not contain silage residues, soil, etc. [AK1]

Table 1 shows the amounts of marketed and recycled agricultural plastic from 2015 to 2020 according to the data of the Estonian Environmental Agency (National waste plan 2023-2028).

Table 1. Quantities of agricultural plastic marketed in 2015–2020 and the use of agricultural plastic in waste management in 2015–2020.

Year	2015	2016	2017	2018	2019	2020
Marketed (t)	921	907	1209	1358	1,355	1502
Collected (t)	727	639	1018	1002	1181	691
Recycled (t)	322	550	561	1240	648	449
Temporary storage (t)	649	1229	1487	1086	1217	1012

The main problems in collecting and recycling agricultural plastic are:

- Manufacturers have not established a collection point for the waste generated from agricultural plastic in every Estonian county. According to the manufacturers, users of agricultural plastic can express their desire to collect agricultural plastic waste, and the manufacturer will arrange for the collection of agricultural plastic waste. Due to the lack of collection points, the collection rounds of agricultural plastic waste are long, which is why users have problems with the storage of agricultural plastic waste.
- Very often, agricultural plastic waste contains a large amount of foreign matter. The user of agricultural plastic is obliged to collect agricultural plastic waste separately from other waste and avoid mixing this waste with other waste or materials. In order to ensure the possibility of handling agricultural plastic waste, it is necessary to collect the generated waste in a weatherproof manner and separately from other waste.

On May 1st, 2013, a legal act came into force in the Republic of Estonia: 'Requirements and procedures for the collection, return to the producer, and recycling or disposal of waste generated from agricultural plastic, as well as the target figures and deadlines for achieving the targets.' Section 4 states that the producer of agricultural plastic is obligated to organize the recycling of waste generated from the agricultural plastic they have sold. The goal is to direct agricultural plastic waste into material recycling for the production of new products. This also ensures a reduction in environmental pollution and the cleanliness of Estonia.

In practice, this means that the farmer can return, free of charge, the same amount of agricultural plastic they have purchased. Usually, they fill out an order form on the website of the company that sold the agricultural plastic, and on the agreed day, it is collected from their farm (transportation is also free).

Handling of silage waste in Estonia

The primary responsibility of every farmer is to minimize or, even better, eliminate the release of all possible waste generated during the farming process into the surrounding environment. Preventing silage juice leaching into nature has been a relevant issue. When wilted silage (with over 30% dry matter content) is made, no silage juice is produced, or it is released in minimal amounts. However, there is still a risk to the environment from the waste generated during the handling of silage (feed). During the mixing process of silage, hay, straw, meal, and minerals in a mixer, some inevitably ends up on the ground, which is later washed away by rainwater. Over time, waste feed accumulates and is leached into nature through ditches.

In Estonia, the storage and handling of silage is regulated by the regulation of the Minister of the Environment (https://www.riigiteataja.ee/akt/104102019004) resulting from the Water Act (https://www.riigiteataja.ee/akt/111062024017). The technical requirements for storages are perfectly described below.

Utilization of silage residues

The use of low-quality or spoiled silage is problematic. In Estonia, the quality of grass silage is considered low when its dry matter per kilogram contains less than 8 MJ of metabolizable energy, 12% crude protein or its organic matter digestibility is less than 50%. Feeding such silage to high-producing animals is limited. Grass silage with a lower nutrient content can be used as an additional substrate in wet fermentation in biogas plants. Unfortunately, this cannot be done limitlessly. A survey conducted by the Estonian University of Life Sciences in 2023 shows that the share of grass silage and silage residues in Estonian biogas plants is between 5.7-9.3% of the total volume of fermented substrates (in Estonian: http://hdl.handle.net/10492/8812).

The main limiting factor for low-quality grass silage in biogas production is its high content of fiber fractions and low digestibility, which is why microbes are not able to break it down to a sufficient extent. Therefore, the use of a large amount of herbaceous biomass (including grass silage) in a biogas plant reduces the total efficiency of biogas synthesis. There is no further use for spoiled silage (butyric acid content in dry matter is greater than 5g/kg or the ratio of ammonium nitrogen to total nitrogen is greater than 10%). Animals usually do not eat spoiled silage because of the specific smell. Adding spoiled silage to TMR (total mixed ration) can cause poisoning in animals, which can even be fatal. Using a large amount of spoiled silage as an additional substrate in a biogas plant causes the destruction of the microbial structure necessary for biogas synthesis.

References

the Estonian Environmental Agency (National waste plan 2023-2028???

https://www.riigiteataja.ee/akt/117032023037

https://www.riigiteataja.ee/akt/104102019004

https://www.riigiteataja.ee/akt/111062024017

Key Takeaways

- Agricultural plastic and silage waste management is a key component of sustainable farming practices.
- Only clean and well-separated plastic can be efficiently recycled — this reduces the use of virgin raw materials and improves nutrient efficiency in silage production.
- Spoiled silage should be minimized through proper silo compaction and feeding speed; if generated, it can be reused as biogas feedstock or as fertilizer, provided contamination limits are respected.
- In Finland, national recycling systems (e.g. SuMaKi) enable free on-farm collection of bale wrap and silo films; clean sorting is crucial.
- Latvia relies on private recycling initiatives that are free for farmers; sorted materials must be clean, dry, and traceable.
- In Estonia, plastic producers (including importers) must arrange the collection and recycling of agricultural plastic waste, ensuring that at least 50% of the waste is processed for recycling. Farmers must return clean, sorted agricultural plastic.
- Coordinated efforts between producers, users, and waste handlers are essential for effective recycling and reduced environmental impact.

15. Links between silage management and carbon balance

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Silage production is pivotal to livestock farming by providing conserved forage for animal feed. However, the production process has significant implications on climate change due to emissions that arise from various stages of fermentation, nutrient loss, and overall management practices. Silage directly contributes to global warming through the release of carbon dioxide (CO_2) and volatile organic compounds (VOC), though its impact is smaller compared to the indirect emissions from enteric fermentation in livestock. To reduce this carbon footprint and improve sustainability, it is crucial to understand the carbon cycle and VOC generation within silage systems and optimize production practices.

15.1. Silage Production Stages Contributing To Carbon Inputs And Outputs

The process of silage production involves multiple stages, each contributing to carbon inputs and outputs (Figure 1). These stages include:

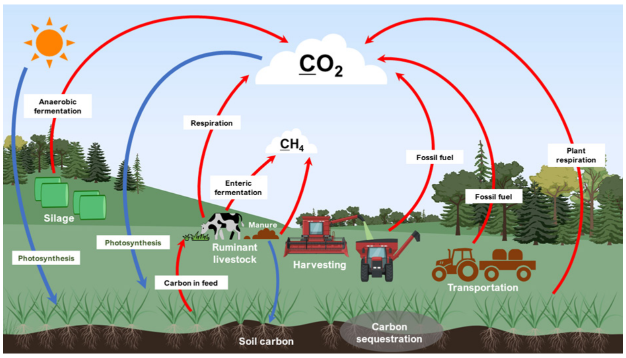

Figure 1. The carbon cycle illustrating silage production and usage highlights carbon flows, with **red cycles** representing carbon emissions (outputs) and **blue cycles** indicating carbon absorption or sequestration (inputs).

Cultivation of forages: Forage production has positive ecosystem effects such as improving soil characteristics (soil structure, organic matter content, water holding capacity), preventing soil erosion, low ecotoxicity due to the low use of pesticides and insecticides, promoting landscape restoration, biodiversity, nitrogen fixation when forage legumes are used, and it might serve as a carbon and methane sink. The carbon cycle begins with photosynthesis, in which forage crops capture CO_2 and convert it to organic compounds in the presence of water and nutrients. Carbon is incorporated into the plant in the form of carbohydrates, proteins and lipids. Well-managed forage systems, particularly those incorporating perennial crops or cover crops, enhance carbon sequestration in soils, reducing atmospheric CO_2 levels. However, the use of nitrogen fertilizers can lead to the release of nitrous oxide (N_2O), a potent greenhouse gas that has a much higher global warming potential than CO_2. Excessive fertilizer application can increase N_2O emissions. Additionally, CO_2 is emitted during cultivation of silage crops due to the use of fossil fuels and machinery.

Harvesting: As forage plants mature, they are harvested and prepared for ensiling by means of activities such as wilting, chopping and compacting. These operations result in CO_2 emissions from fuel combustion and microbial activity. Further carbon losses occur due to respiration and mechanical losses during the collection process. Factors affecting the rate of respiration include forage characteristics, wilting duration and conditions, time between harvesting, compaction and sealing, and the extent of compaction. Respiration rate decreases with increased forage DM content, but increases with temperature. Additionally, legumes have a greater respiration rate than grasses.

WSC + O_2 --> CO_2 + H_2O + heat (16 MJ/kg WSC)

Fermentation/Storage: During the ensiling process, plant material undergoes anaerobic fermentation facilitated by naturally occurring or inoculated microbes, particularly, lactic acid bacteria. Other microbial groups include enterobacteria, clostridia and yeasts. These microbes produce organic acids that lower the pH preserving the forage. Before the fermentation process begins, there is an aerobic phase, where trapped oxygen in the packed forage allows biological and chemical processes to consume nutrients and energy, producing water, heat, CO_2 and free ammonia (McAllister and Hristov, 2000). Gas exchange in the silage is influenced by the pressure differences between the fermentation gas (usually CO_2) and air; this pressure difference is caused by the varying specific gravity of CO_2 and air. This can inadvertently cause a rise in the silage temperature and lead to dry matter (DM), energy and quality losses (Table 1).

Fermentation losses are primarily from the CO_2 production that ranges between 2 to 4% (Zimmer, 1980) depending on the dominant microbial species and the fermented substrate (Table 1). Carbon is released as CO_2 during microbial respiration in the anaerobic fermentation stage. Ensiling losses are generally estimated by assuming the weight loss of silage during ensiling and this is an estimate of the CO_2 production. For each mole of CO_2 produced, 1 mol of H_2O is also produced. Thus, for each gram of weight decreased due to CO_2 losses, 0.44 g of DM is also lost as water. It is counted as an ensiling loss, even if the water is still in the silo. The total DM losses are then estimated to be the decrease in weight of the silo multiplied by 1.44 (Knický and Spörndly, 2015). DM losses during ensiling often occur in two ways; the fermentation of sugars to primarily CO_2 and ethanol, and effluent production, especially if the material has a high moisture content. As seen in Table 1, if microbes other than lactic acid bacteria significantly impact the fermentation process, the DM loss in the form of CO_2 is generally large.

Table 1. The losses of DM and gross energy from silage fermentation pathways adapted from Borreani et al. (2018).

				Loss (% substrate)	
Organism	Pathway	Substrate	Products	DM	Gross energy
LAB[1]	Ho[2]	Glucose	2 lactate	0	0.7
LAB	He[3]	Glucose	1 lactate, 1 ethanol, **1 CO_2**	24	1.7
LAB	He	3 Fructose	1 lactate, 1 acetate, 2 mannitol, **1 CO_2**	4.8	1
LAB	Ho/He	2 Citrate	1 lactate, 3 acetate, **3 CO_2**	29.7	-1.5
LAB	Ho/He	Malate	1 lactate, **1 CO_2**	32.8	-1.8
Enterobacteria		2 Glucose	2 lactate, 1 acetate, 1 ethanol, **2 CO_2**	17	11.1
Clostridia		2 Lactate	1 butyrate, **2 CO_2**, 2 H_2	51.1	18.4
Yeasts		Glucose	2 ethanol, **2 CO_2**	48.9	0.2

[1] LAB = lactic acid bacteria; [2] Ho = homofermentative; [3] He = heterofermentative

Opening/Feed-Out: During the opening process for feeding, silages are exposed to air, aerobic microbes, e.g. yeasts and moulds, can become active in producing CO_2, and causing feed and energy losses. The CO_2 production also plays a key role in the aerobic stability of silages. Inadequate compaction, oxygen infiltration and prolonged storage can lead to an increased CO_2 release and nutrient losses. Poor silo management can also create anaerobic conditions that increase methane production. Silage quality is often accessed according to sensory appraisal (appearance, smell and texture; Table 2), DM losses, pH levels, fermentation by-products, i.e. lactic acid and volatile fatty acids (VFA), protein breakdown, and microbiological health.

Substrates: lactic acid, acetic acid, residual WSC → Products: CO_2, water, heat → Outcome: rising temperature. pH, growth of mould and silage deterioration

Table 2. Sensory symptoms and causes of common silage issues adapted from Mahanna and Chase (2003).

Sensory observation	Caused by	Silage Management Causes
Rancid milk smell	Clostridial fermentation with butyric acid production	High moisture content, low water soluble carbohydrates (WSC), inadequate lactic acid bacteria (LAB).
Vinegar smell	Bacteria fermenting WSC to acetic acid	Wet silage, inadequate LAB, low WSC
Alcohol smell	Yeast fermenting WSC to alcohol	Dry and poorly compacted silages. slow feedout
Mouldy silage	The presence of oxygen and adequate substrate	Stressed crops, slow filling and feedout, long chop length, low moisture and poor compaction
Hot silage	Prolonged respiration, yeast, mould and bacterial growth	Slow silo filling, leaks in silo structure, slow feedout, low moisture, overly mature crop, long chop length, poor compaction

Additionally, when animals consume silage, carbon is metabolized, and CO_2 is released through respiration. In ruminants, the digestion of silage also leads to the production of CH_4 due to enteric fermentation.

Environmental impact

Ways To Minimize Carbon Emissions In Silage Production And Use

- *Suitable forage management: Conservation tillage practices to minimize soil disturbance, precise fertilizer application and crop rotation to help promote carbon sequestration and reduce emission. Reduced tillage can help maintain soil structure and prevent organic carbon loss from the soil.*
- *Efficient silage production techniques: Timely harvesting in good weather conditions, harvesting at proper moisture and stage of maturity levels, proper compaction, effective sealing, proper packing, the use of efficient additives (inoculants or chemical additives) are needed to enhance fermentation efficiency, reduce carbon losses and improve silage quality. The use of silage inoculants promotes the fermentation process by enhancing lactic acid production while acid-based additives restrict fermentation by the drastic acidification of the silage to inhibit microbial activity. The carbon footprint of the production and transportation of chemical additives is likely to be greater than that of inoculants. However, if better silage quality and reduced losses are achieved with efficient chemical additives, the final environmental balance may be better with them. Improving silage management practices will influence carbon sequestration, decrease direct CO2 emissions and also help preserve nutrient yields as well as promote profitability and the overall carbon footprint of livestock production.*
- *Nutrient management: Precise nutrient management practices to improve silage quality and balanced feed formulation for livestock can help optimize digestion and reduce enteric CH4 production, which can lower overall carbon emissions from silage feeding. A well-maintained silage reduces spoilage.*
- *Energy efficient practices: Energy inputs required for planting, harvesting and storing silage impact the carbon balance of the farming system. Using renewable energy sources (e.g biogas using CH4 from manure, solar energy) for silage production operations, such as harvesting and transportation, can help reduce the carbon footprint of silage. Efficient energy use helps lower fuel consumption and associated CO2 emissions. Using silage crops as feedstock for bioenergy production (biogas) can contribute to carbon neutrality by replacing fossil fuels with renewable energy sources, lowering net carbon emissions in the long term.*
- *Enhanced feed efficiency: Using high quality silage results in a better livestock feed conversion. Animals fed well-preserved, nutrient-dense silage produce less methane per unit of product and are more efficient in digesting feed.*
- *Manure management: Better silage and feed efficiency result in less manure and lower methane emissions of livestock waste, reducing the environmental impact of farming.*

15.2. Volatile organic compounds

Volatile organic compounds (VOC) are a group of compounds generated during silage production that later evaporate into the atmosphere. Their production starts during crop growth, increases during harvesting/transporting, packing and sealing and continues during fermentation, storage, feedout and feeding of silage. While some VOC are naturally produced by living organisms during silage fermentation, excessive amounts can result in poor fermentation quality, spoilage, and environmental pollution.

These VOC can also negatively affect feed intake due to their unpleasant smell, which impacts animal performance and the metabolism of dairy cows. Studies show silage-related VOC emissions account for about 5% of all anthropogenic sources in both the US and the EU (Howard et al., 2010). These emissions are important contributors to smog and ground-level ozone production that lower air quality and lead to health problems, such as respiratory diseases and premature death.

In maize silage, VOC ranges between 30 and 40 g/kg (on the basis of DM). CO_2 production during fermentation can carry VOC out of the silage storage structure due to gas flow. VOC emissions are influenced by the concentration of VOC in silage, temperature and silage moisture levels. Most VOC production occurs during silage fermentation and storage, while the majority of the emissions happen during feeding. Though much of the VOC is emitted into the air, some also have nutritional significance when consumed by animals, as they contain high energy content. Research on VOCs in maize is more extensive compared to grass. Reducing VOC emissions from silage is important not only for environmental reasons, but also to maintain good silage quality and animal performance.

There are about 50 VOC-s present in silage, but they can be grouped into 4;

- Organic acids
- Alcohols
- Aldehydes
- Esters

Acids: This group comprises major fermentation acids that are often produced during ensiling, such as lactic acid and VFAs, propionic, butyric, isobutyric and isovaleric acids, which are acetic. This is the second most abundant group of VOCs and they have low volatility and reactivity. These acids are generated by various microorganisms during fermentation, such as heterofermentative lactic acid bacteria, enterobacteria or clostridia (McDonald et al., 1991). The acetic acid concentration in maize silage could be between 10 and 50 g/kg, while the concentration of propionic acid could be between 1 and 10 g/kg.

Alcohols: They are the most predominant VOCs and make up about 70% of the total mass of VOCs in maize silage, apart from acids. Ethanol and propanol are the most prominent alcohols found in silage. Others include methanol, 1-Propanol and 1-Butanol. They contribute to air quality, because they have high volatility. They are mostly produced by yeasts and obligate heterofermentative lactic acid bacteria by the fermentation of water soluble carbohydrates (WSC). Ethanol concentrations in maize silage may exceed 10 g/kg and the 1-propanol concentration can range between 0.1 to 10 g/kg after silage storage. Methanol concentrations comprise less than 10% of ethanol. Ethanol is the main VOC from maize silage, while methanol is the highest in alfalfa silage.

Aldehydes: They can either be formed directly or as a product of acetic acid and alcohol oxidation, such as acetaldehyde and propionaldehyde. They are produced by certain lactic acid bacteria and yeast using sugars and amino acids as substrates. While the concentrations of aldehydes in silage are often below 1 g/kg, their high reactivity makes them significant contributors to secondary air pollution.

Esters: They can negatively affect feed intake and have very low reactivity. These compounds can be formed by lactic acid bacteria and through esterification reactions with alcohols. Their production depends on the concentrations of ethanol and acetyl-CoA as well as pH, temperature, yeast abundance and strain type during silage fermentation.

Factors contributing to VOC production in silage

The concentration of VOC in silage is majorly determined by silage management practices or the type of crop/forage ensiled.

Plant stress: Plants release VOC as a result of abiotic or biotic stresses to communicate with insects and other plants. Harvesting triggers this stress response, increasing VOC emission. Methanol is the dominant VOC emitted before and during harvest and it increases immediately after cutting the crop. Minimizing the time between harvest and covering the silo (ideally within one day) will help reduce VOC emissions.

Feedout management: Smaller daily removal thickness coupled with low density, high temperature, high wind speed can contribute to greater VOC losses. For example, daily removal of 15 cm during feedout can cause about 10% loss of ethanol.

Silage management practices: Management practices, such as inadequate packing/sealing or poor storage conditions, can lead to aerobic spoilage and elevated VOC production. Fermentation processes are primarily driven by lactic acid bacteria in anaerobic conditions; however, the infiltration of oxygen can allow aerobic microbes to thrive, resulting in the production of unwanted VOC. Additionally, the presence of undesirable microbial activity, which thrive in anaerobic conditions, e.g Clostridia and Enterobacteria, can lead to the production of VOC and other harmful compounds. Delayed sealing can also increase the risk of spoilage microorganisms, resulting in high VOC production.

Crop/Forage type: Forage composition plays an important role in VOC production. Forages rich in starch, e.g maize, undergo rapid fermentation leading to the production of ethanol and other VOCs. Also, forage of poor quality or buffering capacity may not ferment adequately, leading to the production of VOCs.

Environmental impact:

Ways To Minimize VOC Emissions In Silage Production

- *Use of silage additives: This is based on the specific mode of action, which can affect fermentation patterns and aerobic stability, ultimately influencing the production of VOCs. The use of antifungal chemical additives, such as potassium sorbates, sodium benzoate, are effective in reducing ethanol production and the formation of ethyl esters. The use of lactic acid bacteria inoculants has also been shown to help in the reduction of some of the VOCs by improving fermentation processes. However, silage additives can only reduce some VOC productions, not all.*
- *Improved silage management: This includes optimum silage particle size and density, rapid filling, effective compaction and proper sealing during silage making. Airtight plastic covers should be used to prevent oxygen infiltration.*
- *Silage monitoring: changes in microbial communities, regular temperature and pH during storage and feedout can help detect VOC production early and prevent spoilage.*
- *Good silo management reduces oxygen ingress that will limit acetic acid production, however, the reduction in their concentration could increase ethanol production, because acetic acid helps in suppressing yeasts.*
- *Timely Harvesting: Harvesting forage at the right stage of maturity and moisture content helps minimize plant stress and VOC emissions. The timely sealing of the silo after harvesting is crucial in reducing exposure to oxygen and lower VOC production.*
- *Optimizing the Fermentation Process: Achieving a stable and rapid fermentation process is key to minimizing VOC emissions. Ensuring that the ensiling environment remains anaerobic will reduce the activity of undesirable microorganisms, such as yeasts and moulds, contributing to mitigating VOC formation.*
- *Efficient Feedout Practices: When feeding out silage, removing a sufficient thickness of silage daily and avoiding prolonged exposure to air by covering the silo face with plastic can help minimize losses and VOC emissions.*

Key take-aways

- Use no-till or reduced till farming to protect soil health, avoid soil erosion and prevent carbon loss.
- Rotate crops and apply fertilizer precisely to boost soil carbon storage and reduce emissions or leaching.
- Harvest crops at the right stage and moisture level to improve silage quality.
- Chop forage to the right size (1-3 cm) to enable proper silage compaction and the exclusion of oxygen.
- Choose suitable additives that will help control fermentation and keep silage fresh.
- Add antifungal products, like potassium sorbate or sodium benzoate, to reduce harmful bacteria in silage and improve aerobic stability.
- Fill the silo quickly to reduce oxygen penetration in order to improve silage preservation.
- Keep air out of the silo to prevent the loss of acetic acid that helps keep yeast growth in control and stops excess ethanol production. Avoid punctures in plastic used for covering silo or packing silage, and repair holes as soon as noticed.
- Pack and seal silage tightly to prevent nutrient losses and improve fermentation.
- Regularly check the temperature and pH of your silage to detect problems early and prevent spoilage.
- Be alert to the smell of silage (strong ammonia smell, pungent and unpleasant).
- Remove a sufficient amount of silage daily (10 to 15 cm) from the entire silage face to prevent an increase in the production of microbes that contribute to unstable silage.
- Plan silo size adequately to achieve a correct daily feed-out rate depending on season.
- Discard mouldy or spoiled silage appropriately.
- Use renewable energy (e.g biogas or solar power) for farming operations like harvesting and transportation to reduce fuel use and emissions.
- Balance feed nutrients to improve digestion and reduce methane emissions from animals.
- Reduce waste during silage production as much as possible.

15.3. Carbon footprint estimation

There are several carbon footprint calculators available online for farmers to estimate the carbon footprint of livestock production.

ValioCarbo Farm Calculator: is a sophisticated carbon footprint calculator developed for Finnish dairy farmers, aimed at tracking carbon emissions' reduction targets set at 30% by 2025. The calculator uses Intergovernmental Panel on Climate Change (IPCC) methodology and data from Valio's own scientific work. One setback of the calculator is that the carbon balance of the soil is not included in the life cycle assessment model.

Y-HIILARI: This is another carbon footprint calculator that was developed in Finland.

Biocode: developed in Finland.

GHG Protocol: The greenhouse gas protocol is an online website that contains tools that enable industries and farmers to track the inventories of their GHG emissions as well as their progress in achieving climate goals.

Cool Farm Tool: It is a carbon footprint calculator that aids in quantifying carbon, water use and the biodiversity footprint. It was standardized using IPCC methods and empirical research data sets. This tool is designed for the full accounting of greenhouse gas emissions and carbon sequestration at the farm level. It helps farmers evaluate management options to improve their carbon balance performance over time.

Arla's FarmAhead™ Check: Although primarily used by Arla's cooperative farmers across Northern Europe, this tool can be useful for dairy farmers in Estonia and Latvia. It follows ISO standards for the life cycle assessment and the International Dairy Federation guidelines on carbon footprint methodology.

Environmental impact:

Mitigating methane emissions

» *Feed additives that have proved to be effective in reducing methane production in dairy production. They include 3-nitrooxypropanol (Bovaer), seaweed, oils and fats, the use of digestible forage, nitrates, tannins.*

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16. Closing remarks

This manual is the result of a collaborative effort contributed to by practitioners, advisors and researchers from three Baltic Sea countries. Agriculture is constantly evolving, and this joint undertaking reminds us of the power of cooperation. Through collaboration, we can create knowledge and gain new insights that benefit farmers, animals and the environment alike.

Livestock farming in Finland, Estonia and Latvia mainly takes place in climate conditions well suited for forage production. We have the necessary natural resources and, most importantly, educated and capable farmers. This gives us a strong position on the global stage – one that we must maintain and strengthen.

Although our cattle farms differ in size and tradition, we share common challenges: changing climatic conditions, environmental regulations, rising production input costs, and the need to ensure food security.

High-quality feed is never produced by chance. It is the result of knowledge-based management, experience, and precise timing. Successful silage production requires the willingness to acquire and apply science-based skills, learn from neighboring success stories, and often from past mistakes.

This manual is an example of how cross-border cooperation adds value to food production across the entire region.

Our sincere thanks to everyone who contributed their time, knowledge, and experience to this work!

Are Selge, Editor.