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SMART STEP

Climate-Smart Steps in Grassland Management and Improvement

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SMART STEP

Contents

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1. Introduction

Rangelands represent one of the largest terrestrial ecosystems on Earth. Beyond serving as the most economical and fundamental source of roughage for ruminant production systems, these ecosystems provide a wide array of critical ecosystem services, including the conservation of biodiversity, climate change mitigation through carbon sequestration, prevention of soil erosion, and regulation of hydrological cycles [1; 2].

From a global perspective, grasslands and rangelands cover approximately 26–30% of the Earth's ice-free terrestrial surface [3; 2]. These extensive ecosystems directly support the livelihoods of millions of people worldwide and constitute a cornerstone of global food security, particularly in terms of meat and milk production. However, global rangeland resources are increasingly threatened by degradation driven by climate change-induced drought stress, overgrazing and mismanaged grazing regimes, agricultural expansion, and inappropriate land-use policies [4; 1].

Within the European context, grasslands (permanent grasslands and pastures) form an integral component of agricultural landscapes, rural economies, and cultural ecology. According to European Union data, permanent grasslands account for approximately one-third (around 30–34%) of the total Utilised Agricultural Area (UAA) across the continent [5; 6]. Unlike many other regions of the world, grassland management in Europe is not solely production-oriented but is strongly supported by comprehensive environmental protection frameworks. In particular, under the Common Agricultural Policy (CAP), the conservation of grasslands is central to achieving environmental sustainability, biodiversity conservation, and rural development objectives [7].

Therefore, the sustainable management and rehabilitation of grasslands, both globally and within Europe, constitute a strategic imperative for enhancing resilience to environmental challenges and securing the future of agricultural production systems. This study focuses on successful management practices and case studies implemented in European grassland ecosystems.

2. Best Grassland Management Practices

2.1. Austria

2.1.1. Grassland Improvement Practices in Austria

Due to the pronounced natural differences between the Pannonian-influenced eastern lowlands, the inner-Alpine dry areas, and the high-rainfall mountain regions, Austria comprises highly diverse grassland and pasture sites. Permanent grassland is a central element of Austrian agriculture and cultural landscapes and represents the most important, or rather the most extensive, agricultural land-use type in the country. Austrian agriculture is also strongly characterized by family farming structures, which means that grassland in Austria is predominantly privately owned. Private ownership is likewise widespread in alpine pasture areas, although common property systems play an important role. However, the importance of grassland varies considerably between regions: while the proportion of grassland in eastern Austria is often below 5%, it exceeds 90% in many Alpine areas [99]. In this context, alpine pastures are of particular importance. According to AMA (2026), alpine pastures, including their grazing areas and other alpine land, cover around 20% of Austria's total cadastral area and are of high spatial, ecological, and economic significance.

Austria's permanent grassland area has declined considerably over time. Between 1960 and 2015, a total of 1.04 million hectares of permanent grassland were lost. The majority of this decline, amounting to 835,000 hectares, affected extensively used grassland [101]. The causes of this loss are diverse: on the one hand, extensively used grassland was partly abandoned or afforested; on the other hand, some areas were intensified. This development highlights that ecologically valuable and traditionally extensive grassland sites were particularly affected by changes in land use.

The development of grazing-relevant livestock populations in Austria also indicates substantial long-term structural change. Cattle numbers initially increased from 2.28 million animals in 1950 to 2.58 million in 1990, but subsequently declined continuously to 1.84 million animals in 2023 [102]. This development is also relevant for the use and management of pasture areas, particularly in regions where the maintenance of open landscapes is closely linked to livestock farming.

The main challenges of Austrian pasture and alpine grazing systems differ markedly between regions. In the drier eastern regions, drought stress and water deficits are increasing, whereas in many mountain regions the maintenance of open alpine pasture land is becoming more difficult due to declining livestock numbers, high labor requirements, and difficult management conditions. Accordingly, the challenges of grassland and pasture management in Austria are strongly influenced by natural, climatic, and farm-structural conditions. In more favorable production areas, intensification processes are of particular relevance, whereas in disadvantaged regions land abandonment, afforestation, and changes in vegetation composition play a more important role. In alpine pasture systems, bracken encroachment may also become a significant problem, as it reduces forage quality and the usability of grazing land and, if it becomes more widespread, can displace valuable forage plant species [103].

Pasture-based farming is of particular importance in Austria, especially for organic farms. This is because the EU organic regulation requires herbivorous livestock to have access to open-air areas and, preferably, to pasture whenever weather conditions, soil conditions, and animal health allow [104]. For many organic farms, pasture is therefore not only a traditional component of feeding and livestock husbandry, but also a central legal and operational requirement for compliance with organic farming standards. At the same time, pasture use on organic farms plays an important role with regard to animal welfare, the use of farm-based feed resources, and the conservation of grassland and pasture ecosystems.

As in other countries, sustainable grassland and pasture management in Austria requires site-adapted utilization concepts. These include grazing systems adapted to regional conditions, the avoidance of overuse and underuse, appropriate maintenance measures, and strategies to preserve productive and ecologically valuable vegetation. In view of climate change, changing management systems, and declining livestock numbers, the development and implementation of sustainable management strategies is therefore of central importance.

In Austria, various stakeholders are involved in issues relating to grassland and alpine pasture management. On the one hand, this includes the Chambers of Agriculture as the official professional representation of farmers, as well as organic farming associations. On the other hand, research institutions under the responsibility of the Federal Ministry of Agriculture, as well as universities such as the University of Natural Resources and Life Sciences, Vienna, contribute substantially to the scientific investigation of grassland- and pasture-related issues.

2.1.2. Case 1

Use Case A: Ground-Truth Data Collection in Satgrass Project for Satellite-Based Real-Time Monitoring of Grassland Management in Austria

The crop type grassland is somewhat more difficult and complex to monitor compared to arable crops due to the composition of different plant species. The species present in permanent grassland have slightly different development cycles, which are repeatedly interrupted by cuts. The cutting system is usually site-specific and describes the frequency of use during the growing season. If this period is long and the climate is favorable for grassland plants, harvesting can occur more frequently, which also leads to variations in species composition.

The yield in grassland depends on site factors, but it is strongly and individually influenced by the specific plant population, whose species composition depends on both the site and management practices such as fertilization, maintenance, and utilization [8]. To be able to observe the yield and quality progression over several growth cycles, multiple surveys are re-quired during a single growth cycle. The annual yield is determined by combining the yields of all growth cycles, which, in Austria, range from 2 to 6 per year in production grassland.

A single growth cycle includes the growth between two cuts, or in the case of the first growth cycle, begins with the start of the growing season. An important parameter for describing grassland and its utilization is therefore the cutting date of each growth cycle. For all survey areas within a grassland monitoring network, this date must be meticulously recorded. Models developed to estimate cutting dates, often based on satellite data, form the foundation for all models that include yield and quality dynamics, as well as management intensity [9; 10].

Beyond recording cutting dates, observations during the growth cycle represent the central ground-truth data basis for grassland monitoring. Using the SatGrass project as an example, a practical and standardized process for collecting ground-truth data for the crop type permanent grassland is presented. By demonstrating the mobile survey application in the following chapter, we show how the systematic collection of ground-truth data constitutes a fundamental and extremely important step in the application of satellite data. As an introduction, the following out-line provides an overview of the workflow and possible survey parameters that are suitable for assessing the vegetation of a grassland area and using it to interpret multispectral Sentinel-2 da-ta:

a) Selection of representative test plots: According to scientific principles, sampling of grassland area is carried out in triplicate. For this purpose, three square-meter plots must be selected within the survey area that best represents the entire field. As shown in Figure 1, the selection must correspond to the plant population detected by the Sentinel-2 sensor across the entire field to enable ground-truth and satellite information to be com-pared during model calibration and validation with the lowest possible error. Specialized grassland expertise is required for good selection. In the SatGrass project, additional quality assurance criteria were established: Test plots must be at least 20 meters from the field boundary and at least 10 meters apart from each other.

Figure 1. Selection of sampling areas in triplicate

b) Positioning of a harvest frame and georeferencing: To determine the biomass of one square meter precisely, a defined boundary of this test plot must be established. In Sat-Grass, a steel frame was constructed for this purpose, which is carefully placed into the plant population, containing all aboveground biomass located within this frame. Plant parts that are pressed down by the frame must be manually positioned either inside or outside the frame according to their shoot axis. By taking a photographic image of the plant population inside the placed frame, and with geolocation activated on the recording device, the geographical coordinates are automatically stored in the EXIF data of the im-age and later transferred to the ground-truth database. The primary purpose of this pho-to is the documentation of the plant population to be evaluated later.

c) Assessment of the plant population: Within the test plot, the projective cover is determined, which corresponds to the percentage of the plot area covered when the above-ground plant parts are projected vertically [11]. By viewing the plants from above, gaps in the plant population can be identified. A well-developed plant population shows a protective cover of more than 85%. Subsequently, the ratio of the species groups – grasses, herbs, and legumes – is estimated in weight percent to evaluate yield contributions, following the guidelines of Peratoner and Pötsch (2019).

d) A balanced and high-performing grassland population typically consists of approximately 50–70% grasses, 10–30% herbs, and 10–30% legumes. These data are only valid if collected by trained personnel. Subjective impressions must be strictly avoided by following a standardized method supported by extensive practical experience [11]. The purpose of these observations, together with photo documentation, is to assess extreme yield and quality values, in order to decide whether the data collection from this test plot can be included in the modelling or excluded as outliers.

e) Measurement of growth height: The growth height allows for a rough estimation of the biomass located within the test plot. Since the measurement is simple and quick, it is conducted in addition to yield measurements, providing potential input for models that are frequently the subject of scientific studies [12; 13; 14; 15; 16]. In the Sat-Grass project, these measurements were conducted using a folding ruler and a Rising Plate Meter (RPM). For the folding ruler method, three height measurements of the plant population are taken at different positions within the test square meter and then aver-aged. It must be ensured that not only creeping plants or tall grasses are considered, but rather the average height of all plants is captured. The RPM measurements were carried out using an EC09 Electronic Platemeter, which automatically averages three measurements and displays a calculated dry matter yield. The plate is lowered along a rod, de-pending on the resistance of the biomass, and the distance to the ground is interpreted as a yield-relevant height value (see Figure 2, Image 1).

f) Recording of key plant species: Information about the species that make up the majority of the plant population facilitates the interpretation of yield values and ensures quality, as model results can be evaluated based on these records. In SatGrass, up to five different species could optionally be recorded and entered.

g) Measurement of Leaf Area Index (LAI): On all SatGrass survey plots monitored by project staff, the LAI was measured in addition to other observations. This requires specialized equipment, which cannot be provided to all participants in a large survey network. In SatGrass, an AccuPAR LP 80 Ceptometer [26] was used and applied to approximately half of all surveys. As shown by Klingler et al. (2020), the LAI is particularly suitable as a vegetation parameter for grassland, since, unlike other vegetation indices, it does not experience rapid signal saturation during the growth cycle, allowing for differentiated monitoring of biomass development until harvest. This parameter makes an extremely valuable contribution, especially for yield estimation [17].

h) The AccuPAR LP 80 is equipped with eight sensor segments and is placed beneath the plant canopy. At the same time, a reference or ambient radiation measurement is taken using a pyranometer positioned horizontally on a metal rod above the canopy as a reference sensor. The device measures in the range of photosynthetically active radiation (400–700 nm), capturing the radiation difference between the two sensors below and above the plant canopy. For reliable shading information, sufficient sunlight intensity of more than 600 micromoles per square meter per second is required. At lower light intensities, the difference between irradiation and shading detected by the sensors beneath the plant canopy becomes too small. To ensure the most vertical light incidence and high radiation intensity, measurements must be conducted around midday, with the sun at its highest point, and must follow the convention of taking such measurements between 9:00 AM and 4:00 PM. The LAI device with the sensor is repositioned for each of the three replicate measurements within each of the three test plots. To avoid casting shadows on the sensors, skilled handling of the device is necessary (see Figure 2, Image 2).

i) Harvest and determination of fresh matter: The aboveground biomass within the square meter frame is cut at a defined cutting height (e.g., 5 cm). In the SatGrass project, a hedge trimmer was used for this purpose (see Figure 2, Images 3 and 4). The harvested material must then be carefully collected using a garden rake, completely placed into a labeled sample bag, and weighed with a precision scale. This process is repeated for each of the three test plots, and the measured fresh matter weights are recorded. After recording the fresh matter weights, a composite sample was created from the three replicates in the SatGrass project.

Figure 2. Measurement of crop height using a rising plate meter and leaf area index, as well as harvesting of biomass within the sampling area marked out with a red steel frame.

If sufficient resources for chemical analysis are available, the individual samples can, of course, be processed separately without mixing. For the composite sample, all three fresh matter samples are carefully mixed in a suitable container and chopped using a sample cutter (see Figure 3). From this mixture, an exact 1000-gram sample is taken and dried. The dried harvest material is then ground and analyzed in the laboratory.

Figure 3. Preparation of the composite sample from a triplicate sampling area harvest

The entire workflow is comparatively complex due to the variety of surveys conducted using different methods and therefore requires precise instructions if the demand for data quality is to be high. Only with flawless data can unnecessarily large errors in modeling be avoided, which is why quality assurance must receive special attention in systematic ground-truth surveys. Based on the experiences from SatGrass, the use of a mobile app has proven to be the most effective way to avoid problems with data logistics and uncertainties in the workflow. In the following chapter, the implementation of such an app is demonstrated using SatGrass as an example.

2.1.3. Case 2

Use Case B: Establishment and Management of Intensively Trampled Pasture Areas

2.1.3.1. General Information

Initial Situation

Under the current organic farming requirements Bio-VO (EU) 2018/848, all farms need to provide grazing access for ruminants and equines. As a result, pasture areas close to the farmstead are often used much more intensively than before. These heavily frequented paddock-type grazing areas place different demands on the sward than conventional pasture systems. In such situations, high yield and maximum forage quality become less important, while sward stability, persistence, regenerative capacity, and resistance to trampling move to the forefront. This requires a shift in botanical composition towards creeping and wear-tolerant grasses that are normally only included at low levels in standard pasture mixtures. The source also notes that stronger technical intervention generally improves establishment of the target species, but such areas need more time afterwards to become stable and trafficable again.

Objective

The aim was to improve already existing, heavily used pasture areas through reseeding with more suitable grass species. For this purpose, newly composed seed mixtures were introduced into established pasture swards on two commercial farms. Over several years, three establishment techniques and three seed mixtures were compared under practical farm conditions. This on-farm approach made it possible to evaluate not only establishment success, but also the later usability, resilience, and management implications of the treated areas.

Implementation on Two Farms

Practical Setup

The work was carried out on two farm sites with pasture areas already exposed to intensive hoof traffic. On both farms, three establishment methods and three seed mixtures were compared. In addition, both spring sowing and late-summer sowing were tested. The results showed that both sowing windows were generally suitable, but the actual success depended mainly on weather conditions in the weeks immediately after sowing. The text highlights that sufficient soil moisture after sowing is one of the decisive factors for successful establishment.

It also notes that, from a practical point of view, late summer is often considered favorable because the risk of prolonged summer drought is lower and young plants can establish well before winter [18].

Sowing and Early Management

Because most of the species used are fine-seeded and largely light germinators, sowing depth and seed-to-soil contact were critical. Grassland overseeding machines with a following roller proved particularly suitable, because they place the seed near the surface, incorporate it only lightly, and ensure sufficient reconsolidation for germination. On both farms, the newly sown areas were not grazed immediately after sowing, since young seedlings are highly sensitive to pressure. Instead, a first maintenance cut after about six weeks was recommended, followed only later by careful grazing once the soil had regained sufficient firmness. Where reseeding was carried out into an existing sward, fertilization was not recommended, because it would increase the competitive pressure of the old sward on the new seedlings. These practical steps are in line with general recommendations for successful pasture establishment and grazing management [18; 19].

Establishment Methods Compared

Methods Tested

Three establishment techniques that are relatively practical for farm use were compared: the heavy tine harrow, the rotary harrow, and the reverse rotary harrow. The objective in each case was to open the sward sufficiently for the desired species to establish, while still keeping the area suitable for later grazing use.

Results of the Technique Comparison

All three methods were fundamentally successful, but they differed in the share of the desired sown grasses that became established. Total grass cover remained broadly similar across all methods, at around 80%, but the heavy tine harrow achieved lower proportions of the target grasses than the rotary harrow and the reverse rotary harrow. This was attributed to the weaker soil opening and the stronger competitive effect of the remaining old sward. The difference was reported at roughly 10% and 7% lower than the other two methods.

The reverse rotary harrow provided good establishment results, but at clearly higher cost and with lower practical availability. The rotary harrow achieved very strong establishment as well, in some cases even slightly better, but it also left the soil surface very uneven on both trial sites, and this was still clearly visible in the third year after sowing. The heavy tine harrow required less effort and lower cost and allowed quicker return to use, but the lower establishment success also meant lower resilience and regenerative capacity of the treated sward.

Figure 4. Strong harrow

Figure 5. Reverse rotary harrow

Seed Mixtures Compared

Mixtures Used on the Two Farms

On the two farms, specially composed mixtures for intensively trampled pasture areas were compared with a commercially available quality pasture mixture. Depending on site conditions, a site-adapted mixture, a broadly usable universal mixture, and the ÖAG mixture KWEI were sown on the trial areas. The purpose was to assess whether site-specific adjustment was necessary or whether one broadly suitable mixture could perform well across different conditions.

2.1.3.2. Results and Evaluation

Comparative Results

According to the results, KWEI alone showed the lowest grass proportions and also the lowest share of the desired sown species. The specially composed mixtures for intensively used paddock systems performed clearly better. A further differentiation by dry or moist site was not considered necessary on the basis of the observed results, and the universal mixture showed the best overall performance among the directly compared alternatives.

Recommended Mixture

For the final practical recommendation, the text goes beyond the universal pure-grass mixture shown in the comparison table. It recommends a 50:50 combination of the two ÖAG pasture mixtures KWEI and Dauerweide H, applied at a seeding rate of 26 kg/ha. This recommendation is intended to maintain forage quality while at the same time establishing species that are particularly tolerant of trampling and intensive use.

Practical Management Recommendations

The practical observations from the two farms show that successful improvement of heavily trampled pasture areas depends on the interaction between soil preparation, seed quality, sowing technique, and follow-up management. After using the reverse rotary harrow or rotary harrow, the soil should be sufficiently reconsolidated before sowing. Standard overseeding machines with a following prism roller are described as particularly suitable.

Where available, high-quality ÖAG mixtures should be preferred, as their high germination capacity allows sowing rates of about 25–26 kg/ha.

The timing of return to grazing is equally important. Areas overseeded with a tine harrow should be cut once, preferably early, before grazing resumes. Areas established after complete soil opening need more time until they are sufficiently firm again. For spring sowings, grazing should generally not begin before the following late summer. For late-summer sowings, at least one spring cut is recommended before grazing starts. The source also stresses that even heavily trampled pasture areas require ongoing maintenance, including dragging at the beginning of a rest period and timely control of unwanted plants before seed set. Regular reseeding with suitable mixtures is also recommended.

Conclusion

The experience from two commercial farms shows that heavily trampled pasture areas can be improved successfully by targeted reseeding, but that the outcome depends strongly on the interaction between establishment technique, seed mixture, and follow-up management. More intensive soil disturbance generally improves establishment of the desired species, but also increases cost, delays the return to grazing, and may leave the surface uneven for a longer period. Less intensive methods are cheaper and quicker to reintegrate into use, but they usually achieve a weaker shift in species composition.

From a practical point of view, such pasture areas must be managed with priorities that differ from conventional forage pastures. Sward durability, regrowth capacity, and trampling resistance become the central criteria. A 50:50 combination of KWEI and Dauerweide H at 26 kg/ha, combined with careful establishment, delayed re-grazing, and regular maintenance, provides a practical option for improving heavily used pasture areas under farm conditions.

2.1.4. Case 3

Use case C: Monitoring of Yellow Rattle in Extensive Grassland

2.1.4.1. General Information

Information about the Grassland and the Target Species

Yellow rattle (*Rhinanthus minor*) is a characteristic species of extensively managed grassland. Botanically, it belongs to the group of hemiparasitic plants. This means that the species is able to photosynthesize independently, but also extracts water and mineral nutrients from host plants through its root system. It mainly parasitizes grasses and legumes, while other herbaceous species are generally less affected [21].

The species is widely distributed in temperate regions of northern Europe and North America and typically occurs in natural and semi-natural grasslands [21]. In the field, yellow rattle can usually be identified by its upright growth, square stem, and opposite leaves. However, its morphology may vary considerably depending on growing conditions and the degree of parasitism, which can make field identification more difficult in weakly developed individuals [22].

Relevance for Extensive Grassland Management

Extensive hay meadow systems with a late first cut generally support the desired diversity of flowering forbs. At the same time, however, such management conditions also favor the development of yellow rattle. Since the species is annual, it depends entirely on successful seed production each year. If mowing is carried out only after seed maturation, the plant can complete its life cycle and replenish the seed bank for the following season. Heavy infestations are associated with two main disadvantages. First, forage yield can decline substantially because host plants, especially grasses, are weakened by the parasitic effect of yellow rattle. Second, severe infestations may also negatively influence the floristic composition of the sward, as less competitive species can be displaced [23].

Objective

The objective of this study was to assess practical measures for limiting the spread of yellow rattle in species-rich extensive grassland. Particular attention was given to the interaction between cutting date and moderate fertilization

Figure 6: Extensive Meadow heavily infested with Yellow Rattle

Improvement Methods Applied

Experimental Setup

A field trial was established in May 2020 on a species-rich meadow at 710 m above sea level. The site was dominated by tall oat-grass (*Arrhenatherum elatius*) and showed a relatively uniform vegetation structure at the beginning of the study [24; 25]. During the previous ten years, the grassland had been managed without fertilization under a two-cut hay system. The trial was designed to test the combined effects of fertilization and cutting date on the occurrence of yellow rattle

Fertilization Treatments

Control (zero treatment): no fertilization, maintained as a reference.

Organic commercial fertilizer: 45 kg N ha^{-1} applied as "Provide Verde®" (containing soil microorganisms, alginates, and organic matter).

Compost: 45 kg N ha^{-1} applied as compost derived from farmyard manure.

Cutting dates:

Early cut: mowing on 19 June 2020 (before yellow rattle seed maturation).

Standard cut: mowing on 8 July 2020 (typical timing for haymaking).

Assessment Method

To evaluate treatment effects, the projective cover of the main species groups in the sward was estimated. The assessment included grasses, legumes, forbs, and specifically the projective proportion of yellow rattle, following the approach described by Peratoner and Pötsch (2019). The initial survey was carried out in June 2020 across both fertilized and unfertilized plots and served as the baseline for evaluating the effects of the different cutting regimes

2.1.4.2. Before and After Comparison

Before Improvement

At the start of the trial in 2020, the meadow showed a relatively uniform botanical composition. Yellow rattle was already present in the sward and was considered a relevant species for management due to its potential impact on forage grasses and legumes

After Improvement

The comparison between the 2020 baseline and the 2021 assessment showed that the response of yellow rattle depended mainly on the timing of the first cut. Differences between the fertilization treatments were less pronounced for the parasite itself, but fertilization influenced the competitiveness of the sward, particularly the grass component.

2.1.4.3. Results and Evaluation

Effect of Cutting Date on Yellow Rattle

The timing of the first cut proved to be the key factor in controlling yellow rattle. Where mowing was carried out at the usual later date, the proportion of yellow rattle increased markedly from 2020 to 2021 in all fertilization treatments. In contrast, advancing the first cut by around three weeks led to a clear reduction of the parasite in every treatment. This effect was especially evident in the unfertilized control. Under the early cut, the proportion of yellow rattle in the following year was reduced to 2.5%, whereas under the standard late cut it would have increased to 15.8%. These results show that a timely early cut can effectively interrupt the life cycle of this annual species by preventing seed production.

Effect on Functional Plant Groups

The early first cut did not only reduce yellow rattle, but also affected the overall composition of the sward in a way that was favorable for forage production.

Grasses: The grass proportion increased significantly under the early cut, whereas it remained unchanged or even declined under the later cut.

Legumes: Legumes, including clover species, also benefited from the earlier mowing date and showed significant increases across all fertilization treatments.

Forbs: The response of the remaining forbs was more differentiated. This underlines that changes in cutting date influence not only problem species, but also the broader ecological balance of species-rich grassland.

Effect of Fertilization

No direct fertilization effect on yellow rattle itself was observed. The parasite occurred at comparable levels in the control, compost, and organic fertilizer treatments.

However, fertilization had an indirect influence through its effect on host plant competitiveness. Fertilized plots showed a significantly higher grass proportion because grasses responded positively to improved nitrogen availability. The proportion of forbs, excluding yellow rattle, was lowest in the compost treatment.

Discussion and Practical Recommendations

The results demonstrate that a single, well-timed early cut is a highly effective short-term measure for reducing yellow rattle in extensive grassland. By mowing before seed maturation, the annual reproductive cycle of the species is interrupted and replenishment of the soil seed bank is prevented.

At the same time, several practical and ecological aspects must be considered.

Long-term sustainability: Repeated early cutting may gradually alter the plant community. In particular, late-flowering species of high ecological value may be prevented from setting seed, which could lead to their decline over time.

Fertilization as a management tool: Although fertilization does not directly suppress yellow rattle, it can strengthen the competitive ability of grasses. From a biodiversity perspective, however, nutrient inputs should remain very moderate. On species-rich extensive grassland, either no fertilization or only highly restricted applications of organic fertilizer are advisable.

Haymaking versus mulching: Traditional haymaking is generally preferable to mulching, since handling and removing the harvested material can help distribute the seeds of desirable species. Nevertheless, yellow rattle populations should be monitored closely so that corrective mowing can be carried out in time where necessary.

Conclusion

In extensively managed grassland, yellow rattle can be controlled effectively by adjusting the timing of mowing. A single cut before seed maturity can substantially reduce infestation levels in the following year. However, this measure should be used selectively and with caution. It may not be permitted on all areas, especially where conservation-related management restrictions apply, and it should not be repeated too frequently in order to avoid negative effects on ecologically valuable meadow species. In practice, early cutting is therefore an effective tool, but one that should always be adapted to site conditions and management objectives

2.2. Poland

2.2.1. Grassland Improvement Practices in Poland

It is estimated that over 50% of permanent grasslands in Poland are degraded, resulting in low yields of approximately 5.0 $t \cdot ha^{-1}$ of dry matter (below the production potential of most habitats) and unsatisfactory feed quality in relation to the nutritional needs of ruminants. The key factor determining the production of high-nutritional-value roughage from permanent grasslands are the appropriate species composition of the grassland sward. A relatively cheap and effective method of improving the condition of permanent grasslands is over drilling, which involves sowing legume (fabacae) seeds and valuable grass species adapted to local soil and water conditions. Another method of improving the floristic composition of the sward is the full cultivation method. This method involves the complete destruction of the old sward and redrilling. The full cultivation method is only used where other renovation methods are ineffective [28, 29, 30, 31, 33].

The presented examples of improving the condition of permanent grasslands in Poland were obtained as a result of a multi-year study carried out in 2011–2015 under the name "Production of high-quality feed from permanent grasslands" by the Institute of Technology and Life Sciences – National Research Institute. The programme was financed by the Ministry of Agriculture and Rural Development. As part of the programme, three private farms located in different locations (Dymnik, Kąty Milewskie, Kodeń) in north-eastern and eastern Poland were selected. Measures aimed at improving the condition of grasslands were carried out on these farms.

2.2.2. Case 1

2.2.2.1. General Information

Location

Dymnik (53°58′N, 19°28′E), warmińsko-mazurskie Province, Elbląg County, northern part of the Iława Lake District.

Characteristics of permanent grassland

Permanent grasslands located on a farm in Dymnik were used for mowing and grazing. The farm was engaged in beef cattle breeding.

The grasslands that underwent restoration were located on leached brown soil, formed from light silty clay, with varying phosphorus and potassium content (from medium to very high). It was established several years earlier on arable land. They were used in a mowing-pasture system. Before renovation, the soil was very acidic and had a high magnesium (Mg) content.

In the meadow classification, these are dry meadows located on mineral soil. The grass and herb communities were dominated by *Lolium perenne*, *Dactylis glomerata*, *Phleum pratense*, *Festuca arundinacea* and *Elymus repens*.

Improvement Methods Applied

In the village of Dymnik, the renovation of permanent grassland on a farm was carried out using two methods:

the full cultivation method,

direct drilling method.

In addition, a control area was left untouched, where no renovation was carried out.

All grasslands intended for renovation was limed in autumn 2011 due to the very acidic soil (pH < 4.5).

The meadow designated for renovation using the full cultivation method was prepared in autumn 2011: liming and ploughing were carried out. In spring 2012, pre-sowing cultivation was carried out, and on 20 April, a mixture of grasses and legumes was sown with a grain drill at a sowing rate of 40 kg·ha^{-1}, without a cover crop (photos 1, 2).

Renovation by direct drilling was carried out on 13 April 2012 using a Väderstad Rapid seed drill (photo 3), at a drilling rate of 20 kg·ha^{-1}. The seed mixture was adapted to local soil and water conditions and variable use of the sward (Table 1, photos 4, 5, 6). In all years, only mineral fertilisers in the form of polyphosphate and ammonium nitrate were used. The average annual doses of fertiliser components were: approximately 116 kg N, 20 kg P and 50 kg K·ha^{1}.

Table 1. Composition of seed mixtures used for meadow sward renovation in Dymnik

Species	Full cultivation		Overdrilling	
	Variety	Share [%]	Variety	Share [%]
Festulolium x hybridum (4n)	-	-	Sulino	15
Festuca pratensis	Pasja	20	Pasja	15
Cocksfoot	Berta	5	Berta	5
Phleum pratense	-	-	Kaba	15
Poa pratensis	Skiz	15	Skiz	10
Lolium perenne	Bajka	15	Bajka	10
Lolium perenne (4n)	Jaran	15	Jaran	10
Lolium x hybridum (4n)	Nadzieja	5	-	-
Lolium multiflorum	Turtetra	5	-	-
Trifolium pratense	-	-	Rozeta	10
White clover	Romena	20	Romena	10

Source: Authors' study.

Weather conditions

In the year of renovation (2012), after the treatments carried out in April, thanks to good soil moisture conditions, rapid emergence of the sown species was observed. However, a drought occurred in May, which caused some of the seedlings to die and limited the effects of renovation. In 2013, the amount and distribution of rainfall were favourable and did not limit the growth of ground cover biomass. In 2014, moisture conditions were unfavourable. Total precipitation during the growing season was 29% lower than the long-term average for 1971–2000. Although monthly precipitation totals in April and May were higher than the long-term averages, there were significant water shortages from July to October. The year 2015 was also characterised by unfavourable pluviothermic conditions. Dry or extremely dry conditions occurred in May, June and August, which resulted in reduced yields of subsequent litter regrowth (Table 2).

Table 2. Pluviothermic extreme conditions in Dymnik in the vegetation season (2012-2015) expressed by Selyaninov's coefficient (k)

Months	Years							
	2012		2013		2014		2015	
	k value	period	k value	period	k value	period	k value	period
April	2.55	very wet	2.41	wet	1.03	rather dry	3.32	extremely wet
May	0.58	very dry	1.36	optimum	1.42	optimum	0.91	dry
June	2.23	wet	0.97	dry	2.24	wet	0.89	dry
July	1.98	rather wet	3.09	very wet	0.47	very dry	1.35	optimum
August	1.09	enough dry	0.95	dry	1.04	rather dry	0.2	Extremely dry
September	0.91	dry	2.67	very wet	0.7	very dry	2.35	wet

Source: Authors' study based on data from the Agro-Meteo Station in Helenowo, Elbląg municipality;value HTC (period): <0.41—extremely dry, 0.41–0.70—very dry, 0.71–1.00—dry, 1.01–1.30—rather dry, 1.31—1.60—optimum, 1.61–2.00—rather wet, 2.01–2.50—wet, 2.51–3.0—very wet, >3.00—extremely wet.

2.2.2.2. Results and Evaluation

Botanical composition of the sward

Analysis of the species composition of grassland sward showed that after redrilling in April 2012, there was a several percent increase in the proportion of perennial ryegrass and other components of the mixture, especially *Festulolium x hybridum* and *Festuca pratensis*, which persisted in subsequent years. On the other hand, the proportion of native grasses decreased slightly, and the proportion of dicotyledonous weeds decreased significantly. As a result of the limited effectiveness of enriching the sward with leguminous plants (*papilionaceous*), there was only a slight improvement in its utility value (expressed by the Unv index). This sward, like the control object, was rated "good" according to the Filipek's method [32].

The sward of the fully cultivated plots was dominated by a mixture of grasses and legumes. In 2013–2014, native grasses and dicotyledonous weeds accounted for only a few per cent of the sward. In 2015, the high proportion of all sown components continued, with perennial ryegrass and hybrid ryegrass dominating. In total, in the last year of the study, grasses accounted for 62% of the yield.

As a result of the drought that occurred in August and September in both 2014 and 2015, the proportion of white clover in the sward decreased from about 45% in 2014 to about 18% in

2015. The utility value of the sward (Unv) after full cultivation was rated as "very good" on average.

Therefore, the number of utility values (Unv) can be a useful indicator for assessing the effectiveness of enriching the floristic composition of the sward using various methods (Table 3).

Table 3. Influence of sward renovation method on participation of plant groups in the I[st] cut in the following years of the meadow.

Group of plants	Control				Overdilling				Full cultivation			
	2012	2013	2014	2015	2012	2013	2014	2015	2012	2013	2014	2015
Grasses	60	59	78	57	64	70	84	61	82	50	54	62
Legumes	10	6	3	2	15	5	3	12	16	45	46	18
Herbs and weeds	30	35	19	41	21	25	13	27	2	5	0	20
Unv	7.2	6.6	7.2	6.3	8.1	7.4	7.3	7.1	9.6	9.5	9.6	8.4

Source: Authors' study; UVN – useful value of litter according to Filipka's method [1973], UVN: 10-8.1 – very good useful value, 8.0-6.1 – good useful value, 6.0-3.1 – average useful value, ≤3.0 – low useful value.

Sward yield and its feed value

The renovation of permanent grassland, both by direct over drilling and full cultivation, significantly increased yields compared to the control plot, which was not subjected to any treatment.

The dry matter yield in the control sward was 6.17 $t \cdot ha^{-1}$. Over drilling resulted in an increase to 8.68 $t \cdot ha^{-1}$, which was 140% of the control value (increase compared to the control 40%), while with full cultivation the yield reached 8.15 $t \cdot ha^{-1}$ (increase compared to the control 32%).

Similar trends were observed in the yields of quality components. The total protein yield in the control sward was 857 $kg \cdot ha^{-1}$, while after redrilling it increased to 1263 $kg \cdot ha^{-1}$, and after full cultivation to 1361 $kg \cdot ha^{-1}$. The yield of simple sugars was also higher in the renovated sward – 918 $kg \cdot ha^{-1}$ with redrilling and 987 $kg \cdot ha^{-1}$ with full cultivation, compared to 702 $kg \cdot ha^{-1}$ in the control (Table 4.).

Table 4. Meadow yield and feed quality on the farm in Dymnik (average for 2012-2014 in t DM ha·ha^{-1})

	Mowing and grazing		
	Control (without redrilling)	Over drilling	full cultivation
Yield [t DM ha^{-1}]	6.17	8.68	8.15
Increase/decrease compared to the control [%]	-	40	32
Total protein yield [kg·ha^{-1}]	857	1263	1361
Simple sugar yield [kg·ha^{-1}]	702	918	987

Source: Authors' study.

In summary, both methods of renovation significantly improved both the quantity and quality of yields, with redrilling slightly exceeding full cultivation in terms of dry matter yield, while full cultivation yielded higher total protein and simple sugar yields.

2.2.2.3. Photos

Field prepared for sowing a mixture of grasses and legumes (*photo: K. Terlikowska*)

Effect of renovation using the full cultivation method [30]

Vederstad Rapid direct seed drill prepared for work *(photo: K. Terlikowska)*

Direct over drilling in Dymnik farm (*photo: K. Terlikowska*)

Result of the direct drilling drill in Dymnik farm (*photo: K. Terlikowska*)

Grassland sown in spring 2012 (*photo: J. Terlikowski*)

2.2.3. Case 2

2.2.3.1. General Information

Location

Kąty Milewskie (53°22′N 22°59′E), Podlaskie Province, Mońki County

Characteristics of permanent grassland

Permanent grassland, which underwent renovation on a farm in Kąty Milewskie, was used for haymaking or grazing. The farm specialised in beef cattle breeding.

Most of the grassland used for haymaking was located on brown soil leached from medium clay, mainly with a high phosphorus content and low potassium content, the soil pH was very acidic (pH < 4,5). The remaining part, used for grazing, was located on brown soil leached from light clay, with low or medium phosphorus content and low potassium content. The grasslands were mainly classified as dry meadows located on mineral soil.

The sward of the 15-year-old meadow was dominated by *Dactylis glomerata, Festuca rubra* and *Poa pratensis*, with a large proportion of dicotyledonous plants. The pasture was dominated by *Poa pratensis* and *Trifolium pratense*.

Improvement Methods Applied

On the farm located in Kąty Milewskie, grassland was renovated using two methods:

- the full cultivation method,
- over drilling method.

In addition, a control area was left untouched, where no renovation was carried out.

Before the treatment, the grassland was limed in autumn 2011. Over drilling with a mixture of grass and legume seeds was carried out at the end of the first ten days of April, using a Vredo seed drill equipped with disc coulters.

As part of the full cultivation method, in spring 2013, a new meadow was established on an area of 2 ha by sowing a grass-legume mixture with 30% legumes, intended for compact and medium-compact soils. The sowing rate was 20 kg·ha^{-1} for redrilling and 40 kg·ha^{-1} for full cultivation (Table 5).

Table 5. Composition of seed mixtures used for meadow renovation in Kąty Mielewskie.

Species	Over drilling		Full cultivation	
	Variety	Share [%]	Variety	Share [%]
Cocksfoot	-	-	Amera	5
Festuca pratensis	Passion	15	Pasja	20
Poa pratensis	Skiz	5	Skiz	10
Perennial ryegrass (2n)	Bajka	10	-	-
Perennial ryegrass (4n)	Jaran	10	Jaran	10
Phleum pratense	Skala	15	Skala	10
Lolium x hybridum (4n)	Gosia	5	-	-
Festulolium x hybridum	Felopa	10	Felopa	15
Tall oatgrass		10	-	-
Trifolium pratense	Bona	15	Bona	25
White clover	Romena	5	-	-
Lotus corniculatus	-	-		5

Source: Authors' study.

Both mineral and organic fertilisers were used to fertilizing the grassland. The average annual nitrogen dose was 100 kg N·ha-1. In the spring, urea was used for fertilisation at a rate of 46 kg N·ha-1, and after subsequent regrowth or mowing, a total of approximately 60 kg N·ha-1 in the form of ammonium nitrate was applied twice. Phosphorus and potassium fertilisation was mainly applied in the form of polyphosphate, at a rate of 30 kg P·ha-1 and 70 kg K·ha-1. No first dose of nitrogen was applied to land fertilised with natural fertilisers.

Weather conditions

In Kąty Milewskie in 2012, after sowing, favourable pluviothermal conditions occurred for seed germination and the growth and development of grass and legume seedlings (Table 6). In the following year, both the amount and distribution of precipitation did not limit the growth of ground cover biomass. However, in 2014, good moisture conditions occurred only in the spring months, while in the summer – in July, August and September – significantly lower precipitation was recorded, which could have limited ground cover growth. There were highly variable pluviothermal conditions in 2015: April and May were optimal, but from June until the end of the growing season there was a drought, which limited the yield of subsequent regrowth of meadow ground cover and resulted in the absence of one regrowth on the pasture.

Table 6. Pluviothermic extreme conditions in Kąty Milewskie (experiment II) in vegetation season (2012–2015) expressed by Selyaninov's coefficient (k)[34].

Months	Years							
	2012		2013		2014		2015	
	k value	period	k value	period	k value	period	k value	period
April	1.89	rather wet	3.18	extremely wet	0.79	dry	1.59	optimum
May	1.22	rather dry	1.95	rather wet	1.60	optimum	2.92	very wet
June	1.95	rather wet	1.42	optimum	1.88	rather wet	0.55	very dry
July	1.46	optimum	1.62	rather wet	1.13	rather dry	1.15	rather dry
August	2.14	wet	1.20	rather dry	1.12	rather dry	0.12	extremely dry
September	0.63	very dry	4.61	extremely wet	0.49	very dry	0.81	dry

Source: Authors' study based on data from the Meteorological Station in Białystok. value HTC (period): <0.41—extremely dry, 0.41–0.70—very dry, 0.71–1.00—dry, 1.01–1.30—rather dry, 1.31—1.60—optimum, 1.61–2.00—rather wet, 2.01–2.50—wet, 2.51–3.0—very wet, >3.00—extremely wet.

2.2.3.2. Results and Evaluation

Botanical composition of the sward

As a result of redrilling meadows and pastures in April 2012, a significant increase in the share of two grass species was observed in 2013–2015: *Lolium perenne* (from 2 to 9%) and meadow fescue (from 4 to 7%). An increase of over 3% in the proportion of timothy was also recorded in the pasture. At the same time, the proportion of native grasses, herbs and dicotyledonous weeds decreased, which is desirable from the point of view of yield and the utility value of the sward.

Grass and legume species sown in seed mixtures (meadow fescue, *Dactylis glomerata*, *Phleum pratense*, *Poa pratensis*, *Trifolium repens* and *Trifolium pratense*) were also present in the sward before sowing, but in much smaller quantities than after renovation, which made it difficult to distinguish them from local ecotypes. Nevertheless, the reseeding contributed to an improvement in the utility value of the sward (Unv), especially in the case of pasture sward. The positive effect of meadow overseeding was smaller – a significant increase in the proportion of herbs and weeds in 2015 meant that the utility value of the sward (Unv) on the under sown site increased by only 0.9 units compared to the control sward. It should be emphasised that after direct sowing, the proportion of legumes also increased, with a simultaneous decrease in the proportion of dicotyledonous herbs and weeds. A comparison of the botanical composition of unseeded and seeded sward shows that the enrichment of both meadow and pasture sward with clover and valuable grass species had a positive effect.

The sward of the fully cultivated site was dominated by components of the sown mixture of grass and legume seeds. In 2013–2014, native grasses and dicotyledonous weeds accounted for only a few per cent of the sward. In 2015, the high proportion of sown species continued, with a predominance of legumes (approximately 40% of the yield), *Lolium perenne* (10–16%) and *Festuca pratensis* and other grasses used in the mixture (20–25%). The utility value of the meadow sward (Unv) after renovation using the full cultivation method was assessed as very good (Unv – 9.2–9.5) (Table 7, 8; Photo 9–14).

Table 7. Influence of sward renovation method on the proportion (%) of plant groups in the first cut in subsequent years of the meadow.

Group of plants	Renovation method											
	Control				Over drilling				Full cultivation			
	2012	2013	2014	2015	2012	2013	2014	2015	2012	2013	2014	2015
Grasses	58	68	65	66	63	66	68	67	-	58	56	50
Legumes	5	6	6	3	18	22	18	13	-	42	43	45
Herbs and weeds	37	26	29	31	19	12	14	20	-	0	1	5
Unv	7.4	7.2	7.2	7.0	8.5	8.5	8.4	7.9	-	9.5	9.4	9.2

Source: Authors' study; UVN – usable value of grass according to Filipka's method [1973], UVN: 10-8.1 – very good usable value, 8.0-6.1 – good usable value, 6.0-3.1 – average usable value, ≤ 3.0 – low usable value.

Table 8. Influence of sward renovation method on the proportion (%) of plant groups in the first cut in subsequent years of the pasture

Group of plants	Renovation method							
	Control				Over drilling			
	2012	2013	2014	2015	2012	2013	2014	2015
Grasses	55	61	60	58	61	65	66	72
Legumes	20	14	7	6	25	23	13	15
Herbs and weeds	25	25	33	36	14	12	21	13
Unv	7.9	7.7	7.0	6.6	8.7	8.8	8.1	8.6

Source: Authors' study; UVN – usable value of grass according to Filipka's method [1973], UVN: 10-8.1 – very good usable value, 8.0-6.1 – good usable value, 6.0-3.1 – average usable value, ≤ 3.0 – low usable value.

Sward yield and its feed value

The renovation of permanent grassland in Kąty, both by over drilling and full cultivation, significantly improved yields compared to the control site, which was not subjected to any treatment.

In grassland use, the dry matter yield in the control plot was 6.03 $t \cdot ha^{-1}$, while after over drilling it increased to 7.30 $t \cdot ha^{-1}$ (increase compared to the control 21%), and after full cultivation it reached 9.22 $t \cdot ha^{-1}$ (increase compared to the control 53%). The total protein yield in the meadow sward increased from 758 $kg \cdot ha^{-1}$ in the control to 968 $kg \cdot ha^{-1}$ after reseeding and 1153 $kg \cdot ha^{-1}$ after full cultivation. Simple sugar yields also increased significantly – from 573 $kg \cdot ha^{-1}$ in the control to 844 $kg \cdot ha^{-1}$ after reseeding and 1275 $kg \cdot ha^{-1}$ after full cultivation.

A similar trend was observed in pasture use, although the effects were slightly smaller. Dry matter yield increased from 5.67 $t \cdot ha^{-1}$ in the control to 6.69 $t \cdot ha^{-1}$ after redrilling (increase compared to the control 18%). The total protein yield increased from 929 to 1122 $kg \cdot ha^{-1}$, and the simple sugar yield from 550 to 594 $kg \cdot ha^{-1}$ (Table 9).

Table 9. Yields of meadows and pastures on the farm in Kąty Milewskie (average for 2012-2014 in t DM ha^{-1}) and their feed value

	Meadow use			Pasture use	
	Control	Over drilling	Full cultivation	Control	Over drilling
Yield [t DM ha^{-1}]	6.03	7.30	9.22	5.67	6.69
Increase/decrease compared to the control [%]	-	21	53	-	18
Total protein yield	758	968	1153	929	1122
Simple sugar yield	573	844	1275	550	594

Source: Authors' study.

In summary, both renovation treatments improved the quantity and quality of yields. The highest increases in dry matter, total protein and simple sugar yields were obtained in grassland after full cultivation, while over drilling provided moderate but clearly beneficial effects, especially on pastures.

2.2.3.3 Photos

Seed drill used for direct over drilling.

Over drilling of pasture using a seed drill in Kąty farm (photo: J. Barszczewski)

Turf after passing with a seed drill in Kąty farm (photo: J. Barszczewski)

Effect of renovation by over drilling in Kąty, (pasture, 2015[a]; 2014[b]) (photo: B. Wróbel).

Effect of renovation by over drilling in Kąty, sward before the second cut, full cultivation method (meadow, 2013) (photo: B. Wróbel)

Effect of renovation using the full cultivation method in Kąty (meadow, 2014) (photo: B. Wróbel)

2.2.4. Case 3

2.2.4.1. General Information

Location

Kodeń (51°54′N 23°36′E), Lublin Province, Biała Podlaska County.

Characteristics of permanent grassland

The renovated grasslands were located in the village of Kodeń. The farm specialised in beef cattle breeding. Both permanent grasslands and temporary grasslands were used for mowing and grazing. The majority of these grasslands were classified as habitats characteristic of proper oak-hornbeam forests, while the rest were located in impoverished oak-hornbeam forest habitats. The soil, formed from medium or loose sand, was classified as pseudopodzolic, with medium phosphorus content and low potassium content.

The soil pH was very acidic (pH < 4.5). The phosphorus content varied from medium to very high, while the potassium content remained very high. Due to the acidic pH, the grasslands were limed in autumn 2011.

Mineral fertilisers were used to fertilise grasslands, applying them in two or three doses in amounts of approximately 60 kg N, 30 kg P and 60 kg $K \cdot ha^{-1}$. Natural fertilisers (manure) or slurry were applied annually to an area of approximately 4 ha, each time to a different plot. After applying natural fertilisers to these plots, no spring mineral fertilisation was applied.

The grass-herb community was dominated by *Poa pratensis*, *Festuca pratensis*, *Dactylis glomerata* and *Holcus lanatus*, with a significant proportion of herbs and weeds, mainly *Taraxacum officinale*. The floristic composition of the meadow was improved by over drilling in the seventeenth year of its use and by full cultivation in the eighteenth year.

Improvement Methods Applied

On the farm, the renovation of permanent grassland was carried out using two methods:

- the full cultivation method,
- direct redrilling method.

In addition, a control area was left untouched, where no renovation was carried out.

A Vredo seed drill equipped with disc coulters was used for redrilling the grasslands in Kodeń. Over drilling with a mixture of grass and legume seeds was carried out at the end of the first ten days of April. On the farm 1.8 ha of pasture was ploughed. Then sown using a grass-legume mixture intended for light mineral soils, with the same species composition as in Table 10.

Table 10. Composition of seed mixtures used for meadow renovation in Kodeń

Species	Over drilling		Full cultivation	
	Variety	Share [%]	Variety	Share [%]
Cocksfoot	-	-	Amera	5
Festuca pratensis	Pasja	15	Pasja	20
Poa pratensis	Skiz	5	Skiz	10
Perennial ryegrass (2n)	Bajka	10	-	-
Perennial ryegrass (4n)	Jaran	10	Jaran	10
Timothy	Skala	15	Skala	10
Lolium x hybridum (4n)	Gosia	5	-	-
Festulolium x hybridum	Felopa	10	Felopa	15
Tall oatgrass		10	-	-
Trifolium pratense	Bona	15	Bona	25
White clover	Romena	5	-	-
Lotus corniculatus	-	-		5

Source: Authors' study.

Weather conditions

In Kodeń in 2012, during the emergence period, very unfavourable pluviothermal conditions occurred (Table 11). The amount and distribution of precipitation from April to the end of July were lower than the long-term averages, which became a significant limiting factor for both the emergence and development of grass and legume seedlings. In subsequent years (2013–2015), moisture conditions in the spring months were favourable for the growth of biomass in the first and second cuts. However, severe water shortages in the summer were the main cause of weaker regrowth in the third cut.

Table 11. Pluviothermic extreme conditions in Kodeń in the vegetation season (2012–2015) expressed by Selyaninov's coefficient (k)

	Years							
	2012		2013		2014		2015	
Months	k value	period	k value	period	k value	period	k value	period
April	1.2	rather dry	2.59	very wet	0.72	dry	1.33	optimum
May	0.65	very dry	2.06	wet	2.55	very wet	2.57	very wet
June	0.96	dry	1.46	optimum	2.15	wet	0.34	extremly dry
July	0.58	very dry	0.57	very dry	0.51	very dry	0.81	dry
August	1.94	rather wet	0.23	extremely dry	1.15	rather dry	0.09	extremely dry
September	0.47	very dry	2.75	very wet	0.65	very dry	2.25	wet

Source: Authors' study based on data from the Meteorological Station in Włodawa; k. value HTC (period): <0.41—extremely dry, 0.41–0.70—very dry, 0.71–1.00—dry, 1.01–1.30—rather dry, 1.31—1.60—optimum, 1.61–2.00—rather wet, 2.01–2.50—wet, 2.51–3.0—very wet, >3.00—extremely wet.

2.2.4.2. Results and Evaluation

Botanical composition of the sward

On the farm, as a result of over drilling, a 5% increase in the proportion of *Festuca pratensis* was recorded in the first year after the treatment, and in subsequent years this proportion more than doubled. In the first and second years after over drilling, an increase in the proportion of *Dactylis glomerata* in the sward was also observed, by 5% and 4%, respectively. However, no species sown in the seed mixture were observed in the sward: *Lolium perenne*, *Lolium x hybridum*, *Festulolium x hybridum*, *Arrhenatherum elatius*, *Phleum pratense*.

Over drilling with a mixture containing meadow grass resulted in a marked increase in its share in the sward in 2013 and 2014, i.e. in the first and second years after the treatment. At the same time, over drilling significantly reduced the share of herbs and weeds compared to the control object. Enriching the meadow sward with intensive short-term grass species (*Festulolium x hybridum* and *Lolium x hybridum*) and legumes by direct sowing in light, sandy soils did not have a significant effect on improving the sward's utility value (Unv). The slight increase in the useful value index of the sward (Unv) was mainly due to the increased proportion of *Festuca pratensis*, *Poa pratensis* and *Dactylis glomerata*.

The method of full cultivation in a proper oak-hornbeam forest habitat, located on mineral soil made of slightly clayey sand and light clayey sand, in dry conditions, resulted in no hybrid ryegrass or *Festulolium x hybridum* being found in the sown components, while *Lolium perenne* occurred only in trace amounts. Apart from *Festuca pratensis* and *Poa pratensis*, the third dominant component of the sward was *Phleum pratense*, even though it accounted for only 5% of the mixture. Under the habitat conditions of this meadow, a significant improvement in the utility value of the sward was achieved by using the full cultivation method (Table 12).

Table 12. Influence of sward renovation method on participation of plant groups in the Istcut in the following years

Group of plants	Control				Over drilling				Full cultivation			
	2012	2013	2014	2015	2012	2013	2014	2015	2012	2013	2014	2015
Grasses	60	63	64	76	65	71	75	77	-	85	80	78
Legumes	20	8	6	5	20	8	5	4	-	13	10	9
Herbs and weeds	20	29	30	19	15	21	20	19	-	2	10	13
Unv	7.9	7.2	7.0	7.2	8.2	7.9	8.3	7.5	-	9.3	8.8	8.7

Source: Authors' study; UVN – usable value of litter according to Filipka's method [1973], UVN: 10-8.1 – very good usable value, 8.0-6.1 – good usable value, 6.0-3.1 – average usable value, ≤ 3.0 – low usable value.

Sward yield and its feed value

On the farm, the renovation of permanent grassland yielded different results depending on the method used. In meadow use, the dry matter yield in the control plot was 6.48 t·ha^{-1}. After redrilling, the yield decreased slightly to 6.26 t·ha^{-1} (97% of the control), while after full cultivation it reached 7.80 t·ha^{-1} (increase compared to the control 20%). The total protein yield in the meadow sward increased significantly only after full cultivation – from 742 kg·ha^{-1} in the control to 965 kg·ha^{-1}, while after redrilling it decreased slightly to 727 kg·ha^{-1}. A similar trend was observed in simple sugar yields: in the control, they amounted to 655 kg·ha^{-1}, after redrilling 662 kg·ha^{-1}, and after full cultivation they increased to 838 kg·ha^{-1} (Table 13).

Table 13. Yields of meadows and pastures on the farm in Kodeń (average for 2012-2014 in t sm ha^{-1})

	Meadow use		
	control	redrilling	full cultivation
Yield [t DM ha^{-1}]	6.48	6.26	7.80
Increase/decrease compared to the control [%]	-	-3.4	20
Total protein yield [kg ha^{-1}]	742	727	965
Simple sugar yield [kg ha^{-1}]	655	662	838

Source: own study.

In summary, in the Kodnia experiment, the full cultivation method improved both the quantity and quality of the sward, ensuring higher yields of dry matter, total protein and simple sugars. Over drilling did not bring any clear benefits compared to the control plot, and in the case of dry matter yield, it even resulted in a slight decrease.

2.2.4.3. Photos

Effect of renovation by over drilling in Kodeń, (meadow, 2013) (photo: B. Wróbel)

Effect of renovation by over drilling in Kodeń, full cultivation method (meadow, 2014) (photo: B. Wróbel).

Cattle in the paddock covered by the study on one of the farms participating in the project (photo: J. Barszczewski)

2.3. Serbia

2.3.1. Grassland Improvement Practices in Serbia

Grasslands in Serbia extend from lowland areas to high mountain zones and cover about 469,228 ha [35]. They represent an important feed resource for domestic and wild animals and, as such, a key prerequisite for livestock production. Beyond production, Serbian grasslands play a major ecological role by supporting biodiversity and may serve as source communities for the reintroduction of rare or threatened species. Their dense root systems contribute to soil stabilisation, so establishing and maintaining grasslands is also an effective measure against erosion [36]. In hilly and mountainous regions, yields are often low, with average hay yields of 1.6–2.2 t ha^{-1} on meadows and 1.2–1.8 t ha^{-1} on pastures (Statistical Yearbook of the Republic of Serbia, 2025). Low productivity is frequently associated with unfavourable soil fertility—particularly low phosphorus availability—and other site limitations [37; 38].

Many associations, such as Agrostidetum-Juncetum effusi, Beckmanietum erucaeformis, Deschampsietum caespitosae, Molinietum coeruleae, Phalaridetum arundinaceae, and Caricetum vulpinae-ripariae, are characteristic of wetland areas. Valley–lowland regions are dominated by Agrostidetum albae, Agrostidetum vulgare, Alopecuretum pratensis, Arrhenatheretum elatioris, Festucetum pratensis, Festucetum pseudovinae, and Cynosuretum cristati; hilly areas by Agrostidetum vulgarae, Agrostideto-Chrysopogonetum grylli, Brometum erecti, Danthonietum calycinae, Festucetum vallesiacae and Chrysopogonetum grylli; and mountainous regions by Agrostidetum vulgarae, Brometum erecti, Danthonietum calycinae, Festuco-Armerietum canescentis, Festucetum rubra-fallax, Festucetum spadiceae, Nardetum strictae, Festucetum sulcate, Festucetum vallesiacae, Potentilla recta and Poetum violaceae. Hay yields vary: wetland grasslands produce 3.5–4.5 t/ha, valley–lowland grasslands 2.0–3.2 t/ha, hilly grasslands 0.9–1.6 t/ha, and mountainous grasslands 0.7–1.2 t/ha [38].

Rangeland improvement measures are applied to enhance floristic composition and improve utilisation, particularly on low-yielding semi-natural grasslands where management inputs are limited [36]. The main objective was to quantify the effects of fertilisation, liming, and mowing timing (two phenological stages) on the floristic composition, biomass yield, and biomass quality of *Danthonietum calycinae* grasslands [36]. The *Danthonietum calycinae* community is reported as widespread in Serbia and is especially typical of hilly and mountainous regions [39; 40; 41]. A specific focus was placed on functional shifts toward a higher share of legumes and higher-quality grasses and a reduced share of species with low economic value. The project also assessed responses in soil microbial abundance and selected soil chemical indicators to support an evaluation of ecological safety alongside productivity gains [36].

2.3.2. Case 1

2.3.2.1. General Information

The grassland improvement study was conducted at Mitrovo Polje, on the slopes of Mount Goč (Serbia), within the *Danthonietum calycinae* plant community and at an altitude of 684 m.

The experimental area covered 1,400 m² in total and is located at 43°30′17″ N, 20°52′24″ E. The site is characterized by a temperate mountain climate, with a 10-year mean air temperature of 8.56 °C and average annual precipitation of 908 mm [36].

The soil, where grassland improvement was implemented, was extremely acidic and carbonate-free, very poorly supplied with phosphorus and potassium, and rich in humus (Table 14).

Table 14. Chemical characteristics of soil [36]

pH (H20)	pH (KCl)	Total N mg/100g	P2O5 mg/100g	K20 mg/100g	Humus %	CaCO3 %
5.58	4.06	0.29	2.65	7.96	8.29	0.00

A pre-experiment phytocoenological survey recorded 51 plant species. According to the phytocoenological relevé conducted using the Braun–Blanquet method [36], *Danthonia calycina* showed the highest abundance/cover score (2.2), followed by *Agrostis capillaris* (2.1). Several grasses (e.g., *Festuca rubra* 1.1; *Cynosurus cristatus* 1.1; *Sieglingia decumbens* 1.+) and legumes (*Trifolium* spp.) were present mostly with low cover (+) or as rare occurrences (R), indicating a species-rich stand with a few dominant species and many companion species [36].

The edificator species *Danthonia calycina* and the recorded dominance pattern indicate the presence of the plant association *Danthonietum calycinae*, which occurs across dry, moderately moist, and moist habitats. This association is generally stable due to the dominance of perennial grasses, which account for 58–80% of the floristic composition [42; 43]. *Danthonia calycina* is a thermophilous species typically associated with skeletal and sandy soils [44]. In addition, *Danthonia cornubiensis* was recorded.

Figure 7. Danthonia calycina (Vill.) Rchb., a synonym of Danthonia alpina Vest

Well-developed, “true” (climax) stands of *Danthonietum calycinae* are currently difficult to find [36]. Instead, most sites represent transitional vegetation between *Danthonietum* and *Agrostietum*, suggesting that the original community has been modified by past grassland use and management. This transition reflects a departure from the presumed original composition rather than shrub encroachment. Historical use of Mitrovo Polje for livestock feed production likely contributed to this shift, favoring grasses such as *Agrostis capillaris* and legumes including red and white clover (*Trifolium* spp.) and bird’s-foot trefoil (*Lotus corniculatus*). Other notable species indicating past anthropogenic influence include *Centaurea jacea* and *Rumex acetosella* [36].

Shrubs and woody plants were not reported as a prominent feature of the site; however, *Rosa canina* was recorded as rare (R) in the pre-experiment survey, indicating only sporadic woody occurrence [36]. Hay yield on these grasslands typically ranges from 1.5 to 2.85 t ha^{-1} and may exceed 8 t ha^{-1} under appropriate fertilization [45; 46].

Livestock Using the Rangeland

The selected study describes the grassland as primarily utilized through mowing for hay production (cutting at defined phenological stages) and does not report grazing management, livestock numbers (LSU), or the grazing season. Despite an extensive review of the accessible literature on Serbian grasslands, it was not possible to identify a case study that consistently provides these grazing-related parameters for the site, which limited the completeness of the dataset.

Improvement Methods Applied

The experimental site covered 1,400 m². The site was established and the initial (baseline) vegetation status was recorded in autumn 2012. Improvement treatments were then applied and monitored over a three-year period from 2013 to 2015. The study used a completely randomized block design with four replications. The basic plot size was 10 m² (5 × 2 m). Buffer zones were 1 m between replications and 0.5 m between treatments within each replication [36].

The improvement approach in the selected study relied on nutrient management (mineral fertilization and, where applicable, liming) combined with mowing management (cutting at defined phenological stages). No other improvement measures (e.g., shrub removal, tillage, overseeding, aeration, harrowing, rolling/dragging, infrastructure for grazing, fencing/shade, or sown pasture establishment) were reported.

Fertilization was applied annually throughout the study using a P–K base rate of P60K60 combined with different N levels (N0, N60, N120, N180) and, in some treatments, microbial inoculants (P60K60 with Klebsiella planticola or Bacillus subtilis). Nitrogen was supplied as ammonium nitrate (33% N), phosphorus as single superphosphate (SSP; 18.5% P_2O_5), and potassium as KCl (60%); inoculants were surface-applied at the start of the vegetation period (Enteroplantin 15 L ha^{-1}; Extrasol 20 L ha^{-1}), diluted 1:30 with water [36].

Mowing was applied as a management measure by cutting the sward at two phenological stages of the dominant community species: (a) early heading (panicle emergence) and (b) full flowering.

For liming, ground quicklime (calcium oxide, CaO) was applied at a rate of 1,000 kg ha^{-1} and manually spread over the grassland surface in autumn 2012.

Rotational Grazing Plan

Rotational grazing was not implemented in the selected case study; however, dry-matter yield and seasonal regrowth dynamics were measured under controlled defoliation and fertilisation management. These empirical outcomes were therefore used as the evidence base for an analogous (simulated) rotational grazing plan that is consistent with the site's productive potential and seasonal regrowth constraints reported in the case study.

Based on the measured 2014 productivity outcomes, the grazing area was conceptually divided into 10 grazing parcels (paddocks) for the purpose of this simulation. Since rotational grazing design is fundamentally driven by (a) the timing and frequency of defoliation and (b) the capacity for regrowth under the site's climatic constraints, the economically justified 'optimal improvement' fertilisation level was used to derive a conservative rotational-grazing simulation consistent with the case-study evidence. Stocking targets were derived from the 2014 DM yield using a forage-supply approach and a conservative utilisation factor ($U = 0.50$, accounting for residual biomass and unavoidable losses).

The rotational grazing simulation is structured across three seasonal periods, specifying the planned residence time (days) in each parcel:

Early Period (30 Apr–20 Jun): Given the high spring regrowth potential under the favourable 2014 hydrothermal conditions, the simulated plan applies a fast rotation with 2 days per parcel (≈20-day cycle across 10 parcels). The target stocking rate is 2.0 LSU/ha, reflecting peak forage supply under the economically justified "optimal improvement" fertilisation level used as the reference scenario in the case study.

Mid Period (20 Jun–10 Aug): Because the case study indicates that summer conditions can constrain regrowth and limit repeated biomass removal, the simulated rotation is slowed to protect sward recovery, with 3 days per parcel (≈30-day cycle). The target stocking rate is reduced to 1.4 LSU/ha (approximately −30% relative to spring) to operationalise drought/regrowth risk into grazing pressure.

Late Period (10 Aug–30 Sep): Toward the end of the season, the plan prioritises maintaining sward residual and preventing depletion. The simulated rotation therefore uses the longest residence time, 4 days per parcel (≈40-day cycle), with a moderate target stocking rate of 1.6 LSU/ha, remaining below spring levels while allowing cautious utilisation where late-season recovery is adequate.

Fertilization Plan

During 2013–2015, fertilisation was applied annually according to the experimental plan. Each experimental plot measured 10 m² (5 × 2 m). Mineral nutrients were supplied as ammonium nitrate (AN, 33% N) for nitrogen, single superphosphate (SSP, 18.5% P_2O_5) for phosphorus, and potassium chloride (KCl, 60% K_2O) for potassium.

In general, the PK base (and the autumn nitrogen fraction where applicable) was applied in autumn, the main nitrogen fraction (where applicable) at the start of the vegetation period in spring, and an additional nitrogen fraction after the first cut in the N-fertilised treatments (N60/N120/N180).

Overall, the study included six fertilisation treatments and one control, each with four repetitions [36]. Fertilisation treatments were expressed as kg ha^{-1} of pure nutrients:

1. N0P0K0 (Control): No fertilisers were applied.

2. N0P60K60 (PK): The total P60K60 dose was applied in autumn.

3. N0P60K60 + Klebsiella planticola (Kp): P60K60 was applied in autumn, followed by spring inoculation with Enteroplantin (15 L ha^{-1}; 1:30 dilution) applied to the sward surface at the beginning of the vegetation period.

4. N0P60K60 + Bacillus subtilis (Bs): P60K60 was applied in autumn, followed by spring inoculation with Extrasol (20 L ha^{-1}; 1:30 dilution) applied to the sward surface at the beginning of the vegetation period.

5. N60P60K60 (N60): N20P60K60 was applied in autumn; N20 at the start of the vegetation period in spring; and N20 after the first cut.

6. N120P60K60 (N120): N20P60K60 was applied in autumn; N80 at the start of the vegetation period in spring; and N20 after the first cut.

7. N180P60K60 (N180): N20P60K60 was applied in autumn; N140 at the start of the vegetation period in spring; and N20 after the first cut.

Note: The index accompanying the nutrient designation indicates the amount of pure nutrients in kg ha^{-1}.

2.3.2.2. Before and After Comparison

In this study, a true pre-treatment dataset from 2012 (e.g., hay yield per cut) was not reported. Therefore, the unfertilised, unlimed control plots (N0P0K0), managed under the same mowing regime as all treatments, were used as the baseline (no-improvement reference). “After improvement” refers to plots receiving improvement measures (fertilisation and/or liming and/or microbial inoculation), compared against the control.

Before Improvement:

Here, ‘before improvement’ is operationally defined as the unfertilised, unlimed control (N0P0K0), because pre-treatment yield data for 2012 were not provided.

Across the three experimental years, the share of economically valuable species was 32–47%, while poor and non-valuable species accounted for 48–68% (control plots).

In terms of hay production, the total dry matter yield on the control plots was 3.26 t ha^{-1} in the first year and 5.32 t ha^{-1} in the second year (both totals reflect the mowing regime used in the experiment). For the first cut, the control produced 3.05 t ha^{-1} (baseline yield under mowing), while the crude protein content ranged from 76 to 85 g kg^{-1} and crude cellulose ranged from 322 to 365 g kg^{-1} over the three-year period.

Given that grazing management was not included in the study and the site was utilized through mowing for hay production, grazing pressure was not reported and is considered not applicable.

After Improvement:

Following the application of improvement measures (fertilisation ± liming and/or microbial inoculation) under the same mowing regime, the floristic and productive characteristics of the grassland shifted toward a higher forage value.

Over the three-year period, the proportion of economically valuable species ranged from 48% to 68%, while the proportion of poor and non-valuable species ranged from 29% to 52% (ranges across improvement treatments). This indicates a shift toward a higher share of economically valuable species and a lower share of poor/non-valuable species.

Total dry matter yield increased relative to the control, ranging from 3.37 to 5.86 t ha^{-1} in the first year and from 5.69 to 9.50 t ha^{-1} in the second year (treatment ranges). For biomass quality in the first cut, the N180P60K60 treatment produced crude protein values ranging from 84 to 99 g kg^{-1} over the three years; crude cellulose under the same treatment ranged from 351 to 391 g kg^{-1} [36].

Sustainability was not directly quantified; however, it can be interpreted as productivity and forage-value gains achieved through managed nutrient inputs and mowing, relative to the control baseline [36].

2.3.2.3. Results and Evaluation

Results are evaluated relative to the unfertilised, unlimed control (baseline), which represents the no-improvement reference under the same mowing regime. Overall, nutrient management—particularly the application of nitrogen together with phosphorus and potassium—promoted a floristic shift toward a higher proportion of economically valuable species (especially medium-quality grasses) and reduced the contribution of poor and non-valuable species from other families. Treatments based on PK, as well as PK combined with microbial inoculants (Klebsiella planticola or Bacillus subtilis), improved the forage value of biomass mainly through an increased share of legumes and a reduced share of poor/non-valuable species. In addition, mowing at the beginning of panicle emergence (early heading) consistently increased the forage value of biomass across all three years, supporting its recommendation for wider practical application [36].

Agrotechnical improvement measures also resulted in a clear increase in biomass yield across the experimental years. Mineral nitrogen at constant PK (P60K60) produced significantly higher yields than PK-only treatments, with or without inoculation. Increasing nitrogen up to 120 kg ha^{-1} (N120P60K60) led to a linear yield increase, while increasing the dose from 120 to 180 kg ha^{-1} did not produce a proportional additional gain, indicating diminishing returns at higher N rates. Liming, although it did not improve the forage value of the grassland or the quality of biomass, can be recommended due to its positive effects on biomass yield and the abundance of certain microbial groups [36].

From an ecological perspective, mineral fertilisation did not reduce the total number of microorganisms nor the abundance of fungi, actinomycetes, or Klebsiella planticola, suggesting that appropriately managed fertilisation can be considered safe for the studied microbial groups. Microbial inoculation with Klebsiella planticola did not produce a significant effect, while Bacillus subtilis increased biomass yield in the third year; however, the associated increase in protein yield was small, therefore, this type of inoculation is not recommended for wider practice [36]. The study concludes that maximum utilisation of this grassland type was achieved with N120P60K60 combined with early mowing (beginning of panicle emergence/early heading) [36].

The results indicate that targeted nutrient management combined with timely mowing can enhance productivity and shift species composition toward more economically valuable functional groups without adverse effects on the studied microbial communities. At the same time, diminishing yield returns beyond N120 highlight the importance of optimising nitrogen inputs to balance productivity gains with input efficiency and environmental responsibility [36].

Local governance and advisory services can support the sustainable improvement of these grasslands by promoting evidence-based fertilisation rates (avoiding unnecessary N inputs above the economically justified level), encouraging timely mowing as a practical management tool, and integrating liming into improvement plans where yield stability is a priority. In parallel, extension activities can help translate these measures into farm-level guidelines and monitoring routines aligned with local soil and climatic conditions [36].

2.3.2.4. Photos


Rangeland Condition – Before Improvement

Rangeland Condition – After Improvement


Improvement Activities (during the study): Soil sampling for chemical and microbiological analysis.

2.3.3. Case 2

2.3.3.1. General Information

Suva Planina is a mountain massif located in southeastern Serbia and represents one of the most important mountain grassland areas in the central Balkans. Its high-altitude pastures support traditional livestock production and provide habitat for diverse plant communities typical of semi-natural mountain grasslands [47].

These grasslands developed through centuries of extensive grazing and mowing. However, during the last decades many of these pastures have been threatened by the decline of traditional livestock farming, which leads to shrub expansion, gradual succession and loss of open grassland habitats.

The sustainable use of Suva planina pastures therefore depends on maintaining traditional grazing systems that preserve both biodiversity and livestock production.

This case study presents the management-based improvement of a 280 ha mountain pasture near Kosmovac village on Suva Planina [48].

Information about the Improved Grassland

Name / Location of the Rangeland:

Pasture in the vicinity of Kosmovac village

https://maps.app.goo.gl/HDN9YLYAWNy53xjY7

Area (ha): 280 ha

Altitude (m):

800–1200 m

Annual Precipitation:

700–900 mm

Soil Structure:

The soil structure of secondary pastures surrounding Kosmovac village reflects the diverse geological foundation of Suva Planina's transitional zone (700–1,200 m a.s.l.) [47].

Shallow, rocky profiles with excellent drainage characterize limestone areas. These xerothermic conditions support drought-resistant vegetation, though summer dryness limits productivity.

Gentler slopes feature deeper, dark, humus-rich soils locally known as planinska crnica ("mountain crnitsa"), which provide better moisture retention and nutrient availability for grass-dominated plant communities [45].

Proximity to Crvena River and natural springs ensures reliable water supply, enhancing pasture viability despite the karstic terrain's inherent limitations.

Vegetation Before Improvement:

The Kosmovac pastures on Suva Planina Mountain were covered by semi-natural mountain grasslands of mainly secondary origin. The vegetation included xerothermic grassland communities typical of open limestone habitats, dominated by perennial grasses and legumes, while more productive meadow-type stands occurred only locally in more favorable sites.

Due to reduced grazing pressure, parts of the pasture became affected by shrub encroachment and natural succession, leading to the gradual decline of open pasture habitats [45].

Livestock Using the Rangeland

Traditional pastoral systems historically played a key role in shaping the grassland landscapes of Suva planina, and are are still present in parts of Suva planina.

Typical livestock species include sheep, cattle and horses with sheep being a dominant livestock species.

The Sheep (Number / LSU): 100/10

Cattle (Number / LSU): 30/30

Horses (Number / LSU): 6/4.8

Total LSU: 44.8

Grazing Season: May–October (potentially extending to November), aligning with the vegetation growth period of xerothermic associations on Suva Planina.

Livestock are moved seasonally to higher pastures during the summer grazing season, following traditional transhumance patterns.

Improvement Methods Applied

Start and end year of the improvement application:

Start year: 2021

End year: 2023

Shrub Removal:

Periodic manual removal of shrubs where encroachment begins in order to maintain open pasture structure.

Optimal Livestock Stocking Adjustment:

At the start of the improvement process, the baseline livestock number recorded for 2020 was 100 sheep, 30 cattle and 6 horses, corresponding to 44.8 LSU or 0.16 LSU/ha on 280 ha. This grazing pressure was below the level required for proper pasture maintenance. With the support of local authorities, livestock numbers were increased to 250 sheep, 50 cattle and 8 horses in 2021, corresponding to 81.4 LSU or 0.29 LSU/ha in 2021. This level entered the target range for sustainable grazing management and was maintained in the following period, allowing the effects of balanced grazing and natural nutrient cycling to become established across the pasture system.

Sustainable Grazing Management:

The adjusted stocking level was applied within a traditional extensive grazing system, which helped maintain open grassland habitats and supported more balanced vegetation management.

Pasture Maintenance:

Traditional grazing routes and seasonal pasture use were maintained by local shepherd communities, helping to ensure regular use of the pasture and a more even distribution of grazing pressure.

Watering points:

Reservoirs for rainwater collection were constructed on the pasture to secure water for grazing animals. In periods of prolonged drought, they are refilled by water tankers.

Others: Natural nutrient cycling - nutrient redistribution through seasonal altitudinal grazing. Sheep, cattle, and horses graze progressively from lower to higher elevations in spring and summer, then gradually return to lower areas as winter approaches, contributing to the redistribution of nutrients across the pasture system.

Rotational Grazing Plan

Although a formal rotational grazing scheme is not strictly implemented, grazing follows a seasonal altitude-based grazing pattern:

Early period (May–June)

Lower mountain pastures are used.

Mid period (June–August)

Livestock graze on higher mountain plateaus where vegetation productivity peaks.

Late period (September–October)

Livestock gradually return to lower pastures before winter.

Fertilization Plan

No mineral fertilization is applied on these mountain grasslands due to the protected status of Suva Planina Nature Park, where artificial fertilization is prohibited to preserve natural habitat integrity and biodiversity.

Grassland productivity is maintained through natural nutrient cycling associated with extensive grazing systems – livestock manure provides essential nutrients (N, P, K) while controlled stocking density (0.25–0.4 LSU/ha) prevents over-fertilization and supports sustainable regeneration of xerothermic grasslands.

2.3.3.2. Before and After Comparison

Before Improvement:

Hay Production:

Estimated usable forage biomass: 1.2–1.8 t DM/ha

The pasture showed generally low to moderate forage quality, typical of xerothermic mountain grasslands. Vegetation was dominated by xerothermic communities such as Mirsineto-Ischaemetum and Potentillo-Caricetum humilis, characterized by tough, lignified plants with limited nutritional value. Grazing conditions were more favorable in spring and autumn, while forage quality declined markedly during summer due to drought and shallow limestone soils. More productive meadow-type communities such as Teucrieto-Chrysopogonetum occurred locally on silicate substrates, but their limited extent did not significantly improve the overall pasture potential [47].

Grazing Pressure:

Stocking density was low, at 0.16 LSU/ha (44.8 LSU on 280 ha), which was below the optimal range for pasture maintenance. This undergrazing encouraged shrub encroachment, reduced the stability of open grassland communities, and contributed to the gradual degradation of pasture condition.

After Improvement:

Hay Production:

Estimated usable forage biomass: 2.0–2.5 t DM/ha (+30–40%)

Vegetation Change:

Vegetation structure improved through reduced shrub encroachment, better ground cover, and more even biomass distribution across the pasture. The share of desirable species typical of open xerothermic grasslands, such as Bromus erectus and Festuca valesiaca, increased by 25–35%, while the presence of less valuable vegetation, including aggressive mosses and weeds, declined. Vegetation structure also became more diverse, with sward height increasing from 15–20 cm to 40–50 cm, ground cover improving from 65% to 85%, and bare areas decreasing from 20% to less than 5%. As a result, the pasture remained open, functionally more stable, and better suited to extensive grazing.

Biodiversity: Active management improved both biodiversity and habitat structure. A seasonal altitudinal grazing regime, combined with controlled stocking rates of 0.25–0.4 LSU/ha (0,29 LSU/ha in 2021) helped preserve the ecological value of Suva Planina while also increased grassland productivity.

Sustainability: The implemented grazing management demonstrates long-term sustainability by relying exclusively on natural nutrient cycling through livestock manure, eliminating external inputs while achieving productivity gains and biodiversity enhancement.

Improved pasture productivity enabled a gradual increase in stocking levels and supported a more balanced ecological and economic use of the 280 ha pasture system.

2.3.3.3. Results and Evaluation

Achievements: The implemented grazing management improved pasture yield by approximately 30–40%, enhanced vegetation structure and biodiversity, and maintained compliance with protected-area regulations by relying solely on natural nutrient cycling without mineral fertilization.

Sustainability Impact: Optimized grazing pressure (0.25–0.4 LSU/ha) effectively prevents shrub encroachment while promoting vegetation regeneration, conserving xerothermic biodiversity, and ensuring long-term preservation of semi-natural grasslands on fragile limestone/silicate substrates.

Local Governance Role: Through support from local authorities and subsidies for rearing livestock—particularly native breeds—the animal numbers have increased, while advisory services have delivered training on optimal pasture utilization, bringing grazing pressure closer to levels ideal for maintaining semi-natural grasslands and preserving biodiversity.

2.3.3.4. Photos

Rangeland Condition – Before Improvement [48]

Rangeland Condition – After Improvement [48]

Improvement Activities (During) [48]

2.3.4. Case 3

2.3.4.1. General Information

Sandy grasslands are a specific type of semi-natural habitat widely distributed in the Pannonian biogeographical region of Europe. In Serbia, they occur mainly in the sandy landscapes of northern Vojvodina, particularly in Subotička peščara (Subotica Sands) and Deliblatska peščara (Deliblato Sands), where they form a valuable mosaic of open habitats with high biological diversity. These ecosystems support numerous specialized plant and animal species and are therefore of high conservation importance [49].

The area has a temperate continental climate, with warm, dry summers and cold winters. The average annual temperature is around 11 °C, while annual precipitation ranges from 550 to 600 mm [50].

Within parts of the Subotica Sands, some grassland areas remained without active management for about 20 years, which led to secondary succession and the gradual development of shrub and forest-steppe vegetation. To reverse these processes and support the restoration of natural sandy grasslands, habitat restoration activities were initiated in 2002, including the removal of shrubs and woody vegetation and the reconversion of some former orchards and vineyards [51].

Management activities are implemented within the protected area “Subotica Sands”, in accordance with the official management plan and national nature protection legislation [51], with the involvement of relevant institutions and professional organizations [49].

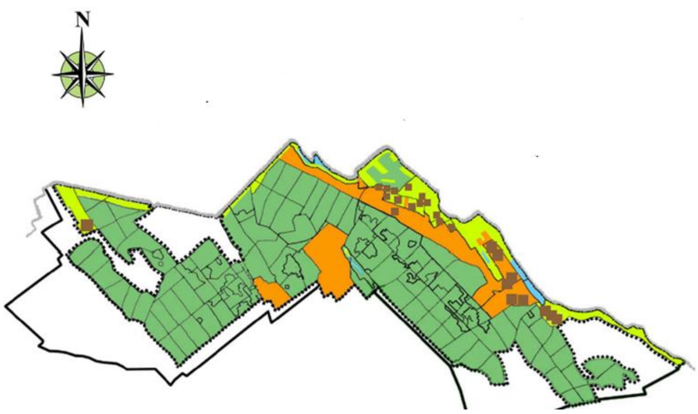

Figure 8. Grasslands and pastures (light green areas) within the protected area of Subotica Sands

Information about the Improved Grassland

Name / Location of the Rangeland:

Protected Landscape of Outstanding Features “Subotica Sands” / City of Subotica, Autonomous Province of Vojvodina, Republic of Serbia

https://maps.app.goo.gl/71JDHZJqQgYiqatB6

Area under active management:

230 ha

Altitude:

102–132 m a.s.l.

Annual precipitation:

550–600 mm

Soil structure:

The area is characterized by aeolian sandy soils with poorly developed humus horizons. These soils are highly permeable, with low water retention capacity, limited natural fertility, and a light mechanical composition. As a result, they are sensitive to vegetation degradation, shrub encroachment, and wind erosion [49].

Vegetation before improvement:

Prior to the introduction of active management measures, the grasslands were undergoing succession, with significant shrub encroachment (e.g. *Crataegus monogyna*, *Prunus spinosa*, *Rosa canina*) and a gradual transition towards forest-steppe vegetation. The long-term abandonment of traditional land-use practices, particularly grazing and mowing, contributed to an increase in woody vegetation cover, fragmentation of open grassland habitats, and the decline of typical Pannonian steppe species [49].

Livestock Using the Pasture Area

Sheep (Number / LSU): negligible

Total LSU: negligible

Stocking rate: negligible

Grazing season: Not applicable

Before the implementation of management measures, the area was not subject to systematic grazing, which contributed to accelerated succession and the gradual loss of open grassland structure [49].

Improvement Methods Applied

Start and end year of the improvement application: 2002–present Grassland restoration was initiated in 2002, while periodic mowing and controlled sheep grazing were introduced in 2017 and have since been continued as part of the active management regime.

Low-input management measures were implemented to restore and maintain open grassland areas suitable for sheep grazing. At the same time, controlled grazing was used as a management tool to support the long-term maintenance of open habitats and prevent further shrub encroachment [49]. The main measures include:

Shrub Removal: Shrubs and woody vegetation were mechanically removed from overgrown areas to restore open grasslands. Since the early 2000s, this also included former orchards and vineyards gradually returned to more natural habitat conditions. The process was supported by periodic mowing and controlled grazing [50].

Ploughing: Ploughing of former orchard and vineyard plots was carried out in 2002 as an initial technical measure to prepare these areas for the re-establishment of open grassland conditions.

Mowing: Periodic mowing was applied as a low-input management measure to remove excess biomass and maintain the open grassland structure. It was generally carried out twice per year, typically in June and September.

Grazing: Controlled extensive sheep grazing was introduced in 2017 as a key management measure for maintaining grassland vegetation and preventing further succession.

Rotational Grazing Plan

Since these pastures are agricultural land located within a protected natural area, national legislation permits controlled grazing exclusively by sheep (not cattle) under regulated management conditions [51]. Therefore, conventional rotational grazing is not envisaged within the grassland restoration project. Instead, controlled grazing has been implemented since 2017 during the vegetation period under shepherd supervision, with spatial rotation across designated grazing zones. During the 2021 assessment, the actual stocking rate was 0.12 LSU/ha (270 sheep, equivalent to 27 LSU, over an area of 230 ha) [50].

Fertilization Plan

No fertilization is planned within the grassland restoration project, in accordance with regional legislation restricting the use of fertilizers in protected natural areas [51].

2.3.4.2. Before and After Comparison

Before Improvement

Hay Production: Before the introduction of restoration measures, grassland productivity was low due to long-term abandonment and shrub encroachment. Vegetation was increasingly dominated by woody species such as *Crataegus monogyna*, *Prunus spinosa*, *Rosa canina*, and *Fraxinus ornus*, while typical grassland species declined [50].

Vegetation cover was heterogeneous and increasingly affected by succession. In the pre-management state, vegetation height reached up to 80 cm, while dense shrub cover reduced the extent of open grassland habitats [50].

Vegetation Quality: Grassland biodiversity and habitat quality declined as shrub and woodland species became increasingly dominant. The vegetation structure gradually shifted from open Pannonian sandy grassland towards shrub and forest-steppe communities [50].

Grazing Pressure: Traditional grazing was largely absent before the restoration programme which allowed succession and shrub encroachment to progress across the area.

After Improvement

Hay Production: Active grassland management restored the open grassland structure and increased biomass availability suitable for grazing and occasional hay production. In grazed areas, vegetation height was reduced to approximately 12–30 cm, which improved forage accessibility [50].

Vegetation cover improved significantly across managed sites, ranging from 10% to 100% and reaching up to 100% in some areas. At the same time, the open grassland structure was maintained through mowing and controlled grazing, which supported the continued productive use of the area [50].

Vegetation Change: Field data confirmed clear differences in vegetation structure among management regimes. Maximum vegetation height (MVH) ranged from 12 to 80 cm, with the lowest values recorded at grazed sites and the highest in the pre-management state, reflecting ongoing succession [3]. The highest number of plant species was recorded at the mown sites (115 species), followed by the grazed sites (85 species), whereas only 59 plant species were recorded in the pre-management state. At all sites, particularly those under grazing, species of the Poaceae family were prevalent, and *Festuca* was the dominant genus [50].

Sustainability: The introduction of controlled grazing and mowing successfully halted succession processes and contributed to the restoration of typical Pannonian sandy grassland habitats. The area is currently grazed by approximately 270 sheep on about 230 ha, corresponding to an actual stocking rate of 0.12 LSU/ha, which supports the long-term maintenance of open sandy grassland ecosystems [50].

2.3.4.3. Results and Evaluation

Achievements: The restoration measures led to improved vegetation cover, reduced erosion pressure and better forage availability. At the same time, they supported the recovery of open sandy grassland habitats and contributed to the maintenance of extensive sheep farming in the protected area of Subotica Sands [48;49]. Active management through controlled grazing, mowing and shrub removal also resulted in a more favorable habitat structure and higher biodiversity compared with the pre-management condition.

Biodiversity: The combination of controlled grazing and periodic mowing was particularly important for limiting shrub encroachment and supporting plant and animal diversity. In total, 164 vascular plant species, 31 pollinator species and 61 bird species were recorded in the study area, confirming the positive effect of active grassland management.

Sustainability Impact: The introduction of controlled grazing and mowing successfully halted succession processes and contributed to the restoration of typical Pannonian sandy grassland habitats.

Local Governance Role: The area is managed within the protected area management plan for Subotica Sands. Grazing, mowing and shrub removal are coordinated by protected area managers in cooperation with local livestock breeders, in line with biodiversity conservation objectives.

2.3.4.4. Photos

Rangeland Condition – Before Improvement [48]

Rangeland Condition – After Improvement [48]

Improvement Activities (During) [1]

Improvement Activities (During) [1]

2.4. Spain

2.4.1. Grassland Improvement Practices in Spain

Mediterranean semi-arid grasslands in Extremadura, typically developed on acidic, nutrient-poor Cambisols, face structural phosphorus deficiencies that limit high-quality legume growth [53]. Under a climate characterized by severe summer drought and high interannual variability, the herbaceous layer is dominated by annual species (*therophytes*), making pasture persistence dependent on effective self-seeding mechanisms [54].

To enhance ecosystem resilience, the intervention combines phosphorus fertilization with adaptive grazing. P-correction overcomes edaphic limitations, promoting the development and persistence of self-seeding annual legumes [55]. Complementary adaptive management, including rotational grazing and nutrient recycling through sheep folding (*majadeo*), is essential to regulate seed production and maintain desirable species composition [56]. This synergistic approach mitigates biomass variability and strengthens pasture sustainability through ecological intensification.

2.4.2. Case 1

2.4.2.1. General Information

Name / Location of the Rangeland:

Dehesa de Sijuela, Monterrubio de la Serena (Badajoz, Extremadura, Spain)

Location: https://maps.app.goo.gl/xePHZv2AsdEdoNa87

Area (ha): 250.54

Altitude (m): 460−570

Annual Precipitation: ~550 mm

Soil Structure: The grassland sits on acidic Cambisols derived from Paleozoic slates, characterized by low organic matter and structural phosphorus deficiencies that limit legume persistence [53]. As shown in Table 15, soil analyses reveal spatial heterogeneity, with textures predominantly sandy clay loam and pH values (mean 5.86) indicating acidity. Phosphorus levels range from deficient (<15 ppm) to moderate, confirming the need for targeted fertilization.

Table 15. Summary of Physical and Chemical Soil Properties (12 paddocks)

Parameter	Mean	Range
Clay (%)	24.39	20.0 – 38.0
Silt (%)	27.58	20.50 – 36.5
Sand (%)	48.03	31.57 – 55.57
USDA Texture	Predominantly Sandy clay loam; also loam	—
pH (H_2O)	5.86	5.21 – 6.26
Electrical Conductivity (dS/m)	0.08	0.03 – 0.13
Organic Matter (%)	1.70	0.97 – 3.86
Available P (ppm)	22.82	8.78 – 53.06
CEC (meq/100 g)	18.00	14.34 – 27.03

Vegetation Before Improvement: Vegetation composition is determined by soil depth. Medium-depth soils are dominated by annual grasses, with perennial species (Dactylis glomerata, Phalaris spp.) restricted to favorable microsites [54]. High-value annual legumes (*Trifolium subterraneum*, *Medicago* spp. *Ornithopus* spp., *Biserrula pelecinus*) are present but limited by low fertility [56,57]. According to regional technical standards, this legume proportion classifies the pasture as "Improveable", identifying fertilization and management as the required intervention rather than reseeding [56]. Deeper soils support higher botanical diversity. No shrub removal or tillage was performed prior to improvement.

Livestock Using the Pasture Area

Cattle (Number / LSU): None.

Sheep (Number / LSU): Before improvement: 550 / 55. After improvement: 750 / 75.

Goats (Number / LSU): None.

Total LSU: Before improvement: 55. After improvement: 75.

Grazing Season: Year-round grazing is practiced with seasonal adjustments based on pasture phenology [53]:

- Autumn: Low grazing pressure is maintained to allow seedling establishment and root development.
- Winter: Intensity increases to control competitive grasses and promote legume branching.
- Spring: Stocking rate is reduced at flowering onset to replenish the seed bank and ensure persistence [55].
- Summer: High pressure consumes dry biomass (fire prevention) and facilitates seed–soil contact through trampling [54].

This adaptive management is critical for regulating botanical composition under Mediterranean conditions.

Improvement Methods Applied

Start and end year of the improvement application: 2019 – ongoing

Shrub Removal: None. Existing shrub layer is preserved to maintain structural diversity and protect soil.

Soil Tillage: None. Soil profile and native seed bank are preserved without plowing.

Overseeding: None. Initial legume presence (23%) classified the pasture as "Improveable" rather than "Poor" [56], so the strategy relies on stimulating the native community through nutrient correction.

Fertilization: Continuous phosphorus correction using superphosphate of lime (18% P_2O_5) [3]:

- Year 1: 27 kg P_2O_5 ha^{-1} (150 kg ha^{-1}) to trigger legume development.
- Subsequent Years: 18 kg P_2O_5 ha^{-1} (100 kg ha^{-1}) for maintenance.

Aeration: None.

Harrowing: None.

Roller: None.

Dragging: None.

Water Troughs: 12 float-controlled troughs ensure continuous water availability for rotational grazing.

Fencing / Shade: 12 fenced paddocks with *Quercus ilex* trees providing natural shade.

Sown Pasture Establishment: None.

Others: *Majadeo* (nutrient recycling). Sheep are confined overnight in portable folds to concentrate manure and facilitate seed incorporation via trampling, enhancing fertility [56].

Rotational Grazing Plan

The system employs a rotational scheme across 12 paddocks, adapting stocking rates to pasture phenology [55,58]. The seasonal strategy is defined as follows:

- Autumn (20 Sept – 20 Dec): Low pressure (~4 days/paddock) allows seedling establishment ("deferment").
- Winter (21 Dec – 21 Mar): Intensity increases (~8 days/paddock) to control grass competition against legumes [58].
- Spring (22 Mar – 22 Jun): Reduced pressure (~4 days/paddock) promotes seed bank replenishment.
- Summer (23 Jun – 19 Sept): High intensity (~8 days/paddock) removes dry biomass and enhances seed–soil contact (*majadeo*).

Additionally, specific functional sub-periods fine-tune the cycle:

- Early (30 Apr – 20 Jun): Controlled grazing ensures flowering and seed set.
- Mid (20 Jun – 10 Aug): Heavy grazing reduces dry matter accumulation.
- Late (10 Aug – 30 Sep): Regulated grazing maintains ground cover prior to autumn rains to prevent erosion.

Fertilization Plan

To address structural phosphorus limitations in acidic slate soils and enhance legume persistence, a low-input fertilization strategy was designed [59]. Applications were performed in early autumn to synchronize nutrient availability with the germination of annual legumes [55].

The strategy followed regional technical recommendations in two phases [55]:

- Corrective Phase (2019): Uniform application of 27 kg P_2O_5 ha^{-1} (150 kg ha^{-1} superphosphate) across the whole farm to trigger legume establishment.
- Maintenance Phase (2020–ongoing): Annual rotational application of 18 kg P_2O_5 ha^{-1} (100 kg ha^{-1} superphosphate) following a three-year cycle (Table 16).

Table 16. Phosphorus Fertilization Schedule by Year and Treated Area

Year	P_2O_5 Dose (kg ha^{-1})	Treated Area (ha)	Application Type
2019	27	250.54	Corrective – Whole farm
2020	18	84.39	Rotational Group A
2021	18	64.40	Rotational Group B
2022	18	101.75	Rotational Group C
2023	18	84.39	Rotation repeated (A)
2024	18	64.40	Rotation repeated (B)
2025	18	101.75	Rotation repeated (C)

This rotational strategy optimizes fertilizer inputs while ensuring sustained fertility, which is key to improving pasture resilience against climatic variability.

2.4.2.2. Before and After Comparison

Pasture recovery in Mediterranean dehesas must address structural phosphorus deficiencies and severe climatic variability, which accelerate degradation [53]. Effective restoration requires adaptive management to stabilize production against climate stress. Recent evidence confirms that rotational grazing buffers warming impacts on pasture quality [59] and enhances mineral-associated organic carbon (MAOC) storage [61].

Accordingly, the improvement strategy aimed to:

- **Stabilize yields** and optimize spring biomass utilization against climatic variability.
- **Correct protein deficits** by promoting productive annual legumes and their long-term legacy [54].
- **Enhance resilience** by shifting botanical composition from degraded species toward high-quality native legumes [55].

Before Improvement

Hay Production: 1,750 kg DM ha^{-1} (2018–2019 baseline). Productivity was constrained by seasonal rainfall variability and nutrient limitations [54].

Heterogeneous cover exposed soil to erosion and limited the storage of Particulate and Mineral-Associated Organic Carbon (POC and MAOC) [61].

Vegetation Quality: Crude protein averaged 10% and legumes 23%. However, high-quality annuals (*Trifolium subterraneum*, *Medicago* spp.) were scarce due to structural phosphorus deficiency and climatic stress [56,57,60].

Grazing Pressure: Moderate, with a baseline carrying capacity of 55 LSU. However, the lack of strategic resting periods reduced utilization efficiency and hindered the self-seeding of desirable species, limiting long-term resilience [61].

After Improvement :

Hay Production: 2,310 kg DM ha^{-1} (mean 2024–2025). This increase confirms the combined effect of P-correction and adaptive grazing on yield stability under high rainfall variability [54,60].

Continuous cover reduces erosion and enhances mineral-associated organic carbon (MAOC) storage via plant–microbial mediation [61].

Vegetation Change: Crude protein increased to 13% and legumes to 32%. The shift from degraded-condition indicators toward productive annual legumes confirms the response to sustained P-inputs and rotational management [58]. See Table 17.

Sustainability: Carrying capacity increased from 55 to 75 LSU (+36%) without external intensification. Higher legume contribution strengthens resilience and recovery after drought [61].

Table 17. Temporal evolution of legume composition (% of total botanical composition (indicator grouping after [57] based on [58])).

Species	Indicator group	Year 2019 (Before) %	Year 2022 (Transition) %	Year 2025 (After) %
Trifolium arvense	Degraded pasture indicator	7	3	1
Trifolium campestre	Degraded pasture indicator	5	2	1
Trifolium cherleri	Improvement-stage indicator	2	4	4
Trifolium glomeratum	Improvement-stage indicator	1	4	3
Trifolium striatum	Improvement-stage indicator	1	3	3
Ornithopus spp.	Improvement-stage indicator	3	2	3
Trifolium subterraneum	Improved pasture (productive)	3	6	10
Medicago polymorpha	Improved pasture (productive)	1	4	7
Total legumes		**23%**	**28%**	**32%**

2.4.2.3. Results and Evaluation

Achievements: phosphorus correction and adaptive grazing significantly enhanced ecosystem performance. Hay production rose by 32% (from 1,750 to 2,310 kg DM ha^{-1}), consistent with legume enhancement effects in Mediterranean wood pastures [54]. Ground cover increased from 75% to 95%, reducing erosion risks and fostering soil carbon stabilization

(MAOC) [61]. Botanical composition shifted toward productive legumes (rising from 23% to 32%; Table 17), replacing degraded-condition indicators [56] based on [57]. Consequently, crude protein increased from 10% to 13%, driven by strategic spring rests [60,62]. These improvements allowed a 36% increase in carrying capacity (55 to 75 LU), demonstrating successful ecological intensification.

Sustainability: ecologically, legume-rich pastures enhance nitrogen fixation and drought resilience [54], while improved ground cover reduces erosion and boosts mineral-associated organic carbon (MAOC) stabilization [60]. Productively, higher forage yields and protein levels were achieved without soil tillage, aligning with conservation principles that prioritize soil integrity [53]. Regarding resilience, adaptive rotational grazing buffered climatic variability by regulating plant competition and enhancing post-drought recovery [60,61]. Furthermore, the phased phosphorus fertilization strategy optimized nutrient inputs, reducing environmental risks while improving fertility [55]. Overall, the intervention demonstrates that the efficient management of natural resources enables the improvement of Mediterranean grasslands, increasing their productivity and reinforcing biological resilience to climatic variability.

Local Governance Role: the improvement model aligns with regional policies for sustainable dryland pasture management [55]. Local governance mechanisms play a crucial role by facilitating technical advisory services and innovation adoption [63], while promoting adaptive grazing to enhance climate resilience [64]. Crucially, the intervention supports the transition toward results-based agri-environmental schemes that reward carbon sequestration and fire prevention rather than land tenure alone [65, 66]. By ensuring productivity coexists with ecosystem integrity through low-disturbance management [53], this case study serves as a scalable demonstration model for future eco-schemes within the Common Agricultural Policy (CAP).

2.4.2.4. Photos

Rangeland Condition – Before Improvement

Rangeland Condition – After Improvement

Improvement Activities (During)

2.4.3. Case 2

2.4.3.1. General Information

The European project LIFE MONTADO & CLIMATE - A NEED TO ADAPT (LIFE15 CCA/PT/000043) promotes the adaptation of dehesas and montados in the Iberian Peninsula through innovative farm-scale management strategies [67]. Its central approach is the implementation of Integrated Dehesa Management Systems (SIGD), designed to improve the environmental, social, and economic sustainability of these ecosystems in an integrated way [68,69].

The dehesa is a multifunctional agrosilvopastoral system whose persistence depends on the balance between trees, grassland, soil, and grazing management under increasingly arid and climatically variable Mediterranean conditions [70,71]. Within this context, Dehesa del Guijo serves as a relevant demonstration area where measures were implemented to improve pasture productivity, conserve soil and water, promote tree regeneration, and diversify farm production [69]. The economic-financial assessment concluded that the implemented system represents a long-term strategic investment, with positive net results from 2021 onwards, thus consolidating its value as a transferable sustainability model [72].

Information about the Improved Grassland

Name / Location of the Rangeland: Dehesa del Guijo de los Frailes (DDG), located in the municipality of Malpartida de Plasencia, Cáceres province, Extremadura, Spain [69]. The farm is included within the Natura 2000 Network and the Monfragüe Biosphere Reserve, and part of its area lies within Monfragüe National Park.

Area (ha): The farm covers a total of 3,227 ha, of which 100 ha were included in the project for the implementation of adaptation measures [72].

Altitude (m): The dehesa has an undulating relief with a maximum elevation of 379 m above sea level [73].

Annual Precipitation: The area has a Mediterranean climate with marked interannual variability. Mean annual rainfall is around 550 mm, mainly concentrated in autumn and winter, with critical water deficit periods during the growing season [69].

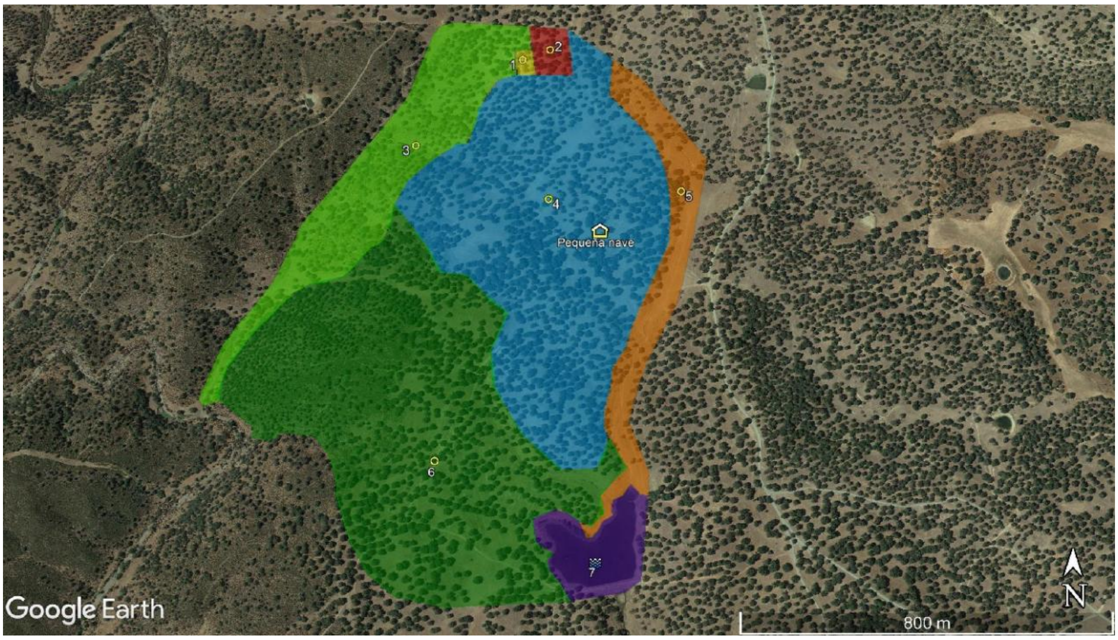

Figure 9. Integrated Dehesa Management System (SIGD) map of Dehesa del Guijo [3].

Soil Structure: The dominant soils are Dystric Regosols developed over slates and schists, generally shallow to very shallow, with abundant rock fragments at the surface and silty to silty-clay texture [73]. They are acid soils with low cation exchange capacity, very low extractable phosphorus levels, and noticeable compaction below 5 cm depth. Potassium levels range from medium to high, whereas iron levels are high and manganese shows strong variability, with possible toxic effects on vegetation [73].

Vegetation Before Improvement: The farm is dominated by a mixed dehesa of holm oak and cork oak, with about 1,846 ha of wooded pastures, including 1,398 ha of holm oak dehesa and 448 ha of cork oak dehesa, with densities of 30-40 trees ha^{-1} [3]. In the study plot, the formation corresponds to a mature holm oak stand, with only about 2% cork oaks, very limited natural regeneration, and clear signs of pressure from grazing and previous interventions [73]. The eastern side shows good tree cover, pasture, and livestock use, whereas the western side has lower tree cover, dense shrub vegetation, and steeper slopes. In addition, pasture biomass remained below its potential at several points during monitoring, reflecting soil and water limitations together with high use pressure [73].

Livestock Using the Rangeland

Cattle (Number / LSU): The farm permanently maintains 180 suckler cows, equivalent to approximately 180 LSU [69].

Sheep (Number / LSU): Around 1,000 meat sheep graze permanently on the farm, equivalent to approximately 150 LSU [69].

Goats (Number / LSU): Goats are not currently reported on the farm. However, goat grazing formed part of the traditional use of the property due to the low fertility of its soils, although it was later replaced by cattle and sheep [73].

Total LSU: The permanent stocking level of the farm is approximately 330 LSU, corresponding to the cattle and sheep owned by the property [69].

Grazing Season: Cattle and sheep graze on the farm throughout the year. In addition, between 350 and 450 Iberian pigs use the grassland and acorns under a rental arrangement during the montanera period, which extends from November to March [68,69].

Improvement Methods Applied

Start and end year of the improvement application: The implementation of the improvement measures was carried out between October 2018 and January 2022 [69].

Shrub Removal: No generalized shrub removal was conducted. Interventions were limited to specific areas intended for diversification or planting, maintaining vegetation cover to prevent soil erosion [69].

Soil Tillage: Discontinuous furrows were created using a ripper along contour lines to improve water infiltration, reduce runoff, and limit erosion processes on sloping areas [69].

Overseeding: Permanent biodiverse pastures were established using mixtures dominated by legumes, aiming to increase ground cover and improve forage quality [69].

Fertilization: Phosphorus fertilization with superphosphate was applied to correct soil deficiencies and enhance legume establishment and productivity [69].

Aeration: Not reported.

Harrowing: Not specifically reported for pasture areas; only minor soil preparation in plots allocated to diversification activities [69].

Roller: Not reported.

Dragging: Not reported.

Water Troughs: Water management was improved through the installation of floating cork platforms with aquatic vegetation, enhancing water quality and supporting biodiversity [69].

Fencing / Shade: More than 3,000 m of electric fencing were installed to enable adaptive grazing management and protect improved areas. Shade conditions remained dependent on existing tree cover.

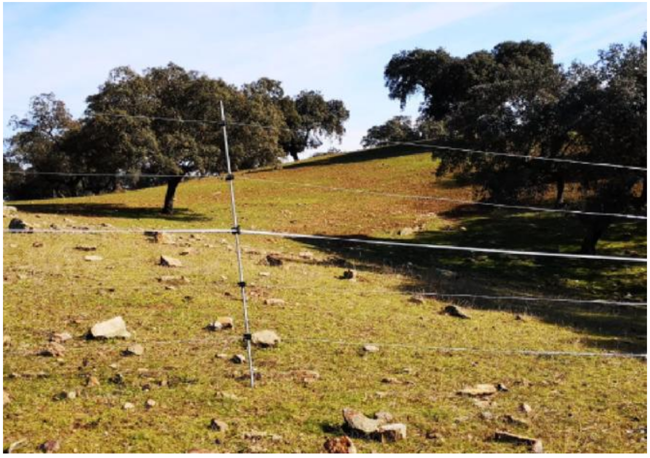

Figure 10. Electric fencing used for adaptive grazing management in the Guijo dehesa.

Sown Pasture Establishment: Permanent legume-rich pastures were established to improve productivity and soil fertility through biological nitrogen fixation [73].

Others: Additional measures included the installation of 50 nest boxes to promote insectivorous fauna and the use of individual tree protectors (PVC tubes and “cactus” systems) to ensure tree regeneration under grazing pressure.

Figure 11. Nest box installed in Dehesa del Guijo to promote insectivorous fauna and biological pest control.

Rotational Grazing Plan

Adaptive rotational grazing was implemented in the Guijo dehesa starting in the 2018–2019 season, supported by the installation of more than 3,000 m of mobile electric fencing, which allowed the subdivision of the 100 ha intervention area into multiple grazing parcels [69].

Year and Number of Grazing Parcels: From 2019 onwards, the grazing system was organised into temporary paddocks defined by mobile electric fencing, with flexible subdivision depending on forage availability and management needs. This approach enabled short grazing periods and adequate recovery times, improving pasture use efficiency and soil restoration processes [68,69].

Grazing Periods and Number of Days in Each Parcel

Grazing management followed the seasonal dynamics of Mediterranean pastures, with short occupation periods (typically 1–5 days per parcel) and variable rest periods depending on climatic conditions and pasture growth.

Early Period (30 Apr–20 Jun): Grazing was carefully regulated to avoid excessive pressure during the reproductive stage of key species, allowing grasses and legumes to reach flowering and seed production, which is essential for natural reseeding and pasture persistence [68].

Mid Period (20 Jun–10 Aug): High-density, short-duration grazing was applied to remove dry biomass and promote seed incorporation into the soil through trampling (manure and hoof action), contributing to soil fertility and regeneration processes [69].

Late Period (10 Aug–30 Sep): Grazing intensity was reduced and controlled to maintain a minimum vegetation cover, protecting the soil from solar radiation and erosion prior to autumn rains.

Figure 12. Electric fencing used for adaptive grazing management in the Guijo dehesa.

Fertilization Plan

Fertilization in the Guijo dehesa was designed as part of a broader soil restoration strategy, focusing on correcting structural nutrient deficiencies and enhancing biological processes rather than intensive input use [68,69].

Year: Main applications were carried out during the initial implementation phase (2018–2019), with maintenance strategies based on soil response and vegetation development.

Parcel Area: Fertilization was applied selectively in areas designated for pasture improvement within the 100 ha intervention zone, particularly in former degraded or low-fertility plots.

Nitrogen (N): No direct nitrogen fertilization was applied. Nitrogen inputs were mainly provided through biological fixation by sown legume species, contributing to long-term soil fertility improvement [69].

Phosphorus (P_2O_5): Phosphorus was supplied through superphosphate application, targeting the correction of structural deficiencies typical of dehesa soils and supporting legume establishment.

Potassium (K_2O): No specific potassium fertilization was reported, as soil levels were considered adequate or not limiting for pasture development.

Fertilizer Type: Mineral fertilization (superphosphate) combined with organic nutrient recycling through grazing, including manure deposition and trampling effects.

Application Time: Fertilizer applications were carried out in autumn, prior to the onset of seasonal rains, to enhance nutrient availability during pasture establishment and early growth stages.

2.4.3.2. Before and After Comparison

Before Improvement

Hay Production: In 2018, the study area showed rather low pasture biomass values, below its productive potential and below the reference values expected for this type of dehesa [72,73].

Pasture cover and productivity were constrained by low soil fertility, limited water availability, and high use pressure. The system showed a gradual loss of productivity associated with tree decline and livestock pressure [72,73].

Vegetation Quality: In 2018, 40 taxa were identified in the farm. However, the functional quality of the pasture was limited by low herbaceous productivity, intense grazing pressure, and insufficient regeneration of the tree system, all of which reduced the overall ecological stability of the site [73].

Grazing Pressure: The farm was under high grazing pressure, associated with the permanent presence of cattle and sheep and the overall intensive use of the dehesa. This situation limited pasture recovery and natural regeneration and contributed to soil compaction and degradation in some areas [72,73].

After Improvement

Hay Production: After implementation of the adaptation and management measures, pasture biomass in 2021 reached values within the reference range for this type of ecosystem, indicating functional improvement compared with the initial situation [73].

The implemented actions promoted vegetation cover maintenance and better soil protection, especially through the establishment of permanent biodiverse pastures, erosion reduction, and improved water infiltration and retention [68,69].

Vegetation Change: Monitoring showed an enrichment of the herbaceous layer in 2021 through the appearance of new taxa compared with 2018. However, this increase in diversity did not necessarily imply higher pasture quality, since some of the newly identified species were nitrophilous taxa associated with grazing [73].

Sustainability: The intervention improved the general functioning of the system and consolidated an economically viable adaptation model. The economic-financial assessment concluded that the implemented strategy should be understood as a long-term strategic investment and that the farm showed positive net results from 2021 onwards, reinforcing its value as a transferable example of sustainability and climate resilience [72].

2.4.3.3. Results and Evaluation

Achievements: Implementation of the SIGD in Dehesa del Guijo led to positive operational results from 2021 onwards, confirming the initial viability of the model [72]. Main achievements included productive diversification through the introduction of aromatic crops and improved forage resources, as well as the creation of a spin-off based on a phytoremediation technology developed during the intervention [69,72]. Supporting measures and infrastructure were also consolidated, including dry-stone walls to reduce gully erosion, nest boxes for auxiliary fauna, and individual protectors to promote tree regeneration [69].

Sustainability Impact: The economic-financial assessment indicates that the implemented system should be understood as a long-term strategic investment, with positive projections for the farm [72]. From an environmental perspective, the measures contributed to improving system functioning through soil and water conservation, biodiversity enhancement, and greater resilience to drought and extreme temperatures, despite some limitations observed in shrub plantings [69].

Local Governance Role: The Dehesa del Guijo case relied on collaboration between the farm ownership, the University of Extremadura, and ADPM, combining practical management, technical monitoring, and adaptive planning [69]. This model reinforces the value of demonstration farms as spaces for validating and transferring climate adaptation solutions to other dehesa owners and land managers [68].

2.4.3.4. Photos

Rangeland Condition – Before Improvement

Initial condition of the grassland in Dehesa del Guijo (2017-2018), showing low herbaceous biomass and very limited young tree regeneration.

Rangeland Condition – After Improvement

Ecosystem condition in 2021 after SIGD implementation, showing a dense herbaceous layer and a well-structured dehesa system with improved tree vitality.

Improvement Activities (During)

Installation of individual tree protectors to support tree regeneration under grazing conditions.

2.4.4. Case 3

2.4.4.1. General Information

The LIFE Regenerate project (LIFE16 ENV/ES/000276) revitalizes Mediterranean agrosilvopastoral systems—dehesas and montados—currently declining due to rural abandonment and low productivity. Its primary goal is to demonstrate a sustainable business model for small and medium-sized farms through natural regeneration, multi-species rotational grazing, and biomass recycling [74]. Implemented at the Muñovela (Spain) and Elighes Uttiosos (Italy) pilot farms, the project began with a comprehensive baseline study. This report details the agroecological monitoring at Muñovela to compare the impact of rotational grazing (Adaptive Multi-Paddock, AMP) against control management [75], aiming to ensure the resilience of these High Nature Value systems against global change [76,77].

Information about the Improved Grassland

Name / Location of the Rangeland:

The Muñovela farm is located in the municipality of Barbadillo, Salamanca province, western Spain (40º54’00’’N, 5º45’30’’W; Figure 13). It belongs to the Institute of Natural Resources and Agrobiology of Salamanca (IRNASA-CSIC), which has managed it for experimental purposes since 1954 [78].

Area (ha): In 2018, the farm covered 72 ha, mainly used as permanent grassland and arable land (Figure 13) [78]. Altitude (m): The farm is located at 817 m above sea level, in an area of gentle slopes. Mean slope is 3°, ranging from 0° to 20° [78].

Figure 13. Aerial view of the Muñovela pilot farm taken by UAV on 2 February 2018.

Annual Precipitation: Climate data come from the meteorological station located on the farm, at 817 m above sea level, in a flat area near the stream. For the 1976-2003 period, mean annual rainfall was 476.9 mm and mean annual temperature was 11.5 °C. Mean temperatures were 20.6 °C in July and August, and 3.4 °C in January (Figure 14) [78].

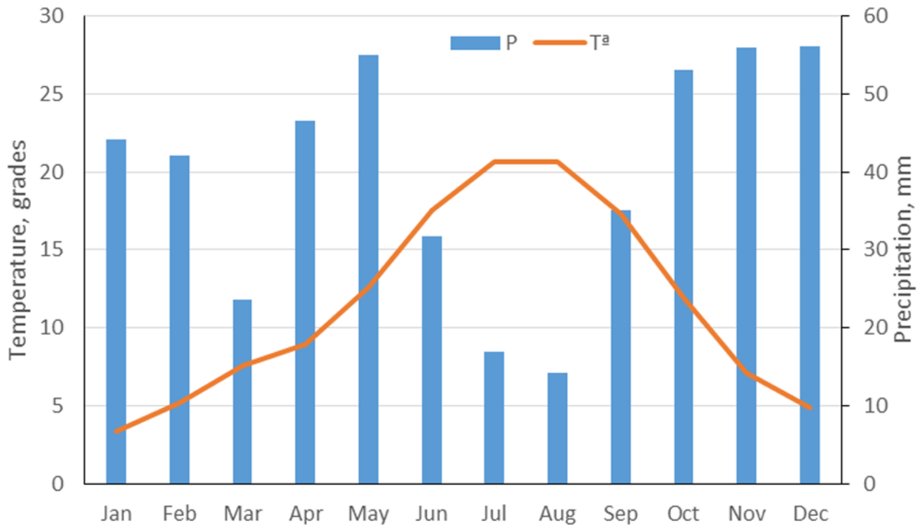

Figure 14. Climodiagram of the Muñovela farm for the 1976-2003 period.

Soil Structure: Soils mainly developed over Miocene sediments with red conglomerates and a clay-rich matrix. Four main soil units can be distinguished on the farm: an upper area dominated by Gley Chromic Luvisols, eroded stepped areas with very low-fertility Calcic Regosols, an irrigated plain with Eutri-Chromic Cambisols, and lower open pastures located on an alluvial terrace, dominated by Calcic Fluvisols and Gleic Cambisols (Figure 15) [78].

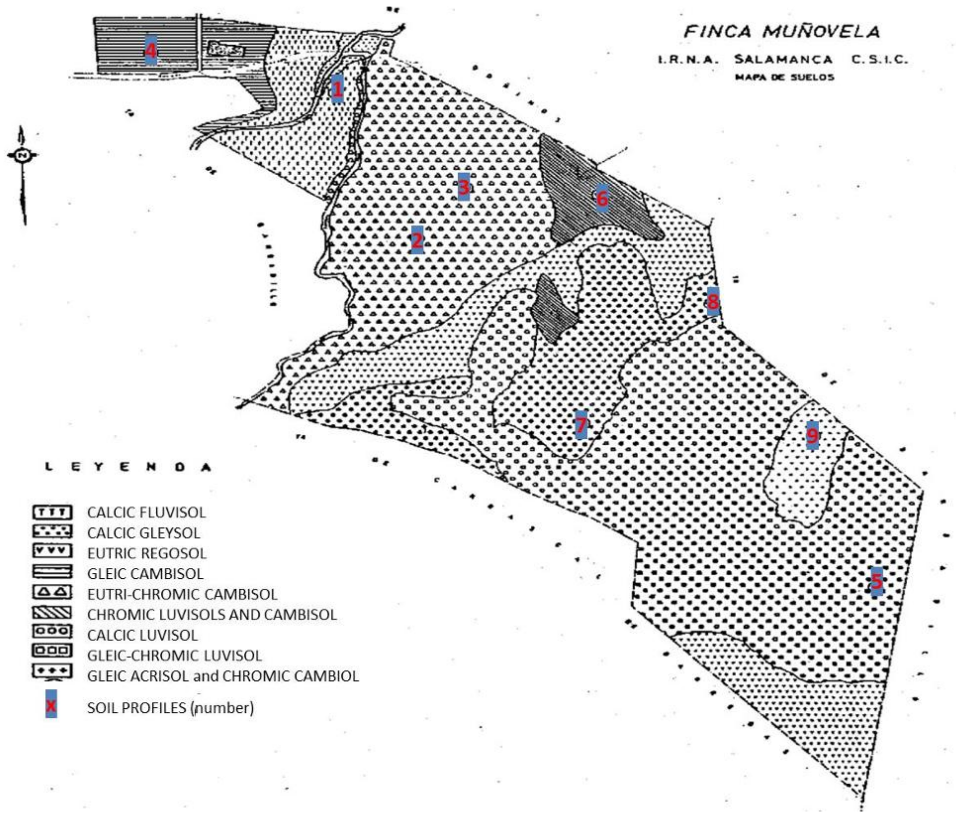

Figure 15. Soil map of the Muñovela farm.

Vegetation Before Improvement: The farm includes irrigated crops, mainly forage crops (12.4 ha), rainfed crops, mostly cereals (30.0 ha), and grazing areas used by sheep and cattle from the farm itself. These grazing areas form a mosaic of open pastures (4.7 ha), wood pastures or dehesa (18 ha), and forest (2 ha). A small non-commercial fruit tree area is also present [78].

Livestock Using the Rangeland

Cattle (Number / LSU): The AMP experimental unit consisted of 1 bull, 16 cattle, and 16 calves under 6 months, managed on 20.75 ha divided into 10 main paddocks (Figure 17). The control group was managed on 14.17 ha distributed in two zones: a wet riverside grassland area (4.67 ha) and a dehesa area (9.5 ha) under continuous grazing. According to the livestock composition table, the control group included 1 bull, 11 cattle, and 11 calves under 6 months [78].

Sheep (Number / LSU): The AMP group also included 9 sheep, 1 ram, and 9 lambs, integrated into the rotational grazing system [78].

Goats (Number / LSU): None.

Total LSU : Total stocking was 17.40 LSU in the AMP group and 12.22 LSU in the control group (Table 18) [78].

Grazing Season: In Mediterranean ecosystems, a growing season and a non-growing season can be distinguished. At Muñovela, under normal weather conditions, the growing season extends approximately from mid-October to mid-June, with a winter slowdown period from early November to mid-February [78].

Table 18. Total LSU (livestock units) in the AMP and control groups.

	AMP GROUP						CONTROL GROUP		
	Bull	Cattle	Calf <6 months	Ram	Sheep	Lamb	Bull	Cattle	Calf <6 months
Number	1	16	16	1	9	9	1	11	11
UGM Value	1	0.66	0.36	0.09	0.07	0.04	1	0.66	0.36
Total UGM	1	10.56	5.76	0.09	0.63	0.36	1	7.26	3.96
TOTAL GROUP	17.40							12.22	

Improvement Methods Applied

Start and end year of the improvement application: November 2017-June 2022.

Shrub Removal: None.

Soil Tillage: yes; keyline tillage was applied in paddocks 3 and 4 [78].

Overseeding: During the first years of the project, fodder production in cropland was necessary because pasture production was not sufficient to feed the flock. Part of these cropland areas was converted into permanent pasture and incorporated into the rotational system. Plots P1, P2, P3, P4, and P9 corresponded to former cropland converted into pasture (Figures 17 and 18) [78].

Figure 16 . Direct sowing of meadows in Muñovela, October 2018.

Fertilization: Soil fertility improvement was included as part of pasture establishment, combining direct seeding, reduced tillage, and the application of organic manure and compost. These measures aimed to improve soil health and productivity and support pasture establishment [78].

Aeration: Not reported.

Harrowing: Not reported.

Roller: It was used only in paddocks 3 and 4 during pasture establishment. No further technical details are provided in the management plan [78].

Dragging: Not reported.

Water Troughs: Portable water tanks were used to supply drinking water to livestock in the AMP paddocks. The same system was also used for supplementary irrigation of some planted trees during summer when needed.

Fencing / Shade: The AMP system was organised into 10 main paddocks delimited by solid fences and further subdivided using movable and/or electric fencing. In former cropland plots incorporated into the system, perimeter trees were also planned to provide shade and shelter for livestock.

Sown Pasture Establishment: Yes. Where the existing seed bank was considered insufficient, herbaceous species were planned to be sown, with emphasis on legume-rich permanent pastures. Sowing was planned in plots 1, 2, 3, and 4 within the AMP area, and in Plot 21 for the control herd.

Others: A small initial group of 5 Dehesa turkeys (4 females and 1 male) was also included in the AMP system to graze in the trial paddocks. This measure was consistent with the multi-species grazing approach of the plan and with their potential contribution to biological control and manure and nutrient recycling.

Rotational Grazing Plan

Pastures managed under the AMP (Adaptive Multi-Paddock) system were compared with a similar area managed under continuous grazing. The AMP area covered 20.75 ha, divided into 10 main paddocks, whereas the control area covered 14.17 ha in two zones: wet riverside grasslands (4.67 ha) and a dehesa area (9.5 ha) [78].

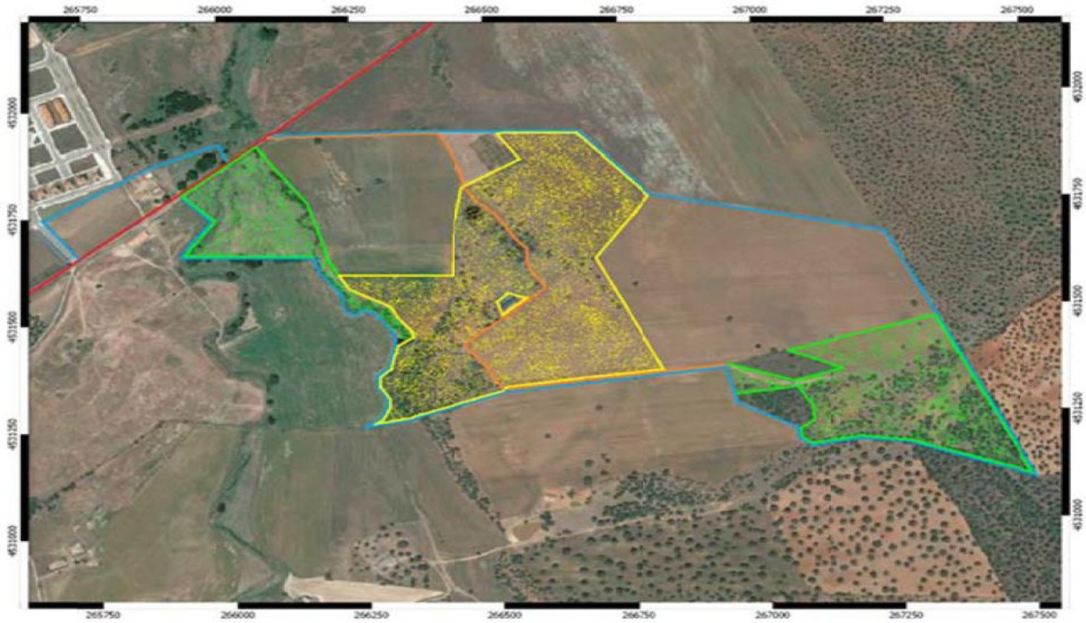

Figure 17. Muñovela farm with the area managed under rotational grazing (yellow) and the area managed under continuous grazing (green).

The AMP group consisted of 17 bovines (16 mother cows and 1 stud bull), whereas the control group included 12 bovines (11 mother cows and 1 stud bull). The main AMP paddocks were further subdivided using movable and/or electric fencing to adjust rotation and occupation time [78].

Figure 18. Layout of the 10 main paddocks in the AMP grazing area.

Each sub-paddock was grazed for short periods, followed by long resting periods to allow full pasture recovery after brief episodes of heavy grazing. During the growing season (open period), the estimated grazing period per sub-paddock ranged from 2 to 10 days, depending on the number of available divisions [78].

Stocking rates were recorded from 2019 to 2022, and the monthly mean values show that annual stocking levels were very similar in both treatments, thus maintaining the comparability of the trial (Table 19) [78].

Table 19. Mean stocking rates in the AMP and control treatments from 2019 to 2022.

YEAR	TREAT	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	LU/Ha
19-20	AMP	17.4	18.8	18.7	18.7	18.3	15.8	15.8	16	16	16	16.4	19	0.85
19-20	Control	12.22	13	13	13	13.8	12.2	11	10.6	10.6	10.6	10.6	10.8	0.83
20-21	AMP	14.85	16.21	19.3	19.1	19.5	17.6	17.2	17.8	18.3	17.1	19.1	18.7	0.90
20-21	Control	16.7	12.1	12.1	10.5	10.6	9.4	10.7	10.7	10.7	10.7	13.1	13.9	0.83
21-22	AMP	19.4	19.2	19.6	21.1	19.9	18.3	15.6					0.91	
21-22	Control	14.8	15.8	15.8	15.4	10.6	7.4	7.4					0.91	

Timing and planning through charts or spreadsheets were key elements of AMP grazing management [78].

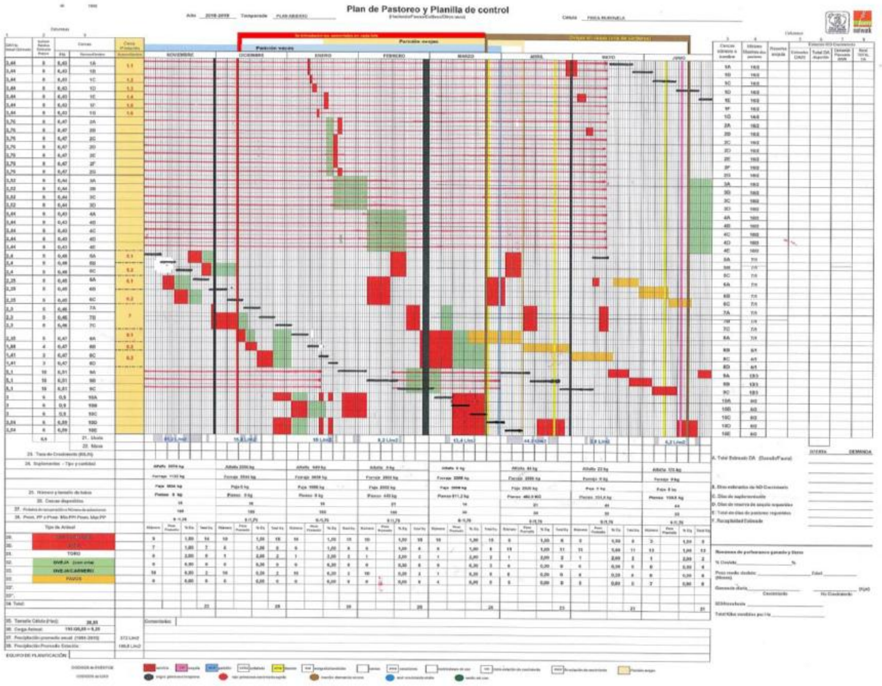

Figure 19. AMP grazing open-period chart.

Fertilization Plan

Fertilization was applied selectively in specific AMP paddocks and in one control plot, mainly to support the establishment and productivity of newly sown pastures on former cropland. Applications varied according to year, month, plot, and fertilizer type, combining compound NPK fertilizers with nitrogen sources such as calcium ammonium nitrate and ammonium nitrate. The application schedule is summarized in Table 20.

Table 20. Fertilization schedule applied in the AMP paddocks and control plot at Muñovela.

YEAR	MONTH	AMP 1-2	AMP 3-4	AMP 9	CONTROL plot 2
2017	October		0-18-0 NPK		.
2018	October			NPK 0-7-14; 1,000 kg/ha	3-16-7 NPK (with MgO and B); 350 kg/ha
2019	March	3-16-7 NPK (with MgO and B); 350 kg/ha	3-16-7 NPK (with MgO and B); 350 kg/ha	NH4NO3 27%; 220 kg/ha	.
2019	October				8-15-15 NPK; 250 kg/ha
2020	February	8-18-0 NPK; 300 kg/ha	8-18-0 NPK; 300 kg/ha	Calcium ammonium nitrate (27% N); 250 kg/ha	Calcium ammonium nitrate (27% N); 125 kg/ha
2020	November	0-14-7 NPK; 690 kg/ha	0-14-7 NPK; 750 kg/ha	0-14-7 NPK; 750 kg/ha	0-14-7 NPK; 400 kg/ha
2021	May			NAC 27; 150 kg/ha	.
2021	August			NAC 27; 400 kg/ha	.
2022	March			Calcium ammonium nitrate (27% N); 190 kg/ha	.

2.4.4.2. Before and After Comparison

Before Improvement:

Hay Production: No direct baseline data on pasture yield or hay equivalent were available before improvement. After a prolonged dry period, including autumn 2017, and a delayed spring, pasture biomass was very low on 5 April 2018.

Vegetation Quality: The baseline assessment carried out on 5 April 2018 using the Rangeland Health Index (RHI) showed negative values at all monitoring points, with total scores ranging from -10 to -25, indicating a degraded initial condition. The use of RHI is consistent with established field-based approaches for interpreting rangeland condition through qualitative indicators [6]. The detailed indicator values are presented in Table 21, while the overall baseline scores for the six monitoring points are summarised in Figure 20 [78].

Table 21. Initial pasture condition assessment in the Muñovela monitoring points, April 2018.

No.	Process/State	Indicator	1 Control 1	2 Control 2	3 Control 3	4 Trial 1	5 Trial 2	6 Trial 3
1	Bare Soil	% Soil cover by plants	0	-10	-10	0	0	-10
2	Soil Compaction	Soil crust	0	0	0	0	-5	0
3	Soil Erosion	Rills and gullies	0	0	0	0	0	0
4	Soil Life	Activity (ants, earthworms)	0	0	0	0	0	0
5	Dung Decomposition	Age of the dungs	5	5	0	5	0	0
6	Perennial Grasses	Cover and vigour	0	0	0	0	0	0
7	Leguminous	Cover and vigour	0	0	0	0	0	0
8	Shrubs	Cover and vigour	0	0	0	0	0	0
9	Trees	% Healthy trees	10	10	10	10	10	10
10	Tree Regeneration	Abundance and height	-20	-20	-20	-20	-20	-20
11	Plant Productivity	% Potential for three strata	-5	-5	-5	-5	-5	-5
		Total score	-10	-20	-25	-10	-20	-25

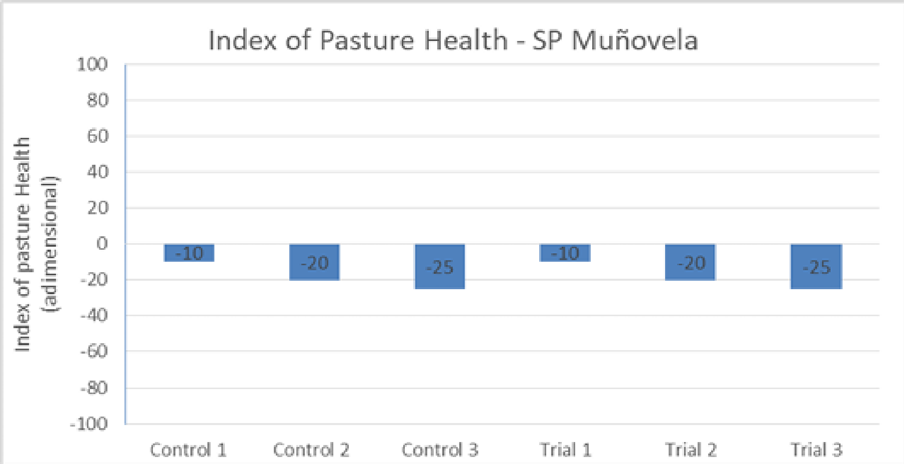

Figure 20. Initial Rangeland Health Index (RHI) values at six monitoring points in Muñovela farm.

Grazing Pressure: Before AMP implementation, the farm followed the usual continuous grazing management in the control areas. No specific baseline grazing pressure value was available for the April 2018 assessment.

After Improvement:

Hay Production: Pasture yield was recorded in spring from 2018 to 2022 and is summarized in Table 22 [78]. Overall, there was a trend towards higher yields under AMP than under the control treatment, although production was low in both treatments in 2021 and 2022 due to weather conditions. However, the decrease was less pronounced in AMP than in the control.

No single indicator was available as a specific hay production coverage rate. However, post-treatment vegetation cover remained generally high in the monitored plots. This is consistent with the positive vegetation response observed after AMP implementation.

Table 22. Pasture yield in Muñovela pilot farm.

Pasture dry matter (t ha-1)	Control	AMP Dehesa	AMP Field Crops (rainfed / irrigated)
Reference period (1986-1993)	1.33		
Reference period (2015)	1.50	1.52	
Spring 2018	1.11	1.19	
Spring 2019	0.44	0.62	
Spring 2020	2.15	2.48	
Spring 2021	1.62	2.20	6.48 / 12.18
Spring 2022	0.62	1.05	2.78 / 11.14

Vegetation Change: Pasture quality, assessed through the Rangeland Health Index (RHI), showed a general improvement in Muñovela. Mean values increased from -15 in the control and -8.75 in AMP in 2019 to 13.33 and 17.5, respectively, in 2022, indicating a general trend of ecosystem regeneration. This interpretation is consistent with the use of field indicators to assess changes in rangeland health over time [6]. In addition, AMP plots located on former cropland showed a particularly positive NDVI response, with a stronger increase than the control and AMP dehesa plots (Figure 21) [78].

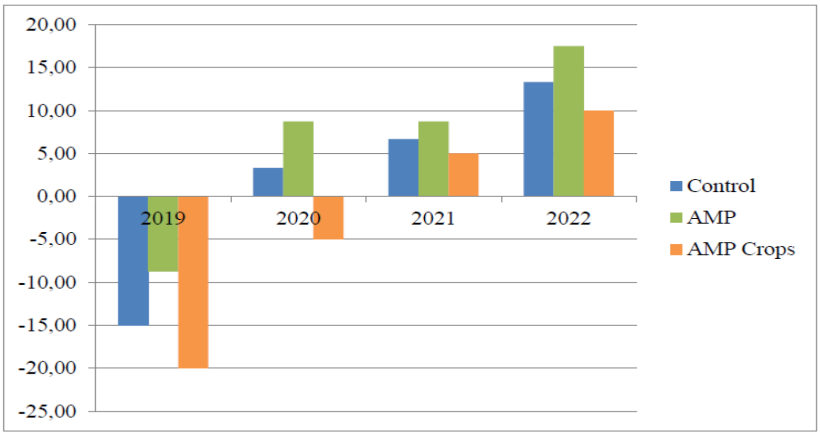

Figure 21. Results for the RHI of different treatments during the 2019-2022 period.

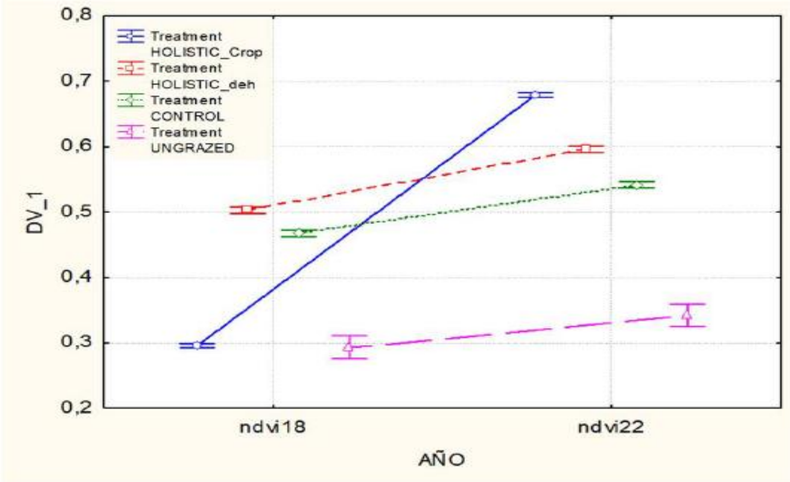

Figure 22. Mean NDVI values of pastures under four different treatments.

Sustainability: The results indicate improved system functioning under AMP, with greater production stability, better pasture use, and signs of ecological recovery. Although some improvements were also observed in the control, the AMP system showed a more favourable response in productivity and pasture recovery.

2.4.4.3. Results and Evaluation

Achievements: Pasture production varied markedly among years, but it tended to be more stable and higher under AMP than in the control. Overall, pasture production increased by 31% under holistic grazing. Pasture quality also improved, as reflected by RHI and NDVI, and grassland use became more efficient, with a 55% higher grass consumption rate under AMP. These results confirm a positive response of the system in both productivity and ecological functioning.

Sustainability Impact: Although stocking rates were kept similar in both treatments for comparison purposes, AMP reduced the annual need for supplementary fodder per animal by 37% in the last year of the project. In addition, body condition and weaning weight were higher under AMP, with increases of 7.8% and 6.5%, respectively. Altogether, these results indicate improved production efficiency and a greater regenerative capacity of the system.

Local Governance Role: The Muñovela case highlights the value of demonstration farms and continuous technical monitoring for validating transferable regenerative practices. The comparison between AMP and control provides a useful basis for dissemination, training, and replication of adaptive grazing strategies in similar Mediterranean systems. This fits well with the practical and demonstrative purpose of the project's digital best practices guide.

2.4.4.4. Photos

Rangeland Condition – Before Improvement, May 2018

Rangeland Condition – After Improvement

Improvement Activities (During)

2.5. Türkiye

2.5.1. Grassland Improvement Practices in Türkiye

Due to its diverse climatic characteristics, soil, and topographical structure, Türkiye is home to a highly varied and rich vegetation, and consequently, pasture areas with different ecological characteristics. Grasslands and pastures, which constitute the primary source of roughage for livestock farming throughout the country, also have a critical ecological function in terms of soil conservation, watershed protection, and the sustainability of biodiversity [80].

Türkiye's grassland and pasture areas have experienced a significant reduction over the years. Approximately 44 million hectares of grasslands and pastures existed in the 1950s, but due to the expansion of agricultural areas and various land-use changes, this figure has decreased to approximately 14.6 million hectares today [81]. In addition to this reduction, there have been serious declines in the quality and productivity of grasslands and pastures. Only 1% of Türkiye's pastures are in very good condition. Of the remaining pastures, 11.7% are in good condition, 52.56% are in moderate condition, and 34.8% are in poor condition [82].

The main causes of pasture degradation include the application of incorrect grazing practices such as early grazing without considering the growth stages of plants, overgrazing where the number of animals exceeds the carrying capacity of the pasture, and late grazing, as well as drought and climatic imbalances [83]. This situation leads to a decrease in valuable forage plants in the botanical composition of pastures, and their replacement by invasive and low-nutritional value plants.

Pastures in Türkiye also show great differences according to their geographical regions. While the Eastern Anatolia Region has the most productive meadows and pastures in Türkiye thanks to its high altitude and cool climate, the pastures in the Central Anatolia and Southeastern Anatolia regions are more susceptible to drought stress and have the characteristics of short, less productive steppe pastures 84]. Irregular rainfall patterns and increasing temperatures brought about by climate change also constitute an additional stress factor on pasture ecosystems, especially in arid and semi-arid regions.

Since the main problem for pasture areas is grazing pressure, sustainable pasture management requires the development of grazing plans appropriate to the ecological conditions of the regions, the integration of improvement practices such as overseeding or fertilization, and the implementation of resting periods to allow vegetation to recover.

According to the Pasture Law No. 4342, enacted in Türkiye in 1998, pastures are under the control and ownership of the state. However, the right to use these areas is allocated to producers residing in the settlements where the pasture is located. Maintenance and improvement work on pastures is carried out by units of the Ministry of Agriculture and Forestry. Universities and research institutes also provide scientific support by acting as consultants for improvement projects. Between 2000 and 2025, 3,163 pasture improvement and management projects were carried out on 2,469,156 hectares of land throughout Türkiye 98]. The examples given in this source have been selected from these studies conducted in Türkiye.

2.5.2. Case 1

2.5.2.1. General Information

The region where the study area is located has a marly-gypsum soil structure. In this region, gypsum is generally found together with clay, marl and sometimes limestone layers [86].

Excluding microclimate areas, continental climate characteristics prevail throughout the province; summers are hot and dry, and winters are cold and rainy [87]. According to the long-term data of the General Directorate of Meteorology (1991-2024), the average annual rainfall is 355.9 mm. The average annual temperature is 11 °C, the lowest average temperature is 0.1 °C in January, and the highest average temperatures are 22.0 °C and 22.1 °C in July and August, respectively [88]. Ertuğrul Neighborhood, where the reclamation work is carried out, is also located in the region where continental climate characteristics are observed.

The improvement project for the area was planned and implemented by the Ministry of Agriculture and Forestry, Geçit Kuşağı Agricultural Research Institute.

Information about the Improved Grassland

Name / Location of the Rangeland:

Eskişehir / Sivrihisar / Ertuğrul

Location: https://maps.app.goo.gl/yY8JqtjZFvPriuiLA

Area (ha): 25 ha

Altitude (m): 900 m

Annual Precipitation: 355.9 mm

Soil Structure: As a result of the analysis of soil samples taken from the pasture at the beginning of the project, it was determined that the pasture soil is clayey-loamy, non-saline, slightly alkaline, deficient in available phosphorus, and poor in organic matter. In addition, it was determined that it has high erodibility, and it was assessed that the area is under a serious threat of erosion. The soil analysis results for the area where the rehabilitation application was carried out are given in Table 23 [89].

Table 23. Soil analysis results

Total Salt %	0.04
pH	7.94
Lime (CaCO3) %	48.96
Available Phosphorus (P_2O_5) (t ha^{-1})	0,02
Available Potassium (K_2O) (t ha^{-1})	2,75
Organic Matter %	1.8
Very Fine Sand %	6.42
Sand %	28.98
Silt %	29.17
Clay %	41.85
Moisture %	4.64
Bulk Density (gr/cm^3)	1.34
Field Capacity %	27.85
Wilting Point %	16.2
Hydraulic Conductivity (cm/saat)	1.04
Erodibility (K Factor)	0.032

Vegetation Before Improvement: Before the study started, a pasture vegetation study was conducted in the pasture area. As a result of the study, *Koeleria cristata* (7%), which is a declining species, and *Hedysarum varium* (2%) and *Festuca ovina* (6%), which are increasing species, were determined in the area. Invasive species were found to be quite dominant in the area, and among these species, *Thymus sibthorpii* (22.25%), *Salvia wiedemannii* (14.75%), *Alyssum pateri* (5.5%), *Bromus tectorum* (3.75%), *Adonis vernalis* (3.5%) and *Astragalus strictispinis* (2.25%) were identified. It was determined that there was no vegetation cover in 32% of the pasture area and the soil surface was bare [89].

Figure 23. Application area soil profile

Livestock Using the Pasture Area

Cattle (Number / LSU): 100

Sheep (Number / LSU): 5000

Total LSU : 508

Grazing Season : It was determined that uncontrolled grazing was taking place in the pasture area prior to the rehabilitation work.

Improvement Methods Applied

Start and end year of the improvement application: 2015 - 2017

The area where the improvement project is being implemented is a marginal area.. Considering that the shallow soil depth, marl composition, low annual rainfall, and dry and hot vegetation period would reduce the chances of success of other reclamation methods, it was planned to prevent erosion and increase roughage production in the area by planting four-winged saltbush (*Atriplex canescens* Pursh Nutt.).

Atriplex canescens is a member of the Chenopodiaceae family and is a C4 plant. It has significant resistance to salinity, drought, low temperatures, heavy metals, and other abiotic stresses [90]. It is widely used as a feed source for cattle, goats, and sheep. In addition, plantations are established for the reclamation of degraded soils, reduction of carbon emissions, and erosion prevention [91]. *Atriplex canescens* generally develops in a rounded form, has a highly branched structure, and can reach a plant height of up to 3 meters. Although it has a hard woody stem, it is preferred by animals due to its abundant leaves. The species remains evergreen in warm climates, while it is deciduous in cold climates [92].

In the breeding study, the land was first prepared for planting by deep tillage with a plow in the rows. Four-winged saltbush (*Atriplex canescens* Pursh Nutt.) seedlings, which were obtained in containers, were planted at 6 m row spacing and 3 m plant spacing, and the soil was pressed down by foot to ensure that the roots were in contact with the soil. After the planting application, watering was done, but no other irrigation and fertilization application was carried out. The created plantations were closed to grazing until they reached an average height of 1-1.5 m for ensure to grow and develop.

Rotational Grazing Plan

To protect the saplings planted, the reclaimed area was closed to grazing for two years. At the end of this period, grazing was resumed after it was determined that the area had developed a sufficient root structure to withstand grazing.

Number of Grazing Parcels: 4

Grazing Periods and Number of Days in Each Parcel

Early Period (15 May–25 Jun):

Each plot is grazed for 10 days, after which grazing continues on the next plot.

Mid Period (25 Jun–20 Aug):

Each plot is grazed for 7 days, after which grazing continues on the next plot.

Late Period (20 Aug –30 Sep):

Each plot is grazed for 10 days, after which grazing continues on the next plot.

Fertilization Plan

No fertilization is planned in the reclamation project.

2.5.2.2. Before and After Comparison

Before Improvement:

Grass yield was not determined before breeding.

After Improvement:

There is no assessment of feed yield after improvement in the area. However, in a study conducted in a nearby location in 2012, it was reported that a green feed yield of 631 gr/plant was obtained from four-winged saltbush (*Atriplex canescens Pursh Nutt*.) for a distance of 3 m [93].

2.5.2.3. Results and Evaluation

Achievements: As a result of the reclamation practice, the percentage of vegetation covered by plants has increased and the level of erosion has decreased. The amount of fodder obtained in the area has increased, contributing to the livestock farming in the region.

Prior to the project, the villagers had numerous complaints about dust being carried into the settlement area due to wind erosion; however, these complaints decreased significantly after the project. The reclamation practice also had social benefits, including increased fodder production, generating income, and improving the quality of life for people living in rural areas. Therefore, the project was deemed successful and supported by the public. This synergy created a multiplier effect in the region, enabling the implementation of new reclamation projects.

Sustainability Impact: Following the implementation of this project, the Ministry of Agriculture and Forestry initiated new studies on four-winged saltbush (*Atriplex canescens Pursh Nutt.*) and other shrubby plants with fodder value that can be used in the reclamation of marginal areas. In 2025, a comprehensive nationwide project was launched to improve pastures using shrubby plants in marginal areas where other reclamation methods have been unsuccessful.

2.5.2.4. Photos

Rangeland Condition – Before Improvement

Improvement Activities (During)

Rangeland Condition – After Improvement

2.5.3 Case 2

2.5.3.1. General Information

In many humid regions of Türkiye, rangelands have gradually transitioned into forested landscapes due to the increasing dominance of shrub and tree species. The rangeland of Elifli Village, located in the Bafra district of Samsun Province, represents a clear example of this process. A successful rangeland improvement program was implemented in the Elifli Village Rangeland between 2016 and 2018, after which a partial grazing management program was introduced to ensure the sustainable use of the area. The rangeland covers 88.1 hectares, lies at an elevation of 50 m above sea level, and receives approximately 800 mm of annual precipitation. Prior to rehabilitation, nearly 90% of the area was dominated by woody and thorny species such as oak, Christ's thorn, blackberry, elm, hawthorn, and rosehip, resulting in a very low proportion of high-quality forage species. In addition, before the improvement program, the site was subjected to continuous and uncontrolled grazing without adherence to the recommended grazing season.

The rangeland rehabilitation program was planned and implemented by the Ministry of Agriculture and Forestry (Türkiye) and the Black Sea Agricultural Research Institute (Samsun).

Name and Location: Samsun/Bafra/Elifli Village

Area (ha): 88.1 ha

Elevation (m): 50 m

Annual pecipitation: 800 mm/yıl

The rangeland lies on a southeastern aspect and has an average slope ranging between 3% and 10%.

Pre-Rehabilitation Vegetation Status: Before the intervention began, a rangeland vegetation survey was conducted in the study area. The assessment showed that the site contained decreasing (desirable) species such as *Trifolium pratense* (5%), *Lotus corniculatus* (14%), and *Sanguisorba minor* (1%), as well as increasing species including *Plantago lanceolata* (3%) and *Hordeum violaceum* (1%).

In addition, several low-quality species were identified in the area: members of the *Euphorbiaceae* family (1.86%), *Plantago cretica* (6.82%), *Blymus compressus* (11.78%), *Carex pendula* (5.58%), *Trifolium tomentosum* (4.96%), *Hordeum murinum* (4.96%), and *Pilosella hoppeana* (26.04%).

It was further determined that approximately 90% of the rangeland was covered by woody and thorny species such as oak, Christ's thorn, blackberry, elm, hawthorn, and rosehip.

Stocking Animals on the Rangeland

Cattle (Number / AU): 115

Sheep (Number / AU): 0

Total AU : 115

Grazing Period: Prior to the rehabilitation program, the rangeland was subjected to uncontrolled grazing.

Rehabilitation Method Applied

Project Duration: The rangeland rehabilitation project was carried out between 2016 and 2018.

Approximately 90% of the rangeland parcels were covered with shrubs and trees, and the abundance of high-quality forage species was insufficient; therefore, sown pasture establishment was undertaken. Following the removal of woody and shrubby vegetation, a preliminary crop was sown, after which the sown pasture was established. The species used in the pasture mixture included tall fescue, cocksfoot, perennial ryegrass, alfalfa, white clover, and Italian ryegrass.

Several trees were intentionally retained within the rangeland to provide shade for grazing animals. In addition, a total of four watering troughs were constructed within the area.

Grazing Management

Before the rehabilitation, all rangeland parcels were subjected to continuous grazing. After the rehabilitation process, a rotational grazing system was planned by taking the grazing capacity of the parcels into account [94, 95]. During the implementation period, the area was closed partially to grazing to ensure a successful establishment of the improved vegetation. The amount of forage produced by the rangeland was calculated, and the carrying capacity of the site was subsequently determined.

Since the area was heavily dominated by low-quality species prior to the rehabilitation, the carrying capacity of the rangeland was not calculated at that stage. With the rehabilitation program, the total rangeland area was divided into four parcels. Following the improvement, the grazing capacity of the rangeland reached 29.39 Animal Units (AU).

Pasture parcels: 4

Table 24. Implemented grazing plan

Years	Parcels	Grazing Seasons		
		Early grazing (30 April-20 June)	Mid grazing (20 June-10 August)	Late grazing (10 August-30 September)
2016	A	Graze	Close-Graze	Graze
	B	Self-seeding period		Graze
	C	Rehabilitation Period		
	D	Close-Graze	Close-Graze	Close-Graze
2017	A	Graze	Close-Graze	Graze
	B	Close-Graze	Graze	Close-Graze
	C	Self-seeding period		OTLAT
	D	Rehabilitation period		
2018	A	Close-Graze	Graze	Close-Graze
	B	Graze	Close-Graze	Graze
	C	Graze	Close-Graze	Graze
	D	Self-seeding period		Graze

Grazing periods and durations

Early Grazing Period (30 April–20 June):

After each parcel completes its 10-day grazing period, grazing is continued in the subsequent parcel.

Mid-Season Grazing Period (20 June–10 August):

After each parcel completes its 7-day grazing period, grazing is continued in the subsequent parcel.

Late Grazing Period (10 August–30 September):

After each parcel completes its 10-day grazing period, grazing is continued in the subsequent parcel.

Fertilization Plan

In the rehabilitation project, different fertilizer applications were carried out between 2016 and 2018 for the areas where the sown pasture was established.

Table 25. Fertilizers applied as part of the improvement projects

Years	Application area (ha)	Fertilizers and Other Plant Nutrients to Be Applied (kg/ha)			
		Pure Nutrient Basis		Applied Fertilizer	
		Nitrogen(N)	Phosphor (P_2O_5)	Type of Fertilizer (kg/ha)	Amount (Ton)
2016	22,3	27	70	DAP 18-46 100 kg/ha	33500
	43,5	26		CAN %26 100 kg/ha	44000
2017	22,3	27	70	DAP 18-46 100 kg/ha	33500
	44	26		CAN %26 100 kg/ha	44000
2018	44,6	26		CAN %26 100 kg/ha	44500

2.5.3.2 Before and After Comparison

Pre-Rehabilitation:

It was determined that the rangeland parcels had no usable dry matter production prior to rehabilitation. For this reason, the grazing capacity was calculated as zero.

Post-Rehabilitation:

Following the rehabilitation, the usable forage yield of the rangeland parcels increased to a total of 220.42 tons. Moreover, the rangeland, which had been classified as "poor" prior to the intervention, was upgraded to the "good" class after the rehabilitation work.

2.5.3.3. Result and Evaluation

As a result of the rehabilitation activities, shrubs and trees present in the rangeland area were removed and cleared from the site. Through the establishment of a sown pasture within the rangeland parcels, the rangeland was upgraded to the "good" class and the amount of usable dry matter was substantially increased. Consequently, the intervention contributed positively to livestock production in the region.

Within the scope of the project, rangeland rehabilitation activities such as the control of undesirable plant species, fertilization, and the establishment of a sown pasture were implemented to improve the botanical composition of the rangelands and increase forage yield [96, 97]. By the end of the three-year implementation period, the dry matter yield in the rehabilitated areas had reached approximately 220 kg per decare. In parallel with this improvement, the grazing capacity of the rangeland increased from 0 LU to 29.39 LU, which helped prevent overgrazing and ensured a balanced relationship between the rangeland and the livestock.

From a grazing management perspective, the rotational and rest-based grazing system implemented in the project represents an important outcome that supports the enhancement of rangeland plant growth vigor. Keeping livestock out of the rehabilitated areas for a certain period, restricting the grazing season to the interval between 30 April and 1 October, and regulating animal numbers according to the calculated carrying capacity were emphasized as critical measures for enabling the rangeland ecosystem to regenerate effectively.

Overall, the Elifli Village Rangeland Rehabilitation and Management Project can be characterized as follows:

- Establishes a framework that prioritizes the conservation of natural resources,
- Develops a livestock management model aligned with the carrying capacity of the rangeland ecosystem, and
- Aims to reduce producers' dependence on external sources for forage supply.

With these characteristics, the project generates an impact that strengthens environmental, production-oriented, and managerial sustainability in the medium and long term. In particular, the restoration of rangeland productivity and the establishment of a controlled grazing framework are regarded as the project's most significant achievements.

2.5.3.4. Photos

Rangeland Condition – Before Improvement

Rangeland Condition – During Improvement

Rangeland Condition – After Improvement

2.5.4. Case 3

2.5.4.1. General Information

The rangeland of Epçeli Village is located within the boundaries of the Çarşamba district of Samsun and lies under the temperate and relatively humid climatic conditions of the Black Sea Region. The rangeland has been subjected to uncontrolled and above-capacity grazing for many years, which has led to the degradation of the natural vegetation and a substantial decline in its production potential.

In the pre-rehabilitation period, the rangeland within the study area exhibited a weak structure in terms of vegetation cover and rangeland low–condition class. An examination of the botanical composition revealed the presence of species belonging to legumes, grasses, and other families; however, the vegetation was dominated by low-quality species. Prior to rehabilitation, the proportion of low-quality species in the vegetation reached the high level of 63 percent. This situation reflects an unfavorable condition for both the nutritional value of the forage available to livestock and the ecological balance of the rangeland ecosystem.

The rehabilitation program for the rangeland was planned and implemented by the Ministry of Agriculture and Forestry (Türkiye) and the Black Sea Agricultural Research Institute (Samsun).

Name and Location: Samsun/Çarşamba/Epçeli Village

Area (ha): 66.5 ha

Elevation (m): 10 m

Annual precipitation: 849 mm/yıl

Based on the soil analysis, the soils of the Epçeli Köyü rangeland are clay, slightly calcareous, non-saline, and neutral in reaction. In the study area, soil phosphorus levels were found to be very low, potassium levels high, and the organic matter content satisfactory.

Winter and spring flooding in the area indicates the absence of salinity and shows that the waterlogging does not result from a rising groundwater table but rather from rainfall and snowmelt. The presence of an impermeable clay layer causes the accumulated water to remain on the soil surface.

Pre-Rehabilitation Vegetation Status: Before the rehabilitation work began, a rangeland vegetation survey was conducted. The assessment identified decreasing (desirable) species in the area, including *Lolium perenne* (2 percent), *Lotus corniculatus* (4 percent), *Trifolium pannonicum* (3 percent), *Trifolium physodes* (2 percent), *Trifolium pratense* (6 percent), and *Trifolium repens* (6 percent). Increasing species were represented by *Catabrosella parviflora* (3 percent), *Cynodon dactylon* (7 percent), *Cynosurus cristatus* (1 percent), and *Plantago lanceolata* (3 percent).

Low-quality species identified in the rangeland included *Bellis perennis* (3 percent), *Centaurea iberica* (4 percent), *Crepis armena* (2 percent), *Eryngium creticum* (3 percent), *Galium verum* (3 percent), *Lotus angustissimus* (3 percent), *Medicago lupulina* (21 percent), *Ononis spinosa* (3 percent), *Prunella vulgaris* (2 percent), *Rubus discolor* (6 percent), *Taraxacum scaturiginosum* (6 percent), *Trifolium dubium* (2 percent), *Trifolium scabrum* (1 percent), and *Ulmus minor* (4 percent).

It was further determined that 10 percent of the rangeland area was covered with trees, shrubs, and thorny vegetation.

Stocking Animals on the Rangeland

Cattle (Number / AU): 685,4

Sheep (Number / AU): -

Total AU : 685,4

Grazing Period: Prior to the rehabilitation program, the rangeland was subjected to uncontrolled grazing.

Rehabilitation Method Applied

Project Duration: The rangeland rehabilitation project was carried out between 2015 and 2018.

The rehabilitation and management activities carried out in the Epçeli Village rangeland were implemented within the framework of a holistic rangeland improvement approach aimed at restoring the degraded structure of the site and ensuring its sustainable use. During the rehabilitation process, methods designed to enhance the productivity of the rangeland vegetation, reduce the dominance of low-quality species, and re-establish the balance between the rangeland and livestock were evaluated and applied in an integrated manner.

The core component of the rehabilitation practices was the control of undesirable and low-quality plant species. To reduce the influence of low-quality species that dominated the rangeland, were not preferred by livestock, and had low utility, mechanical control measures such as shrub cutting and weed mowing were implemented. This intervention aimed to improve competitive conditions in favor of desirable forage species and to facilitate their development within the rangeland ecosystem.

To support vegetation development and improve the physical properties of the soil, a soil aeration (loosening) treatment was carried out in the rangeland. This practice aimed to alleviate soil compaction caused by many years of intensive grazing, promote root development, and enhance the infiltration of rainfall into the soil profile.

The fertilization strategy was designed to stimulate the growth of grass species, increase dry matter yield, and enhance the overall productive potential of the vegetation. As a result of these applications, notable improvements were achieved, particularly in dry matter yield and the associated increase in grazing capacity.

To increase the effectiveness of the rehabilitation efforts and ensure long-term benefits, structures and facilities regulating grazing were established. In this context, watering troughs, shaded resting areas, and arrangements facilitating the controlled movement of livestock were installed, with the aim of promoting a more balanced and sustainable use of the rangeland by grazing animals.

As a complementary component of the applied rehabilitation methods, a planned and controlled grazing system was adopted in the rangeland. The grazing season was restricted, specific periods of rest were introduced, and the grazing capacity was determined based on scientific calculations. This approach not only enhanced short-term forage productivity but also allowed the vegetation to regenerate effectively in the long term.

Grazing Management

The grazing plan for the rangeland of Epçeli Köyü was developed within a planned, controlled, and capacity-based framework to protect the rangeland ecosystem and ensure the long-term sustainability of the gains achieved through the rehabilitation measures. The core principles of the grazing plan include adherence to the rangeland's carrying capacity, restriction of the grazing season, and the implementation of a rest-based grazing strategy. Due to prolonged and uncontrolled grazing prior to the rehabilitation intervention, the rangeland–livestock balance had deteriorated. Following rehabilitation, a grazing capacity based on scientific calculations was therefore established. Accordingly, the post-rehabilitation grazing capacity of the rangeland was calculated as 124.3 Animal Units (AU), and it was stipulated that livestock numbers should not exceed this capacity. A rest-based and controlled grazing system was implemented in the rangeland. Within this framework, the rangeland was completely rested during specific periods, and a grazing arrangement was adopted to ensure the homogeneous distribution of animals across the site. In this way, the concentration of livestock in limited areas and the resulting overgrazing were prevented, while balanced utilization of the vegetation throughout the entire rangeland was targeted.

The number of grazing paddocks in the grazing plan: 5

Table 26. Grazing plan

Years	Parcels	Grazing Seasons		
		Early grazing (30 April-20 June)	Mid grazing (20 June-10 August)	Late grazing (10 August-30 September)
2015	A	-	-	Graze
	B	-	-	Graze
	C	-	-	-
	D	-	-	-
	E	-	-	-
2016	A	Graze	-	Graze
	B	-	Graze	Graze
	C	-	Graze	-
	D	Graze	-	Graze
	E	Graze	-	Graze
2017	A	Graze	-	Graze
	B	-	Graze	-
	C	-	Graze	Graze
	D	Graze	-	Graze
	E	-	Graze	-
2018	A	-	Graze	
	B	Graze	-	Graze
	C	Graze	-	Graze
	D	-	Graze	-
	E	Graze	-	Graze

Grazing periods and the duration of grazing in each paddock.

Early period (30 April–20 June):

Each paddock is grazed for 10 days, and once this period is completed, grazing continues in the subsequent paddock.

Mid-period (20 June–10 August):

Each paddock is grazed for 7 days, and once this period is completed, grazing continues in the subsequent paddock.

Late period (10 August –30 September):

Each paddock is grazed for 10 days, and once this period is completed, grazing continues in the subsequent paddock.

Fertilization Plan

Fertilization practices in the Epçeli Village rangeland were planned in a controlled and gradual manner to enhance the productivity of the rangeland vegetation, support the development of especially gramineous species, and ensure the long-term effectiveness of the rehabilitation measures. The fertilization program was implemented by taking into account the existing soil properties, vegetation condition, and grazing management of the rangeland, and excessive fertilization was avoided in order to preserve the ecological balance of the rangeland ecosystem.

Fertilizer Type	Applied Amount
TSP	≈ 190–200 kg/ha
Amonium nitrate	≈ 70 kg/ha

Fertilization was applied in early spring (Late March–Early April), prior to the onset of the grazing season. Following fertilization, the paddocks were rested for a short period.

2.5.4.2. Before and After Comparison

Pre-Rehabilitation:

Before rehabilitation, the usable dry forage yield of the rangeland paddocks was determined to be 1350 kg ha^{-1}, corresponding to a total of 89.16 tons. The grazing capacity was found to be 39.6 Animal Units (AU).

Post-Rehabilitation:

Following rehabilitation, the usable forage yield of the rangeland paddocks increased to 4233 kg ha^{-1}, reaching a total of 279.56 tons. Furthermore, the rangeland, which had previously been classified as medium quality, was upgraded to the good-quality class as a result of the rehabilitation measures.

Prior to rehabilitation, the grazing capacity of the rangeland was 39.6 Animal Units (AU). Following the rehabilitation works, the grazing capacity was calculated as 124.3 AU.

2.5.4.3. Results and Evaluation

The rangeland rehabilitation and management works carried out in the Epçeli Village rangeland between 2015 and 2018 aimed to restore the productive functions of the rangeland ecosystem, which had been degraded due to many years of uncontrolled grazing. In this context, the interventions implemented— including tree and shrub removal, improvement of the soil surface, controlled fertilization, and a rest-based grazing management system—constituted an integrated approach designed to enhance the production capacity of the rangeland.

As a result of the rehabilitation interventions, a marked and statistically significant increase was achieved in the usable dry forage yield of the rangeland. Accordingly, the grazing capacity rose from 39.6 Animal Units (AU) to 124.3 AU, representing a substantial improvement toward re-establishing the rangeland–livestock balance. This increase is primarily associated with the nitrogen-based fertilization applied and the balanced distribution of grazing pressure across paddocks and years. When evaluated in terms of botanical composition, the rehabilitation practices reduced the proportion of low-quality species and enhanced the competitive ability of perennial and gramineous species within the rangeland. In contrast, no statistically significant short-term changes were detected in rangeland health and condition class or in the vegetation cover percentage. This outcome indicates that the ecological recovery dimension of rangeland rehabilitation requires longer-term and sustained management practices.

In conclusion, the rehabilitation and management practices implemented in the Epçeli Village rangeland yielded positive outcomes by enhancing productive performance in the short and medium term, promoting planned and regulated rangeland use, and contributing to progress toward sustainable rangeland management. However, to achieve lasting improvements in rangeland health class and vegetation structure, the grazing plan and fertilization program must be consistently maintained over the long term. In this respect, the study serves as an important and instructive example for similar rangeland rehabilitation projects to be conducted under the conditions of the Black Sea Region [20].

2.5.4.4. Photos

Rangeland Condition – Before Improvement


Rangeland Condition – During Improvement


Rangeland Condition – After Improvement

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