Forage and Pasture Plants in the United States: A Comprehensive Overview

I. Introduction: Defining Forage and Pasture Plants and Their Significance

- **1.1 What are Forage and Pasture Plants?**
  - Forage is broadly understood as plant material, primarily the leaves and stems, consumed by grazing livestock.[1] This category encompasses grasses and legumes that serve as feed for animals.[2] The definition extends beyond plants directly grazed in fields to include those harvested and fed to animals, such as hay or silage.[1] According to the USDA Agricultural Research Service, forage consists of grasses and legumes utilized by animals in the form of pasture, hay, or silage.[2] A more encompassing definition describes forage as the edible portion of a plant, excluding separated grain, which is generally above ground and can provide sustenance through grazing or harvesting.[3] Specifically, forage crops are defined as annual or biennial plants cultivated for grazing or harvested in their entirety as feed.[1]
  - Pasture, on the other hand, refers to a designated area of land covered with a variety of vegetation, including grasses, herbaceous legumes, forbs, shrubs, and trees, intended for livestock feeding or environmental conservation; it is often synonymous with grassland.[5] Pasture is also defined as a land use type characterized by vegetation cover primarily composed of introduced or enhanced native forage species used for grazing by livestock.[6] These areas typically undergo periodic management practices such as tillage, fertilization, mowing, and weed control, and may also be irrigated.[6]
  - While all pasture plants can be considered forages, the term forage has a wider scope, including plant materials and utilization methods beyond direct grazing on a pasture. For instance, hay and silage are forms of forage derived from pasture plants or other forage crops but are not consumed by animals through grazing.[1] The term "forage crop" emphasizes the intentional cultivation of these plants for animal consumption, whether through grazing or harvesting.[1]
  - Several terms are used interchangeably with forage, including fodder, fodder plants, fodder trees, forage plants, forage trees, and herbage.[3] These synonyms highlight the diverse plant materials that can serve as feed for livestock.
  - Forages, particularly grasses and legumes, form the cornerstone of the diet for ruminant animals like cattle, sheep, and goats, providing the essential fiber necessary for healthy digestion.[2] Legumes, a vital component of many forage

systems, generally contain higher levels of protein compared to grasses.[2] Forage crops offer a comprehensive array of essential nutrients, including proteins, carbohydrates, vitamins, and minerals, which are crucial for maintaining livestock health and optimizing their production.[7] While ruminants are the primary consumers of forages, non-ruminant animals such as pigs, poultry, rabbits, and horses can also digest some quantities of fibrous forages, which are fermented in their digestive systems to yield energy.[5]

- **1.2 The Importance of Forage and Pasture Plants in the US Agricultural Sector:**
  - Forage and pasture plants serve as the fundamental nutritional source for a wide range of livestock in the United States, including cattle, horses, small ruminants, and various wildlife species.[8] They are the bedrock upon which the nation's livestock industry is built, with a significant portion of livestock diets consisting of these plant materials; for example, approximately eighty percent of a beef animal's lifetime nutrition comes from forages.[9]
  - The forage-livestock food production system constitutes the largest economic segment within the US agricultural sector.[10] In 2008, hay harvested in the United States was valued at approximately $18.8 billion, ranking third in overall crop value, surpassed only by corn and soybeans.[11] The total economic value of forage and grasslands that support ruminant animal production is estimated to be around $45 billion annually.[12] The United States forage market was valued at USD 23.3 billion in 2024, with projections indicating a rise to USD 34.9 billion by 2033.[13] By cultivating forage crops on their own land, farmers can significantly decrease their reliance on commercially produced animal feed, resulting in substantial cost savings.[7]
  - Beyond their economic and nutritional roles, forage plants provide critical environmental benefits. They produce oxygen, help mitigate soil erosion, prevent sediment from entering waterways, offer food and shelter for wildlife, and enhance the aesthetic value of landscapes.[14] Row crops are considerably more prone to erosion compared to pastures and meadows composed of forages.[14] The extensive root systems of forage crops aid in preventing soil erosion and nutrient runoff, while the nitrogen-fixing ability of legumes contributes to soil fertility, thereby reducing the need for synthetic fertilizers.[7] These plants also improve the soil's capacity to retain water.[7]
  - Historically, forages have played an indispensable role in the development of civilization by enabling ruminant animals to convert cellulose-rich plants into valuable products for human use.[14] Grasslands constitute a substantial portion of the total land area in America.[14] Grazing, as the primary method of utilizing pasture plants, offers the most economical way to feed livestock and, when

managed effectively, contributes to maintaining the health of both the plants and the broader ecosystem.[8]

II. Major Categories and Types of Forage and Pasture Plants in the United States:

- **2.1 Broad Categorization Based on Growth Temperature:**
  - Forages are broadly classified based on their optimal growth temperature into cool-season and warm-season varieties.[17] Cool-season forages thrive in cool, wet climates, with the majority of their growth occurring during the spring and fall months.[4] These types are predominantly found in the northern half of the United States.[17] Examples of cool-season forages include Kentucky bluegrass, orchardgrass, tall fescue, and annual ryegrass.[17] Warm-season forages, on the other hand, flourish in hotter, drier climates, with most of their growth taking place during the summer months.[4] They are predominantly found in the southern half of the United States.[17] Examples of warm-season forages include bermudagrass, bahiagrass, big bluestem, and crabgrass.[17] This fundamental division based on temperature adaptation dictates the geographical suitability and seasonal productivity of different forage types across the US.
- **2.2 Categorization Based on Life Cycle:**
  - Forages can also be categorized by their life cycle as perennial or annual.[17] Perennial forages are long-lived plants that regrow every year, offering a more permanent vegetation cover. They are typically slower-growing and require more time to establish.[4] Examples of perennial forages include alfalfa, tall fescue, and bermudagrass.[17] Annual forages, in contrast, complete their life cycle within a single growing season and must be replanted each year. They are generally faster-growing and quicker to establish.[4] Examples of annual forages include annual ryegrass, oats, and forage soybeans.[17] The choice between annual and perennial forages involves a trade-off between establishment speed and effort versus long-term persistence and potential cost savings on replanting.
- **2.3 Categorization Based on Growth Characteristics (Plant Type):**
  - Grasses represent the most common category of forage, accounting for approximately 75% of all forages used in the United States.[17] These are herbaceous plants characterized by long, slender, wrapping leaves and typically possess fibrous root systems.[17] Examples of common forage grasses include Kentucky bluegrass, orchardgrass, bermudagrass, and timothy.[1] Grasses can be further classified by their growth habit as either sod-forming or bunch grasses.[9]

- Legumes constitute the second most prevalent plant family used for forage.[17] These plants have broad, compound leaves arranged alternately along the stem and typically feature taproots.[17] A key characteristic of legumes is their ability to fix atmospheric nitrogen through a symbiotic relationship with rhizobium bacteria in their root nodules.[2] Examples of important forage legumes include alfalfa, clover, vetch, and lespedeza.[2]
- Forbs are another category of herbaceous, broadleaf plants.[17] While all legumes are technically forbs, not all forbs are legumes. Forbs are typically deep-rooted and absorb minerals in different proportions compared to grasses and legumes, contributing to the diversity of pasture ecosystems.[17] An example of a forb found in pastures is dandelion.[1]
- Beyond these primary categories, other forage types include silage, hay, crop residues, and tree legumes.[1] Silage is produced by fermenting chopped green forage crops under anaerobic conditions.[1] Hay is forage that has been cut and dried to a low moisture content for storage.[2] Crop residues are plant materials left after harvest that can be used as forage.[1] Some leguminous trees can also serve as a source of forage in certain agricultural systems.[1]

- **Table 1: Common Forage and Pasture Grass Species in the US**

Common Name	Scientific Name	Season (Cool/Warm)	Life Cycle (Annual/Perennial)	Primary Use (Pasture/Hay/Silage)
Kentucky Bluegrass	*Poa pratensis*	Cool	Perennial	Pasture
Orchardgrass	*Dactylis glomerata*	Cool	Perennial	Hay, Pasture
Tall Fescue	*Festuca arundinacea*	Cool	Perennial	Pasture, Hay
Timothy	*Phleum pratense*	Cool	Perennial	Hay, Pasture
Bromegrass	*Bromus spp.*	Cool	Perennial	Hay, Pasture
Perennial Ryegrass	*Lolium perenne*	Cool	Perennial	Pasture, Hay, Silage

Reed Canarygrass	*Phalaris arundinacea*	Cool	Perennial	Pasture, Silage
Annual Ryegrass	*Lolium multiflorum*	Cool	Annual	Pasture, Hay, Silage
Barley	*Hordeum vulgare*	Cool	Annual	Pasture, Hay
Oat	*Avena sativa*	Cool	Annual	Pasture, Hay, Silage
Rye	*Secale cereale*	Cool	Annual	Pasture, Hay, Silage
Wheat	*Triticum aestivum*	Cool	Annual	Pasture, Hay
Triticale	*Triticosecale spp.*	Cool	Annual	Pasture, Hay, Silage
Bermudagrass	*Cynodon dactylon*	Warm	Perennial	Pasture, Hay
Bahiagrass	*Paspalum notatum*	Warm	Perennial	Pasture, Hay
Big Bluestem	*Andropogon gerardii*	Warm	Perennial	Pasture, Hay
Indiangrass	*Sorghastrum nutans*	Warm	Perennial	Pasture, Hay
Switchgrass	*Panicum virgatum*	Warm	Perennial	Pasture, Hay, Biofuel
Dallisgrass	*Paspalum dilatatum*	Warm	Perennial	Pasture, Hay
Eastern Gamagrass	*Tripsacum dactyloides*	Warm	Perennial	Pasture, Hay

Crabgrass	*Digitaria spp.*	Warm	Annual	Pasture, Hay
Millet	*Setaria italica*, etc.	Warm	Annual	Pasture, Hay, Silage
Sorghum-Sudan grass	*Sorghum bicolor x S. sudanense*	Warm	Annual	Pasture, Hay, Silage
Sudangrass	*Sorghum sudanense*	Warm	Annual	Pasture, Hay, Silage
Teff	*Eragrostis tef*	Warm	Annual	Hay, Pasture

- **Table 2: Common Forage and Pasture Legume Species in the US**

Common Name	**Scientific Name**	**Season (Cool/Warm)**	**Life Cycle (Annual/Perennial)**	**Primary Use (Pasture/Hay/Cover Crop)**
Alfalfa	*Medicago sativa*	Cool	Perennial	Hay, Pasture, Cover Crop
Red Clover	*Trifolium pratense*	Cool	Perennial (short-lived)	Pasture, Hay, Cover Crop
White Clover	*Trifolium repens*	Cool	Perennial	Pasture, Cover Crop
Birdsfoot Trefoil	*Lotus corniculatus*	Cool	Perennial	Pasture, Hay
Sweet Clover	*Melilotus spp.*	Cool	Biennial	Cover Crop, Pasture
Alsike Clover	*Trifolium hybridum*	Cool	Perennial	Pasture, Hay
Crimson Clover	*Trifolium incarnatum*	Cool	Annual	Pasture, Cover Crop
Hairy Vetch	*Vicia villosa*	Cool	Annual	Cover Crop,

				Pasture
Winter Pea	*Pisum sativum*	Cool	Annual	Pasture, Cover Crop
Annual Lespedeza	*Kummerowia striata/stipulacea*	Warm	Annual	Pasture
Arrowleaf Clover	*Trifolium vesiculosum*	Cool	Annual	Pasture, Cover Crop
Ball Clover	*Trifolium nigrescens*	Cool	Annual	Pasture, Cover Crop
Berseem Clover	*Trifolium alexandrinum*	Cool	Annual	Pasture, Cover Crop
Austrian Winter Peas	*Pisum sativum*	Cool	Annual	Pasture, Cover Crop
Annual Medics	*Medicago spp.*	Cool	Annual	Pasture, Cover Crop
Serecia Lespedeza	*Lespedeza cuneata*	Warm	Perennial	Pasture, Hay
Cowpeas	*Vigna unguiculata*	Warm	Annual	Pasture, Hay, Cover Crop
Forage Soybeans	*Glycine max*	Warm	Annual	Pasture, Hay, Cover Crop
Kobe/Korean Lespedeza	*Lespedeza striata/stipulacea*	Warm	Annual	Pasture

III. Geographical Distribution of Forage and Pasture Plant Species:

- **3.1 Influence of Climate:**
  - Temperature plays a pivotal role in determining the geographical distribution

of forage grasses across the United States. Cool-season grasses, such as Kentucky bluegrass, orchardgrass, and tall fescue, are predominantly found in the northern regions of the country where temperatures are cooler and moisture is generally more abundant.[8] These grasses thrive during the spring and fall when conditions are mild. Conversely, warm-season grasses, including bermudagrass and bahiagrass, are well-adapted to the hotter climates of the southern United States.[8] Extreme temperatures can also limit the range of specific species; for example, low summer temperatures can restrict the growth of certain forages at higher elevations, while high summer temperatures can be a limiting factor in the desert southwest and the hot, humid southeast.[36]

  - Precipitation is another critical climatic factor influencing the distribution of forage. Historically, the native grasslands of the Great Plains were distributed along a precipitation gradient, with tall-grass prairies in the more humid eastern areas, mixed-grass prairies in the central regions, and short-grass prairies in the drier west.[37] Drought tolerance is a key characteristic for forage species to survive and thrive in arid and semi-arid environments, affecting the prevalence of species like wheatgrasses and bluestems in these regions.[20]
  - Seasonal variations in temperature and precipitation dictate the growth patterns of different forage types.[4] Cool-season forages exhibit their primary growth during the spring and fall when temperatures are moderate and moisture is typically available. In contrast, warm-season grasses are most productive during the hot summer months, often entering a period of dormancy during cooler times of the year. This seasonal complementarity in growth patterns is often strategically utilized in forage systems to provide a more consistent supply of grazing or hay production throughout the year.
- **3.2 Influence of Soil Types:**
  - The type of soil present in a region significantly affects the productivity of forage and the suitability of different forage species.[8] For instance, the productivity of forages in Arkansas varies considerably depending on the underlying soil composition, ranging from the limestone-based soils of the Ozark Mountains to the alluvial Delta soils of the eastern part of the state.[8]
  - Specific soil characteristics, such as pH, drainage, and salinity, play a critical role in determining where certain forage species can successfully grow.[36] Kentucky bluegrass, for example, thrives in well-drained soils with a near-neutral to slightly alkaline pH.[18] Tall wheatgrass, on the other hand, exhibits a notable tolerance to saline and alkaline soil conditions.[20] Alfalfa requires well-drained soils with a pH above 6.1 [23], whereas arrowleaf clover is not well-suited to soils that are calcareous or prone to waterlogging.[24] These

examples illustrate how particular soil properties can either support or limit the growth of different forage species.

- **3.3 Regional Variations in Species Dominance:**
  - The geographical distribution of forage and pasture plants in the US is marked by distinct regional patterns of species dominance, reflecting the combined influences of climate, soil conditions, and historical agricultural practices. In Arkansas, for example, tall fescue and bermudagrass are the primary forage species, with cool-season varieties more prevalent in the northern part of the state and warm-season varieties dominating in the south, mirroring the state's temperature gradient.[8] Kentucky bluegrass is a key component of permanent pastures in the northeastern United States, where the cooler and moister climate favors its growth.[18] The southeastern US sees extensive cultivation of white clover and annual lespedezas, which are well-adapted to the region's climatic conditions.[28] Alfalfa, while adaptable to a range of climates, requires well-drained soils and is a dominant legume forage crop across many parts of the US, particularly for hay production.[23] The Great Plains exhibit a clear north-south gradient in grassland types, with C4 warm-season grasses being more dominant in the southern portions and C3 cool-season grasses increasing in prevalence as one moves north.[37] Pastureland tends to be concentrated in the more humid eastern half of the United States.[6] Furthermore, introduced forage species like tall fescue, orchard grass, and bermudagrass have become naturalized and now constitute vital components of pasture-based grazing systems in many states across the country.[6]
- **3.4 Maps of Species Suitability:**
  - Advanced mapping technologies, such as Geographic Information Systems (GIS), are employed to create detailed species suitability maps for forage plants.[36] These maps are generated based on quantitative data regarding the tolerances of different forage species to various climatic factors, including temperature and precipitation, as well as soil characteristics like pH, drainage, and salinity.[36] By integrating these biophysical factors, these maps provide valuable insights into the regions where specific forage species are most likely to thrive.[36] The suitability of a particular species in a given location can be limited by different environmental constraints; for instance, low winter temperatures might restrict the northern range of some species, while insufficient precipitation could limit their westward expansion, and high summer temperatures might be a barrier in the southern parts of the country.[36] While soil characteristics can sometimes limit the suitability of a species, certain management practices, such as the application of lime or the installation of drainage systems, can help to alleviate some of these

limitations.[36] The availability and utilization of these species suitability maps represent a significant advancement in forage management, enabling producers and land managers to make more informed decisions about which forage species are best adapted to their specific environmental conditions, thereby enhancing the potential for successful and sustainable forage production.

IV. Uses of Forage and Pasture Plants in Livestock Farming:

- **4.1 Grazing Management Systems:**
  - Grazing stands out as the most economically efficient method for harvesting forages, as it eliminates the costs associated with mechanical harvesting, such as fuel, labor, and equipment maintenance.[8] This method involves allowing livestock to directly consume growing forage, which includes a variety of plant types like grasses, legumes, and forbs, in pastures or rangelands.[16] Beyond the economic advantages, grazing offers several benefits for animal health, including improved reproductive success due to natural social interactions, a reduced risk of infectious diseases through the dispersal of animals, opportunities for exercise, and a lower incidence of foot problems compared to confined housing systems.[16] In much of the United States, the typical grazing season extends from March or April to October, providing a cost-effective and beneficial feeding strategy for a significant portion of the year.[16]
  - Two primary approaches to grazing management are continuous grazing and rotational grazing. Continuous grazing, where animals have unrestricted access to a pasture throughout the grazing season, often results in lower overall pasture yields and a decline in forage quality because livestock tend to selectively graze their preferred plants, leading to overgrazing of some areas and underutilization of others.[16] In contrast, rotational grazing involves dividing pastures into smaller sections, or paddocks, and moving livestock between these paddocks on a regular basis. This system allows the grazed areas to rest and regrow, leading to more productive pastures, improved forage condition, and an extended grazing season.[16] Rotational grazing also contributes to a more even distribution of manure across the pasture.[38]
  - Maintaining an appropriate grazing height is crucial for the health and regrowth of forage plants. Grazing below a certain level, typically around three inches, can stress the plants by reducing their leaf area, which is essential for photosynthesis, and can deplete their root reserves.[43] A general guideline known as the "Take Half Leave Half" rule suggests that livestock should consume approximately half of the available forage and leave the

other half to allow for regrowth.[39] Balancing the number of livestock with the amount of forage produced, known as the stocking rate, is also essential to prevent overgrazing and maintain the long-term health of the pasture.[40] Finally, some producers utilize a practice called winter grazing, where they stockpile pasture forage during the growing season to extend the availability of grazing into the winter months. This can offer both economic and environmental benefits by reducing the need for stored feed and minimizing associated costs.[6]

- **4.2 Hay Production:**
  - Hay is a form of preserved forage produced by cutting grasses and legumes, allowing them to dry in the field to a moisture content low enough to prevent spoilage, and then compacting and baling them for storage and later feeding to livestock.[2] This method offers significant flexibility in livestock feeding, as hay can be stored for extended periods and used when grazing is not feasible, such as during winter or periods of drought. Additionally, hay can be easily transported to different locations as needed.[8] Hay production represents a substantial agricultural enterprise in the United States, contributing billions of dollars to both state and national economies annually.[10] In Texas, for example, warm-season perennial grasses like bermudagrass are commonly utilized for hay production, but other species such as bahiagrass, johnsongrass, and various small grains are also used.[11] The nutritional value of hay is primarily determined by the type of forage species used and the stage of plant maturity at the time of harvest.[11] Proper drying in the field is essential to preserve the nutritional quality of the hay and prevent the growth of mold or other forms of spoilage.[30] However, hay production can be significantly challenged by weather conditions, particularly rainfall that occurs while the cut forage is drying in the field, which can lead to nutrient losses and a reduction in the overall quality of the hay.[33] Perennial forage species are generally preferred for hay production over annual species due to their lower annual establishment costs.[35] The market prices for hay can fluctuate considerably depending on factors such as the type of hay (e.g., alfalfa hay versus other types), its quality (e.g., dairy-quality hay commands a premium), the specific region, and the overall balance of supply and demand.[45]
- **4.3 Silage Production:**
  - Silage is another important method for preserving forage, particularly when weather conditions are not ideal for drying hay. It involves harvesting forage crops, such as grasses, legumes, or corn, at a relatively high moisture content, chopping them into smaller pieces, and then storing them in anaerobic conditions to undergo a process of fermentation.[1] These anaerobic conditions

are typically achieved by packing the chopped forage tightly in silos or wrapping bales tightly in plastic (baleage). The fermentation process preserves the forage, helping to retain its nutritional value.[30] The quality of the resulting silage is influenced by several factors, including the moisture content of the forage at the time of harvest, the degree of compaction achieved during storage, and the duration of the fermentation period.[30] If the silage contains too little dry matter (too much moisture), it can be susceptible to the growth of mold and the production of mycotoxins.[30] A wide variety of forage crops can be used to produce silage, including grasses, legumes, and corn.[1] Corn silage is a particularly common and highly nutritious feed source for cattle.[33] One of the key advantages of silage production is that it allows for the preservation of forage at higher moisture levels compared to hay, which can be particularly beneficial in regions where weather conditions make it difficult to consistently dry hay to the required moisture content.[32]

V. Common Management and Cultivation Practices:

- **5.1 Soil Fertility and Fertilization Strategies:**
  - The foundation of a successful forage and pasture management program is maintaining optimal soil fertility. Regular soil testing is paramount for determining the specific nutrient needs of the soil and guiding decisions on lime and fertilizer applications.[14] Ideally, soil samples should be collected from each pasture paddock to account for variations within a farm.[49] Soil testing should be conducted every two to three years to monitor nutrient levels and pH.[51] Applying lime is often necessary to adjust the soil pH to the optimal range for the desired forage species. For cool-season grass pastures, a pH between 6.0 and 7.0 is generally recommended, while legume pastures thrive at a pH of 6.5 to 7.0.[49] Proper soil pH is crucial for maximizing the availability of essential nutrients to the plants.[49] Lime application not only reduces soil acidity but also provides essential plant nutrients like calcium and magnesium.[50]
  - Nitrogen is a key nutrient for plant growth, but legumes have the unique ability to fix atmospheric nitrogen through a symbiotic relationship with rhizobium bacteria.[2] In pastures where legumes constitute 30% or more of the plant stand, nitrogen fertilization may not be necessary.[49] However, if the legume component is lower, grasses will likely respond favorably to nitrogen fertilizer applications.[49] While nitrogen fertilization can significantly boost pasture yields, it is considered a short-term management tool.[51] The timing of nitrogen application can be adjusted based on the producer's goals for forage production throughout the year.[51] Phosphorus and potassium are also vital

nutrients for plant production and persistence and should be monitored through regular soil testing.[49] Maintaining optimal levels of these nutrients is particularly important for legumes, as grasses tend to be more competitive for their uptake.[49] In addition to macronutrients, micronutrients such as iron, copper, zinc, manganese, boron, molybdenum, and chlorine are essential for plant health, although they are required in much smaller quantities, and soil often provides sufficient amounts.[55] However, in intensively grazed pastures, sulfur and boron may become limiting and should be assessed through soil tests or plant tissue analysis.[53] Finally, manure from grazing livestock can be a valuable source of nutrients and organic matter for pastures, contributing to soil fertility and improving soil structure.[56]

- **5.2 Irrigation Practices:**
  - In many regions of the United States, particularly those with limited or seasonal rainfall, irrigation is a critical management practice for sustaining or increasing forage production.[52] Various irrigation methods are employed, including flood irrigation, sprinkler systems (such as hand line, wheel line, pivot, and big gun systems), and gated pipe systems.[57] The choice of irrigation method typically depends on factors such as the size and topography of the farm, the availability of water resources, labor availability, and the capital costs associated with different systems.[57] A key aspect of effective irrigation management is scheduling irrigations based on the moisture content of the soil.[57] Monitoring soil moisture levels can help producers determine when to irrigate and how much water to apply. A general guideline is to allow the soil to dry down to about 50% of its water-holding capacity before irrigating back to field capacity.[57] Producers should also consider evapotranspiration rates, which vary by season and affect how quickly soil moisture is depleted.[57] Efficient irrigation management involves understanding the infiltration rate and water-holding capacity of the soil to ensure that water is applied effectively and not lost to runoff or deep percolation.[57] Proper irrigation can significantly enhance forage yields and maintain pasture productivity, especially during dry periods, thereby ensuring a more consistent supply of nutrition for livestock.[57] It is important to avoid leaving large livestock in pastures during irrigation to prevent damage to irrigation equipment and to minimize soil compaction.[57] Additionally, grazing should be delayed for a few days after irrigation to allow the soil to dry somewhat and prevent damage to the plants.[57] In some cases, such as with alfalfa, fall irrigation can be beneficial for plant health and can improve yields in the following year.[60]
- **5.3 Pest and Weed Control Methods:**
  - Effective management of pests and weeds is essential for maintaining healthy

and productive forage stands. An Integrated Pest Management (IPM) approach is widely recommended, as it aims to combine various control strategies in an economical and sustainable manner, linking agronomic goals with environmental and social considerations.[61] The principles of IPM include understanding the biology of pests, taking advantage of natural pest suppression mechanisms, managing the ecosystem to enhance pest control, integrating multiple control methods, monitoring pest populations regularly, and applying interventions only when necessary.[61] A variety of control methods can be employed in forage and pasture systems. Cultural control practices, such as maintaining good pasture management, ensuring proper fertilization, implementing timely mowing, and utilizing optimal stocking rates, can help to prevent or minimize pest and weed problems.[39] Maintaining healthy and competitive forage stands is a key aspect of cultural control.[39] Biological control involves promoting the natural enemies of pests within the forage ecosystem.[61] Chemical control methods include the use of herbicides to manage weeds and insecticides to control insect pests.[52] Selective herbicides can be used to target broadleaf weeds without harming desirable grasses, while non-selective herbicides may be used for total vegetation control in specific areas.[52] Insecticides are available for controlling common pasture pests like armyworms and grasshoppers, with specific formulations and application rates designed for use in pastures to ensure the safety of grazing livestock.[52] Mechanical control methods, such as mowing, can be used to manage forage growth and to remove the seed heads of weeds, preventing their further spread.[64] Common insect pests in pastures include armyworms, leafhoppers, grasshoppers, and aphids, while weeds compete with forage plants for essential resources like sunlight, water, and nutrients.[62] Effective weed management is crucial to prevent reductions in forage quantity and quality and to prolong the productive lifespan of desirable forage species.[32]

- **5.4 Grazing Management Techniques (Rotational Grazing, Stocking Rates):** (Detailed in IV.1)
- **5.5 Cultivation Practices for Establishment and Maintenance:**
  - Establishing a new forage stand is a process that requires careful planning and attention to detail, often beginning a year in advance of planting.[66] A critical first step is selecting forage species that are well-adapted to the specific soil pH, climate conditions (including winter hardiness), and the intended use and type of livestock.[66] Proper seedbed preparation is essential for the successful germination and establishment of small forage seeds. This typically involves creating a fine, firm soil surface, which can be achieved through practices like rolling or cultipacking the soil both before and after

planting.[48] No-till drills can also be used effectively to establish forages, ensuring good contact between the seed and the soil.[48] The seeding rate and planting depth are also important factors; generally, forage seeds should be planted at a depth of 1/4 to 1/2 inch.[48] The timing of seeding can significantly impact establishment success, with spring and fall often being the most favorable periods, depending on the local weather patterns and the specific forage species being planted.[48] Planting early in the spring allows seedlings to become well-established before the onset of hot, dry summer conditions.[48] For legume establishment, proper inoculation of the seed with fresh rhizobium inoculum is crucial to ensure effective nitrogen fixation.[48] Fertilization at planting is also important, particularly the application of phosphorus, which is vital for the establishment of legumes. Nitrogen fertilization is generally not recommended for legumes at planting, as it can inhibit the process of nitrogen fixation.[48] In some cases, companion crops, such as small grains, may be used to help control weeds during the establishment phase, but they must be managed carefully to prevent them from outcompeting the young forage seedlings.[48] Once a forage stand is established, ongoing maintenance practices are necessary to ensure its long-term productivity and longevity. These practices include regular fertilization based on soil testing, effective weed control, and the implementation of proper grazing management techniques.[56] Interseeding, which involves drilling seed directly into existing pasture without significant soil disturbance, can be used to introduce new forage species or to improve the density and productivity of existing stands.[38]

VI. Economic Significance of the Forage and Pasture Plant Industry in the United States:

- **6.1 Market Size and Value:**
  - The forage and pasture plant industry in the United States represents a substantial sector of the national economy, with an annual market valuation in the tens of billions of dollars.[10] In 2024, the market was valued at USD 23.3 billion, and projections indicate a significant growth to USD 34.9 billion by 2033.[13] Hay crop farming, a significant component of this industry, generated an estimated $44.7 billion in revenue in 2024.[68] Notably, hay ranks among the top three crops in the US in terms of economic return to farmers.[10] Millions of acres across the country are dedicated to the production of forage, underscoring the extensive land use associated with this vital industry.[6]
- **6.2 Contribution to Livestock Production:**
  - Forage and pasture plants serve as the primary feed source for the vast livestock industry in the United States, which includes beef cattle, dairy

production, and the raising of small ruminants, all contributing significantly to the nation's agricultural economy.[8] A substantial portion of a beef animal's diet throughout its life consists of forages, highlighting the direct and critical link between the availability and quality of forage and the success of the beef production industry.[9] The beef cattle industry alone generates billions of dollars in annual gross revenue.[69] Similarly, the dairy industry relies heavily on high-quality forages, such as alfalfa, to support milk production.[10] Furthermore, the cost-effectiveness of utilizing forage crops directly impacts the profitability of livestock operations by reducing their dependence on more expensive purchased feeds.[7]

- **6.3 Hay Production Statistics and Value:**
  - Hay production constitutes a significant market within the broader forage industry, with an annual value that reaches into the billions of dollars.[10] In 2008, the value of hay harvested in the United States was approximately $18.8 billion.[11] Each year, millions of acres across the US are harvested for hay, yielding millions of tons of forage that serve as a crucial feed source for livestock.[32] The average prices for different types of hay, including alfalfa hay and other hay varieties, fluctuate based on a variety of market conditions, such as overall supply and demand, the quality of the hay, and specific regional factors.[46] For instance, high-quality alfalfa hay, particularly dairy-quality hay, can command prices of several hundred dollars per ton.[46] Additionally, the United States is an active participant in the international hay market, exporting considerable quantities of hay to countries such as Japan and China.[73]

VII. Current Challenges and Future Trends:

- **7.1 Impacts of Climate Change on Forage Production:**
  - Climate change presents a significant array of challenges to forage and pasture plant production in the United States. Altered weather patterns, including more frequent and intense droughts, as well as shifts in precipitation regimes, are expected to reduce forage yields and quality, especially in regions already susceptible to water scarcity.[74] Rising average temperatures and an increased incidence of heat waves can negatively affect the growth and productivity of many forage species, potentially leading to heat stress in both the plants themselves and the livestock that consume them.[75] While elevated levels of atmospheric carbon dioxide can sometimes stimulate plant growth, they may also result in a decrease in the nutritional quality of forages, such as a reduction in protein content, which can impact the ability of pastures to adequately support grazing animals.[76] Changes in climate can also

favor the proliferation of invasive plant species over desirable native forage species, potentially disrupting the ecological balance of pasture ecosystems.[77] Furthermore, shifts in climate patterns could lead to an increase in the prevalence and geographical distribution of pests and diseases that affect both forage plants and livestock, necessitating adjustments in current management strategies.[76] Finally, rising temperatures and drier conditions in many parts of the country are likely to increase the demand for irrigation to maintain current levels of forage production, placing additional pressure on already strained water resources.[77]

- **7.2 Sustainable Forage and Pasture Management Practices:**
  - In response to the challenges posed by climate change and an increasing awareness of environmental stewardship, there is a growing emphasis on the adoption of sustainable forage and pasture management practices. Rotational grazing systems, where livestock are moved between different paddocks to allow for plant recovery and soil health improvement, are gaining popularity.[40] Adaptive Multi-Paddock (AMP) grazing, which mimics the natural grazing patterns of wild herbivores, is another method being implemented to enhance soil health and biodiversity.[80] Maintaining optimal stocking rates, ensuring that the number of animals grazing an area is in balance with the land's carrying capacity, is crucial for preventing overgrazing and promoting long-term pasture health.[40] Practices that focus on improving soil health, such as minimizing soil disturbance through reduced tillage, the use of cover crops, and the application of compost or other organic matter, can enhance the soil's ability to retain water and nutrients, as well as improve its overall resilience.[7] Implementing efficient water management strategies, including the use of appropriate irrigation techniques and the protection of riparian areas, is essential for conserving water resources and maintaining water quality in grazing systems.[40] Encouraging the growth of native plant species and minimizing the use of synthetic chemical pesticides and fertilizers can support greater biodiversity within pasture ecosystems, leading to enhanced ecological stability.[40] Finally, selecting and planting forage species that exhibit greater tolerance to drought conditions can help to mitigate the negative impacts of changing precipitation patterns.[40]
- **7.3 Emerging Technologies and Research:**
  - The future of forage and pasture plant production in the US will likely be significantly influenced by emerging technologies and ongoing research efforts. Precision agriculture technologies, such as virtual fencing systems that allow for the remote management of livestock movement, and remote sensing techniques for monitoring pasture conditions, hold the potential to

enable more precise and efficient grazing management.[77] Research in forage breeding continues to focus on developing new varieties with improved characteristics, including higher yields, enhanced tolerance to drought and other environmental stresses, increased resistance to pests and diseases, and improved nutritional quality for livestock.[81] There is also growing interest in research aimed at understanding and enhancing soil health in forage systems, particularly the role of soil microbial communities in nutrient cycling and overall soil fertility.[82] The development of decision support systems that integrate climate data, soil information, and forage growth models can provide producers with valuable tools for making more informed decisions regarding forage selection and management practices. Additionally, the use of annual forages is being explored as a flexible strategy to supplement perennial pastures, especially in response to unpredictable weather events like drought or as a way to extend the grazing season beyond the typical perennial forage growth periods.[74]

VIII. Recent Research and Reports on Forage and Pasture Plants in the United States:

- **8.1 Examples of Recent Research Areas:**
  - Recent research has focused on improving the characteristics of native grass species, such as little bluestem and Indiangrass, to enhance their germination rates and overall establishment success, particularly in challenging environments like the Southern Plains.[82] Studies have also been conducted to evaluate the potential of various alternative forage crops and different grazing systems to optimize livestock production and land management.[83] An area of increasing interest is the investigation of soil health and the role of microbial communities within forage systems, with researchers exploring how different management practices impact these vital soil components.[82] The development of forage varieties that exhibit improved tolerance to drought conditions is another key focus of current research, given the increasing concerns about water availability in many regions.[81] Additionally, studies have examined the effects of different grazing management techniques, such as patch burning, on forage production and ecosystem health.[82] Forage variety testing reports, which provide valuable data on the performance of different alfalfa and small grain varieties, are also regularly published.[71] Research continues to explore various aspects of forage quality and utilization by livestock, as well as effective strategies for managing pests and diseases that can impact forage crops.[71]
- **8.2 Specific Recent Reports and Publications:**

- Universities across the United States, through their extension programs, regularly publish reports and guides on various aspects of forage and pasture management. Examples include publications from the University of Idaho on small grains and alfalfa, and resources from Oregon State University Extension covering topics like pest management and the economics of forage production.[45] The USDA Agricultural Research Service (ARS) conducts ongoing research projects focused on improving forage germplasm and understanding the impact of different management practices on forage systems, with regular reports and publications detailing their findings.[82] Reports on the performance of different forage varieties, such as the Northern Idaho Alfalfa Variety Testing Report, provide valuable information for producers making decisions about which varieties to plant.[71] Research articles published in peer-reviewed scientific journals, such as studies on the effects of nitrogen fertilization on soil microbial communities and the field establishment of selected forage populations, contribute to the growing body of knowledge in this field.[82] Additionally, institutions like Texas A&M AgriLife Research conduct extensive research on forage breeding, genetics, and utilization across the diverse ecosystems of Texas, with numerous publications and reports available to producers and researchers.[81]

IX. Conclusion: Summary of the Importance and Future of Forage and Pasture Plants in the US

Forage and pasture plants are undeniably foundational to the agricultural sector of the United States. They provide the essential nutritional building blocks for a vast livestock industry, contribute significantly to the national economy, offer a multitude of environmental benefits, and hold a deep historical significance in the nation's development. The remarkable diversity of forage species, categorized by their adaptation to different temperature ranges, life cycles, and growth habits, allows for their cultivation across the varied climatic and soil conditions found throughout the US. Effective management and cultivation practices, encompassing soil fertility management, strategic irrigation, integrated pest and weed control, and thoughtful grazing techniques, are paramount for ensuring the long-term productivity and sustainability of these vital agricultural resources. The economic impact of the forage and pasture industry is substantial, not only underpinning the multi-billion dollar livestock sector but also generating significant revenue through hay production and related activities. Looking ahead, the industry faces challenges, most notably the increasing impacts of climate change, which necessitate a greater emphasis on the adoption of sustainable management practices and the development of more resilient forage varieties through ongoing research and innovation. The future of forage and pasture plant production in the United States will likely be shaped by the integration of emerging technologies, the continuation of focused research efforts, and a growing commitment to environmentally sound and sustainable production methods. In conclusion, forage and pasture plants will remain an indispensable component of the US agricultural landscape, playing a critical and enduring role in ensuring food security, promoting environmental stewardship, and sustaining the overall agricultural vitality of the nation.

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