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Review

Impact of Salt and Alkali Stress on Forage Biomass Yield, Nutritive Value, and Animal Growth Performance: A Comprehensive Review

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Abstract: This review investigates the impact of saline and alkaline soils on forage biomass yield, nutritive value, and their subsequent effects on animal growth performance, which are critical for sustainable livestock production. Soil salinity and alkalinity, driven by environmental factors and human activities, significantly affect forage yield and quality, with notable consequences for ruminant nutrition. While some forage species exhibit enhanced crude protein (CP) content and improved leaf-to-stem ratios under salt stress, others suffer from reduced growth and biomass yield. Saline-affected forages are often characterized by lower acid detergent fiber (ADF) and neutral detergent fiber (NDF) levels, enhancing their digestibility and making them a potentially valuable feed resource. However, high salinity levels pose significant challenges to consistent forage production in arid and semi-arid regions. Cultivating salt-tolerant forage species has emerged as a promising solution, offering a sustainable approach to addressing the dual challenges of soil salinity and livestock feed shortages. This review emphasizes the need for further research on salinity tolerance mechanisms and the development of resilient forage varieties. By integrating salt-tolerant forages and adopting effective management practices, livestock producers can ensure a reliable and high-quality feed supply while enhancing the growth performance of ruminant animals in salt-affected areas.

Keywords: biomass yield; coastal areas; forage nutritional value; minerals; salt and alkali stress

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1. Introduction

Forages are essential for feeding the world's population, especially grazing animals [1]. However, the increasing salinity and alkalinity of soil in coastal areas pose a significant challenge to forage production [2]. Salinity negatively affects plant growth, so it is important to find solutions to these challenges. Salinity affects plant growth through osmotic processes and ion concentration. Biosaline agriculture involves growing plants in saline-rich soil and groundwater, and the amount of edible biomass produced is crucial. Fortunately, there are salt-tolerant forage crops, like alfalfa, that can be grown in saline–alkali land to provide nutrition for livestock. Proper management and crop selection are vital for successful cultivation in saline areas. Salinity's effect on forage crops varies, with some exhibiting increased protein content and improved quality, while others suffer decreased growth and yield. Therefore, it is important to understand the nutritional value and biomass yield of forage grown in saline and alkaline soil. This understanding will help nutritionists formulate feed for ruminant animals based on factors such as age, growth, physiology, and production potential.

2. Salt and Alkali Soil Overview

A significant portion of the potential arable land resources are covered by saline–alkaline land [3]. More than 8.3 × 10^8 of the world's soil is affected by soil salinization [4–6]. Salt buildup in the soil can really screw things up for farmers in dry areas. Too much groundwater, bad irrigation methods, poor irrigation water quality, and land elevation all contribute to soil salinization, making it hard for plants to thrive and reducing land value and productivity [7]. In arid and semi-arid regions of the world, salt stress and a lack of water are major causes of the scarcity of pasture resources [8]. Potential yield losses are projected to be 17% and 20% under salinity and drought, respectively [9]. The amount of salt in the soil can have a huge impact on how well crops grow. This is becoming more and more of an issue, especially with the intensification of farming and climate change. Salt and alkaline levels do not always go hand in hand. Sometimes, the soil may have a high salt content but a low pH or a low salt content but a high pH. It is a complicated problem [10]. Two different kinds of salts can be found in soils neutral salts, such as NaCl and Na_2SO_4, and alkaline salts, like $NaHCO_3$ and Na_2CO_3, and they can both be pretty stressful for plants. We call this "salt stress" and "alkali stress", respectively [11].

Many factors affect the salinity and alkalinity of soil. Sodium carbonate or sodium bicarbonate in the soil, inadequate cultural practices, high surface evaporation, low precipitation, and excessive chemical fertilizer application are a few of these [12]. Furthermore, electrical conductivity (EC) and pH are correlated in saline soil, making soil salinity and pH significant factors that impact soil quality [13]. Although it can also happen in humid areas with high water tables or poor-quality irrigation water, soil salinity and related issues are more prevalent in arid or semi-arid climates where rainfall is insufficient to remove soluble salts from the soil [14]. Parent material, mineralogy, topography, and human activity all have an impact on the genesis of salt-affected soils and groundwater of low quality [15]. Chemical amendments, salt leaching, better irrigation, agronomic techniques, using salt-tolerant varieties, and alternative land uses are some management strategies for salt-affected soils [16].

Taking everything into account, forages play a vital role in feeding grazing animals and providing food for the world population. Soil salinity and alkalinity pose challenges to crop growth, particularly in coastal areas, and are influenced by factors such as farming practices and climate change. Understanding and managing these issues are crucial for sustainable agriculture and food production.

3. Forage Biomass Buildup on Salt and Alkaline Soil

3.1. The Effect of Salt and Alkaline Soil on Forage Biomass and Seed Yield and Seed Quality

The production of forage biomass is significantly impacted by the salinity and alkalinity of the soil. Salinity affects the growth of plants by interfering with certain ions and osmotic processes, leading to a loss of water content in cells and a decrease in turgor [17]. Research has shown that crop biomass and crude protein yields on saline–alkali land can be comparable to conventionally farmed land when salt content is low [18]. Additionally, some species of plants, for example, *Arundo donax*, have demonstrated resistance to alkaline salt stress and maintained physiological parameters under stress conditions [19]. Studies have also found that transplanting seedlings yields better results than direct sowing [20]. Therefore, it is crucial to choose forage crops resistant to salt and implement appropriate cultivation methods to mitigate the detrimental effects of salt and alkaline soil on forage biomass production.

The salinity of irrigation water has been found to have a direct impact on the biomass yield of Bermudagrass, with an increase in salinity leading to increased biomass production [21]. Furthermore, studies have shown a strong linear correlation between the number of days after salinization and the cumulative biomass accumulation of forages [20,22]. Research studies have also determined the ranking of forages based on the percentage reduction in biomass accumulation (Figure 1) due to higher levels of salinity (25 ds/m) in irrigation water [23]. Moreover, when compared to treatments solely based on salinity, treatments involving $MgSO_4$ and $CaSO_4$ were found to enhance the biomass of tall fescue and red clover [24].

Plant height serves as a reliable indicator of plant stress tolerance. The growth of *S. salsa* (*Suaeda salsa*) was significantly aided by low-salinity irrigation water. As irrigation water salinity increased, there was an initial increase and subsequent decrease in plant height and aboveground biomass Fresh Weight (FW) and dry weight (DW), with the maximum growth observed at 20 g/L salinity. In comparison to lower-salinity irrigation water, the treatment with irrigation water of 30 g/L or 40 g/L salinity showed a decline in plant height and FW and DW aboveground biomass, although they were still higher than those of the control [25]. Salinity, either alone or in combination with sodicity, resulted in a reduction in plant height and biomass accumulation [26]. In the case of exposure to sodic or alkaline conditions, *D. annulatum* (*Dichanthium annulatum*) either maintained its plant height and biomass accumulation or experienced a marginal decrease relative to the control; specifically, there was a decrease of 1.8% at pH 9.5 and 3.78% at pH 10.0. Plant height exhibited a decreasing pattern when subjected to mixed saline sodic stress and saline stress alone.

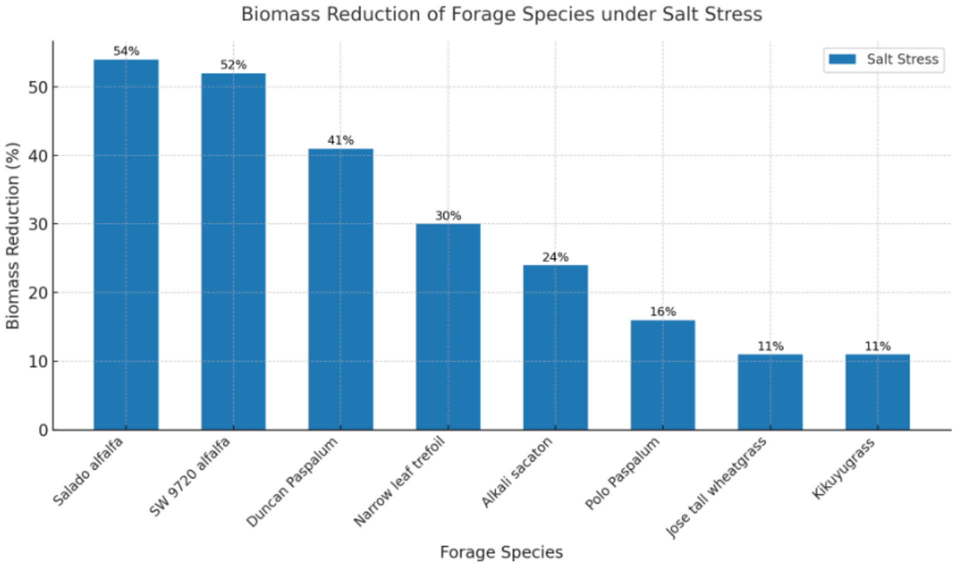

Figure 1. Different forage species exhibit varying responses to salt stress in terms of biomass yield [23].

Some studies emphasize the importance of maintaining an optimal leaf area index and plant height to maximize dry matter yields in forage grasses. Decreases in the leaf area index and plant height have been found to have a significant impact on the dry matter yields of forage grasses, particularly *Sorghum sudanese* and *Pennisetum antidotale* grasses [27]. This finding is consistent with the research conducted by [28–30], who have also reported a decrease in dry matter yields associated with a decrease in the leaf area index and plant height. In saline soils, plants face additional challenges as they need to expend more energy to take up water, resulting in a decrease in water intake from the soil. This situation has a negative impact on both the dry matter yield and quality of forage grasses [31]. To address this issue, an emerging agricultural strategy is the utilization of naturally salt-tolerant species that can provide forage resources in saline and arid environments. The approach proposed by Hessini et al. [31] presents a promising solution for sustaining forage production in the face of challenging soil conditions. Furthermore, a study conducted by Hoffman et al. [32] found that salinity actually increased the ratio of alfalfa leaves to stems, thereby marginally enhancing the quality of the feed. This finding adds another dimension to the understanding of how salinity can affect the nutritional composition of forage grasses.

Forage plants may experience health problems from high salinity and alkalinity. These circumstances may limit the availability of water and impede the growth of other fodder species, which will lower the yield of crude protein and biomass [33]. High salinity and alkali content saline–alkaline soils can reduce crop utilization value and production potential [34]. Nonetheless, some forage plants have demonstrated tolerance to these unfavorable soil conditions, including tall wheatgrass and Panicum coloratum var. coloratum [35,36]. Research has demonstrated that alkalinity can adversely impact photosynthesis and PSII activity in plants, which may lead to growth restrictions in alkaline environments. For ruminant livestock to flourish on saline soils, saline-tolerant forage plants must be developed. However, for these plants to successfully adapt to saline land, certain traits must be understood.

In soil that is alkaline and salted, halophytes can be established as forages. These plants can be grown in coastal areas where there is a shortage of fodder because they can withstand high salinities [37]. According to several studies, halophytes with high levels of organic matter, crude protein, and digestibility—such as Halostachys caspica, Salicornia emerici, Sarcocornia alpini, Sarcocornia fruticosa, Alhagi maurorum, Bassia scoparia, Noaea mucronata, and Cressa cretica—have good forage potential [38–40]. These halophytes offer a sustainable and environmentally beneficial substitute for conventional fodder crops since they can be cultivated in arid–saline conditions [41]. Successful reclamation of saline soils has been demonstrated through the use of halophytes in phytoremediation, which has been demonstrated to improve soil functioning and increase soil microbial diversity.

Forage seed production is significantly impacted by salinity and alkalinity levels in the soil, as these factors can adversely affect seed germination, plant growth, and overall yield. High salinity can lead to osmotic stress, limiting water uptake and causing physiological damage to plants [42,43]. Additionally, alkalinity can alter nutrient availability, further hindering forage quality and quantity [44,45]. These stresses have the potential to upset the equilibrium of ionic distribution and water potential, which could have a negative impact on the development, growth, and yield of fodder crops [33]. Stresses related to salinity have a special effect on cool-season forage crops like red clover, tall fescue, timothy grass, and alfalfa. These factors limit the successful growth of these crops and reduce their yield [46]. Nonetheless, these crops have demonstrated the capacity to sprout and develop in moderately salinized environments, and they can bounce back when salinity conditions are eliminated [47]. The germination and emergence of forage species under varying NaCl concentrations have been assessed in the Cienega de Chapala region, where water scarcity and rising salinity are limiting factors. Some species have demonstrated tolerance to salt concentration, including *Lolium perenne* and *Hordeum vulgare* [48]. Furthermore, halophytes, like alfalfa, can be selected for tolerant cultivars based on their ability to germinate in saline–alkali substrates [37].

Forage seed quality is significantly impacted by salinity and alkalinity. Many studies have been conducted on the physiological mechanisms that tall wheatgrass uses to tolerate abiotic stresses, like salinity and alkalinity [33]. According to [34], salinity is a process of soil degradation that prevents plants from absorbing water and nutrients, which lowers fertility and agricultural productivity. Spice development, growth, and yield are all impacted by salinity and alkalinity stress, which upsets the balance of ionic distribution and water potential [46]. Saline and alkaline soils were found to reduce plant heights and dry matter yields, alter the ratios of neutral detergent fiber to crude protein, and affect the dry matter yields in a study comparing four species of forage grass [49]. Salinity and alkalinity have an impact on alfalfa germination in saline–alkali substrates as well; low salinity encourages the growth of radicals [50]. Forage seed quality is generally negatively impacted by salinity and alkalinity, which also affects plant growth, yield, and nutrient composition.

Overall, salinity and alkalinity significantly impact forage seed production and quality, plant growth, yield, and nutrient composition, affecting the balance of ionic distribution and water potential. Cool-season forage crops are particularly sensitive to these stresses, reducing their growth and yield. However, these crops can still thrive in moderately salinized environments and recover when salinity is eliminated. Some forage species exhibit tolerance to salt concentration. Selecting salt-tolerant cultivars, like halophytes, such as alfalfa, can enhance germination in saline–alkali substrates. Managing these factors is crucial for optimizing forage production and ensuring sustainable agriculture practices in salt-affected areas.

3.2. The Causes or Mechanisms of Reduced Forage Biomass Yield

The reduced plant biomass yield in saline and alkaline soil can be attributed to several factors. One of the main causes is the imbalance in essential nutrients, such as nitrogen (N) and carbon (C), due to salt stress [19]. Salt stress inhibits N and C assimilation, leading to decreased biomass accumulation and seed yield [12]. Additionally, saline–alkaline stress results in trophic ion imbalance and reduced osmotic adjustment capacity, further impacting plant growth and productivity [51]. The presence of high amounts of sodium carbonate (Na_2CO_3) or sodium bicarbonate ($NaHCO_3$) in saline soil exacerbates cellular oxidative stress and reduces the uptake rates of essential nutrients, contributing to decreased plant biomass yield [52]. Furthermore, the poor physicochemical conditions of saline–alkali soil, including high salt content and alkalinity, negatively affect plant physiology and biochemical processes, leading to reduced crop production [53]. Overall, the combination of nutrient imbalance, trophic ion imbalance, and poor soil conditions in saline and alkaline soil contributes to the reduced plant biomass yield.

Salinity has been identified by Khan et al. and Belouchrani et al. [54,55] as a factor that can disrupt the nutritional and water equilibrium in plants, ultimately leading to a decrease in crop yield. The phenomenon of salt tolerance in plants is complex, involving various interconnected factors, such as morphological, physiological, and biochemical processes. The presence of Na^+ and Cl^- ions, while toxic to plants in high concentrations, can be beneficial under certain conditions, helping regulate osmotic potential and supporting plant adaptation in saline environments [56,57]. Among different plant species, legumes were found to be particularly sensitive to salt. For example, the narrow-leaf trefoil exhibited a slope ratio of 0.59, while the alfalfa cultivars had slope ratios ranging from 0.52 to 0.53. The broadleaf trefoil “Big” even perished at 25 dS/m shortly after salinization. Despite its remarkable growth rates under both salinity levels, the “PI 299042” paspalum demonstrated greater sensitivity to salinity with a slope ratio of 0.64, in contrast to the other grasses that exhibited higher salt tolerance, with slope ratios ranging from 0.85 to 1.11. Ideally, forage species with high biomass production potential, high salt tolerance, and excellent forage quality should be considered for use in saline water reuse systems. The performance of the tested forage species in terms of absolute biomass accumulation and biomass accumulation in relation to salinity level varied significantly. Over time, bermudagrass, “Jose” tall wheatgrass, and “PI 299042” paspalum exhibited the highest biomass production at 25 dS/m [58].

In the process of plant growth and development, the accumulation of specific ions, such as sodium and chloride, over time can have a direct impact on internal chemical reactions. This buildup of ions leads to osmotic stress, which can have immediate and detrimental effects on seed emergence and seedling vigor. However, the combined effects of certain ions exacerbate these negative impacts. To counteract the pressures caused by osmotic stress, certain plants that have developed salt tolerance mechanisms are capable of restricting the movement of salt and eliminating it at the source. These plants achieve this by transferring salt ions from the cytoplasm to the shoot [17]. Under various environmental conditions, the root plasma membranes play a crucial role in determining how plants grow and develop [59,60]. These membranes contain sophisticated sensors that can rapidly respond to stressors by transmitting signals from inside the cells to other parts of the plant. They are capable of detecting changes in soil pH, water stress, and nutrient availability [59,61]. In this process of signal transduction and stress response, lipids play a vital role in determining the physicochemical characteristics of the membranes [62,63]. The lipid content of roots is known to vary among different plant species, organs or organelles, growth stages, and environmental growth conditions [60,64–66].

By understanding the interplay between ion accumulations, osmotic stress, salt-tolerance mechanisms, root plasma membranes, and lipid composition, researchers can gain valuable insights into the mechanisms underlying plant responses to environmental stressors. These insights can contribute to the development of strategies for improving crop productivity and resilience in challenging growing conditions.

4. Effects on Forage Nutrient Concentration and Quality

Proteins, fiber, and mineral elements such as phosphorous, potassium, and calcium are essential for the well being of livestock, as they are vital nutrients [67]. When evaluating forages, it is crucial to consider the concentrations of protein, fiber, and mineral nutrients, as they directly contribute to the nutritional value of the feed [68]. The nutritional composition of plants and forages is influenced by various factors, including soil type, water availability, and climate variations [69]. Additionally, the chemical makeup of forages can vary depending on the species or cultivar, as well as the age of the plant and the fertility of the soil. These factors collectively affect the overall nutritional profile of the forage. Salinity levels in irrigation water can trigger different metabolic responses in various plant species, leading to significant variations in the chemical composition and in vitro digestibility parameters of forages [70]. Therefore, it is crucial to analyze the quality of forages to understand how genotype, plant maturity, season, anti-nutritional factors, and management practices affect their composition. However, soil salinity can impact plant metabolism, which in turn can affect the chemical composition of the plant [30]. A decrease in yield due to salinity can result in changes in the chemical composition of the forage, further emphasizing the importance of considering both plant growth and nutrient quality.

In summary, the nutritional value of forages is determined by a complex interplay of factors such as protein, fiber, and mineral concentrations, soil type, water availability, climate variations, salinity levels, and plant metabolism. Understanding these relationships and conducting thorough analyses of forage quality is crucial for ensuring optimal livestock nutrition and management practices.

4.1. Protein and Fiber Content

Salinity tolerance of various forage crops, including alfalfa, big trefoil, narrow leaf trefoil, kikuyu grass, alkali sacaton, paspalum, tall wheatgrass, ryegrass, and bermudagrass, has been studied. The impact of salinity on crude protein (CP) content in these forages has been explored, and the results are not consistent [23]. However, higher salinity levels did increase the CP content in the first and fifth cuttings of forages [23]. As the salinity of irrigation water increased, the crude protein (CP) content initially increased due to improved osmotic regulation but later decreased when salinity reached a threshold that hindered nutrient uptake and plant growth [25]. The highest concentration of CP was recorded at a moderate salinity level of 20 g/L. The neutral detergent fiber (NDF) content of the forages ranged from 42.93% to 50.00% dry weight (DW). When these crops were irrigated with water having a salinity of at least 20 g/L, there was a significant decrease in NDF content [23,71]. Interestingly, ryegrass exhibited a decrease in NDF content and an increase in in vitro digestibility when irrigated with saline water [23]. The estimated metabolizable energy (ME) value, gas production, dNDF (digestible neutral detergent fiber), IVTD (in vitro true digestibility), and gas production of the forages were not significantly affected by the salinity level [23,71]. However, the decrease in NDF content with higher salinity levels of irrigation water is consistent [23].

In alfalfa irrigated with saline water, a lower growth rate results in lower levels of acid detergent fiber (ADF) and neutral detergent fiber (NDF) and higher levels of shoot nitrogen (N). Salt-affected plants may exhibit a 6% increase in the leaf-to-stem ratio, shoot N, and CP due to shorter internodes and decreased height. A high leaf-to-stem ratio is generally an indicator of higher nutritional value in forages [72]. The decreased height of salt-affected plants also leads to decreases in ADF and NDF content, improving forage quality. Additionally, there is a significant increase in CP content among control plants and those subjected to higher salinity levels, reflecting the increased accumulation of leaf N with increased salinity [73]

The changes in protein and fiber content in forages growing in salt and alkaline land can be attributed to various factors. Salinity and alkalinity stress can lead to reduced nutrient uptake and impaired metabolic processes, resulting in a lower nutritional value of forages [33]. However, certain plant species, such as tall wheatgrass and rapeseed, have shown tolerance to these conditions and have mechanisms in place to cope with the stress. These mechanisms include strategies to avoid ion toxicity, acquire essential nutrients, and cope with high pH levels and excess reactive oxygen species [74]. Furthermore, enriching certain crops, like rapeseed, with sodium ions can help reduce soil salinity and improve forage productivity [75]. The genetic characteristics and physiological adaptations of plant species play a crucial role in determining the protein and fiber content of forage growing in salt and alkaline land.

Overall, the impact of salinity on forage crops is complex and varies depending on the specific crop and the level of salinity. While some crops show increased protein content and improved forage quality under higher salinity levels, others may experience decreased growth and yield. Further research is needed to better understand the mechanisms underlying salinity tolerance in forage crops and to develop strategies for improving forage productivity in salt-affected areas.

4.2. Ash and Mineral Content

The ash contents of forage crops are significantly influenced by the salinity and alkalinity of the soil. Research conducted by [53] found that the use of saline irrigation water affected the nutrient status of crops, such as fodder beet and forage corn. Higher levels of water conductivity were associated with an increase in phosphorus (P) content in these crops. While salinity stress resulted in a decrease in crop biomass, it had no discernible impact on the uptake of micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and boron (B) [76]. However, disruptions in the absorption of calcium (Ca) and magnesium (Mg) were observed in the investigated crops [35]. Rapeseed, on the other hand, has the potential to reduce both the total salt content and the Na^+ content of the soil due to its higher enrichment of Na^+ compared to other crops [77]. These findings indicate that the salinity and alkalinity of the soil have an impact on the mineral contents of forage crops. They highlight the importance of controlling fertilization and selecting salt-tolerant cultivars to achieve optimal forage production on saline and alkaline land [34]. A different study by Singh et al. [77] examined the biomass and crude protein content of six field crops (corn, sorghum, wheat, millet, soybean, and rapeseed) planted in saline–alkali soil. The results demonstrated that each crop's biomass and crude protein yield and the ash content of each crop significantly decreased at a specific soil salinity level.

It was found that the chemical makeup and mineral content of S. salsa, a type of plant, were significantly affected by halophytes. Halophytes are plants that grow in brine irrigation. As the salinity of the irrigation water increased from freshwater to high salinity, the ash content of S. salsa increased [25]. The concentration of macro-elements such as sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), and chloride (Cl) also increased with the rise in salinity. The highest concentrations were observed for chloride ions (Cl^-) and sodium ions (Na^+), which were 1.63 and 2.02 times greater than the control, respectively. Additionally, copper (Cu) and zinc (Zn) contents increased significantly compared to the control [25].

The changes in ash and mineral content observed in forage crops growing in saline and alkaline land can be attributed to the high salt concentrations present in the soil. Salinity stress affects plant growth and can lead to reduced crop yield. However, certain forage crops have the ability to tolerate and adapt to high salt levels in the soil. Studies have shown that halophytic grasses and legumes tend to grow in areas with increasing soil salinity, indicating their tolerance to salt stress [78]. Additionally, specific forage crops, like forage pea and rapeseed, exhibit varying levels of tolerance to increasing salt concentrations. Some varieties of these crops have higher germination rates and biomass production compared to others [22,24]. These crops can accumulate sodium ions in the soil, reducing the overall salt content and improving the quality of the land [79]. Therefore, the selection and cultivation of salt-tolerant forage crops can help mitigate the negative effects of salinity on ash and mineral content in saline and alkaline land [77].

In summary, soil salinity and alkalinity significantly affect forage crops, impacting ash contents and mineral composition. Salinity stress reduces crop biomass but has no discernible impact on micronutrient uptake. Calcium and magnesium absorption may be disrupted. Certain forage crops, like rapeseed, can reduce soil salt content. Halophytic grasses and legumes tolerate increasing soil salinity. Selecting salt-tolerant forage crops and controlling fertilization are crucial for optimal production in saline and alkaline land. High salt concentrations in the soil influence ash content and mineral composition. Choosing salt-tolerant forage crops helps mitigate salinity's negative effects.

4.3. Nutrient Digestibilities

The nutrient digestibility of fodder can be influenced by the salinity and alkalinity of the soil. High salt concentrations in saline–alkaline soils can result in lower crop biomass and crude protein yield, consequently reducing the availability of nutrients for animals [34]. Feeding salt-tolerant forages grown on saline–alkaline land can enhance total volatile fatty acid production and improve rumen fermentation. However, it may also reduce feed digestibility throughout the animal's digestive tract [35]. It is important to note that salt-tolerant forages generally have low protein digestibility and content, which may necessitate additional protein supplementation to meet animal needs [18]. In the case of salt-affected soils, certain legume species, such as Medicago sativa, have been found to have higher feed values compared to other species [80]. The impact of saline and alkaline soil on the nutrient digestibility of fodder is determined by variables such as salt content, plant species, and their interactions.

A nutritional evaluation study conducted on *Lotus corniculatus*, *Trifolium alexandrinum*, and *Medicago sativa* revealed that forages and forage–salt interactions had an impact on gas production up to 48 h, organic matter digestibility, metabolizable energy (ME), and net energy lactation (NEL). However, salinity did not affect in vitro gas production or its kinetics and and estimated parameters [81]. In vitro dry matter (DM) digestibility, which has a strong correlation with in vivo digestibility, is commonly used to evaluate the nutritional quality of feeds [82]. In vitro gas production has also been developed as a predictive tool for nutrient content. Despite extensive research on the mechanisms of salt injury and salt tolerance in plants, the effects of salt stress on nutrient content, in vitro gas production, organic matter degradability, metabolic processes, and net energy lactation levels of forages have not been thoroughly studied. Further research in these areas would provide valuable insights into the impact of salt stress on the nutritional quality of fodder [81].

In summary, the nutrient digestibility of forage crops can be influenced by soil salinity and alkalinity. High salt concentrations in saline–alkaline soils can reduce crop biomass and crude protein yield, impacting nutrient availability for animals. Feeding salt-tolerant forages can enhance volatile fatty acid production and rumen fermentation but may decrease feed digestibility. Salt-tolerant forages generally have low protein digestibility, requiring additional protein supplementation. Certain legume species, like Medicago sativa, have higher feed values in salt-affected soils. Further research is needed to understand the effects of salt stress on nutrient content and in vitro gas production of forages. Managing salt-affected soils and selecting salt-tolerant forage crops are important for maintaining nutritional quality in fodder.

5. The Effects of Saline–Alkali Growing Forage on Animal Performances

5.1. Growth Performances

The variation in mineral content affects the composition of plants grown in soils with different salinity and alkalinity levels, subsequently impacting the mineral requirements of animals [83]. To ensure the healthy growth and reproduction of animals, it is essential to meet their daily nutritional, energy, and mineral needs [84]. Insufficient or excessive mineral intake can negatively affect an animal's health, reproduction, and nutrition [83].

When ruminants consume a diet with a salt content exceeding approximately 2%, their nutritional value decreases [85]. Weaned wethers found that when fed a low-salinity diet (Na = 0.2%, K = 1.6%), they consumed 4 L of water and 1.4 kgDM of feed daily [86]. However, when the Na content was increased to 7.4%, the wethers consumed up to 12 L of water daily, with feed intake dropping to 1 kgDM per day. The high salt load not only leads to increased water intake but also negatively affects the ability of rumen microbes to digest feed [86]. The increased water intake caused by the high salt content leads to faster passage through the rumen, resulting in quicker breakdown of organic matter by rumen microbes. However, the limited capacity of the gastrointestinal tract leads to reduced feed intake when animals consume more water. This reduced feed intake has immediate negative effects on animal performance and incurs metabolic costs due to the high dietary salt content [87].

Using a mixture of salt-tolerant forages rather than a single species enhances animal productivity [88]. Salt-tolerant plant species typically have high crude protein, low metabolizable energy, and high salt content [89]. Sheep grazing solely on saltbush experienced reduced feed intake and weight loss [88]. However, when saltbush leaf was combined with oat hay, feed intake and daily weight gain improved. Grazing on a combination of saltbush, legumes, and grasses that tolerate salt, as suggested by [90], maximizes animal output in terms of feed intake and growth rates on saline land. The combination allows for complementarity in feed formulation and better utilization of available feed resources, as high fiber restricts the intake of oaten hay and high salt restricts the intake of halophytes [86]. According to [91], feeding sheep a combination of halophytes and low-quality oaten hay (50 percent of each) resulted in significantly higher live weight gain and feed intake compared to feeding each component alone. Increasing the consumption of salt-tolerant forages in lambs led to increased feed intake but had no effect on average live weight gain or final body weight, resulting in decreased feed efficiency. However, the addition of more salt-tolerant forages to their diet increased lambs' carcass weight, meat output, and meat-to-bone ratio [91].

Higher salt concentrations in the forage will have varying effects on feed intake based on the particular circumstances. According to some research, eating a lot of salt may negatively impact an animal's ability to grow and reproduce. It may also reduce the placenta's ability to regulate hormones and other inflammatory factors [92]. Other research, however, has discovered that, in some circumstances, natural brackish or saline water has no effect on feed or water intake [93]. One way to encourage the development of ruminant livestock on such lands is to develop forage crops that can withstand saline soils [35]. The salt concentration thresholds that may lead to decreased water and/or feed intake and/or diet digestibility require more investigation [34].

In conclusion, the mineral content of plants and the composition of animal diets are influenced by the acidity and alkalinity of the soil. Providing a balanced diet that meets the nutritional, energy, and mineral needs of animals is crucial for their health, reproduction, and overall performance. Using a combination of salt-tolerant forages can enhance animal productivity on saline land.

5.2. Meat Quality

The quality of animal meat can be significantly influenced by the presence of alkaline and saline soil conditions. When saline water is used as a substitute for freshwater, it can have negative consequences on various aspects of farm animals' well being, including their performance, carcass features, and overall meat quality [18]. Elevated pH levels due to saline-induced stress can reduce post-mortem lactic acid, affecting meat acidity, color, and shelf life [94]. Studies show that saline forages, such as saltbush, affect muscle water-holding capacity and texture due to altered ion balance [95]. Importantly, feeding saltbush and similar forages does not negatively impact sensory qualities, making these plants viable in saline-affected regions [95]. However, a potential solution lies in the development of saline-tolerant forage plants that can thrive in saline soils. This development can greatly benefit ruminant livestock, as it leads to improved forage production, enhanced animal performance, and better nutritional outcomes [96]. In regions where both water and soil salinity pose challenges, saltbush hay has emerged as a promising feeding resource. Notably, incorporating saltbush hay into animal diets has been found to have no detrimental effects on the physical, chemical, nutritional, or sensory quality of sheep meat [35]. This makes it a viable option for ensuring optimal meat quality in areas affected by salinity issues.

Generally, the quality of animal meat can be influenced by alkaline and saline soil conditions. The use of saline water instead of freshwater can negatively impact animal well being, performance, carcass features, and meat quality. Developing saline-tolerant forage plants can improve forage production, animal performance, and nutritional outcomes.

6. Conclusions and Future Outlook

The growth of forages is limited by the salinization and alkalinity of the land, which is exacerbated by intensified farming practices and climate change. However, some plant species can tolerate high salt levels and can be grown in saline–alkali land, providing feed for livestock. Despite challenges, forages grown in saline and alkaline soil have higher nutritional values that can enhance meat quality. Nutrient digestibility may be affected, requiring additional protein supplementation. Utilizing salt-tolerant crops and proper management can help overcome these challenges and provide feed for livestock in saline–alkali areas.

In future studies on forages grown in saline and alkaline soil, it is important to focus on understanding the relationship between ions, soil properties, osmotic stress, salt tolerance, root membranes, and lipid composition, which provides valuable insights into how plants respond to environmental stress. Additionally, research should emphasize the selection and management of salt-tolerant forage crops, as well as the potential benefits of utilizing halophytic grasses and shrubs. These insights aid in developing strategies to enhance crop productivity and resilience in challenging conditions. Understanding these aspects will help overcome the challenges posed by high salt levels in the soil and provide improved feed options for livestock in saline–alkali areas.

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