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Review Article

Management practices to offset the declining trend of alfalfa hay production

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Abstract

Agriculture in the United States (US) is a major industry, which is the net exporter of food. The livestock sector is a centerpiece of the industry, and the base for this sector is forage resources. A forage-livestock production system is the largest economic agricultural sector in the US, and it feeds millions of people each day. More than half of the US land area has been devoted to cultivating forage crops mainly for livestock feed. In spite of the several options of forage crops available to growers to choose for production, the suitable choice often relies on the quality and quantity of hay that can be produced by the crop to meet production objectives. Alfalfa (*Medicago sativa* L.), the world's premier forage crop, remains to be the number one choice for livestock feed due to its ability to produce high yields of sustained nutritive value. However, recent data shows that on the national average, alfalfa hay yields are decreasing with a direct and indirect consequent effect on the nation's economy. Implementing efficient agronomic management practices in the alfalfa production system is a step in the direction of successful production. Along with the initial soil fertility status, integrating production factors including phosphorus and potassium fertilization, cultivar, and harvest management can be advantageous to ensure an improved physiology of alfalfa for greater hay production in the long term.

Core ideas

- Alfalfa hay production in the US has been decreasing over the past 3 decades.
- Reduced hay yields of alfalfa pose significant challenges to the forage-livestock production system.
- There is a critical need to continually improve the productivity of alfalfa.
- Appropriate agronomic amendments present opportunities to enhance alfalfa production.
- Annual application of phosphorus and potassium to high-yielding alfalfa cultivar based on the initial soil fertility status, and harvest time have a great potential for higher hay yields.

Introduction

The United States of America is the third largest country in the world by population (338 million), falling far behind China (1.4 billion) and India (1.3 billion). By the year 2060, the United States (US) population is expected to increase to 417 million [1-3]. This means that there will be a continual increase in the US population and therefore, demand for food, especially meat and milk products, will rise significantly. Consequently, the need for forage crops will also increase, because they are the prime source of feed for livestock on thousands of American farms and ranches [4]. Alfalfa (*Medicago sativa* L.), the "Queen of forages," is the most widely grown forage crop in the US [5] and it is primarily used for hay production. It has been well-documented to be the best forage crop in many countries throughout the world [4,6-8] due to its exceptional production abilities.

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Forage yield is the most important factor that determines profit in alfalfa production [9]. In view of this, breeders often release new alfalfa cultivars with improved yield traits in the market every year. However current data indicate that alfalfa growers across the US are faced with the challenge of sustaining high hay yields [10]. Given the importance and high demand for alfalfa hay [11], it is meaningful to invest in proper agronomic practices to sustain improved alfalfa production. Implementing an appropriate agronomic management practice in alfalfa forage systems is important to a successful production. It enhances sustained production in a friendly environment for the benefit of both producers and consumers. This paper, therefore, aims to review the most pressing agronomic practices critical to alfalfa production fortunes.

The declining trend of alfalfa hay yield and its consequences

Since the inception of Western agriculture in the 1850s, several advances have been made to develop alfalfa cultivars with greater yielding potential and better tolerance to diseases and pests. In 1919, the US produced a nearly doubled average alfalfa hay yield (from ~ 5,604 to 10,312 kg ha^{-1}) and a consistent increase through to the mid-1980s [12]. Since then, alfalfa hay production in the US has been decreasing at an alarming rate over the past 3 decades (Figure 1) [10]. The report suggests that improved alfalfa hay yield has a positive correlation with cattle herds (Figure 2), which indicates that the ongoing declining trend of alfalfa hay yield has a high tendency of posing significant challenges to the economic development of the US because cattle production contributes the highest cash receipts (~ $ 78 billion) to the nation's economy [13]. Furthermore, it is suggested to contribute the most to the recent economic and environmental pressure in the dairy sector [13,14]. This comes up with a major problem, particularly for scientists, policymakers, and other stakeholders who are working around the clock to feed a continually increasing population.

A recent study reported that alfalfa acreage has declined by 40% over the past 5 decades and as a result, the expected average hay yield in a region is not achievable with what growers actually receive from their farms [15]. For example, average hay yields obtained in 2019 from Arizona (20,510 kg ha^{-1}), California (17,543 kg ha^{-1}), and Wyoming (3,811 kg ha^{-1}) were about half of the estimated annual average hay yield of 54,000 kg ha^{-1}, 35,999 kg ha^{-1}, and 5,600 kg ha^{-1}, respectively [13,16]. Alfalfa has been the focus of scientific research for the past 3 to 4 decades, and much development has been made throughout this period [17]. The advances made in improving the genetics of alfalfa to develop adapted and resistant cultivars have contributed the most to maximizing alfalfa production. However, it is worth highlighting that alfalfa is a long-lived plant that is capable of growing for many years after planting. For growers to attain the long-term perennial benefits of the plant and sustain high production, there is a need to maintain a healthy and productive stand.

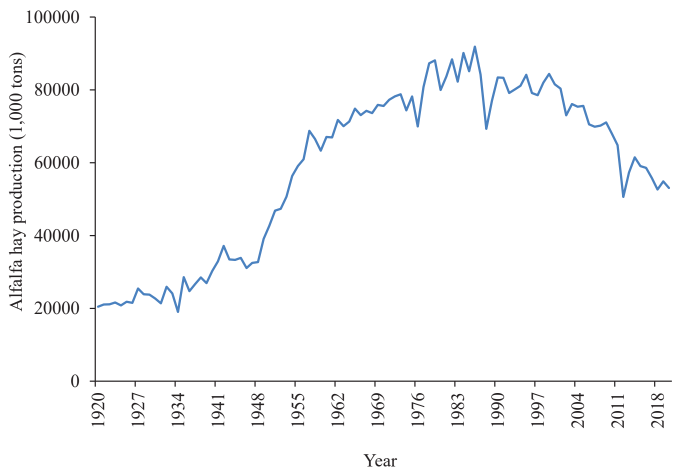

Figure 1: Alfalfa hay production in the United States from 1920 to 2020 [10].

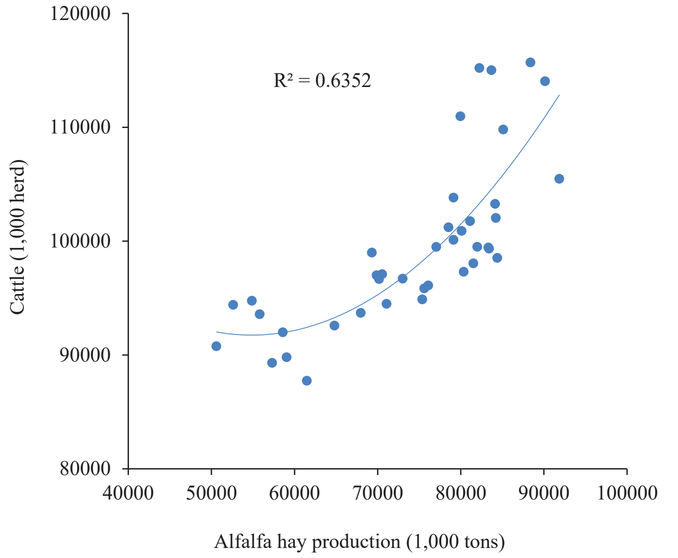

Figure 2: Relationship between alfalfa hay production and cattle herd in the United States [10].

Factors affecting alfalfa's growth and development

As a perennial forage legume, alfalfa often for 4 to 8 years, but it can live more than 20 years depending on the cultivar, climate, soil factors, and management practices [18]. The plant has a deep root system, which typically grows to a depth of 2 meters - 3 meters depending on subsoil constraints. Under favorable conditions, the root can grow to a depth of more than 15 m to reach groundwater and take up nutrients. The deep root system and perennial crowns of alfalfa store carbohydrates as an energy reserve which makes it very resilient, especially to drought. Alfalfa is more drought-hardy than drought-tolerant and its stand life depends on proper management practices [19]. Growing conditions including soil type, soil fertility, local climate, moisture conditions, pest and diseases, and weed pressure are significant factors that influence the growth and development of alfalfa.

Soil type

The type of soil for production affects alfalfa's growth through its physicochemical properties and indirect characteristics such as water holding capacity, soil depth,

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soil aeration, soil temperature, and nutrient availability. For example, unfavorable soil conditions such as a shallow rooting layer create a poor environment for adequate root growth, which limits water and nutrient uptake by the plant root. It reduces the availability of resources required by the plant for satisfactory growth [20] and negatively impacts development by altering growth patterns, which affects productivity. Generally, alfalfa requires well-drained soil for optimum production. Wet soils create conditions suitable for diseases that kill seedlings and established plants. Soils should be deep enough to have adequate water-holding capacity and allow for proper functioning of the deep root system of alfalfa for adequate growth and development [21].

Soil fertility

Optimum growth and development of alfalfa are achievable with good fertility management. A good supply of plant nutrients is important for alfalfa's growth because it is a heavy user of nutrients. The deep root system and long growing season of alfalfa (from early spring to late fall) allow it to be harvested 4 to 5 times a year (depending on the production area), which leads to large removal of nutrients from the soil. Since agricultural soils differ in their fertilizer need, testing the soil prior to planting is the most practical and convenient approach to evaluate the soil's fertility status. This helps to provide the right amount of nutrients to the soil to last for the entire cropping season. A study by Rasnake [22] showed that some soils are capable of supplying nutrients to keep the soil nutrient at the original level for several years. In Michigan, Foth and Ellis [23] reported that enormous differences exist between the number of nutrients in the soil and that needed by plants. Thus, the greater the amount of nutrients absorbed by the plant, the more likely the soil supply will be insufficient for their needs. This suggests that nutrients replenished from the soil's own reserve may not be enough to meet alfalfa's nutrient demand and therefore, fertilizer nutrients must be added to the soil to sustain the fertility level of the soil for satisfactory growth. Adequate fertility allows for good alfalfa stand establishment, promotes early growth, improves winter hardiness and stand persistence, improves the plant's ability to compete for growth resources, and increases forage accumulation and nutritive value [21].

Moisture conditions

Plants utilize more water than any other substance they absorb. Alfalfa's yield is related to its stand density and therefore within the limits of available moisture and other variables, as plant water use increases, stand density improves with a corresponding increase in yield [24]. Although alfalfa does not tolerate wet soil conditions, moisture stress retards its growth and development through a reduction in photosynthesis. Studies have shown that deficit irrigation during the mid-summer reduces alfalfa's yield, but does not stop all plant growth [25-27]. In general, when soil water becomes limiting, deformation and defoliation of leaves occur, which reduces vegetative growth, root density, nutrient uptake, and symbiotic N_2 fixation, because the survival of the stand and activities of rhizobia are influenced by moisture [28]. Undersander, et al. [21] reported that moisture stress in alfalfa stands occurs when available soil moisture falls below 50%. This limits alfalfa production and cannot be made up by irrigating more than necessary following the stress.

Moreover, the rate of salinity buildup increases during the period of limiting moisture conditions. Although alfalfa has resistance to salinity, there can be an associated yield loss due to increased salinity during periods of drought. Thus, when available soil moisture or irrigation water is not sufficient to leach accumulating soluble salts out of the root zone, salinity conditions emerge and interfere with the normal growth and performance of the crop. High levels of salinity reduce alfalfa's vigor and growth by altering water uptake and causing ion-specific toxicities or imbalances. Initially, yield losses are small and negligible, but when left unmanaged, soil salinity and its related problems will exacerbate and eventually cause significant yield losses over time. Therefore, ineffective agronomic practices will lead to more production problems in the alfalfa forage system [29,30]. Practices including planting salt-tolerant alfalfa cultivars, improving drainage to leach salts out of the root zone, and maintaining optimum moisture levels in alfalfa stand throughout the growing season are recommended practices for adequate growth and development of alfalfa.

Insects and pests

Insect and pest infestation can significantly reduce the forage yield, quality, and stand life of alfalfa. In most production regions, alfalfa weevil (*Hypera hypostatic* Gyllenhaal) caterpillars, and various species of aphids are the major insect pests that affect alfalfa production. The alfalfa weevil has been reported to be the most damaging insect of alfalfa in the US [31], and aphids cause the greatest yield loss when infestations begin earlier in the regrowth cycle [32]. Most pests (caterpillars, cutworms, plant bugs leafhoppers, armyworms, thrips) found on alfalfa fields tend to be more sporadic and interfere with alfalfa's growth on a frequent basis (Summers, et al. 2007). Under severe infestations, they skeletonize the alfalfa plant by chewing the leaves, sucking the plant sap, and feeding on the roots to weaken root systems, thus reducing water and nutrient uptake to render roots more vulnerable to diseases. Through their feeding and egg-laying process, photosynthesis is delayed, growth and development retarded, and stand density reduced allowing weeds to invade. Implementing an integrated pest management program on alfalfa fields in combination with knowledge of the conditions that promote pest buildup and the ability to recognize the symptoms of each major insect or pathogen can significantly reduce the loss (Rethwisch, 2006; Summers, et al. 2007).

Diseases

Alfalfa is subjected to several diseases that kill seedlings and shorten stand life to cause major reductions in yield and feed value. In addition to diseases caused by microorganisms such as viruses, bacteria, and fungi, nutritional deficiency conditions as well as certain physiological disorders of the plant are considered as diseases. Often the influence of these

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diseases goes unrecognized, particularly root diseases, because symptoms are usually mistaken for something other than the disease [33]. Diseases such as bacterial wilt, fusarium wilt, verticillium wilt, spring black stem, common leaf spot, phytophthora root rot, and actinomyces are well distributed and severe in all alfalfa growing regions in the US. Their occurrence and severity depend on environmental conditions, soil type, and poor management practices [21]. Symptom varies for each disease, but the outcome is similar. Crown and root diseases weaken the root system to reduce the plant's anchoring, N_2 fixation, nutrient and water absorption, and storage abilities. Foliar diseases exhaust the leaves, which leads to reduced nutritive value. An important approach for managing several alfalfa diseases is through the use of resistant cultivars, and integration of other strategies such as irrigation management, planting methods, promotion of crop vigor, manipulation of harvest schedules, canopy management, and crop rotation [21,33].

Weeds

Weeds compete aggressively with alfalfa for growth resources such as water, nutrients, light, and space during the early stages of seedling establishment and continue throughout the life of the stand. They utilize the available growth resources at the expense of the plant, which leads to poor plant growth. Some weeds release toxic substances that injure the plant limit its competitive ability and reduce the growth and feeding value of alfalfa. Quack grass [*Elymus repens* (L.) Gould] and green foxtail [*Setaria viridis* (L.) P. Beauv.] are examples of some common weeds that invade alfalfa stands and cause significant economic losses. Poor management practices including infertile soils, use of less aggressive cultivars, and inappropriate time of harvesting reduce the plant's vigor to allow weeds to invade the stand. Weed control issues are regionally based and depend on the production area [34]. However, employing efficient weed management practices such as the stale bed approach, tillage, and herbicides prior to stand establishment is important for the good growth and development of alfalfa. Also, maintaining a vigorous alfalfa crop, proper soil fertility, and pH are important factors to consider in suppressing weeds during the established stage.

Key management practices to improve alfalfa hay production

Producing more alfalfa yield per hectare is important to keep alfalfa production economical. To maximize economical alfalfa production, it is necessary to sustain a productive stand of alfalfa. Although selecting and growing the right cultivar is critical to alfalfa's growth, paying attention to crucial production practices does more to influence alfalfa's productivity than cultivar selection alone. According to Mueller and Orloff [35], managing alfalfa to improve productivity requires an understanding of how environmental and management factors influence the plant's production. As a perennial crop, it thrives on well-drained and fertile soils with a neutral pH and depends on all aspects of crop management including establishment, fertilization, irrigation management, harvest scheduling, and control of pests, weeds, and diseases for sustainable long-term production [8]. While these factors affect alfalfa yield production, they also offer the possibilities to be improved to facilitate the plant's growth and development process.

Alfalfa production mainly depends on good agronomic practices. The soil's fertility is the predominant factor that exerts significant impacts on alfalfa production. Potassium (K) is a major nutrient required by alfalfa in substantive amounts for enhanced production. According to the International Plant Nutrition Institute, average native soil K levels in the US region are declining silently and it is close to an agronomic level (150 mg kg^{-1}) critical to crop response [36]. Luxury consumption of K by alfalfa [37] for high yields and the long history of intensive alfalfa production along with the frequent harvesting and baling has been attributed to the depletion of K in alfalfa fields [38]. To restore soil K to optimum levels needed to support greater alfalfa production, it is important to test the soil to ascertain the levels of K and other nutrients in the soil since K functions well when it is in balance with other major nutrients [39]. This helps to establish a sound K fertility program to replenish K in alfalfa stands. However, until the application of K is integrated with other impactful cultivation practices to generate an optimized effect on alfalfa, a sustained production of improved alfalfa could be unattainable. This necessitates the consideration of other crop management practices during K fertilization.

Cultivar is an essential agronomic factor that affects alfalfa's ability to absorb and effectively utilize plant-available nutrients for improved production. This is in direct association with the time of harvest, the only tool under the direct control of a grower, to determine the amount of nutrient taken up by the plant as well as the largest portion of annual yields of alfalfa. Thus, fertilizing alfalfa cultivars of high-yielding traits with K along with appropriate harvest schedules can be an effective strategy to increase alfalfa hay production. This centers on 3 crucial factors, which are soil fertility, cultivar, and harvest management.

Soil fertility

Improved hay yields can be unsustainable until the nutrients removed from the soil as a result of increased production are replenished. Studies have repeatedly reported that soil nutrients, particularly Phosphorus (P) and K are crucial for the proper growth and development of alfalfa [7,37,40-43]. They are key macronutrients that play important roles in alfalfa's physiological processes including photosynthesis, protein formation, nitrogenase activity, control ion homeostasis, maintenance of turgor pressure, and stomatal aperture regulation [44-46]. A report by Lissbrant, et al. [47] indicated that the roles of P and K are interdependent and thus, a balanced combination of P and K produces increased alfalfa yields. The plant's high requirement of P and K leads to the removal of huge amounts of these nutrients from the soil upon harvest [48]. Consequently, the soil's fertility reduces to levels that cannot support higher alfalfa productivity in subsequent growing seasons. With reference to the plant's biology, yield, and root system, alfalfa shows considerable need for P and K nutrition. Therefore, in alfalfa stands it is necessary to amend

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the soil with P and K fertilizer nutrients to restore the nutrient threshold to be available for uptake by alfalfa to optimize the crop's nutrition for greater yield production.

Availability of phosphorus and potassium to be accessible by alfalfa

Studies have demonstrated that when P and K are in combination, they can potentially interact to exert an influence on plant growth [49,50]. However, a study by Macolino, et al. [7] showed that P had no impact on alfalfa yield and also, it did not interact with K in determining the crop's productivity. This is an indication that combinations of P and K do not interact in all cases. According to Gaj and Górski [51], the correct system of P and K combinations for optimum nutrition is based on the regulation of nutrient availability in the soil. Depending on the soil's pH status, solubility and availability of P are regulated by aluminum (Al), iron (Fe), calcium (Ca), and/or magnesium (Mg) compounds present in the soil. At acidic pH, Al and Fe compounds tend to be high in the soil such that P ions bind with the compounds and form very strong bonds with less soluble compounds, which renders P to be less accessible and/or unavailable to the plant roots for uptake. At higher pH values (alkaline soils), P ions react quickly and precipitate with Ca and/or Mg compounds to form less soluble compounds and render P to be less available for uptake [52,53]. Optimum levels of soil pH for P availability range from 6.0 to 7.5, therefore adjustment of soil pH can improve P's availability for uptake. Increasing the soil pH with lime to at least 6.2 helps to improve P availability ([54]. In the soil, K's availability for plant uptake does not depend solely on the soil's K content, but it also depends on the relative amounts of other cations particularly Ca^{+2} and Mg^{+2} [55].

A previous study by Steven [56] showed a significant reduction in plant uptake of K as the Ca^{+2} and Mg^{+2} content of the soil increased. The effect of increased soil Mg^{+2} on reducing plant K uptake was more noticeable than the effect of increased Ca^{+2}. The reverse effect was generally the case; thus, Mg uptake by the plant was inhibited by increased soil K. In Maine, Hoskins [57] reported that inverse and adverse relationships exist between a very high concentration of one cation and the availability and uptake of other cations by the plant. When Ca and/or Mg dominate over K at the exchange complex it could potentially lead to a reduction of available K which can result in K deficiency. This is possible when Ca^{+2} and Mg^{+2} are in disproportionate quantities with soil K^{+} [58,59]. Potassium deficiency caused by such an imbalance is termed an induced deficiency. According to Havlin, et al. [60], both Ca^{+2} and Mg^{+2} compete with K^{+} for plant uptake, and therefore, in the soil solution, the availability of K^{+} is somewhat more dependent on its concentration relative to Ca^{+2} and Mg^{+2} levels than on the total quantity of K present. Thus, in areas with relatively high quantities of soil exchangeable Ca and Mg that are enough to compete with exchangeable K, the exchangeable soil K test values alone may not adequately indicate K's availability for plants [55]. The K: Mg ratios that indicate a balance proportion of soil K and Mg for K's availability include 1.2:1 (in sandy soils); 1:1 (in sandy loam, and loamy soils); 0.7:1 (in clay soils); and 2.2:1 (in peat soils) [58].

Potassium plays a more crucial role to induce an interaction when it is in combination with another nutrient such as P. Therefore, it is important to take into consideration the relative levels of soil exchangeable K^{+}, $Ca^{+2,}$ and/or Mg^{+2} when making decisions on fertilizing alfalfa with appropriate combination rates of P and K for higher hay production.

Alfalfa cultivar

Cultivars of alfalfa differ significantly in their regions of adaptation, resistance to diseases and insects, growth, and morphological characteristics. They are categorized into five general groups: common alfalfa, variegated alfalfa, Turkistan alfalfa, non-hardy alfalfa, and rhizomatous alfalfa [24]. More than 60 species are within the *Medicago* genus and eight subspecies make up the *M. sativa* complex. Scientists use seed characteristics, chromosome numbers, pollen grains, and pubescence to differentiate cultivars [61]. Traditional breeding objectives have included the modification of traits that are directly associated with increased yield, as well as with the improvement of quality and other traits of interest. Most breeding programs utilize recurrent phenotypic selection to develop and select cultivars with improved yield and tolerance to biotic and abiotic stresses. Breeders continually introduce improved breeding approaches have been implemented which has led to the rapid advancement in developing disease resistance, insect/pest tolerance, salt tolerant, persistence, low lignin technology, and several other transgenic cultivars with the potential to address the adverse factors affecting the sustainable production of alfalfa [62-64]. Nevertheless, there has been minimal improvement related to alfalfa yield with a resultant declining trend in recent years (Figure 2). Currently, there are over 300 alfalfa cultivars for sale in the US market. Ideally, several of these cultivars perform very well in any given location, however, selecting which cultivar to plant has many implications for a grower [65]. Forage yield, nutritive value, and stand life are of primary importance when it comes to choosing alfalfa cultivars for improved production. Choosing the right alfalfa cultivar to cultivate is one of the crucial decisions producers make in developing a good forage production system. As a perennial crop, selecting an alfalfa cultivar to grow is a long-term investment that is irreversible, and producers are often stuck with their choice for several years. From the grower's perspective, it is important to find alfalfa cultivars that exhibit better performance than the expected quality for their dormancy group [66]. This contributes significantly to the crop's yielding ability and persistence, which can potentially be worth thousands of dollars per unit of land area.

During the alfalfa cultivar selection process, growers need not only be aware of the yield potential but also, be mindful of the cultivar's fall dormancy, pest and disease resistance, and winter survival ratings. Fall dormancy is a varietal characteristic that indicates the plant's preparedness for winter as well as its ability to remain productive late in the season. It ranges from a scale of 1 (very dormant) to 11 (very non-dormant). Generally, extreme hardiness leads to lower yield potential, which limits forage production. The appropriate cultivar for a specific location must be winter hardy enough to allow

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alfalfa's survival with minimal injuries, but without limiting yields [67]. Adopting cultivars that are highly resistant to the most recurring pests and diseases of a specific location is of utmost importance. This is in relation to the production area, growing conditions, and management practices. Prioritizing these varietal characteristics provides a better estimate of the cultivar's stand persistence and forage production potentials. When alfalfa grazing is of interest, new cultivars specifically for grazing tolerance should be considered. Other factors such as the environment, experience, and objectives of the grower also contribute to selecting a suitable alfalfa cultivar for higher production.

Harvest management

Healthy stand and optimum forage yields with sustained nutritive value are the major considerations in the alfalfa production system. A key element of these characteristics is the use of the appropriate harvest schedules. When careful attention is not paid to the time or maturity stage at which alfalfa will be harvested, the benefits of previous production practices (for example, stand establishment, irrigation, fertilization, disease control, weed and pest management, and many more) can be negated, because a good harvest strategy is a complex compromise between obtaining high forage yield and quality [68]. The cutting schedules adopted within a growth period dictates the total number of harvests possible in a growing season and the number of nutrients absorbed by the plant. This influences the total seasonal yield production. Additionally, when alfalfa is frequently harvested at immature growth stages (short intervals between cuttings), hay yield and nutritive value decrease and increase, respectively. Conversely, frequently cutting alfalfa at mature growth stages (long interval between cuttings) leads to high yield but low nutritive value. This relationship is termed the yield-quality trade-off, which is fundamental to understanding the effect of harvest schedules on alfalfa productivity (Orloff and Putnam, 2007).

The carbohydrate level in alfalfa's roots is an important factor controlling alfalfa's longevity. It provides energy for initial growth, regrowth following harvest, and several physiological processes within the plant. The build-up, storage, and utilization of root reserves follow a cyclic pattern of decreasing during the initiation of regrowth and then accumulating until the plant reach full bloom. Thus, whether alfalfa is harvested once, twice, or more during the growing season, the number of carbohydrate reserves in the root decline with the initiation of growth after each cutting and increases as regrowth approaches flowering [69]. Therefore, frequently cutting alfalfa at immature growth stages does not allow enough time for the plant to replenish root reserves, which adversely affects the vigor and regrowth of the plant following harvest. Stand life and productivity may also be reduced if alfalfa is continuously cut before root reserves are sufficiently restored (Orloff and Putnam, 2007). Adopting alfalfa harvests at matured growth stages will allow enough time for the plant to build up enough root reserves to support vigorous regrowth for higher yield performance. But its quality reduces due to the high amount of fiber associated with the plant at the matured growth stage. Due to this, it is recommended to cut alfalfa at the early bloom stage (when 10% of plants have flowered). Harvesting at this stage provides the best compromise between forage yield and quality as well as maintaining healthy stands [70]. However, such compromises disallow the attainment of alfalfa's full yielding potential for higher production.

Early studies by Kust and Smith [71], and Smith and Nelson [72] reported that it is possible to harvest alfalfa 3 to 4 times in a season without compromising forage yield or nutritive value. Hoveland [73] and Sheaffer [74] observed that a 30 to 35 days interval is an ideal time to harvest alfalfa for higher productivity. According to Undersander [21], from the time forage is harvested until it is fed to livestock, the amount of decline between forage yield and nutritive value is determined during the harvesting process. Proper harvest management in alfalfa production is therefore not limited to the appropriate harvest schedule, but it also includes the time of day when harvest and baling occurs, conditioning, windrow width, appropriate moisture levels for raking and baling, and the use of drying agents or preservatives [68], and other factors. On the other hand, K plays an important role to improve alfalfa's physiology and facilitate the accumulation, transport, and storage of carbohydrate reserve in alfalfa's root [75-77]. It also enhances the winter survival ability of the plant [78]. Supplying K to alfalfa in a timely manner could help accelerate the build-up of sufficient root carbohydrate reserve in the plant for vigorous and healthy regrowth. Harvesting alfalfa can therefore be delayed for a few days to mature and produce greater yields whiles maintaining a normal range of forage quality.

The first harvest and subsequent harvest schedules

Attaining higher yields of alfalfa hay demands that the plant should be healthy and root carbohydrate reserve be adequate for plant regrowth following harvest [79]. Shewmaker [80] concluded that the first harvest period in each year is the most critical in alfalfa harvest management consideration. It provides the largest proportion of the annual yield and also impacts the yields of subsequent harvests. A study by Gardisser [81] showed that a good time for taking the first harvest is during the late bud to first flower stage (1/10 bloom stage). During this time, a good combination of high forage yield and nutritive value is obtainable. Therefore, taking the first harvest at this growth stage allows alfalfa to restore its root reserves that were depleted during winter dormancy, and help to maintain its stand density and longevity. It also enhances the yield potential of the second harvest and can allow for an extra harvest during the growing season. The first harvest can be scheduled at the early bud stage before blooms are visible to avoid alfalfa weevil damage [82]. Predicting when to take the subsequent harvests is challenging and therefore making subsequent harvests on a calendar date basis may be the best approach [80]. This helps to maintain vigorous and healthy alfalfa stand to increase stand longevity and forage production.

Fall or final harvest

Alfalfa often prepares for the winter during late summer and early fall by developing cold resistance and storing energy in their roots. During this period (critical fall period), the timing

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of when to harvest the plant has a high chance of interfering with the process. Deciding on when to take the final cut of the season, therefore, deserves considerable attention. Clipping alfalfa at a time that allows a few weeks of regrowth prior to the occurrence of killing frost (-4 ºC to -3 ºC) reduces energy reserves in the roots, significantly. The harvesting process, on the other hand, removes stubble which grasps snow and serves as a layer of insulation from extremely cold air temperatures. Both situations increase the plant's risk of winter kill with an adverse effect on production traits including plant vigor and stand life. Ideally, the fall or final harvest of alfalfa should be made 4 to 6 weeks prior to the first killing frost [82]. This allows sufficient time to replenish adequate root reserves before the next harvest. Also, when conditions are conducive for sufficient growth, a late harvest or grazing can be possible during late October or early November [82,83]. The risks to winter kill of alfalfa could be minimized by 1. taking at least one cut at the one-tenth bloom growth stage in the summer, 2. Harvesting only young stands since they are less vulnerable to winter injury, 3. maintaining optimum soil fertility, and 4. clipping only disease tolerant and winterhardiness cultivars (PennState Extension, 2013)[69].

Since it is challenging to predict when the first killing frost may occur, alfalfa growers can only rely on their experience along with previous weather data to make decisions on when to take the final harvest. Due to this, in alfalfa stands where final cuts of alfalfa are made close to the first killing frost, the stands should be made to grow to the late maturity stage during spring of the following growing season before the first harvest begins. The penalty for not doing this is the low-yield production of future harvests.

Summary

With efficient management practices, there are opportunities to improve the hay yields of alfalfa in successive growing seasons. It is evident from existing literature that alfalfa's superior potential of producing greater yields places its highest demand on the soil nutrient reserves including P and K. Replenishment of P and K in alfalfa stands can eventually restore the soil P and K to optimal levels for an improved alfalfa. In addition to P and K fertilization, careful consideration of crucial production factors, particularly soil nutrient status, cultivar, and harvest time is paramount to maintain optimum levels of the required nutrients and be accessible by alfalfa for adequate growth and survival during the growing season and winter period, respectively. This optimizes the effect of the absorbed nutrients to enhance the physiological plant processes for improved production. Integrating these strategies with appropriate practices including disease, pests and weed control, and irrigation management has a great potential to sustain an increased and profitable alfalfa hay production in the long run.

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