ALFALFA BREEDING WITH IMPLEMENTATION OF MOLECULAR TOOLS

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Bernadette Julier. ALFALFA BREEDING WITH IMPLEMENTATION OF MOLECULAR TOOLS. World Alfalfa Congress, Nov 2022, San Diego (CA), United States. pp.126-130. hal-03987402

PROCEEDINGS

2022 WORLD ALFALFA CONGRESS

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November 14-17, 2022

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MANAGEMENT OF NEMATODES IN ALFALFA

Dr. Donald R. Miller[1]

ABSTRACT

Management of the potential economic damage to alfalfa production fields due to nematodes is generally accomplished by a combination of several factors: **alfalfa genetics, cultural practices, nematode specific crop rotations, bio-fumigants, and to a lesser extent chemical control**. The selection of a highly resistant variety is the first line of defense in combating nematodes. Cultural practices can be very effective in preventing the initial spread of the nematodes into new production fields and help minimize the damage in established alfalfa fields. Fields with existing nematode infestations can be managed by utilizing "non-host" crop rotations and/or fallowing, combined with the use of a nematode specific bio-fumigant crop species. However nematode control in established alfalfa fields is difficult, especially since most of the major damage occurs at or below the soil surface. Once an alfalfa field is planted, there are few if any chemical controls available that are effective and/or economical.

Keywords: Alfalfa, nematology, cultural practices, pest management, nematode control, alfalfa nematodes, stem nematode, root knot nematode, southern root knot nematode, northern root knot nematode, columbia root knot nematodes, lesion nematode, crop rotation, integrated pest management, bio-fumigants

INTRODUCTION

Much progress has been made by alfalfa breeders in the last 30 years in improving the genetic resistance of alfalfa varieties to nematodes. Utilization of these genetic advances in the selection of adapted resistant varieties is still the best and most economical means of insuring maximum yield, quality, and stand life. Variety selection, beyond yield and forage quality, should be based on knowledge of which alfalfa nematodes are most prevalent in a grower's field or are historically known to reduce yield and stand life in the region. Knowledge of any potential new nematode reported in the area should be also considered in the selection of a variety with resistant traits. It should be noted that having genetic resistance to one nematode species doesn't necessarily provide resistance to other nematode species.

Selecting an adapted variety that has a high level of nematode resistance, combined with proper cultural practices, is the grower's best defense in minimizing nematode incurred production losses. Selecting a good resistant variety, adapted to his or her farm, is also the cheapest line of defense against potential production losses. It is hard not to over emphasize this point. The variety choice the grower makes at planting, will often determine the extent and severity of any future nematode outbreaks, and more importantly the length of time that field will remain profitable. Growers often become fixated on the initial cost of the alfalfa seed, but often fail to realize that the choice they make will determine the profitability of that field for many years. A poor choice can cost money in the form of lost yield and/or quality due to stand losses and the

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resulting weed encroachment. A poor variety choice can result in the grower having to prematurely take fields out of production. The unexpected replanting costs can be significantly more than what the producer would have paid in seed costs for a better nematode resistant variety. Picking a low-cost inferior susceptible variety often results in the grower having to fight an uphill battle to optimize forage production and profit.

For the most part, once a variety is planted, there are only a limited number of options available to the grower to prevent or eliminate nematodes from damaging an established field. There are few chemical controls available that are effective and/or economical. Proper cultural practices implemented during the life of the stand can limit the spread and extend of damage. However complete control in established fields is often difficult once a nematode has become established.

ALFALFA NEMATODES

Nematodes are microscopic wormlike animals that live in the water held between soil particles. These plant parasitic animals are generally more prevalent in moderate to clay soils and have a high reproductive rate. They can persist in soil for many years in the absence of a host and move from field to field on farm equipment and/or irrigation water contaminated from runoff water of infested fields. Numerous plant parasitic nematodes are known to occur in alfalfa fields, but most of the damage is attributed to the following five.

Major Nematodes Species that Damage Alfalfa

1. Stem Nematode (Ditylenchus dipsaci)
2. Southern Root Knot Nematode (Meloidogyne incognita.)
3. Northern Root Knot Nematode (Meloidogyne hapla)
4. Columbia Root Knot Nematodes (Meloidogyne chitwoodi)
5. Root Lesion Nematodes (Pratylenchus penetrans)

Management of Nematodes in Alfalfa: What Are Your Options?

The best control option is to eliminate or reduce the nematode threat prior to planting. This can be approached in several ways. First take a soil sample and send it to a lab to see if any harmful nematodes are present. Your local soils lab or extension office should be able to help you locate a nematode lab. The nematode lab can identify any problem nematodes found in the soil you send them. I recommend sending soil and plant samples (if field is not fallow) to get the most accurate evaluation. Depending on where the nematode is in its life cycle it may be more prevalent in the soil or the plant tissue.

Approximate Nematode Threshold Levels for Soil Samples/gram:

(Samples that contain a majority of female nematodes is more of a concern)

- STEM – any number
- NRKN – 500
- CRKN – 1,000
- LESION – 2,000

If an alfalfa parasitic nematode is present, you can use the following management options to eliminate or minimize the number nematodes in the field:

-Fallow The Field: Cultivation of the field drastically reduces the number of nematodes and eliminates their food source. Most parasitic nematodes can only survive on living plants.

-**Trap Crop**: Some species of nematodes can lay dormant in the soil for a period of time even following field fallowing. Planting a specific crop that is known to stimulate the dormant parasitic nematode to hatch and feed, is a method of control called a "Trap Crop". Plowing down this "trap crop" before the newly hatched nematodes have a chance to reproduce, can be effective in further reducing a nematode population.

-Non-Host Plant Rotation: This is a practice of planting a rotational crop that the problem nematode can't feed or reproduce on. Growing a non-host crop for 1-2 years can reduce nematodes numbers, especially if used in conjunction with other control measures.

-Fumigation (Chemical or Bio-Fumigation): Chemical fumigation is generally considered too expensive for new fields for alfalfa production. However, some alfalfa growers have taken advantage of rotating with high value crops where soil fumigations are cost effective, such is the case for potatoes. Alfalfa following the potato crop can take advantage of the prior fumigation by starting out with few if any nematodes in the soil profile.

A more cost-effective alternative to chemical fumigation, is bio-fumigation. Certain species of plants when grown and subsequently plowed down and incorporated into the soil, release a natural bio fumigant that controls parasitic nematodes. Several varieties of radish and mustards (i.e., white mustard) are currently available to growers to use in short term rotations for this purpose. Bio-Fumigation can be a very effective tool in an integrated approach of controlling nematodes prior to planting a new alfalfa field.

The following is some specific information on the nematodes known to damage alfalfa in order of importance:

Stem Nematode (Ditylenches dipsaci)

Conditions that promote damage:

- Cool moist spring
- Sprinkler irrigation (surface moisture on lower plant canopy increases stem nematode infestation of lower plant stems and crown buds).
- Susceptible plant and weed hosts
- Alternate host in rotation- potatoes, garlic, and beets

Symptoms:

- In the spring or fall sporadic white stems or "White flags" may be seen throughout the alfalfa field.
- Stunting in somewhat circular patterns in the field
- Swollen stem buds

- Shortened internodes and swollen nodes on lower stems
- In advanced stages lower stem may blacken
- Fewer symptoms may be seen during summer months

Control:

- Plant alfalfa variety with Resistance (R) or High Resistance (HR)
- Rotate with non-host crop for 2-3 yrs.
  (Non-host crops-sorghum, small grains, beans, and corn)
- Utilize a bio-fumigant crop in the rotation just before planting a new alfalfa crop.

Root Knot Nematode (Meloidogyne spp.)
(Northern, Southern, and Columbia)

Conditions that promote damage:

- Susceptible crop species in rotation and weed hosts

Symptoms:

- Stunting in somewhat circular patterns in the field
- Stand reduction
- Excessive root branching and small galls on roots

Control:

- Plant alfalfa variety with Resistance (R) or High Resistance (HR)
- Crop rotation with a non-host is generally not feasible due to wide host range
- Fallow field for one growing season (if non-host crop is not an option)
- Utilize a bio-fumigant crop in the rotation just before planting a new alfalfa crop

Lesion Nematode (Pratylenchus spp.)

Conditions that promote damage:

- susceptible crop species in rotation (i.e., corn) and weed hosts

Symptoms:

- Stunting in somewhat circular patterns in the field
- Major symptoms occur in the form of black lesions on the outside of the root. Lesions may become severe enough to completely darken taproot.
- Taproots appear stunted with reduced lateral root growth.

Control:

- Resistant varieties
- Crop rotation with a non-host is generally not feasible due to wide host range
- Fallow field for one growing season
- Utilize a bio-fumigant crop in the rotation just before planting a new alfalfa crop

INTEGRATED APPROACH TO NEMATODE CONTROL: BENEFIECIAL CULTURAL PRACTICES AND CROP ROTATION OPTIONS

Cultural Practices:

- Don't reuse tail-water for irrigation from infested fields (nematodes can be spread in the water from infested fields)

- Clean equipment between infested fields to prevent spread into un-infested fields

Crop Rotation Options for Stem Nematode Control:
Alfalfa => 2yrs small grain => Bio-fumigant crop => Alfalfa (Plant Variety with High Resistance to Stem Nematode)

Crop Rotation Options for Root Knot Nematode spp. Control:
Alfalfa => fallow => Bio-fumigant crop => Alfalfa (Plant Variety with High Resistance to Root Knot Nematode)

Crop Rotation Options for Lesion Nematode Control:
Alfalfa => fallow => Bio-fumigant crop => Alfalfa (Plant Variety with Resistance to Lesion Nematode)

SUMMARY

An alfalfa grower's first line of defense against nematodes should always be a nematode resistant variety, if available. A resistant variety's built-in genetic protection is the best insurance policy a grower can get against yield losses. Whenever conditions occur that are favorable for nematode buildup, the genetic protection is always there and doesn't have to be applied by the farmer. **Purchasing a variety that lacks adequate resistance may result in an uphill battle in preventing yield and stand losses due to nematode**. Alfalfa is a perennial crop, so a poor variety choice at planting time is one that the farmer will have to live with for many years. Following the selection of a good, adapted resistant variety, the grower should use good common sense agronomic practices to prevent the spread and/or limit the buildup of nematodes on their farm.

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STRATEGIES FOR RODENT MANAGEMENT

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ABSTRACT

Pocket gophers (*Thomomys* spp.) and voles (also known as meadow mice; *Microtus* spp.) are often the most damaging vertebrate pests in alfalfa. The amount and form of damage they cause can be quite varied but includes a loss in vigor and/or mortality of plants, damage to subsurface drip lines, and loss of irrigation water down burrow systems. Many control options are available including the use of toxic baits, burrow fumigation, and trapping. An Integrated Pest Management (IPM) program that incorporates several of these approaches, and potentially other techniques, can have many positive attributes for controlling pocket gophers and voles, not the least of which is greater control than is typically observed by focusing on any single method. In this paper, I highlight some of the tools that are used to manage pocket gophers in alfalfa. Primary tools continue to include rodenticides, burrow fumigants, and trapping, although other tools such as cultivation, burrow flooding, biocontrol, and repellents may have a role in effective management programs as well.

Key Words: alfalfa, baiting, Integrated Pest Management, fumigation, *Microtus* spp., pocket gopher, *Thomomys* spp., trapping, vole

INTRODUCTION

Many vertebrate pests cause problems in alfalfa including pocket gophers (*Thomomys* spp.), meadow voles (also known as meadow mice; *Microtus* spp.), and ground squirrels. Pocket gophers are short, stout burrowing rodents, usually 6–8 inches in length. They spend most of their time below ground where they use their front legs and large incisors to create extensive burrow systems. Meadow voles are small, blunt nosed stocky rodents with small eyes and short ears and legs. They are typically dark grayish brown in color with size intermediate to that of a house mouse and a rat.

Pocket gophers will breed anywhere from 1 to 2 times per year, although in more southern irrigated alfalfa fields, they may reproduce up to 3 times per year. Female voles may produce from 5 to 10 litters per year. Although pocket gophers and voles can breed at different times throughout the year, there is typically a pulse in reproduction in late winter and early spring depending on location and weather patterns. As such, control measures implemented before this reproductive pulse will often be more effective as there will be fewer pocket gophers and voles to control at that time. Additionally, because voles mature rapidly and can bear many litters annually, vole populations can increase rapidly. Typically, their numbers peak every 6 to 8 years when population numbers can be as high as hundreds of voles per acre.

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If left unchecked, pocket gophers (8.8% loss in revenue when present) and voles (11.3% loss) will cause extensive damage to alfalfa (Baldwin et al. 2014b). This damage includes consumption of tap roots and above-ground vegetation that can result in reduced vigor and/or mortality of alfalfa plants, loss of irrigation water down burrow systems, and chewing on subsurface drip lines. Pocket gopher mounds can result in additional problems including serving as weed seed beds, burying of plants, and causing damage to farm equipment.

A number of options are currently available for controlling pocket gophers but most control centers on toxic baits, fumigants, and trapping. Other control options are available as well, although their efficacy is less clear. For voles, control in alfalfa centers on toxic baits and cultural practices. I will briefly detail each of these approaches in the following section.

CONTROL METHODS

Toxic baits

Pocket gophers. There are three primary toxic baits for pocket gopher control: 1) strychnine, 2) zinc phosphide, and 3) anticoagulants (e.g., chlorophacinone and diphacinone). Both strychnine and zinc phosphide are considered acute toxicants. This means they kill after a single feeding. Strychnine has typically been promoted as the more effective of the two. Up until a few years ago, strychnine came in two concentrations in California: 0.5% and 1.8%. However, the 1.8% strychnine is no longer available, and the 0.5% product can be difficult to find at times. Zinc phosphide is also available for pocket gopher control; it comes in a 2.0% concentration. Bait acceptance can be an issue with zinc phosphide, as it has a distinctive odor and taste that pocket gophers are often averse to. Anticoagulants such as chlorophacinone and diphacinone are multiple feeding toxicants. With these rodenticides, pocket gophers generally need to consume the bait multiple times over the course of 3 to 5 days to receive a lethal dose. This means larger amounts of bait are required to maintain a ready supply over this period of time. Because of this, acute toxicants are typically preferred over anticoagulants for pocket gopher control. Extensive laboratory trials have shown that strychnine products are far more efficacious than other rodenticides currently registered for pocket gopher control (Witmer and Baldwin 2014). Subsequent field trials indicated 100% removal of pocket gopher populations across three vineyards, so strychnine can be highly efficacious (Baldwin et al. 2015b). However, pocket gophers do develop a behavioral or physiological resistance to strychnine if repeatedly used over time (Lee et al. 1990, 1992, Marsh 1992). Therefore, strychnine baiting should be used only as one part of an Integrated Pest Management (IPM) program.

There are two primary methods for baiting in alfalfa fields: 1) hand baiting with an all-in-one probe and bait dispenser, and 2) a burrow builder. Hand baiting can be effective if you have relatively few pocket gophers in a field. For this approach, an all-in-one probe and bait dispenser is used to locate a tunnel. The bait is then directly deposited into the tunnel. The opening left by the probe is covered up with a dirt clod or rock to prevent light from entering the burrow. When using this method, care must be taken not to bury the bait with loose dirt as this will limit access to the bait. Typically, it is recommended that burrow systems be treated at least twice to maximize efficacy. Recent research has shown that the experience of the individual who applies the bait is very important; those applicators who have been properly trained on how to use the equipment, and who can detect the difference between extant versus back-filled tunnels, are more than twice as efficacious as those individuals who have not received the proper training (Baldwin 2014).

Although hand baiting can be effective for smaller pocket gopher populations, the burrow builder can be a more practical method for treating larger areas. The burrow builder is a device that is pulled behind a tractor on a 3-point hitch and creates an artificial burrow at a set depth. Bait is then deposited at set intervals along the artificial burrow. While engaging in normal burrowing activity, pocket gophers will come across these artificial burrows and consume the bait within. This device must be used when soil moisture is just right. If the soil is too dry, the artificial burrow will cave in, but if it is too wet, the burrow will not seal properly and will allow light to filter in; pocket gophers will not travel down burrows if they are not sealed. The depth of the burrow builder must also be adjusted for each field (and occasionally within the same field) to ensure that the artificial burrows are created at the depth where most tunnels are found within that field. The artificial burrows must also be checked regularly to make sure that bait is being applied; the applicator often plugs, and if no bait is deposited, the process will obviously not work. Although convenient to treat large areas, the efficacy of this method has varied quite extensively from grower to grower. Experimentation is key to determining the applicability of this approach for each grower.

Voles. The use of toxic baits is the primary method for controlling voles in alfalfa. Within alfalfa fields, only zinc phosphide can be applied. Zinc phosphide is a restricted-use rodenticide; it can only be used by or under the direct supervision of a Certified Applicator. Zinc phosphide is applied directly to vole burrows and runways through spot treatments or broadcast applications. Spot treatments are used when only a few burrows are to be treated. Otherwise, broadcast applications are more efficient. If overused, problems with bait shyness can occur. As such, zinc phosphide should not be applied more than twice per year. Additionally, zinc phosphide must be applied when new growth is less than 2-inches tall. Zinc phosphide can off-gas when it comes into contact with water. As such, it should not be applied during heavy fog or when dew or precipitation are expected within the following 24–48 hours. Carefully read the label for more information on restrictions for zinc phosphide application in alfalfa.

Both zinc phosphide and anticoagulant baits (e.g., chlorophacinone and diphacinone) can be applied in non-crop areas adjacent to alfalfa fields. If adjacent fields or non-crop areas harbor large vole populations, these areas should be treated as well to reduce immigration into alfalfa fields after bait application.

Fumigation

Pocket gophers. Primary fumigants for burrowing rodent control have historically included gas cartridges and aluminum phosphide. Studies have shown that gas cartridges are not effective for pocket gophers. Aluminum phosphide, however, is quite effective. Aluminum phosphide is a restricted-use material; it can only be used by or under the direct supervision of a Certified Applicator. That said, it is quite effective and has a low material cost if used over small areas. The primary method for applying aluminum phosphide is similar to that of hand baiting. You use a probe to find a pocket gopher tunnel, then wiggle the probe to enlarge the opening (if the probe hole is not already large enough to allow passage of the aluminum phosphide tablets into the tunnel), and drop the label specified number of tablets or pellets into the tunnel. You then seal up the opening to eliminate light from entering and the toxic gases from exiting the tunnel. Once again, care must be taken not to bury the tablets with loose soil as this will render them ineffective. Typically, each burrow system is treated twice to maximize efficacy. The key with aluminum phosphide treatments is to only apply when soil moisture is relatively high. If you can ball up a clump of soil at the tunnel depth and it maintains that ball in your hand, then soil moisture is high enough to fumigate; if the clump falls apart in your hand, it is too dry. Because of this, fumigation is typically most effective in late winter and early spring. However, fumigation after irrigation can also be a good strategy.

In addition to aluminum phosphide, carbon monoxide generating machines can now be used to control pocket gophers. As their name implies, these devices generate carbon monoxide and inject it into the burrow systems which then asphyxiates the inhabitants. Trials have indicated that this approach is moderately effective (56–68%; Orloff 2012, Baldwin et al. 2016, 2017a), although efficacy is less than typically observed with trapping, aluminum phosphide, and strychnine. Additionally, equipment can be expensive to purchase. However, many more burrow systems can be treated during a day of application with this approach, so these machines likely have utility moving forward, particularly for growers and pest control professionals who have large acreage to treat.

A carbon dioxide injection device is now registered for use against pocket gophers as well. Data on efficacy of this tool is limited at this point, although the expectation is that efficacy should be relatively equivalent to that observed for pressurized exhaust machines. In contrast to pressurized exhaust machines, the carbon dioxide injection device requires a tank of carbon dioxide. This could make it more challenging to use over large acreage given the potential need for multiple tanks per day.

Voles. Fumigants are not typically used for vole control in alfalfa given the large amount of labor required to treat every burrow opening.

Trapping

Pocket gophers. Trapping is safe and one of the most effective, although labor-intensive, methods for controlling pocket gophers. Nonetheless, the cost and time for application is often offset by effectiveness (Baldwin et al. 2016). Several types and brands of pocket gopher traps are available. The most common type is a two-pronged, pincher trap such as the Macabee, Cinch, or Gophinator, which the pocket gopher triggers when it pushes against a flat, vertical pan. Another popular type is the choker-style trap. Historically, these have been box traps that require extra excavation to place, and may be a bit bulky to be practical in a large field setting. More recently, we've seen substantial use of a cylinder-type trap called the GopherHawk, which is a choker style trap that takes little excavation and is quick and easy to set. Of trap types tested, the Gophinator trap (Trapline Products, Menlo Park, CA) appears to be one of the most effective. In particular, it has proven more effective than the Macabee trap (The Macabee Gopher Trap Co., Los Gatos, CA), which is likely the most commonly used pocket gopher trap in the western U.S. (Baldwin et al. 2013). The increased effectiveness of the Gophinator is due to its ability to capture larger individuals at a greater rate. If an individual has old stockpiles of Macabee traps, their effectiveness can be increased by placing a cable restraint (0.06 inch in diameter, 9 inch in length) to the front of the Macabee trap to help keep larger individuals from escaping. However, the Gophinator trap is still more effective (Baldwin et al. 2015a).

For trap placement, the first step is to probe near a fresh mound to find the main tunnel, which often is on the side closest to the plug of the mound. The main tunnel usually is 6 to 8 inches deep; the probe will drop quickly about 2 inches when the tunnel is encountered. Traps will then need to be placed in as many tunnels as are present, as you will not know which side the pocket gopher currently is using. After placing the traps, you can cover the hole to keep light out of the tunnel. However, covering trap sets only marginally increases capture efficiency when temperatures are high (perhaps >85°, although the exact impact of temperature is not known) and provides no increase in capture success at other times (Baldwin et al. 2013). Therefore, if setting a large number of traps, a substantial amount of time in setting and checking traps can be saved if the trap-holes are left uncovered. Various attractants have been tested to see if they will increase capture success. They do not appear to increase capture success, although if using covered trap sets, there could be a slight increase in capture success when using an attractant such as peanut butter (Baldwin et al. 2014a). Human scent also does not influence capture success, so there is little reason to worry about handling traps with bare hands (Baldwin et al. 2015a). Trap sets are typically only operated for 24 hours. If no activity is present in that timeframe, they should be moved to a new location to maximize capture probabilities.

Pincer-type traps can also be placed in lateral tunnels, which are tunnels that lead directly to the surface. To trap in laterals, the plug is removed from a fresh mound and a trap placed into the lateral tunnel so that the entire trap is inside the tunnel. Pocket gophers will come to the surface to investigate the tunnel opening and will be caught. This approach is quicker and easier to implement than trapping in the main tunnel. However, trapping in lateral tunnels may be less effective at certain times of the year (e.g., summer) and for more experienced and larger pocket gophers (e.g., adult males).

Voles. Trapping is not typically used to control vole populations. Voles can easily be captured with standard mouse snap-traps, but the amount of labor, time, and resources required to remove voles from an alfalfa field is counter-productive.

Other control approaches.

A variety of other control options are sometimes used to control pocket gophers and voles in alfalfa. They are briefly discussed in the following paragraphs.

Biocontrol. This approach relies on natural predation to control pocket gopher and vole populations. From a management perspective, this typically involves the use of barn owl boxes to encourage owl predation of rodents over alfalfa fields. Barn owls consume a large number of rodents annually. However, no replicated scientific study has yet shown how effective barn owls are at reducing pocket gopher and vole populations in alfalfa fields, although recent investigations have shown a reduction of small rodent numbers in areas occupied by barn owls. Additional research is underway to better quantify the impact that barn owls have on rodent populations. At a minimum, erecting barn owl boxes on the perimeter of alfalfa fields cannot hurt management efforts, and may potentially help to keep pocket gopher and vole numbers lower than they would be without barn owl assistance.

Cultural practices. Habitat modification is an example of a cultural practice. This approach involves altering rodent habitat to reduce its desirability for that site. This can be a good approach for reducing pocket gopher populations in many other commodities, but unfortunately is not as practical in alfalfa given the pocket gopher's strong affinity for this crop. Likewise, cover removal can be very effective at controlling vole populations but is not practical in alfalfa.

Cultivation is a more practical example of a cultural practice in alfalfa. If you have an alfalfa field that you are going to replant, deep ripping will eliminate many of the pocket gopher and vole burrow systems and will kill some pocket gophers and voles in the process. Destroying the burrow systems helps slow down potential reinvasion into fields, and when combined with an aggressive pocket gopher and vole management program post-cultivation, can provide a "clean slate" for a newly planted alfalfa field.

Flood irrigation. Where still feasible, flood irrigation can help control pocket gopher and vole populations. When a field is flooded, the pocket gophers and voles must come to the surface or drown. When at the surface, they can be picked off by a number of predators; growers and their dogs can also actively seek out pocket gophers and voles at this time to further reduce populations of these damaging pests.

Gas explosive device. This instrument injects a mixture of propane and oxygen into the burrow system and then ignites this mixture thereby potentially killing the burrowing rodent through a concussive force. This approach has the added benefit of destroying the burrow systems, which should slow down reinvasion rates by burrowing rodents. However, studies have not shown it to be overly effective for many burrowing rodent species. Additionally, there are potential hazards associated with this device including damage to buried pipes and cables, injury to the user, and the potential to catch things on fire. These devices are also quite loud; as such, they are not practical for use in or around residential areas. That said, this device does kill some pocket gophers and voles and may be useful in some specialized settings, particularly where destruction of pocket gopher burrow systems is required.

Repellents. No substantive studies have shown that chemical repellents effectively keep pocket gophers from inhabiting fields. However, a recently registered repellent called Protec-T (active ingredient is methyl mercaptan) has shown some repellency in a minimally replicated study in alfalfa (R. Baldwin, unpublished data). The product is added to irrigation water and fed through subsurface drip irrigation (SDI) tubing. If effective, it could be a good tool to use to supplement other management strategies in SDI alfalfa fields, but additional research is required to provide a more robust assessment.

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STRATEGIES TO CONTROL WEEDS IN ESTABLISHED ALFALFA

Tom Getts[1]

ABSTRACT

Alfalfa is grown for its high-quality forage and controlling weeds in alfalfa is a crucial part of producing a profitable crop. Weeds can reduce the palatability of the product to livestock and the marketability to their owners. Like many pest management activities weed control is best addressed using an integrated pest management approach. The first step is to identify the weed and learn about the biology of the plant, to best control the weed and prevent reproduction. Reducing the number of seeds produced in and around the field is essential for long lasting weed free stands. Alfalfa is a highly competitive dense crop and weeds can be limited, first and foremost by good agronomic practices. Proper irrigation and fertilization are practices that immediately boost crop productivity and competitiveness. Other cultural methods such as early cutting can prevent weeds from going to seed. Often in established stands herbicides are relied upon to kill weeds when they are small and before they have a chance to produce seed. Utilizing all tools available can allow growers to produce a high-quality crop free of the weeds that reduce the quality marketability of the product being produced.

INTRODUCTION

Weed control in established alfalfa is paramount to producing a quality palatable forage for livestock. While not all weeds are poisonous or cause physical harm to livestock most will affect quality and yield and in turn the marketability of the hay. Buyers do not like to purchase hay that has a bunch of brown weeds contaminating it, and in normal years the price paid will be significantly less than weed free hay.

Alfalfa is a highly competitive crop that is excellent at excluding weeds once established. Following proper establishment practices, such as variety selection, irrigation practices, and initial weed management will go a long way to starting off a thick stand. Thick competitive stands are fundamental to successful weed management with limited inputs. Once a stand is established, what weed management practices take place depends on climate, corresponding dormancy, and frequency of cutting. There are both cultural and chemical components that play into weed control.

USING IPM TO CONTROL WEEDS

When dealing with weeds it is important to think about how they reproduce and preventing reproduction is paramount to any weed control strategy. Prevention starts with identification of the

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weed. Once a weed is identified, understanding the biology of the weed will allow you to choose what methods will best prevent it from reproducing.

What season does the weed germinate?
How long do the seeds last in the soil?
Will it reproduce by its roots?
What herbicides are it susceptible too?

Are just a few of the questions that can be answered after a weed is identified. Answers to these questions will help you choose when, what, and how to target the weed to prevent reproduction. Being able to ID the weeds when they are small is fundamental as large weeds are not often as easily controlled. The name of the game when it comes to weed control in established alfalfa stands is prevention. The goal is to prevent conditions that favor weeds, while also preventing weeds that are present from being able to reproduce.

Proper stand management is essential for competitive hay that will crowd out weeds. Alfalfa that is under-irrigated will favor weeds that do well in dryer conditions, where over-watering alfalfa will lead to weeds that are more competitive with wet feet. In addition, not keeping up with fertility will limit the growth potential of the crop favoring weeds that do well with less. Allowing longer periods between cutting can favor the sugar reserves deep in the roots of the crop, allowing for more vigorous regrowth following cutting. Any agronomic practice that favors crop growth and stand longevity will favor weed suppression because of alfalfa's competitive nature. Cutting stands frequently to meet dairy hay quality will often lead to weaker alfalfa stands that become weedier more quickly overtime.

Physical weed control methods are a pillar of an IPM program, however in established stands their uses are limited in the permanent crop. In regions where the crop goes dormant, hitting the fields with a drag, or spring tooth harrow prior to green up, can be a good way to uproot winter annual weeds that have recently germinated. There is a downside to dragging as it may lead to crown damage leading to an increased risk of diseases and infection. If weeds are not controlled the act of harvesting can be utilized as a physical control tool to suppress weed seed production. Keeping an eye on the weeds and cutting them in combination with the crop during the early flower stage of the weed will prevent or reduce the amount of seeds that go back into the soil seed bank. Keeping in mind that these weeds will often "stool" branching and growing shorter to still put on some seeds not completely eliminating reproduction. Cutting earlier than desired is also a double edge sword, as the crop might not be cut at the optimal quality/yield intersection if cutting is timed for weed control. Cutting after weeds have flowered and seeds have been formed, can also concentrate weed seed under the windrow (photo one). Cutting does have its place in an IPM program to suppress weeds if done at the right time.

Chemical methods are often relied upon for weed control. In colder climates conventional methods use tank mixes of a burn down herbicide and a residual herbicide either in the fall, or late winter to control winter annuals in the first cutting. During this slow growth period cold tolerant winter annual weeds have the conditions needed to grow at a time when the alfalfa is less competitive. In strong stands, after first cutting secondary herbicide treatments are often not needed in a competitive crop. In older stands with lots of bare ground subsequent applications may be needed of preemergent products to reduce summer annual weed populations. Often products such as trifluralin and pendimethalin are utilized mid-season to prevent weed seed germination.

In warmer desert climates, where alfalfa never goes dormant, things shift. As opposed to making applications of herbicides in the cooler parts of the year many residual products, that do have some foliar actively, are applied during the warmer months as the plant growth slows and approaches a summer dormancy with little growth because of the heat. Multiple applications of herbicides with both foliar and residual actively are needed in warmer climates to suppress weeds. Well irrigated alfalfa in warm conditions is the perfect environment for residual herbicide to experience microbial degradation and break down over time. Herbicide programs should focus on multiple applications with residual products throughout the year to prevent weed contamination in all cuttings.

Perennial weeds are often very difficult to control in an established alfalfa stand. Certain perennials can be controlled or suppressed, but it is a best practice to control these weeds by rotating out of alfalfa. Rotating out of alfalfa is a good way to alter the section pressure to the population of weeds which have developed under the condition of an alfalfa stand. Rotation also allows mechanical methods such as tillage, or an herbicide not registered in alfalfa to be utilized. Often rotating to an annual graminoid or grain crop for two years will help clean up a field from common alfalfa weeds, as well as diseases. One major exception to controlling perennial weeds in established stands is in Roundup Ready alfalfa. Roundup Ready alfalfa can be an excellent option to clean up dirty fields infested with either annual or perennial weed species. Multiple applications of the broad-spectrum product glyphosate can be applied per year, helping kill roots and reducing seeds in the seedbank. However, there are some drawbacks to the Roundup Ready systems which have been documented, such as the interaction with frost in cold climates. Generally, as glyphosate does not provide any pre-emergence control of weeds it is best to tank mix it with a residual material for extended control.

Herbicide resistance is also something that should be considered when managing weeds in alfalfa. There have been 513 cases of herbicide resistance documented globally as of 2020 (with many more suspected). Fifteen of these cases have been documented to have developed in alfalfa production, seven in Australia, six in the United States, and one in Israel and Italy respectively. Many of the other weeds which have developed resistance in other crops still have the ability to grow in alfalfa. Weeds have developed the ability to withstand application of not just one mode of action, but in certain cases multiple modes of action. Italian ryegrass is resistant to four modes of action and has been documented to be growing in alfalfa within California. In order to combat herbicide resistance, the best management practice of always using multiple effective modes of action during an application is encouraged. If a weed is already resistant to a mode of action, that mode of action should not be considered effective in a tank mix. Glyphosate resistance is widespread throughout parts of the globe, which can impact the effectiveness of the RR system.

In the United States the WSSA did a survey of weed scientists who work in Alfalfa for what weeds are most problematic in broadleaf crops. The survey was conducted in 2016 as well as in 2019. Results can be found in table one. Pigweed species, including palmer amaranth red root pigweed etc. moved to the top of the list in both most common and most troublesome in a three year period.

Photo two shows a suspected resistant palmer amaranth population in alfalfa. Considering the rise of herbicide resistant pigweeds, that could be a good explanation of the shift of them being problematic in the United States alfalfa production.

WSSA Survey Weeds in Alfalfa			
2016		2019	
Most Common	Most Troublesome	Most Common	Most Troublesome
Mustard spp.	Canada thistle	Pigweed spp.	Pigweed spp.
Dandelion	Mustard spp.	Mustard spp.	Canada thistle
Foxtail spp.	Dandelion	Bromus	Bromus
Pigweed spp.	Downy Brome	Kochia	Dandelion
Bromus spp.	Kochia	Dandelion	Mustard spp.

Table one: Most common and troublesome weeds courtesy of the WSSA 2016 and 2019 surveys https://wssa.net/wssa/weed/surveys/

Photo One: Strips of shepardspurse in an alfalfa field. It was suspected this field was contaminated the previous year, and cut after seed production. Seeds were then concentrated in the windrows resulting in strip of heavy weed pressure the following year.

Photo Two: Suspected herbicide resistant palmer amaranth population in Alfalfa down in the low desert. Photo courtesy- of Michael Rethwisch UC Farm Advisor-Palo Verde Valley

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PROFITABLE ALFALFA PRODUCTION SUSTAINS THE ENVIRONMENT

Dan Putnam and Emily Meccage[1]

ABSTRACT

Although alfalfa, or lucerne (*Medicago sativa L.*), is frequently characterized as a 'low value' crop, this is a misnomer. Alfalfa forage is frequently the number three economic crop in the US, with corn and soybean #1 and 2. However, this valuation does not include the wider economic value of the food end-products that nourish consumers each day originating with alfalfa. Alfalfa is an 'engine of food production', and on-farm profitability can sometimes rival that of high value crops such as processing tomato. High yield is the primary driver for economic value in alfalfa hay. Since high yields are positively correlated with healthy deep root systems, excellent stand density, soil conservation, stand longevity, high CO_2 fixation and high levels of N_2 fixation, high yields of intensive alfalfa production also contribute to environmental goals. These environmental services often go unrecognized, but include soil health, benefits to crop rotations, wildlife habitat, and reduction of the applications of fossil-fuel fertilizers. These benefits are well-known to farmers, but are rarely valued by our society as a whole and minimally monetized. Although the crop is often criticized for its water-wasting ways, the reverse is actually true: the deep roots, high water use efficiency, salinity tolerance, and (most importantly) its ability to produce some economic yield when water supplies are scares make alfalfa an important component for a water-challenged future. 'Profitable alfalfa production sustains the environment' – the title of this year's Alfalfa Congress is a statement of fact as well as a vision for the future.

ALFALFA AND ECONOMIC VALUE

Alfalfa is one of the world's oldest domesticated crop with a history dating to before 2,000 CE. However, what is its relevance today? Alfalfa competes with wheat as the 3rd or 4th most important economic crop for farmers (Table 1), in spite of the decline in acreage over the past 20 years (Figure 1). Alfalfa is important in many other regions of the world as well. It remains a vital component of modern cropping systems due to its high yield, and its high-quality production for dairy animals and other livestock, and its value in rotations. It is a vital component of cropping systems that benefits many farmers. Although not widely recognized as a food-producing crop, hundreds of millions of people consume a food product originating with alfalfa each day.

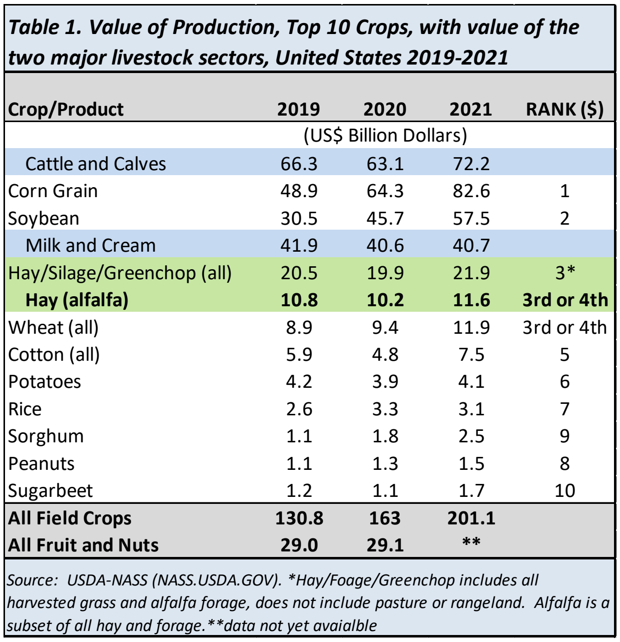

Table 1. Value of Production, Top 10 Crops, with value of the two major livestock sectors, United States 2019-2021

Crop/Product	2019	2020	2021	RANK ($)
	(US$ Billion Dollars)			
Cattle and Calves	66.3	63.1	72.2	
Corn Grain	48.9	64.3	82.6	1
Soybean	30.5	45.7	57.5	2
Milk and Cream	41.9	40.6	40.7	
Hay/Silage/Greenchop (all)	20.5	19.9	21.9	3*
Hay (alfalfa)	**10.8**	**10.2**	**11.6**	**3rd or 4th**
Wheat (all)	8.9	9.4	11.9	3rd or 4th
Cotton (all)	5.9	4.8	7.5	5
Potatoes	4.2	3.9	4.1	6
Rice	2.6	3.3	3.1	7
Sorghum	1.1	1.8	2.5	9
Peanuts	1.1	1.3	1.5	8
Sugarbeet	1.2	1.1	1.7	10
All Field Crops	**130.8**	**163**	**201.1**	
All Fruit and Nuts	**29.0**	**29.1**	**	

*Source: USDA-NASS (NASS.USDA.GOV). *Hay/Foage/Greenchop includes all harvested grass and alfalfa forage, does not include pasture or rangeland. Alfalfa is a subset of all hay and forage.**data not yet avaialble*

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What is the Value of Alfalfa? Often, the economic ‘value’ of a crop is simply calculated as the ‘farm gate’ value. In this ranking, alfalfa is either 3rd or 4th in the US (Table 1), pretty high. However, is that the only way to understand economic value? Wheat, for example is frequently considered a ‘low value’ crop since returns to growers are relatively low, but thousands of loaves of bread can be produced from an acre of wheat (Table 2). The ‘low value’ (low price) of a crop is often due to its high productivity! Table 2 compares several ‘low and high- value’ crops produced in California, the farm gate value, and projects a consumer value of common products produced from these crops on an acre basis. Although the calculation of ‘milk yields’ coming from an alfalfa field is complex (alfalfa is only one ingredient in a dairy ration), a projection was made using the milk/ton equation from the University of Wisconsin. Alfalfa fields are capable, using average figures in irrigated regions, of producing a potential of over 2,000 gallons of milk per acre.

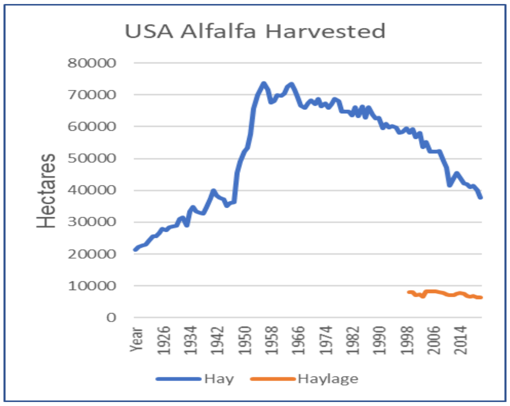


Figure 1. *Alfalfa hectares have been reduced in recent years due to various factors (data USDA-NASS).*

Table 2. Acreage, yield, and per-acre and consumer value of Several important California Crops (2020-2021 data) - Retail value produced per acre given as examples.

Farm Production					Products produced: Value to the Public				
Crop	**CA Acreage**	**Crop Yield**	**Farm Gate Value $$/unit**	**Value ($/acre)**	**Common Retail Product**	**Units Produced**	**Retail Per Unit**	**Retail Value Per Acre**	**California Consumer Value**
	acres	lbs/a	$/pound	$/acre	Item	Product/acre	$/unit	$/acre	
Wheat (grain)	100,000	4,640	$ 0.11	$ 510.40	Loaf of Bread (1 lb)	4,408	$2.50	$11,020	$1,102,000,000
Rice (grain)	407,000	7,200	$ 0.16	$ 1,152.00	Bag of White Rice (1 lb)	6,840	$0.60	$4,125	$1,678,679,640
Alfalfa (hay)	510,000	14,400	$ 0.13	$ 1,800.00	Bottle of Milk (gal.)	2,459	$3.53	$8,680	$4,426,937,700
Almonds (shelled)	1,250,000	2,040	$ 1.76	$ 3,590.40	Nuts in a Can (1 lb)	1,836	$5.50	$10,098	$12,622,500,000
Lettuce (head)	80,000	38,000	$ 0.30	$ 11,400.00	Head of Lettuce (1 lb)	36,100	$1.78	$64,258	$5,140,640,000
Tomato (Processing)	248,900	94,000	$ 0.05	$ 4,794.00	Can of Tomato Sauce (lb)	21,858	$0.89	$19,454	$4,842,006,018
Grapes (wine)	580,000	11,760	$ 0.34	$ 3,963.12	Bottle of Wine (1 liter)	3,772	$8.08	$30,478	$17,677,100,800

**Note; These crops differ significantly in dry matter content. Production data from NASS sources and CA ag. statistics sources. Most retail prices taken from consumer price Index. Wheat and rice assumed to produce products at 95% of crop yield and almonds 90% of nut yield. Alfalfa to milk calculation using the University of Wisconsin milk/ton calculation. Conversions of grapes and tomato based upon industry estimates.*

Why is this type of comparison of interest? First, it illustrates the tremendous productivity of agriculture to the consumer. Secondly, since all crops utilize precious land and water resources, the public needs to know whether such allocations are ‘worth it’. Water is widely considered a public resource, and this becomes particularly important in fights over water during drought. Witness the frequent discussions in the media about producing ‘low value’ crops with water resources, forgetting that these are typically the staples of human diets and of enormously importance to the consumer.

However, are food products and farm profitability the only benefits of alfalfa?

ENVIRONMENTAL SERVICES OF ALFALFA

Sustainability for agriculture has become a catch phrase for government agencies, businesses, farmers and researchers in recent years. Many businesses have ‘Sustainability Officers’, recognizing the importance of environmental impacts of their activities and supply chains. As the global population closes in on 8 billion souls, the uncertainties of climate change, water supply, loss of habitat, and limitations of soil and water are real concerns for agricultural systems and farmers, as they work to meet global energy and sustenance demands. Of particular concern is the use of water to produce food sustainably, and the protection of soil, water and air resources. After all, a mere 1-meter deep fragile layer of the earths' crust, on only a fraction of terrestrial area suitable for agriculture, must produce sufficient food and fiber for these populations with declining water and energy resources and changes in climate. History and current evidence illustrate the fragility of soil resources (Figure 2).

Figure 2. The dust bowl of the 1930s in the US Great Plains and more recently, water erosion (right) in row crops, is a reminder of the fragility of our soil resource. High-yielding alfalfa crops protect soils from erosion.

Table 3. Environmental Sustainability Benefits of Alfalfa Compared with the two other major crops in the USA and use of short-term cover crops. (adapted from Meccage, 2021)

Sustainability Benefit	Alfalfa	Corn[1]	Soybean[1]	Short Term Cover Crops
Nitrogen Credits in Crop Rotation	++		+	+
Carbon Sequestration	++	0/-	0/-	+
Improved Soil Structure	+			+
Reduced Water Erosion	+			+
Reduced Wind Erosion	+			+
Decreased Nutrient Leaching/runoff	+			+
Increased Soil Microbial Diversity	+			+
Wildlife Habitat Benefit	++			
High Water Use Efficiency	+	+	+	+
Resilience to drought/climate	+			+

1.It should be noted that crops like soybean and corn can also be managed in a way to improve environmental impacts of row cropping, such as conservation tillage, use of compost, crop rotation with legumes, and management of crop residues.

There are a wide range of environmental benefits observed in alfalfa (Table 3). There have been major efforts to introduce short term cover crops (e.g. triticale, vetch) into row-crop rotations, recognizing their benefits on soil preservation and improvements in soil tilth. Each of these benefits of alfalfa have tremendous potential to contribute to societal goals of sustainability.

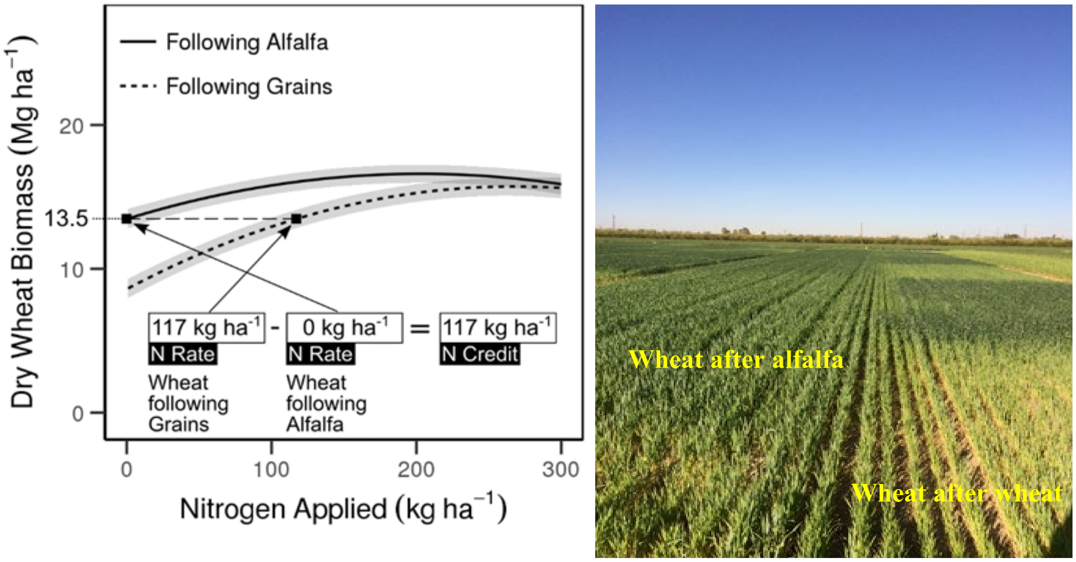


Figure 3. *N benefit of alfalfa to subsequent wheat crops in California - 70-160 kg/ha N is credited from the alfalfa crop to wheat, depending upon location, reducing costs and fossil fuel use in agriculture (Lin et al., 2015).*

Nitrogen benefits and Crop Rotation. Nitrogen is a critical nutrient for plants, and typically the most limiting nutrient in terrestrial cropping systems, especially for cereal grains (wheat, corn, rice) and vegetables. Seventy-eight percent of the atmosphere consists of nitrogen (N_2), which is unavailable to plants, but can be made available through N_2 fixation by *Rhizobium* bacteria in symbiosis with legumes. Cropping rotations that include corn after alfalfa often do not require synthetic inputs of nitrogen for at least one year, with many fields requiring decreased nitrogen fertilizer even the second year out of alfalfa as well (Creech et al., 2019; Undersander and Barnett, 2008; Sheaffer, 2004, Lin et al., 2015). Figure 3 illustrates this benefit to the subsequent crop – in this case wheat, but we've found similar benefits to corn, tomato and other non-legumes. This leads to significant financial savings, as nitrogen inputs represent a large portion of the input costs (and carbon costs) in row crop production. Furthermore, nitrogen presented to the soil in the form of legume-synthesized nitrogen, versus the more mobile form from synthetic nitrogen fertilizer is more slowly available and decreases the potential for nitrogen leaching into groundwater and aquifers.

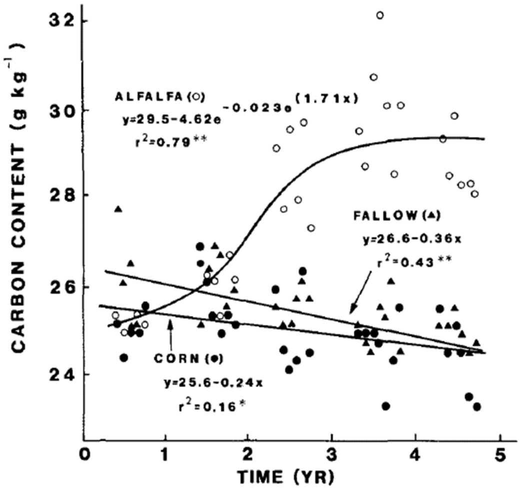


Figure 4. *Soil Carbon accumulation under alfalfa, corn and fallow (data from Angers, 1992)*

Carbon sequestration. Historical data suggests that alfalfa can sequester significant amounts of carbon in the soil and improve carbon concentrations deeper in the soil than many other crops (Figure 4). Jarecki et al. (2005) found that when compared to continuous corn cropping, alfalfa sequestered 22% more soil organic carbon (SOC), in agreement with Cates et al. (2016)

which found that alfalfa sequestered 26% more SOC than rotations that included only annual crops (corn and soybean). Angers (1992) found that alfalfa accumulated carbon in the soil over 5 years, while corn or fallow fields showed a decline (Figure 4). Saliendra et al. (2018) found that when comparing perennial alfalfa to perennial grassland, the amount of SOC was greater in the alfalfa, even when the aboveground biomass was harvested as hay. The amount of C sequestered increased in this study if the alfalfa was irrigated, correlating to the amount of both aboveground and belowground biomass that was produced. This illustrates the concept that high-yielding alfalfa is positively correlated with carbon benefits to soils.

Additionally, alfalfa is deeper-rooted than many crops (Figure 5), especially grasses and annual crops. With many of the other closely studied crops, most of the sequestered carbon is stored in the top 10 cm of soil, close to the soil surface. However, it appears that alfalfa has the ability to place carbon deeper in the soil, with gains found at 30-60 cm (Cates et al., 2016). Interestingly, in that same study the corn-soybean rotation found losses in SOC in those deeper layers.

Alfalfa growers have not widely participated in carbon markets. Further data is needed, but the ability of alfalfa fields to contribute to carbon capture should not be ignored.

Soil health and mitigation of nutrient leaching.

Although ‘soil health’ is not often specifically defined (nor is ‘human health’ for that matter!), it is a major goal of farmers and those interested in sustainability of systems. It generally refers to the optimal soil structure (aggregates), mix of particles, minerals, pH, air and water, organic matter and microbial biome all of which contribute to the soil’s ability to grow crops. This is related to the concept of ‘tilth’, and improving soils for future generations. Many studies have found that multi-year use of alfalfa in cropping rotations significantly improves soils. Alfalfa improves the size of soil aggregates (Angers, 1992), which helps to improve moisture retention, drainage and water movement, and nutrient availability in the soil. It results in more stable soils that are resilient to changes in climate such as periods of drought or heavy rains. Alfalfa helps to decrease erosion, a benefit that has been shown by research studies that included alfalfa. Wu et al. (2011) found that soils in rotation with alfalfa had infiltration rates that were 1.77 times that of bare soil, and sediment transportation movement away from the field decreased by 78.4%, due to a marked improvement in soil structure.

Figure 5. *The deep vigorous roots of alfalfa (>2meters) contribute to carbon capture, protect soil from erosion, improve the soil micro-biome and soil structure, and allow for efficient water-use.*

Included in soil health benefits are qualities such as alfalfa’s ability to decrease nutrient leaching, critical in mitigating runoff into water sources. Due in large part to its deep taproot system (Figure 5), alfalfa can “soak up” large amounts of nutrients in the soil that otherwise have the potential to contaminate nearby water sources. Other options such as many species of cover crops are also able to decrease significant amounts of nutrient contaminants; however, alfalfa can reach deeper levels in the soil. It is also efficient at decreasing levels of toxic metals in the soil and has been used in soil remediation and reclamation efforts.

The Carbon Benefit of N_2 Fixation. Another important consideration is the environmental cost of using synthetic nitrogen fertilizers. Most reports estimate that industrial production of urea produces approximately 3 tons of carbon per ton of urea produced, and 2 tons of carbon per ton of ammonium nitrate produced. Added to that is the amount of carbon that is produced during the transport and application process, representing a large financial and environmental cost to growing that non-legume crop. Utilizing alfalfa decreases the dependence on synthetic fertilizers, saving both dollars as well as carbon emissions.

Wildlife Habitat, Biodiversity and Ecosystem benefits. Alfalfa is a great habitat for many species of wildlife, from large herbivores like elk and deer, to smaller mammals such as rodents, as well as soil-dwelling organisms, to a wide range of insects and pollinators (Figure 6). Many bird species (for example, the migratory threatened Swainson's Hawk) prefer alfalfa fields over neighboring landscapes. Pollinators (Figure 6) are critical for a healthy food production system, and alfalfa hosts many species of pollinators. Bees are necessary for alfalfa seed production. Alfalfa is also an important 'insectary' – with up to 1,000 species observed in fields (ask an entomologist!). Over 25% of California's wildlife use alfalfa for cover, reproduction or feeding (Putnam et al., 2001), and similar numbers on a national scale (Fernadez et al., 2019). Alfalfa is commonly used in strips in organic systems due to many 'beneficial' predator insects (e.g. ladybird beetle, Figure 6) which help to control pests such as aphids. Whether it be insect species, diseases or weeds, alfalfa can be utilized to disrupt growth cycles, and decrease the overall negative impact they have on production.

Figure 3. *Examples of biodiversity, wildlife and insect habitat in alfalfa. Alfalfa is the beginning of a high-value food chain. Top left: leafcutter bee pollenating alfalfa flower, top right curlew in alfalfa, bottom left, ladybird beetle which helps control aphids, and bottom right, deer. (Photos by M. Wagner, Washington State)*

WHAT ABOUT WATER AND IRRIGATION?

Approximately 50% of US alfalfa is produced with full- or partial-irrigation (Figure 7). In many areas of the world (Middle East, N. Africa, southern Europe, China, India/Pakistan and Australia, irrigation of alfalfa is the norm. Alfalfa is a very successful crop under irrigation – average yields in long-seasoned California and Arizona (~100% irrigated) are about 20 Mg/ha (9 tons/acre), and maximum yields under good management are 35 Mg/ha (16 tons/acre). The high yields of alfalfa under irrigation exhibit high water-use efficiencies, a key measure of water stewardship.

However variable rainfall and water availability is a major challenge. Over the past 10 years in the USA, major alfalfa growing areas were affected by severe, extreme or exceptional drought much of the time, sometimes over 40% of US acres (Figure 8). Drought conditions can cause reductions in yield, or complete dry-downs of fields. In dry regions like the US West, it is anticipated that drought will become a frequent visitor, challenging farmers and society as a whole. It is important to note that while drought severely limits the production of alfalfa in that given period, alfalfa is unique among the top commodity crops in that it can regrow as soon as moisture returns, and provides perennial cover to protect the soil from erosion.

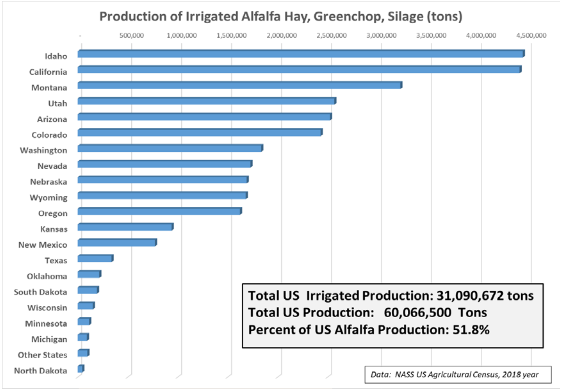


Figure 7. Irrigated alfalfa production in major US states, USA (2018 data)

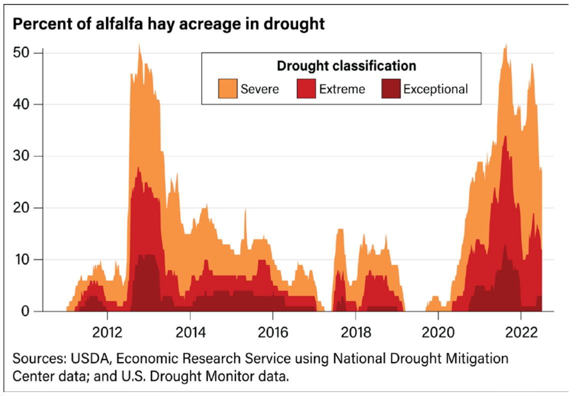


Figure 8. Percentage of US alfalfa hay produced under severe, extreme and exceptional drought, past 10 years.

Increases in extreme weather variation is a frequently predicted outcome of climate change – severe droughts followed by torrential rains. This makes alfalfa's ability to grow once moisture returns even more important, as it can help to provide ground cover during those torrential rains and begin utilizing that moisture versus an annual crop that dies out from lack of moisture.

The need for <u>resiliency</u> of agricultural food-producing systems given the certain <u>variation</u> in water supply is a current and future reality. What are alfalfa's biological properties that are relevant to a water-challenged future?

CHARACTERISTICS OF ALFALFA THAT PROMOTE SUSTAINABILITY OF WATER USE

Although often the target of criticism due to high water use (and low value), alfalfa has a series of qualities that are actually positives when it comes to water resiliency and efficiency.

High Water-Use Efficiency, High Harvest Index. The harvest index (HI), the percentage of above-ground crop harvested for economic product of alfalfa is about 100%, whereas most crops the harvest index range from 10-50%. This, in addition to its high yield and deep roots, is the reason that alfalfa is among the most efficient plants in Water Productivity (sometimes called Water-Use Efficiency) – the amount of dry matter produced per unit water. The Water Productivity is even higher with optimum varieties and management: illustrating that high yields and profitability are positively correlated with environmental benefits.

Deep Roots and Utilization of Residual Moisture. Alfalfa roots have been documented as deep as 15 feet (5 m), and routinely explore soils in the 3-9 foot (1-3 m) range when soils provide no impediments (Figure 5). Residual moisture from previous irrigation and rainfall events (months earlier) are often very important in sustaining alfalfa production during periods of insufficient surface water from rain or irrigation (Figure 9). The deep roots of alfalfa prevent over-irrigation past the root zone, improving utilization of water to produce crop yield (water-use efficiency). These vigorous root systems also improve soil water infiltration (through soil channels and microbial action) and soil health.

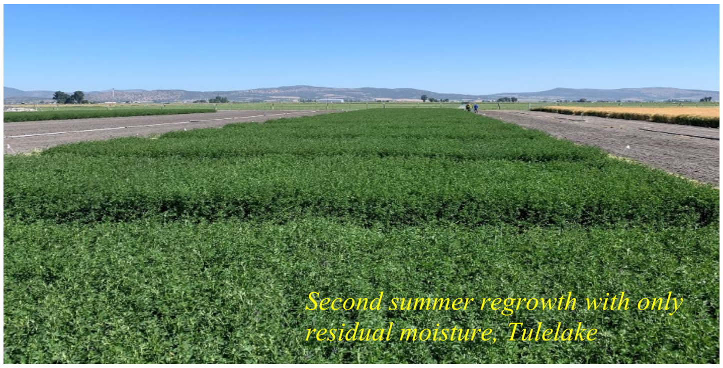


Figure 4. *The resilience and deep rootedness of alfalfa was demonstrated during the 2021-22 drought at Tulelake, CA, where near full yields of alfalfa was observed with zero irrigation, with approximately 14" (350mm) winter rainfall over 2 years. (Photo, July, 2021. D. Culp).*

High flexibility during droughts. There is now considerable data that confirms the ability of this crop to sustain forage production when water is reduced during droughts (Figure 10). No grower would prefer to under-irrigate their crop, but when necessary, this crop tolerates short-term droughts in most cases. Yields are almost always lower when under-irrigated, but the crop can still produce adequate yields when

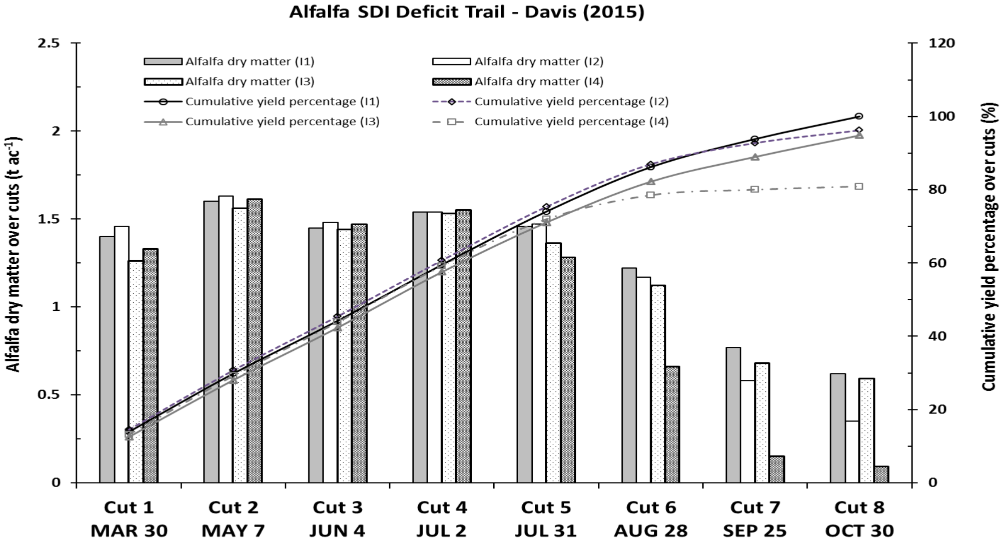


Figure 10. *Cutoff of irrigation water after July 4 of 50% of irrigation applications resulted in about 80% of full yield, while cutoff at 75% of ET irrigation demand resulted in 95% of full yield. Savings of up to 20" of irrigation water were observed. This is due to high productivity in early harvests, and use of residual moisture after irrigations cease (data Davis, CA, 2015).*

irrigations cease (Figure 10). Yield penalties from deficit irrigation strategies widely vary by soil type and environment (Cabot et al., 2017, Montazar, 2020). Alfalfa often enters a 'summer dormancy' in most cases after utilizing residual moisture. This is not a zero-irrigation strategy, but offers the ability to 'turn off the tap' when water is simply not available or needed for other uses. Savings in water during summer months can be as much as ½ of full watering normally applied through irrigation systems (Figure 10). In MOST cases, alfalfa can recover from these summer droughts, to be re-watered in subsequent years.

Multiple Harvests, Partial Season Production. While most crops are harvested once during the year, alfalfa is harvested multiple times. In short-seasoned environments, harvest range from 2 to 5 and in longer-season environments 7 to 12 harvests. Yields typically decline later in the season, even if fully watered. "Summer slump" (Ottman and Putnam, 2017) is a common observation in alfalfa (notice yield trends, Figure 10). In most environments, over 60% of the production is realized by mid-summer. The highest alfalfa yields (and highest quality) occur during the first few months of production at a time of highest water use efficiency and lowest ET. This enables partial-season production with limited water (Figure 10).

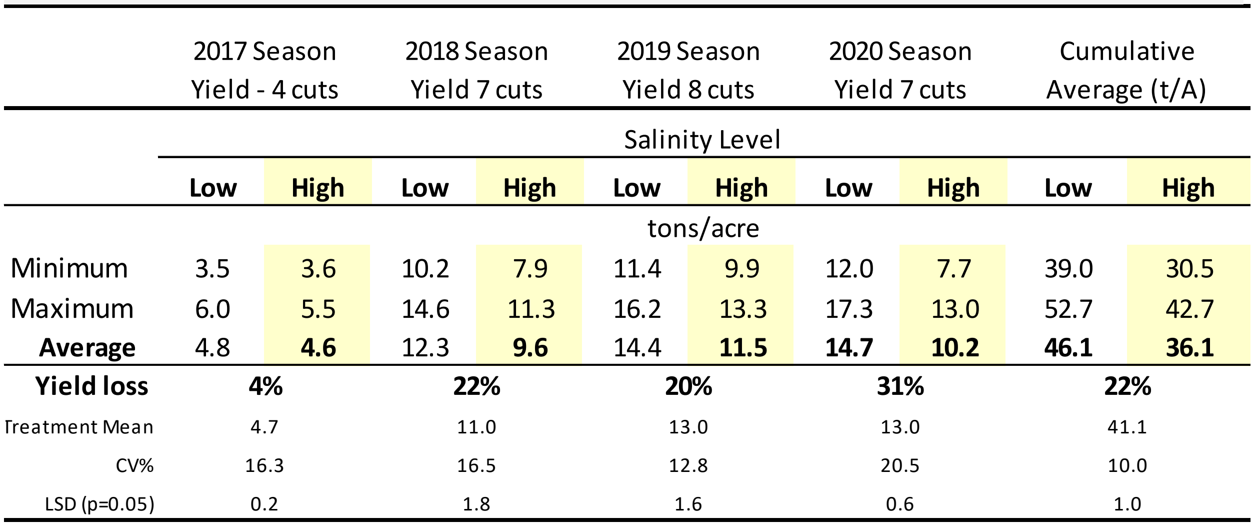
When partial-season dry-downs are necessary, will the crop survive and recover to produce when watered again? They answer is generally 'yes'. When deficits were applied in Colorado studies (Cabot et al., 2017), in virtually all cases, the fully-watered crop recovered in the following year. In several of these on-farm Colorado studies, the production of re-watered crops following two years of stress was superior to fields that were previously well-watered. We've found similar recovery of previously-stressed alfalfa in California studies (Frate et al., 1991); The only exception to this result are on the harsh cracking-clay soils under high salinity and intense head of the Imperial Valley, where stand decline from summer deficits is more common.

Ability to be over-watered in Winter to Recharge Aquifers. Given the high variation in annual precipitation (Figure 7), the value of excess capture has not escaped the attention of water managers. The concept of Flood-MAR (Managed Aquifer Recharge) which promotes flooding of fields during times of high river flows have been studied (DWR, 2021b). Alfalfa has been found to be suitable to this practice, with up to 30 feet of water applied to permeable soils with minimal crop damage in Intermountain and Valley locations (Dahlke et al., 2018). More recently, Bali et al. (2022, unpublished) have shown winter flooding events not to damage alfalfa yields, in fact benefitted yields due to the early irrigate events if done carefully. Alfalfa has an advantage vs. fallow or other crops, in that nitrate contamination of groundwater is likely to be a lower risk. However, it is well known that alfalfa can be damaged with excess flooding, so only care must be taken to reduce oxygen deficits since flooding can kill alfalfa.

Water Early, Apply Deficits Late. Due to this seasonal production pattern, emphasis on early production is key. Irrigation water is typically more available early in the season or winter periods, and more precious in mid-late-summer. We found that early season (February-March) irrigations not only increased yields in the first three cuttings, but also sustained stands and yields later in the year, even when deficits were applied in the summer. Early season irrigation followed by summer cutoffs are recommended to cope with lack of water over the summer months. This technique may be an important strategy to cope with droughts.

Salinity tolerance. Buildup of salinity is an unwanted consequence of lack of water and poor drainage. Contrary to some published accounts, alfalfa is highly tolerant of salinity. Over four years of field trials in Fresno County with applications of saline waters (ECw from 8-11 dS/m), we observed a buildup of salinity effects over time, and the average yield effects was about 22% penalty over the four years (Table 1). However, yields in this case were still high and economically viable in high saline plots. It is obviously not desirable to continually build up salinity, but these data confirm the tolerance of this crop to these harsh saline conditions. This would enable alfalfa to be grown utilizing degraded water (municipal wastewater, manure water, drainage water), a valuable trait to extend scarce water supplies.

Table 4. Cumulative effect of salinity on alfalfa yield, average of 35 varieties over four years, Five Points, CA. Trial was planted 3/29/17, so first year data is a partial year result. Water with ECw of 8 to 11 dS/m was applied to the saline plots (high salinity) and water of 1.0-2.0 dS/m to Low Salinity plots. On a deep clay loam soil. Soil salinity at the completion of the trial ranged from 12-17 ECo, depending upon depth. Unpublished data (D.H. Putnam, UC Davis).



	2017 Season Yield - 4 cuts		2018 Season Yield 7 cuts		2019 Season Yield 8 cuts		2020 Season Yield 7 cuts		Cumulative Average (t/A)	
	Salinity Level									
	Low	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
	tons/acre									
Minimum	3.5	3.6	10.2	7.9	11.4	9.9	12.0	7.7	39.0	30.5
Maximum	6.0	5.5	14.6	11.3	16.2	13.3	17.3	13.0	52.7	42.7
Average	4.8	**4.6**	12.3	**9.6**	14.4	**11.5**	**14.7**	**10.2**	**46.1**	**36.1**
Yield loss	**4%**		**22%**		**20%**		**31%**		**22%**	
Treatment Mean	4.7		11.0		13.0		13.0		41.1	
CV%	16.3		16.5		12.8		20.5		10.0	
LSD (p=0.05)	0.2		1.8		1.6		0.6		1.0	

Alfalfa has a key role to play in a water-uncertain future due to its high flexibility during times of insufficient and excess water, due to important biological features: 1) its deep roots which allow the use of residual moisture, 2) multiple harvests can give partial economic yields when water is limited, 3) alfalfa roots survive summer dry-downs, and regrows when re-watered, 4) it can be flooded in winter to recharge aquifers, and 5) high salinity tolerance.

SUMMARY

Though often skewered in the press for its 'low value' and water use, both the on-farm profitability and broader value of alfalfa to the consumer and environment is frequently underestimated. High crop yields are correlated with a range of environmental benefits, suggesting a need for 'sustainable intensification' of alfalfa crop production. The significant role alfalfa plays in, soil conservation, high carbon capture, benefits to non-legumes in rotation, soil health, biodiversity and wildlife habitat, and flexibility during droughts suggest that this crop should be envisioned as a critical aspect of sustainable agricultural systems.

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Keywords: Irrigation, climate change, water-use efficiency, cropping systems, environment

CROPPING ALFALFA TO ENHANCE ABOVE AND BELOWGROUND BIODIVERSITY

Marisol Berti[1], Anastasia Kurth[1], Haley Mosqueda[1], Samuel Bibby[1], and James V. Anderson[2]

ABSTRACT

Biodiversity is a key factor to maintain healthy, resilient, and stable cropping systems. As biodiversity decreases, cropping systems are more susceptible to biotic and abiotic stresses that can lead to reduced productivity and detrimental effects to the environment. Alfalfa (*Medicago sativa* L.) is a key component in crop rotations offering numerous ecosystem services including enhanced above and belowground biodiversity. Aboveground, the high protein content in alfalfa leaves attracts many arthropods, including predators of insect's pests and pollinators. Many other arthropods live below the alfalfa's canopy such as ground beetles, spiders, and crickets to mention a few, which provide many functions to the microecosystem. Researchers have shown that species number and diversity is greater for ground arthropods in alfalfa than in other annual crops. Belowground, the ability of alfalfa to fix atmospheric N_2 in symbiosis with *Sinorhizobia* and other microbial communities increases the availability of nutrients for crops, soil microarthropods, and microbes. Biogeochemical processes in the soil are driven by different groups of bacteria and fungi. These processes alter the soil structure promoting soil aggregation, which in turn provides a habitat for different functional groups of microorganisms ultimately responsible for overall soil health. Previous research has found that cropping systems including alfalfa have significantly greater fungal and bacterial biomass, diversity index, and richness in the soil compared with cropping systems including annual crops such as corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.]. Although efforts to integrate alfalfa into cropping systems are underway, greater efforts are needed to disseminate the benefits of including alfalfa in crop rotations to growers.

Key Words: alfalfa, biodiversity, arthropods, pollinators, soil microbiome

INTRODUCTION

Biodiversity is defined as all the different kinds of living organisms you find in one area, including plants, animals, fungi and microorganisms like bacteria. Biodiversity is a key factor to maintain a healthy, resilient, and stable cropping system. As biodiversity decreases, cropping systems are more susceptible to biotic and abiotic stresses that can lead to reduced productivity and detrimental effects to the environment. Alfalfa offers numerous ecosystem services including biodiversity restoration (Baldwin-Kordick et al., 2022).

Prior to the 1970's, crop rotations in the Midwest U.S. generally included 5-8 crops with alfalfa as a main component of the rotation (Aguilar et al., 2015). However, as conventional intensification of crop production shifted to short-rotations of row crops that rely heavily on

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chemical fertilizers and pesticides, technological improvements, and market forces, diversity drastically declined in rotational cropping systems. Compared with other regions in the USA, the Midwest Corn Belt Region currently has the least crop diversity and the steepest decline in diversity since 1978 (Aguilar et al., 2015).

In addition to the importance of alfalfa in human food production (milk, meat, cheese, etc.), alfalfa also is at the beginning of the food chain that supports many types of arthropods (insects, spiders, mites, and others), small herbivores such as ground squirrels and mice, and large mammals such as deer (Putnam et al. 2001). Indirectly, many other species including birds, mammals, reptiles, and others feed on the small herbivores that feed on alfalfa, which is usually the only crop that is green in the late fall and early spring when no other crop is available for feed. The year-round cover of alfalfa also provides important habitat for many insects, birds, mammals, and others. In California, for example, 182 species of birds, mammals, amphibians and reptiles were observed using the alfalfa crop and borders of fields for feeding, reproduction, or cover (Putnam et al., 2001).

Niemuth et al. (2021) demonstrated that non-native planted cover such as alfalfa can substantially enhance pollinators providing nectar sources and serving as a buffer from pesticides associated with croplands. The high protein content in alfalfa leaves and the cover provided by the canopy attracts many arthropods, including many predators of insect's pests. In fact, beneficial insects compose 99% of the insects present in the alfalfa canopy with pests representing only about 1% (Putnam et al., 2001). Alfalfa is a cross pollinated plant and its flowers attract many pollinators providing them with pollen and nectar (Fig. 1). However, in alfalfa hay production areas where alfalfa is generally cut at late bud or early blooming, alfalfa does not contribute to increase the diversity of pollinators (Mogren et al., 2016). Many other arthropods live below the alfalfa's canopy such as ground beetles, spiders, and crickets, to mention a few and provide many functions to the microecosystem. Researchers have shown that species number and diversity of ground insects and spiders is greater in alfalfa than in other annual crops. In fact, researchers in California have identified over 1000 species of arthropods inhabiting alfalfa fields (Putnam et al., 2001).

Belowground, microarthropods, earthworms, and microorganisms thrive in alfalfa fields and contribute to soil health. The ability of alfalfa to fix atmospheric N_2 in symbiosis with *Sinorhizobia* and its association with arbuscular mycorrhizal fungal (AMF) communities increases the availability of nutrients for alfalfa, crops that follow in the rotations, and soil microarthropods and microorganisms. The rhizosphere (area surrounding the roots) of alfalfa has trillions of microorganisms, 10 to 100 times more than in the soil not associated with the root system (Putnam et al., 2001). The biological activity in the root rhizosphere increases due to the release of nitrogen- and carbon-rich exudates from alfalfa. However, changing the cropping system can alter microbial communities with specific functions such as N_2O reduction to N_2 (Graf et al., 2019). For example, intercropping alfalfa with orchardgrass (*Dactylis glomerata* L.) increased N_2O emissions compared with either crop alone. This resulted from the shift of rhizosphere bacterial communities towards incomplete denitrifiers rather than N_2O reducers (Graf et al., 2019).

Important biogeochemical process occurring in the soil are driven by different groups of bacteria and fungi. These processes are critical for altering soil structure and promoting soil aggregation, which in turn provides habitat for different functional groups of microorganisms that are ultimately responsible for overall soil health (Potter et al., 2021). In addition, the higher diversity index in topsoil due to greater belowground C from alfalfa serves as source material for microbes and reduces vulnerability of communities to tillage.

Previous research has found that cropping systems including alfalfa have significantly greater fungal and bacterial biomass, diversity index, and richness in the soil compared with cropping systems including annual crops such as corn and soybean (Niu et al., 2020; Potter et al., 2022). A different study reported a 62% increase in microbial biomass after 4 years in a rotation including two years of alfalfa and manure application (Baldwin-Kordick et al., 2022). Niu et al., (2020) concluded that 14-years of continuous alfalfa had greater microbial biomass, Shannon-Wiener diversity index and richness at 0-30 cm and 30-60 cm, and functional diversity compared with a 4-5 years of annual crops wheat (*Triticum aestivum* L.)-corn-potato (*Solanum tuberosum* L.) and millet (*Panicum miliaceum* L.).

In addition, alfalfa suppresses weeds that are common in annual crops, by shading them or avoiding seed production by the frequent cuttings. Weed suppression can lead to less use of herbicides benefiting other organisms in the microecosystem. The use of chemical products reduces the diversity of organisms in plants and soils, and limiting chemical use also reduces herbicide-related aquatic toxicity (Liebman et al., 2021). Diversity in the soil weed seed bank can be used as an indicator of cropping system sustainability, with greater diversity indicating greater sustainability in comparison with a less diverse weed seed bank. Liebman et al. (2021) reported that going from a 2-year to 4-year rotation including 2 years of alfalfa increased weed seed bank diversity.

Increasing the acreage of alfalfa in rotation with other crops is needed to reduce the negative environmental effects of row crop monocultures. Many farmers are reluctant to grow alfalfa because they do not have cattle, equipment required to cut and bale alfalfa, and a market to sell the hay. However, there are creative ways to integrate alfalfa into cropping systems. For example, even just adding alfalfa to the non-productive headlands, which have low yield of corn or soybean anyway, can benefit wildlife and soil health. Many growers are starting to plant alfalfa in headlands and usually neighbors are interested in harvesting and taking the hay. With many states under moderate to severe drought conditions any hay is valuable and can be sold.

Preliminary Results of Arthropods Biodiversity in Different Crops in North Dakota

A study was conducted in Hickson and Prosper, ND in the summer of 2022. One of the objectives was to evaluate the biodiversity of arthropods in alfalfa in comparison to summer fallow (no crop), soybean, corn, wheat, forage sorghum (*Sorghum bicolor* L.) and sunflower (*Helianthus annuus* L.) Insects were recorded weekly using pitfall traps for crawling arthropods and sticky traps for flying insects (Fig. 2). Pitfall traps consisted of a cup placed in the soil at soil level with a cover that only left about 2-cm space between the cup surface and the lid. The sticky traps were all placed 60-cm above the soil on a stick (Fig. 2).

In the pitfall traps, 30 different families of arthropods were collected among all crops and at both locations, but the number of families in each crop ranged between 6-7 for all crops. Four families of arthropods accounted for 98% of the collected specimens averaged across locations and crops (Fig. 3). Insects in the Gryllidae and Carabidae families declined over time in all crops while those in the Phlocideae and Sciaridae families increased at the end of the growing season. Phlocidae are a family of araneomorph spiders commonly known as cellar spiders, whereas Sciaridae are a family of flies known as dark-winged fungus gnats. The increase of these last two families at the end of the season is likely related to the presence of dead plant material, since several crops had been harvested by the last three recordings with only residues left in the field. Wheat had the greatest number of specimens collected through the summer (Fig. 4). The last collection on 29 September was equal for all crops. Interestingly, the greater number of collected insects in wheat was due to crickets (Gryllidae) and ground beetles (Carabidae) inhabiting the under canopy of wheat (Fig. 5). Both families of insects declined over time, which might be related to the plant senescence at the end of the season or drier conditions that interrupt the insect's life cycles. The sticky traps in treatments including corn, sorghum, alfalfa, and corn-alfalfa and sorghum-alfalfa intercropping are yet to be analyzed but visual observation indicates greater diversity of arthropods in alfalfa than in corn and forage sorghum monoculture (Fig. 6).

In conclusion, these preliminary results show a trend of increased diversity of arthropods in alfalfa compared with other annual row crops. However, variation in insect's population and diversity is probably also related to other factors such as temperature, rainfall, crop's growth stage and insect's life cycle. The study will be repeated in 2023 at two locations.

ACKNOWLEDGEMENTS

Graduate students: Haley Mosqueda and Anastasia Kurth for arthropods collection.
***Funding source*:** USDA-NIFA-SAS. Fostering Resilience and Ecosystem Services in Landscapes by Integrating Diverse Perennial Circular Systems (RESILIENCE CAP). Award no. 2021-68012-35917

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Figure 1. Pollinators visiting alfalfa flowers (Photos, Marisol Berti)

Figure 2. Soil pitfall traps and sticky traps (Photos of sticky traps, Anastasia Kurth).

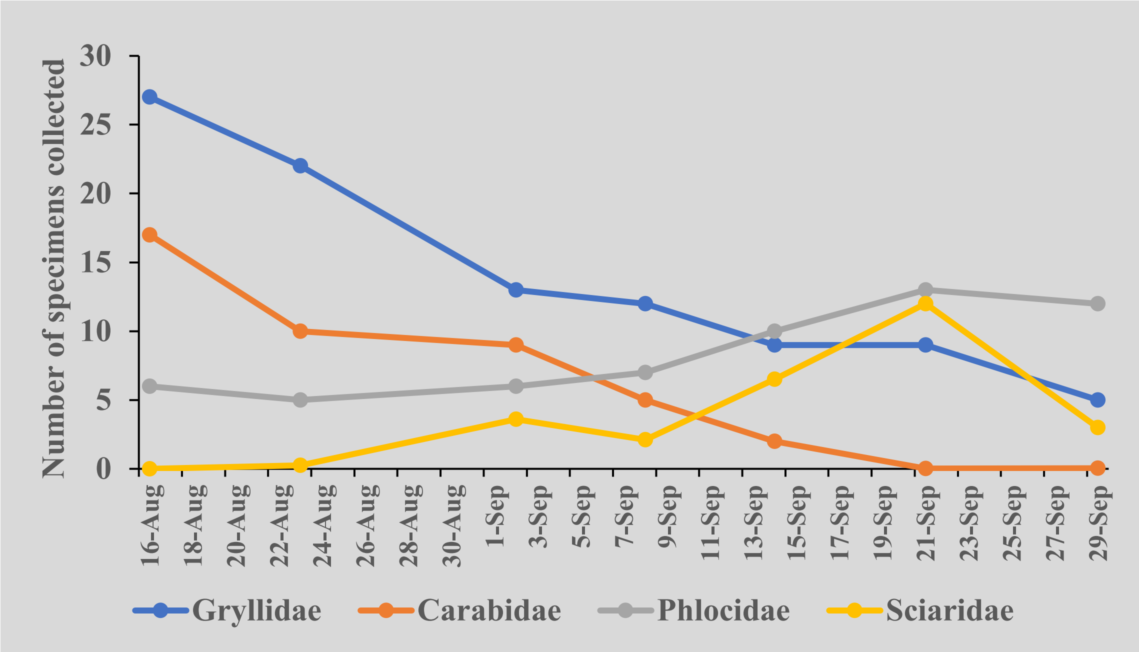

Figure 3. Number of specimens collected weekly in four families averaged across all crops.

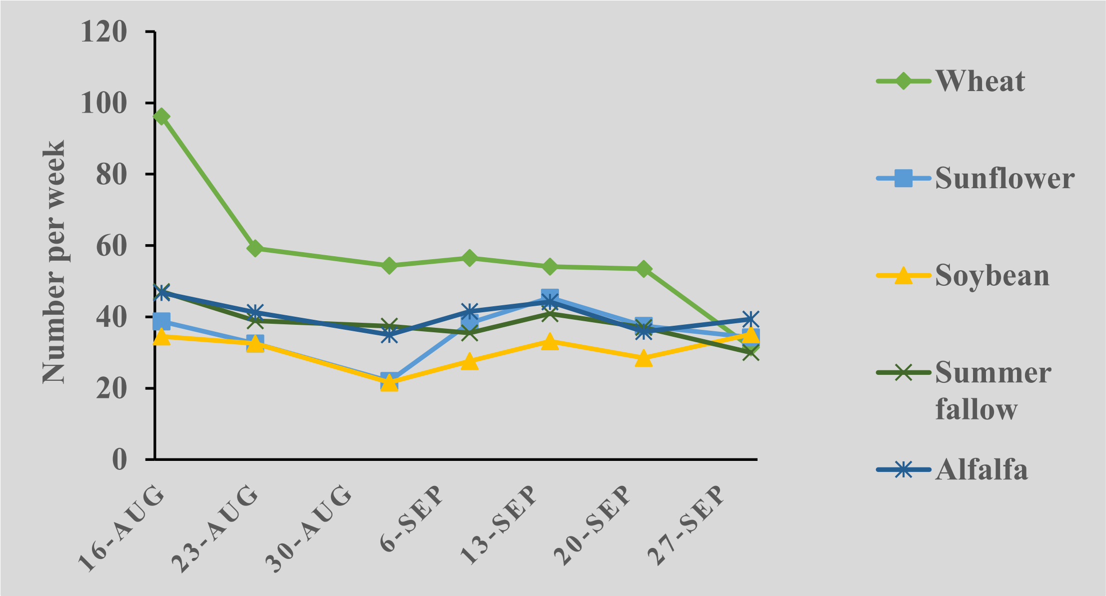

Figure 4. Total number of arthropods by sampling date in pitfall traps averaged across locations

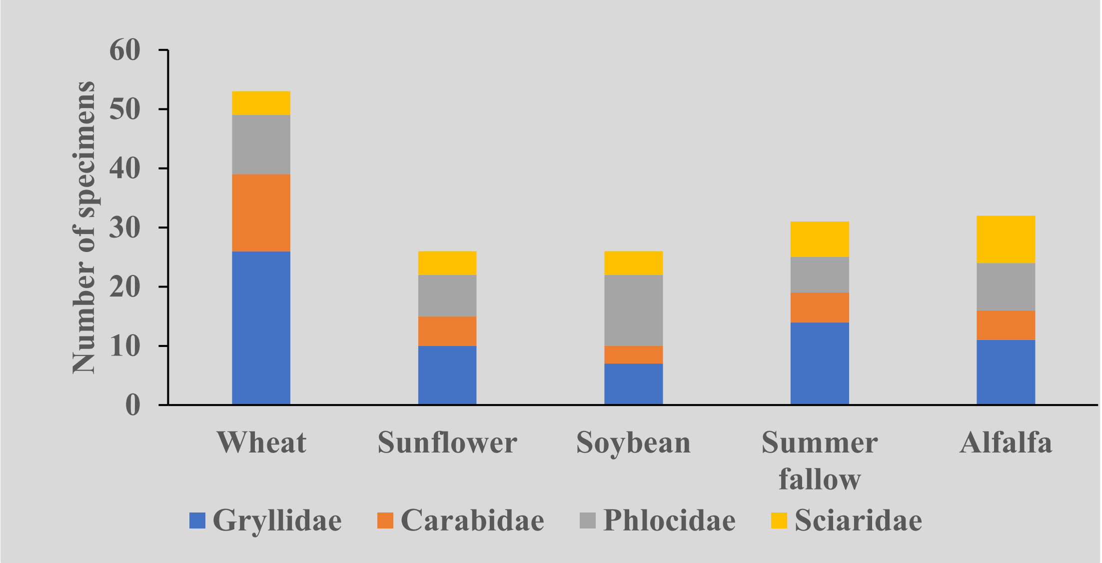

Figure 5. Number of specimens in each crop by family averaged across locations.

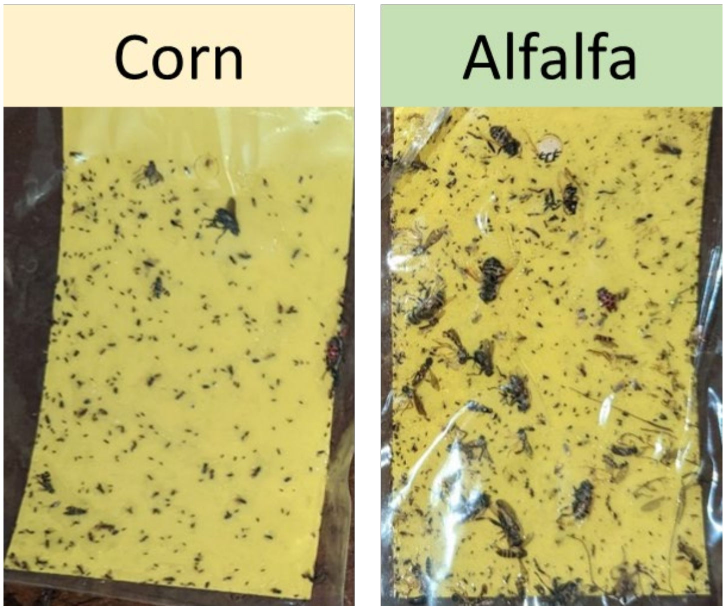

Figure 6. Diversity of insects collected on sticky traps in corn and alfalfa (Photos, Haley Mosqueda).

DEFINING QUALITY IN ALFALFA (DECONSTRUCTING THE PLANT)

David C. Weakley[1]

ABSTRACT

Alfalfa nutrient components play a role in the growth and development of the plant, as well as the nutrition of the ruminant animals consuming it. Despite the fact there is no symbiotic relationship between alfalfa and ruminants, the nutrient composition of alfalfa complements the nutritional requirements of ruminant animals surprisingly well. We know more about the role of some nutrient components (Neutral Detergent Fiber, NDF; Rumen Undegraded Protein, RUP; Starch, Fat, Minerals) than we do about others (Pectin; Water Soluble Carbohydrates, WSC; Rumen Degraded Protein, RDP). Lab analysis of 1070 samples of freshly cut alfalfa plants, hand-harvested from various locations across the United States from 2019-2022, demonstrates the size and range of these various nutrient fractions (expressed as a percent of dry matter).

We know the most about the largest of these fractions, NDF (33.5% ± 5.5), and its digestibility, NDFd (49.4% of NDF ± 4.9), since taken together and expressed as Ruminal Undigested NDF (RuNDF) it can have a profound impact on intake, feed passage rate through the rumen, and subsequent ruminal digestion of the entire diet. As a forage, alfalfa is well suited in this respect since its RuNDF content is relatively moderate, compared to most other forages, because of its moderate NDF content, coupled with its high rate of NDFd.

Crude protein (CP; 22.8% ± 3.2) is another of alfalfa's important nutritional contributions, comprised of RUP and RDP. RUP is a direct contributor to the essential metabolizable protein (MP), or "absorbed" protein supply to the ruminant animal and has been studied extensively (NASEM, 2021). However, no comprehensively validated laboratory method yet exists for its measurement in alfalfa. This is a significant need, since it would also allow for the calculation of alfalfa RDP (i.e., CP minus RUP) which is rich in peptides. Peptides have been shown to improve synthesis of microbial protein in the rumen, which is another important contributor to the ruminant's MP supply.

The least understood of alfalfa's carbohydrate fractions are the non-fiber carbohydrates: starch, pectin, and WSC. While starch constitutes a relatively small fraction (2.9% ± 2.2), pectin (considered by many as "soluble fiber") and WSC taken together constituted an average of 28.2% of the dry matter in this sample set. While we consider these fractions as "benign" energy sources, they warrant further study for potential beneficial effects on rumen function.

With some predictability, we can modify the nutrient composition of alfalfa through variety selection, as well as management of the crop during growth, harvesting, and storage. The key is

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possessing an understanding of how to use laboratory quality measurements to manage the alfalfa crop to the best advantage of the ultimate consumer, the ruminant animal.

Key words: Fat, Minerals, Neutral Detergent Fiber (NDF), Pectin, Rumen Degraded Protein (RDP), Rumen Undegraded Protein (RUP), Starch, Water Soluble Carbohydrates (WSC)

INTRODUCTION

Any discussion of alfalfa forage quality should be based on an understanding of the functional and nutritional components of the plant. The major constituents are crude protein, minerals (ash), fat, fibrous carbohydrates, and non-fibrous carbohydrates. While many excellent reviews discuss each of these fractions in greater detail (Hall, 2015; Mertens, 2015), this discussion will be confined to the key nutritional components in alfalfa having the greatest feeding value for ruminants.

To obtain a better understanding of the relative importance of these various fractions in alfalfa, 1070 samples of freshly cut alfalfa plants were hand-harvested from test plots in WI, CA, WA, ID, KS, PA, IA, and Argentina from 2019-2022 and analyzed to demonstrate the size and range of these various nutrient fractions (Forage Genetics International, Gray Summit, MO, 2022). Hand-harvested plot samples were chosen to minimize confounding of nutrient profiles resulting from differential harvest losses that can occur from commercially procured samples. Samples were procured across multiple cuttings, fall dormancies, and maturities. The numbers of each nutritional assay performed on the sample set are reflected on the y-axis of the following figures, since some assays were not performed on the entire sample set.

For this alfalfa discussion, CP, ash, fat, fibrous carbohydrates, and non-fibrous carbohydrates sum to 100% (on a DM basis). The scheme laid out by M.B. Hall (2015; Figure 1) was used for identifying the carbohydrate fractions (fibrous and non-fibrous carbohydrates).

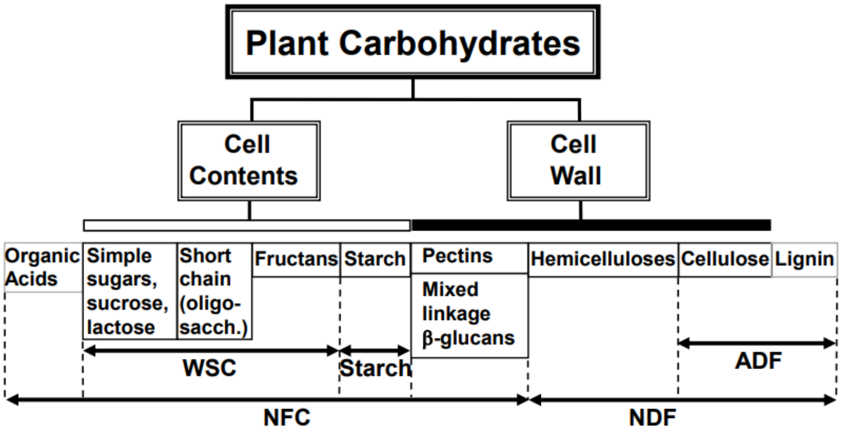


Figure 1. Plant Carbohydrates. ADF = acid detergent fiber, NDF = neutral detergent fiber, NFC = non-fiber carbohydrates, WSC = water-soluble carbohydrates. (Hall, 2015)

CRUDE PROTEIN (CP)

The distribution of crude protein in the sample set is shown in Figure 2. The variation in CP is caused not only by variety differences, but also by cutting, maturity and environmental effects.

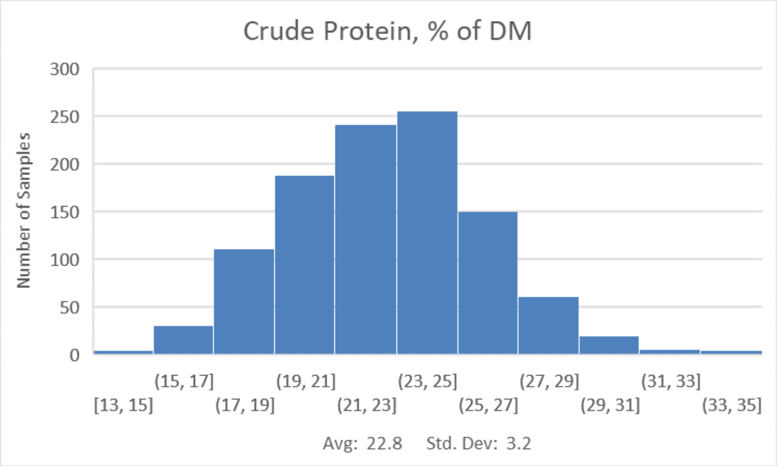
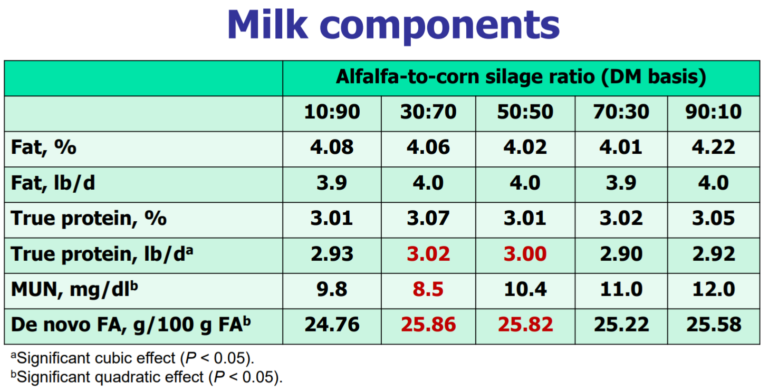


Figure 2. Crude protein from 1070 samples of freshly cut alfalfa samples hand-harvested across multiple cuttings and maturities from test plots in WI, CA, WA, ID, KS, PA, IA, and Argentina from 2019-2022. (Forage Genetics International data, Gray Summit, MO, 2022)

From a nutritional perspective, alfalfa is the highest protein containing forage available to ruminant diets. It contributes to the ruminant's metabolizable protein supply directly through a fraction that escapes ruminal digestion, known as rumen undegraded protein (RUP). Recent in vitro analysis of 71 fresh-cut alfalfa samples suggested this fraction to equal 24% ± 6.4 of CP (Forage Genetics International data, Gray Summit, MO, 2022).

The remaining 76% of the CP fraction is degraded in the rumen and known as rumen degraded protein (RDP). A portion of this fraction is captured by ruminal microorganisms in the form of peptides, amino acids, and ammonia to be used to synthesize microbial protein. Microbial protein, along with the RUP fraction, flows into the small intestine to supply the metabolizable amino acids necessary to meet the ruminant's various protein synthetic requirements.

Many consider that since the RDP fraction of alfalfa is so large, much of it cannot be captured in microbial protein synthesis and must therefore be wasted through rumen ammonia losses across the rumen wall, ultimately being excreted as urinary urea. However, some researchers have shown benefits to the diet from alfalfa's apparent RDP contribution. One such study from the Miner Institute (Grant et al., 2022) fed high producing dairy cow diets that were similar in nutrient content but contained five different ratios of alfalfa hay to corn silage in the forage portion that constituted 62% of the diet DM. Results are shown in Table 1.



Milk components

	Alfalfa-to-corn silage ratio (DM basis)				
	10:90	30:70	50:50	70:30	90:10
Fat, %	4.08	4.06	4.02	4.01	4.22
Fat, lb/d	3.9	4.0	4.0	3.9	4.0
True protein, %	3.01	3.07	3.01	3.02	3.05
True protein, lb/d^a	2.93	3.02	3.00	2.90	2.92
MUN, mg/dl^b	9.8	8.5	10.4	11.0	12.0
De novo FA, g/100 g FA^b	24.76	25.86	25.82	25.22	25.58

^{a}Significant cubic effect ($P < 0.05$).
^{b}Significant quadratic effect ($P < 0.05$).

Table 1. Milk component yield of 105 early lactation cows fed diets varying in alfalfa hay:corn silage in 62% forage diets of similar metabolizable protein and energy content. (Grant et al., 2022)

As demonstrated by the higher milk protein yields, the lower MUN level (milk urea nitrogen, a reflection of rumen ammonia levels) and higher de novo FA levels (a reflection of milk fatty acid synthesis) shown in red in Table 1, a diet of alfalfa-to-corn silage somewhere between 30:70 and 50:50 was optimum in these diets. Presumably, this resulted from improved ruminal microbial growth and protein synthetic activity from alfalfa being present in the diet at these levels.

In vitro results (Hall, 2017) comparing two RDP sources of different ruminal availabilities would support these findings, where peptides supported greater microbial protein nitrogen synthesis than did urea (Figure 3). The RDP in alfalfa has been shown to be a rich source of peptides, derived primarily from Ribulose-1,5-*bis*phosphate Carboxylase (Rubisco) (Howarth et al., 1977), suggesting alfalfa RDP could stimulate microbial yield in the rumen.

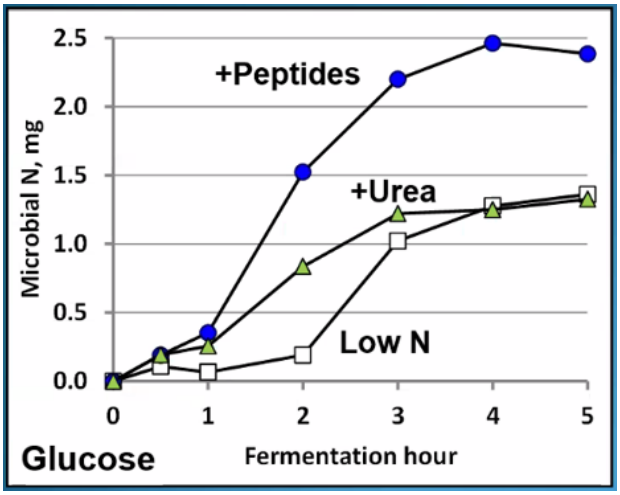


Figure 3. Effect of different rumen degradable protein (RDP) sources, urea, or peptides (tryptone), on synthesis of microbial protein nitrogen (N) in vitro when glucose was the energy source. (Hall, 2017)

While an assay for determining in vitro protein digestibility of ruminant feeds has been developed (Ross et al., 2013), its use in measuring RUP in alfalfa requires further validation.

ASH

While soil contamination can be a significant contributor to the ash content of harvested alfalfa, these samples (Figure 4) should have been relatively free of soil contamination since they were hand-harvested from research plots. Even so, the average ash content was 10.7%, with some samples as high as 17%. This ash is comprised mostly of the macrominerals calcium, potassium, phosphorus, sulfur, and magnesium (NASEM, 2021), most of which contribute to the positive cation exchange capacity (CEC) of alfalfa. This high CEC is linked to alfalfa's contribution to the diet's greater buffering capacity which promotes greater milk fat synthesis by the cow (Robinson, 2014).

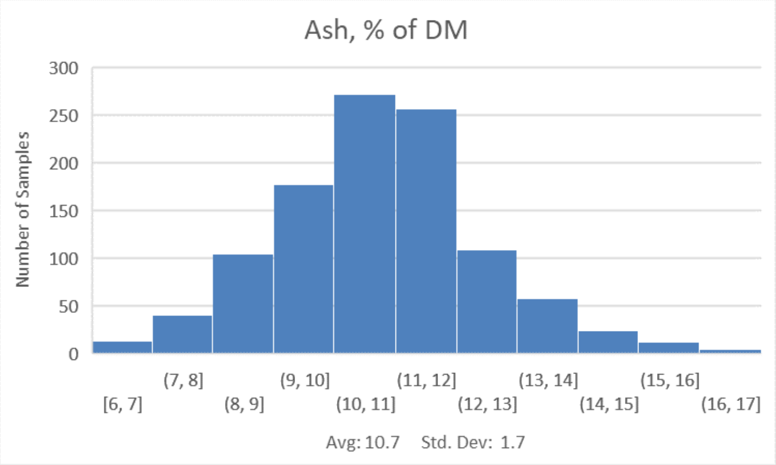


Figure 4. Ash from 1070 samples of freshly cut alfalfa samples hand-harvested across multiple cuttings and maturities from test plots in WI, CA, WA, ID, KS, PA, IA, and Argentina from 2019-2022. (Forage Genetics International data, Gray Summit, MO, 2022)

While the macrominerals in ash can have a beneficial effect on animal performance through their effect on the CEC and mineral nutrient supply, ash can also have a direct negative effect since it provides no other value to the animal and dilutes down the nutritive value of the forage. Therefore, it is important to avoid soil contamination of alfalfa during harvesting.

FAT

While fat is an energy-dense nutrient and contains about 2.25 times the energy found in carbohydrates, its content in alfalfa is relatively low (Figure 5). The average fat content, as measured after acid hydrolysis, in a subset of 72 samples from the sample set was only 3.1%, with some samples as high as 5%.

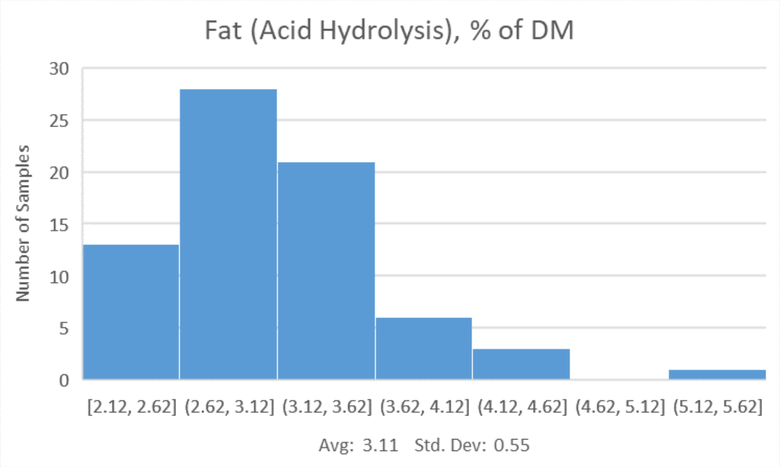


Figure 5. Fat (acid hydrolysis) from 72 samples of freshly cut alfalfa samples hand-harvested across multiple cuttings and maturities from test plots in WI, CA, WA, ID, KS, PA, IA, and Argentina from 2019-2022. (Forage Genetics International data, Gray Summit, MO, 2022)

FIBROUS CARBOHYDRATES

The largest functional and nutritional component of alfalfa is the neutral detergent fiber (NDF) fraction which represents the cell wall, or fibrous carbohydrate, portion of the plant comprising 33.5% ± 5.5 of the DM (Figure 6). Its digestibility (NDFd; 49.4% of NDF ± 4.9) shown in Figure 7 was measured following 48 hours of in vitro digestion with a buffered mixed rumen culture (Goering and Van Soest, 1970).

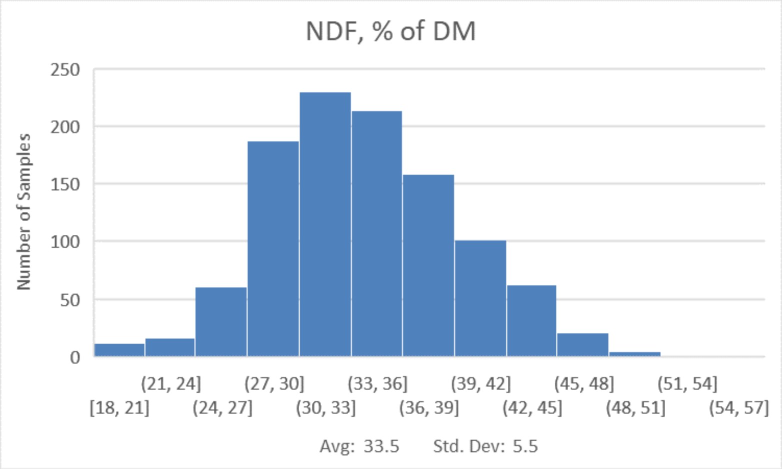


Figure 6. Neutral Detergent Fiber (NDF) from 1070 samples of freshly cut alfalfa samples hand-harvested across multiple cuttings and maturities from test plots in WI, CA, WA, ID, KS, PA, IA, and Argentina from 2019-2022. (Forage Genetics International data, Gray Summit, MO, 2022)

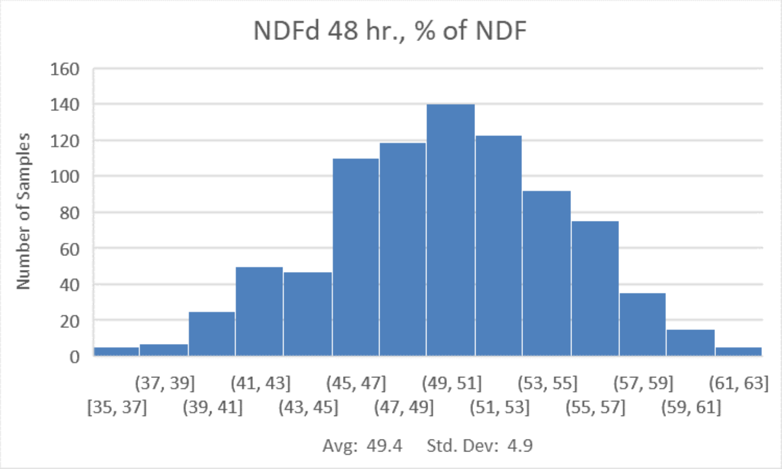


Figure 7. NDF digestibility (NDFd) from 1070 samples of freshly cut alfalfa samples hand-harvested across multiple cuttings and maturities from test plots in WI, CA, WA, ID, KS, PA, IA, and Argentina from 2019-2022. (Forage Genetics International data, Gray Summit, MO, 2022)

The importance of both these measurements rests in their contribution to the Ruminal Undigested NDF (RuNDF) content of the diet. For a particular forage, the amount of RuNDF is calculated by multiplying the undigested NDF (100% - NDFd, express on an NDF basis), by the NDF content of the forage. The sum of the RuNDF amounts from each of the forages in the diet represents an approximation of rumen fill.

The amount of rumen fill is a critical factor in controlling animal performance as shown in Figure 8. Too little rumen fill results in an increased ruminal passage rate of the diet, leading to greater intake and milk production, but at lower ruminal digestibility and poorer feed efficiency. Excessive rumen fill results in a reduced ruminal passage rate of the diet, leading to reduced intake and milk production, but at improved ruminal digestibility and feed efficiency. Most diets are formulated at an optimum compromise in rumen fill where intake and milk production are maximized at a reasonable feed efficiency. This usually occurs at an RuNDF level of approximately 11% of diet DM (Weakley, 2015). As a forage, alfalfa is well suited in this respect since its RuNDF content is relatively moderate, compared to most other forages, because of its moderate NDF content, coupled with its high rate of NDFd. Recent genetic modification of the lignin content in HarvXtra® alfalfa (Forage Genetics International) has allowed greater flexibility in fine-tuning the NDFd advantage.

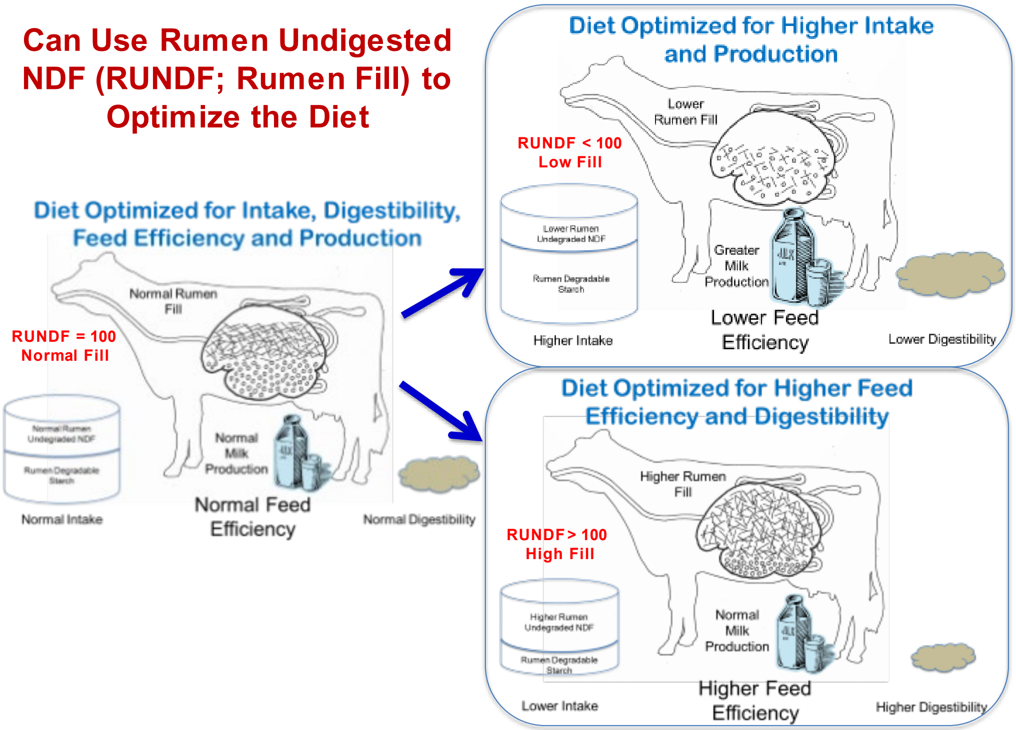


Figure 8. Influence of rumen undigested NDF (RuNDF) on intake, feed efficiency and production in dairy cows. (Weakley, 2015)

Recently, there has been increasing interest in the amount of ash in NDF (NDFash; Figure 9). While this has implications for nutritional modeling, for purposes of this discussion, it allows for the calculation of non-fibrous carbohydrates.

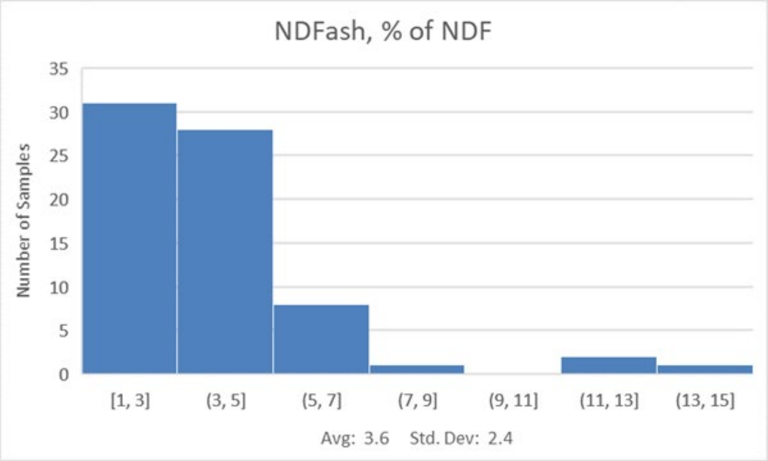


Figure 9. Ash in NDF (NDFash) from 71 samples of freshly cut alfalfa samples hand-harvested across multiple cuttings and maturities from test plots in WI, CA, WA, ID, KS, PA, IA, and Argentina from 2019-2022. (Forage Genetics International data, Gray Summit, MO, 2022)

NON-FIBROUS CARBOHYDRATES

As represented in Figure 1, the non-fibrous carbohydrate fraction is composed of many substances. For simplicity, pectin, starch, and water-soluble carbohydrates (WSC) will be the fractions discussed regarding alfalfa. As observed in Figure 10, the average starch content of a subset of 71 alfalfa samples was relatively low (2.9% ± 2.2), except for a few samples of higher content.

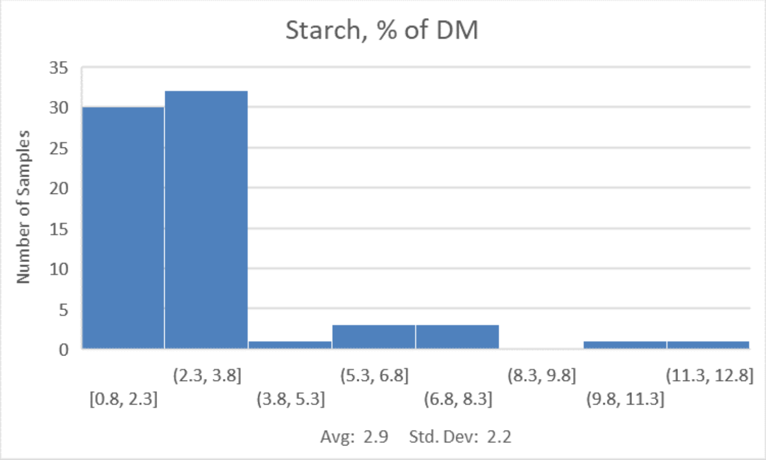


Figure 10. Starch from 71 samples of freshly cut alfalfa samples hand-harvested across multiple cuttings and maturities from test plots in WI, CA, WA, ID, KS, PA, IA, and Argentina from 2019-2022. (Forage Genetics International data, Gray Summit, MO, 2022)

Direct measurement of the pectin and WSC content of a forage is very expensive, so their content is usually determined by difference. For this alfalfa discussion, [pectin + WSC] = 100 – [CP + Fat + (Ash – NDFash) + NDF + starch]. While [pectin + WSC] cannot be calculated for each individual sample in the sample set (due to some samples missing values), it can be calculated as an average for the sample set as a whole. As such, [pectin + WSC] = 100 – [22.8 + 3.1 + (10.7 – 33.5 x .036) + 33.5 + 2.9] = 28.2%.

The reason for going to the trouble of calculating this fraction is because it is a relatively large portion of the alfalfa plant that we know relatively little about. Alfalfa has been reported to contain 10-14% pectin (Hatfield and Weimer, 1995; Jung et al., 2001), which means the remainder of the 28.2% is WSC. Pectin is rapidly degraded by rumen microbes producing acetate and propionate, but not lactate like rapidly fermented starch (Hatfield and Weimer, 1995). It can be assumed that the WSC fraction also has a high rate of ruminal digestion. Therefore, the criticism that alfalfa lacks a rapidly, ruminal digestible carbohydrate fraction like that found in corn silage, is unfounded (28.2% [pectin + WSC] + 2.9% starch = 31.1% rapidly digestible carbohydrates which will rival the starch content of an average corn silage).

IMPORTANCE OF LEAVES

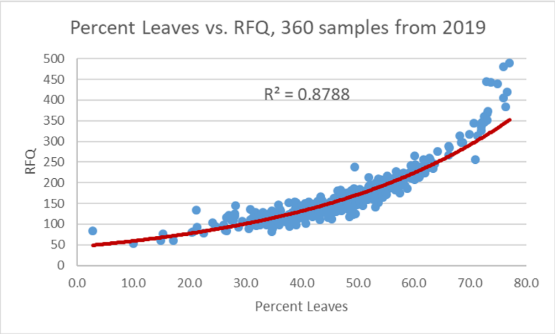
Work conducted in the Forage Genetics International Digestibility Lab, (internal data, 2021), separating alfalfa leaves from stems, demonstrated the nutritional differences between the two fractions (Table 2). As observed, leaves contain a higher concentration of protein and minerals, and less of NDF than stems. Moreover, the average Relative Forage Quality (RFQ) value, a measure of alfalfa quality, confirms most of the nutritional value of alfalfa is contained in the leaves (RFQ = 442.3 vs. 84.3 in leaves vs. stems, respectively). A study in the same lab with a different set of 200 alfalfa samples showed that every 1% improvement in leaf retention garnered a 4.6 percentage unit improvement in RFQ (Figure 11; Weakley and Rodger, 2021). This relationship became even more rewarding the greater the leaf retention. These findings emphasize the importance of retaining leaves during the growing and harvesting phases to best capture the nutritional benefits of alfalfa, as well as improve harvested yield.

Nutritional Analysis of Leaves and Stems

	CP, %DM	Ash, % of DM	NDF, %DM	NDFd, %NDF	RFQ	RFV
LEAVES						
Average	29.1	11.2	19.7	60.3	442.3	367.3
Std. Dev.	2.2	0.7	1.4	4.0	36.3	29.5
STEMS						
Average	11.8	7.4	60.5	39.4	84.3	78.9
Std. Dev.	1.0	0.8	2.5	3.5	10.4	5.8

Table 2. Nutrient profile of leaves vs. stems from 36 alfalfa samples collected from WI. CP = crude protein, NDF = neutral detergent fiber, NDFd = NDF digestibility, RFQ = Relative Forage Quality, RFV = Relative Feed Value. (Forage Genetics International internal data, 2021)

Leaves influence RFQ in a curvilinear way



% leaves	RFQ
40	132
45	150
50	172
55	196
60	224

I percentage unit leaves = 4.6 units of RFQ

Figure 11. Relationship between percent leaves and RFQ (Relative Forage Quality) from 200 alfalfa samples collected from WI, ID, and CA. (Weakley and Rogers, 2021)

CONCLUSION

While there are many factors contributing to alfalfa's nutritional value in diets, it's apparent that NDF, NDFd, RUP, RDP, and ash are important nutrient components contributing to its feeding value for ruminants. The content of NDF, and its digestibility, can have a major impact on intake, digestibility, and feed efficiency through their contribution to the RuNDF content of the diet. The amount of RUP and RDP will contribute to the metabolizable protein content of the diet both directly and indirectly, through supporting ruminal microbial protein synthesis. Knowing the proportions of RUP and RDP in the CP of alfalfa could help optimize the correct dietary balance to maximize the metabolizable protein supply to the ruminant at the greatest efficiency of CP use. Lastly, it is important to monitor ash, as levels above average amounts are likely to be of soil origin and detrimental to the overall nutrient and energy content of the alfalfa forage.

While NDF, NDFd, CP and ash are components of the RFQ quality index calculation (Moore and Undersander, 2002), the calculated value is insensitive to changes in CP, which is a concern. An improvement to RFQ (or a new quality index) could be the addition of coefficients for the concentrations of RUP and RDP in alfalfa samples.

An important aspect of optimizing the above analytical nutritional constituents is to preserve leaves in the alfalfa crop during growth, through to the point of feeding. Lastly, additional study on the large fraction of pectin + WSC in alfalfa may identify benefits for ruminant feeding beyond that as an energy source in the rumen.

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LINKING FORAGE QUALITY WITH ECONOMIC VALUE

Bill Weiss[1]

ABSTRACT

Forage quality is often defined as the ability of a forage to support milk production when fed to cows, but that definition is very difficult to quantify. Relative forage quality (RFQ) was developed to quantify forage quality and should allow the price of forage to better reflect the milk production potential of a forage. The price of alfalfa hay is correlated with RFQ and depending on local markets a 10 unit increase in RFQ may increase the value (price) of alfalfa hay by $12 to $16/ton. The RFQ equation includes concentration of NDF (negative relationship) and in vitro NDF digestibility (IVNDFD) (positive relationship) and is essentially a proxy for energy intake. Energy intake is usually what limits milk production, but other nutrients are needed to produce milk and they also have economic value. Rather than using an index, a better approach would be to use actual nutrients. The nutrients that have the greatest value in forages are energy (expressed as NEL) metabolizable protein (MP) and NDF. Feed labs routinely measure NDF and generate estimated NEL concentrations in samples and MP can be estimated from measured crude protein (CP) concentrations. Methods are available to estimate the economic value of nutrients ($/Mcal of NEL; $/lbs. of forage NDF; and $/lbs. of MP). To arrive at a baseline value for hay, you need to calculate the amount of NEL, MP and NDF in 1 ton of hay, multiple each by its economic value and then sum. RFQ (or RFV) gives CP no value; it is not in the equations. The concentration of CP is moderately correlated with RFQ ($r^2 = 0.35$), but an alfalfa sample with an RFQ of 200 could range in CP from about 18% up to 27%. In addition to supplying nutrients, forage also affects feed intake. A lab measure that has a strong positive relationship to intake and milk production is IVNDFD. On average a 1 unit increase in IVNDFD increases intake and milk by 0.26 and 0.47 lbs./day, respectively. The baseline value calculated above needs to be adjusted based on the difference in IVNDFD between your sample and the average IVNDFD (this can be positive or negative). The adjustment depends on the price of milk and the cost of feed. For example, if feed dry matter is $12/cwt and milk is $24/cwt a 1 unit increase in IVNDFD above average is worth about $7.4/ton of alfalfa hay dry matter which would be added to the value based on nutrients. The calculations are more complicated than simply using RFQ but the calculations straightforward and more accurately values alfalfa which should benefit both the seller and buyer.

Key words: protein, energy, fiber, price, alfalfa

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INTRODUCTION

Although alfalfa is an excellent feed for dairy cows, diets do not have to include it. Therefore, the inclusion rate for alfalfa in diets depends on its perceived value relative to other feedstuffs and the nutrient needs of the cow. What is needed is a method to estimate the value of alfalfa and other forages and feedstuffs to determine which ingredients should be included in diets. The value of a feed should be related to its nutrient concentrations and its effect on yields of milk components (milk fat and protein). Over the last several years, researchers at Ohio State have attempted to integrate readily obtainable data into a system that can estimate the value of different forages, including alfalfa. This should aid both the seller and buyer of forages.

IMPORTANT NUTRIENTS

Alfalfa is routinely sampled and analyzed for nutrient composition. Labs can analyze feed samples for a wide array of nutrients and feed characteristics which all have use in some applications. However, to estimate the economic value of a feed we only need estimates of its concentrations of energy, protein, and fiber and energy, and in vitro fiber digestibility.

Energy. Cows require energy to live and produce milk. Net energy-lactation (NEL) is the most common expression of feed energy used by most dairy ration software programs. Labs cannot measure NEL but standardized equations based on measured components are available to estimate NEL. If comparing different forages, the same NEL equation must be used for all samples.

Protein. Labs measure crude protein (CP) but that assay is not the best measure of protein to compare across feed stuffs. For example, 1 lbs. of CP from a typical forage will support less milk protein synthesis than 1 lbs. of CP from soybean meal. Metabolizable protein (MP) is a more accurate estimate of the protein value of a feed. MP is based on ruminal degradability of the CP and the digestibility of the undegraded protein. Based on expected protein degradability and digestibility, factors have been developed to convert CP into MP (Table 1). For haycrop forages (hays and silages), a conversion factor of 0.56 should be used.

Fiber. Neutral detergent fiber (NDF) is the best current method to estimate fiber in feeds and is routinely measured by labs. Some of the NDF can be digested and provide NEL but the main economic value of NDF comes from its effects on rumen and cow health. NDF contained in larger particles stimulate chewing and rumination which are essential to maintain good rumen health. Various methods have been proposed to estimate effective NDF but for many situations simply separating NDF provided by forage from that provided by other feeds is adequate. Forage NDF (fNDF) is assumed to promote chewing and represents ‘effective NDF’. All the NDF in alfalfa is fNDF and adds to its economic value.

In vitro NDF digestibility. In vitro digestibility of NDF (IVNDFD) is not a nutrient but it is needed to accurately estimate NEL and to estimate the milk production potential of forages.

Diets containing forages with high IVNDFD can be consumed in greater amounts which results in greater milk production. Most labs can measure IVNDFD at either 30 or 48 hours of incubation. Either incubation time will work but when comparing different feeds, the same incubation time must be used for all samples.

Table 1: Example of calculating metabolizable protein for common forages and soybean meal[1].

		% of CP			
Ingredient	CP, %DM	RDP	dRUP	MP[2], %DM	MP/CP
Alfalfa hay, immature	23	79	13.5	12.7	0.55
Alfalfa hay, mature	18	73	17.8	10.2	0.56
Alfalfa silage	22	79	14.6	12.4	0.56
Corn silage,	8.8	67	24.7	5.3	0.60
Grass hay, mature	13	58	25.2	7.3	0.56
Soybean meal, 89% DM	53	67	30.0	34.7	0.65

[1] Composition data from NASEM (2021)

[2] Metabolizable protein = CP × (RDP × 0.53 + dRUP) ÷ 100, %DM

THE ECONOMIC VALUE OF NUTRIENTS

Knowing the nutrient composition of a feed is not adequate to assign it an economic value, you must know what each nutrient is worth. To estimate the value of 1 Mcal of NEL you could take the price of corn per pound and divide it by its NEL concentration, but this ignores the value of the other nutrients in corn and it assumes the price of all NEL is equal to that of corn. The price of a pound of MP or a pound of fNDF could be calculated the same way but that has the same problems. A procedure (SESAME) developed at Ohio State several years ago uses the price of many feeds (usually about 30) including forages, grains, protein meals, and byproducts and their composition to estimate the average price of NEL, MP, and fNDF. To obtain the most accurate estimates of economic value, current local prices should be used. Prices can change substantially over time and location. Nutrient prices generated for the Midwest (bimonthly) can be found in the Buckeye Dairy Newsletter (dairy.osu.edu/newsletter/buckeye-dairy-news) and other places (e.g., *Progressive Dairyman* publishes nutrient prices for different regions every other month). For this article, I used West Region prices published in the September 12, 2022 edition of *Progressive Dairyman* and the Midwest 5 year average prices from September 2022, Buckeye Dairy News (Table 2). Those two sources calculate the value of effective NDF but as explained above, I am assuming fNDF equals effective NDF.

Table 2. Dollar value of nutrients calculated using SESAME for Western and Midwestern US. Data are from Progressive Dairyman (Sept 12, 2022) and Buckeye Dairy News (Sept, 2022).

Nutrient	**West region**	**Midwest price**	**5 Yr Midwest Average**
NEL, $/Mcal	0.132	0.115	0.08

MP, $/lb.	0.519	0.538	0.41
fNDF, $/lb	0.312	0.125	0.09

VALUE OF NUTRIENTS FOR A FEED

After obtaining nutrient data from the lab and dollar value from published sources, calculate the amount of each nutrient in a ton of the feed, multiply by dollar value of each nutrient and sum to obtain total value of the feed. For example, a truckload of alfalfa hay has the following assayed nutrient composition and amounts per ton were calculated based on those data (Table 3).

Table 3. Nutrient composition and amounts per ton for an example alfalfa hay.

	Concentration	**Amount per ton of as-fed hay**
Dry matter	88.0%	1760 lbs.
CP	23.0% of DM	405 lbs.
MP	12.9% of DM	227 lbs.
NEL	0.69 Mcal/lb of DM	1214 Mcal
fNDF	39% of DM	686 lbs.
IVNDFD	55% of NDF	NA

The values of those nutrients and for the feed are then calculated (Table 4) using the data in Table 2 and 3.

Table 4. Value based on West and Midwest US markets (fall, 2022) for an example alfalfa hay.

	Amount per ton	**Value (West)**		**Value (Midwest)**	
		$/unit	$/ton	$/unit	$/ton
MP	227 lbs.	0.519	117.8	0.538	122.1
NEL	1214 Mcal	0.132	160.2	0.115	139.6
fNDF	686 lbs.	0.312	214.0	0.125	85.8
Total	**2000 lbs.**		**492**		**347**

This method works very well when comparing the value of different concentrates; for example, distillers grains versus soyhulls. Those feed, if fed in reasonable diets do not affect feed intake. Forages, however, can have a substantial effect on intake resulting in a substantial effect on milk production.

ADJUSTING FOR “FORAGE QUALITY”

Currently, the single best assay to evaluate intake potential of a forage is IVNDFD. Based on several studies, a 1 unit increase in IVNDFD (expressed as % of NDF) within a forage family (e.g. legumes or grasses) increases intake by 0.26 lbs/day and milk yield by 0.47 lbs/day (Oba and Allen, 2005). Those values are appropriate for a change in IVNDFD, not an absolute value.

For example, if cows were changed from a diet with a forage that had an IVNDFD of 50% to one with an IVNDFD of 55%, we would expect milk to increase by 2.4 lbs./day (5 x 0.47). We would expect the same increase when IVNDFD increased from 35 to 40%. Because we can only evaluate change in IVNDFD, we need to compare the forage of interest to a standard (Table 5). We chose to set the standard equal to mean values for alfalfa, grass, and corn silage from NASEM (2021).

Table 5. Average (NASEM, 2022) NDF and IVNDFD concentrations for common forages.

Forage	Mean NDF, % of DM	IVNDFD, 48 hour
Alfalfa	43	49
Corn silage	41	52
Cool season grasses	62	64

To calculate the quality adjustment, the difference between IVNDFD of the forage of interest and standard values are calculated (use the same incubation time period for both the sample and standard): IVNDFD(sample) – IVNDFD(standard). That value can be positive or negative. It is then multiplied by 0.47 to estimate the change in milk yield when the forage is fed. Change in milk yield then must be converted to a dollar value, which is a function of milk price and feed price. Dry matter intake is expected to increase 0.55 lbs. for every 1 lb. increase in milk yield (conversely if milk yield drops by 1 lb. we expect dry matter intake to decrease 0.55 lbs.). The value of the change in dry matter intake depends on the price of the diet. Lastly, to put these numbers on a per ton of forage dry matter basis, we need to assume a certain intake of forage dry matter. We chose 22 lbs. (55 lbs. of dry matter intake that was 40% of the forage of interest).

Example calculation of quality adjustment.

The forage of interest is alfalfa hay that had a 48 hour IVNDFD of 55%.

1. Difference in IVNDFD from standard: 55 – 49 = 6 units
2. Expected increase in milk yield: 6 x 0.47 = 2.8 lbs./day (assumed milk price $0.20/lb.)
3. Expected increase in DM intake: 6 x 0.26 = 1.6 lbs. (assumed feed price $0.10/lb. DM)
4. Expected gain in income over feed cost: (2.8 x 0.20) – (1.6 x 0.10) = $0.40
5. Converting to 1 lb. of forage DM: 0.19/22 = $0.018/lbs. = $32/ton of DM or about $27/ton of hay (85% DM).

That value is added (or subtracted) from the nutrient value calculated as described above. In the example above the alfalfa in Midwest had a nutrient value $347/ton (85% DM) and a quality adjustment of $27/ton; therefore, the total value of the example alfalfa is $374/ton. Table 6 has quality adjustments for various feed and milk prices. A user would use feed and milk price most applicable, find the quality adjustment and add (or subtract) it from the nutrient value.

The values calculated using this method is the maximum a dairy farmer should pay because basically it represents break-even cost for the forage (in other words, the dairy producer is getting what he paid for but the forage is not a bargain or overpriced)

Table 6. Quality adjustment ($/ton of forage DM) per 1 percentage unit change in IVNDFD from the standard. For example, if the forage had 3 percentage units lower IVNDFD than the standard and milk price was $22/cwt and diet cost $0.10/lbs. of DM, the quality adjustment would be -3 x 7.0 = $-21/ton.

	Milk Price, $/cwt					
Diet price, $/lbs. of DM	**16**	**18**	**20**	**22**	**24**	**26**
0.06	5.4	6.3	7.1	8.0	8.6	9.7
0.08	5.0	5.8	6.7	7.5	8.4	9.2
0.10	4.5	5.3	6.2	7.0	7.9	8.8
0.12	4.0	4.9	5.7	6.6	7.4	8.3

Limitations to the method

1. We assume the effect of a change in IVNDFD is the same regardless of forage inclusion rate, which is most likely not true. At low inclusion rates we are probably overestimating the value of quality and at high rates we are likely underestimating the value. We chose an inclusion rate of 40%
2. We assumed the same effect of a change in IVNDFD for all forages. This may or may not be true. The majority of the data in the paper by Oba and Allen (2005) is from corn silage-based diets; however several studies also included alfalfa. Grass was poorly represented in the data set.
3. The same effect of a change in IVNDFD is assumed for all milk yields. High producing cows probably are more sensitive to a change in IVNDFD than lower producing cows.

CONCLUSIONS

Comparing the value of different forages should be based on more than RFQ or RFV. Both those indices ignore the value of protein and only gives negative value to NDF even though forage NDF is a requirement nutrient for dairy cows. The method outlined above gives values to all major nutrients provided by forages and includes a separate adjustment for the effect forage quality has on intake. The calculations can easily be inserted into a spreadsheet and the method does not require analyses that are not typically conducted for forages.

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MODELLING GROWTH & QUALITY OF ALFALFA FOR LIVESTOCK

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ABSTRACT

Modelling alfalfa (lucerne) growth and development requires understanding of how the crop interacts with its environment. Over 20 years of field based research was used to calibrate the APSIM NextGen_Lucerne crop model. Phenological development was independent of grazing regime and fall dormancy (FD2, 5, 10) rating. The thermal time to flower buds visible for regrowth crops decreased linearly from 645 °Cd at a 10 h photoperiod (Pp) to 280 °Cd above a 14 h photoperiod. Buds visible to open flowers took a further 310 °Cd. The vegetative phyllochron was ~31°Cd in spring, but increased to 49 °Cd in fall. Post-buds visible the phyllochron increased to 69 °Cd. Plant height (heightchron; thermal time requirement for an increase of one mm stem height) pre-flowering showed an exponential decay as Pp increased from 4.2 °Cd/mm at 10 h to 0.6 °Cd/mm at 16.5 h for the FD5 genotype but this differed among FD classes. The critical Pp for stem extension, i.e. the day-length below which no stem elongation occurred was 11.1 h. Leaf area expansion rate (LAER) for FD5 decreased during a decreasing Pp from 0.018 $mm^2/mm^2/°Cd$ at 16.5 h to 0.008 $m^2/m^2/°Cd$ at 10 h. Different functions were required for FD2 and FD5 genotypes but a common extinction coefficient showed critical LAI was 3.65. Biomass accumulation was based on a temperature-dependent radiation use efficiency with partitioning and remobilisation to leaves, stems and roots changing with photoperiod and within regrowth cycles. This required functions to account for the seasonal pattern of root biomass partitioning and remobilization. The decrease in root biomass as photoperiod increased (mid-winter to mid-summer) was assumed as remobilization to shoots and carbon loss from maintenance respiration. As photoperiod decreased (mid-summer to mid-winter) root biomass increased as more carbon was partitioned below ground to replenish reserves.

Key Words: Fall dormancy, lucerne, *Medicago sativa* L.

INTRODUCTION

The east coast of New Zealand is typically summer dry with potential evapotranspiration exceeding rainfall for 3-5 months of the year (Salinger 2003). Alfalfa (lucerne; *Medicago sativa* L.) has always been grown in these regions, but it was predominantly conserved as hay with some direct grazing by weaned lambs. This meant it was relegated to <5% of the land area on a farm. It was seen as difficult to manage for direct grazed livestock because of its delayed spring growth. This didn't match lambing and calving times, when feed demand increases dramatically in these pasture-based farm systems. The management of alfalfa was based around the perceived need for the plant to reach 10% flowering before defoliation (Smith 1972; Sheaffer et al. 1988). From the late 1990s, a series of experiments were undertaken to challenge this guideline and examine whether a more flexible grazing regime could be developed. The subsequent 25 years of field experimentation has recently been used to calibrate the Agricultural Production Systems Simulator Next Generation (APSIM

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In: Proceedings, 2022 World Alfalfa Congress 'Profitable Alfalfa Production Sustains the Environment.' November 14-17, San Diego, California. UC Cooperative Extension, Plant Sciences Department, University of California, Davis, CA 95616. (See http://alfalfa.ucdavis.edu for this and other Alfalfa Symposium Proceedings.)

NextGen) for alfalfa. This paper outlines the field experimental results for regrowth (established) crops, their incorporation into the model and the consequences for on-farm management of grazed alfalfa. This paper focusses on results from the 'Kaituna' cultivar, which has a fall dormancy (FD) rating 5, which is the most commonly sown rating in temperate New Zealand. The final experiment of the series examined how an FD2 and FD10 genotype compared with FD5. Much of the experimental results and modelling work has been published, so this paper provides an overview of the main experimental results and modelling approaches applied for these crops grown without water stress.

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EXPERIMENTS

There were four main experiments used to develop relationships. All experiments were conducted at Lincoln University, Canterbury, New Zealand. Experiment 1 (E1) was conducted from 1997-2001 and compared the growth rates of alfalfa (FD5), chicory (*Cichorium intybus* L.) and red clover (*Trifolium pratense* L.) under irrigated (I) and rainfed (D) conditions (Brown 2004). Experiment 2 (E2) initially established irrigated and dryland alfalfa (FD5) sown at four dates (S1-S4) for two years. Experiment 3 (E3) was then imposed from 2000-2002, when four grazing regimes were introduced with the expectation that they would change the above and below ground biomass (Teixeira et al. 2007a; Teixeira et al. 2007b). The regimes included a 42±2 day (~300-600 °Cd) defoliation regime labelled Long|Long (LL) or a consistent 28±4 day (~200-400 °Cd) Short|Short (SS) rotation throughout the year. The remaining two treatments (SL and LS) followed the consistent regimes until mid-January (summer) when they were switched. Experiment 4 (E4) included the SS and LL regimes plus an extended 84±4 day regime (HH; ~530-1100 °Cd) and FD2, FD5 and FD10 genotypes (Ta 2018; Ta et al. 2020; Yang 2020; Hoppen et al. 2022).

All experiments had a common dataset collected, which included leaf appearance and flowering from marked plants. Fractional radiation interception was measured using a canopy analyser LAI-2000 or a Sunscan plant canopy analyser, both calibrated through regression analysis against destructive LAI measurements (Yang et al. 2022a). Biomass harvests of shoots were taken from 0.2 m^2 quadrats at regular (~two weekly) intervals throughout the growing season. At the end of the rotation roots were excavated from Experiments 3 and 4. Roots included crowns and taproots excavated down to 30 cm depth and represent the perennial biomass (referred to as root) compared with the shoot biomass (leaves, stems and flowers). These results enabled seasonal and within rotation biomass partitioning (to perennial organs) and remobilization (from perennial organs) to be separated. Post-harvest, crops were usually grazed in common with ewes and lambs or excess herbage was removed mechanically.

MODEL

The APSIM NextGen model uses the Plant Modelling Framework (PMF) (Brown et al. 2014) to capture crop responses to intercepted light, water and nutrient uptake on a daily basis. It also allows cultivar specific parameters to be considered to represent different genotypes (Brown et al. 2019). The model requires daily weather inputs that include, maximum and minimum air temperatures, total solar radiation, windspeed, and vapour pressure deficit. These were either measured onsite or were readily available from the Broadfields meteorological station, which is located 2 km north of the sites. The soil type for all experiments is an Udic Ustochrept described as fine silty, mixed, mesic (USDA taxonomy). Model outputs on a daily basis included alfalfa phenological stage, leaf area index (LAI), leaf, stem and root biomass. The simulation of phenological development requires a thermal time (Tt) function to drive progress through sequential pheno-phases and also develop canopy leaf area. A series of Tt functions were tested. A broken stick approach whereby the base temperature is 1 °C (Moot et al. 2001), provided the highest degree of accuracy compared with the more commonly used 5 °C derived from a continental climate (Fick et al. 1988),.

FIELD RESULTS AND IMPLICATIONS FOR MODEL DEVELOPMENT

Phenology

Experiment 1 quantified the linear change of "Tt requirement to flowering" of alfalfa to Pp, which is a characteristic of long day plants (Moot et al. 2003). In subsequent experiments, a function for "time to bud visible stage" was generated for modelling applications (Yang et al. 2021). This took the form of a broken stick function whereby Tt=1559-91.5*Pp when Pp <14 h and a constant Tt=278 °Cd at Pp ≥14 h ($R^2 = 0.67$). In practice, this gave a Tt requirement for 50% bud visible of 644 °Cd at a 10 h Pp and 278 °Cd at Pp greater than 14 h. The subsequent Tt requirement from "bud visible to open flowers" was constant at 310 °Cd. Node appearance (i.e. the inverse of the phyllochron) was also affected by Tt, but modified by Pp and plant phenophase. Vegetative nodes appeared consistently every ~31 °Cd under an increasing Pp, but increased from 35 to 49 °Cd as Pp declined from 16.5 to 10 h. For the very long periods of regrowth in HH crops, there were several regrowth rotations that had extended periods of flowering. This allowed a phyllochron value appropriate for the reproductive stage of ~61 °Cd to be estimated, which is approximately double the vegetative value. Stem extension has an impact on forage quality, with lignified stems of lower quality (Brown & Moot 2004). There were also field data that showed that node accumulation occurred before stem extension (Moot et al. 2003), so a function was developed to estimate crop height in response to thermal time (heightchron). For FD5 an exponential decay function was fitted (Yang et al. 2021) with a critical Pp of 11.1 h below which stem extension was minimal. This parameter was adjusted to account for the post-flowering phase in HH (84 day) crops and also differences in the FD2 and FD10 genotypes, based on results from Experiment 4.

Canopy development

This summary of results draws on the published data from Yang et al. (2022a). Leaf area expansion rate (LAER; mm/mm/°Cd) was used as a simple parameter to drive canopy expansion in response to temperature. This was calculated as the slope of the linear regression between LAI and Tt. The LAER changed with Pp consistently across different experiments. The LAER increased from 0.018 at 12 Pp to 0.022 at a 16.5 h Pp. In contrast, it declined linearly with Pp to a minimum of 0.008 at 10 h in fall. Complicating these LAER seasonal patterns, is the time taken to re-establish the canopy after each defoliation event. There are two scenarios in play; if basal buds are present (LAI>0) post-harvest then recovery from defoliation is rapid, but if they are absent then canopy removal stimulates basal-bud initiation and it takes longer to re-establish the canopy. For all crops, the x-axis intercept values from the linear regressions of LAI against Tt ranged from ~-50 to 200 °Cd. This suggests that some regrowth cycles required up to 200 ˚Cd to reach the calculated LAER, described as a lag phase of canopy expansion; whereas other regrowth cycles with longer periods between defoliation had basal buds present before defoliation occurred (x-axis intercept values ≤ 0 ˚Cd). This prompted faster canopy expansion post-defoliation. The x-axis represents the point at which LAER starts and so, if a single value was used, it can significantly under- or overestimate LAI over time. This leads to inaccuracies for estimating light interception and dry matter production. Therefore, a lag phase reduction factor (LRF) was required to account for the slower canopy expansion in the beginning of each regrowth cycle. This means that it took up to 200 °Cd for crops from the early regrowth stage to reach the maximum value of LAER for any given regrowth cycle. To do this, Tt since defoliation date increased from 0 to 200 °Cd, as the LRF increased from 0 to 1. In contrast, for the very long regrowth crops (HH treatment) that were left well into flowering before defoliation, basal buds were frequently present at harvest and were not removed during the harvest process. A basal bud function was developed to account for the initial leaf area post-defoliation (default = 0). An optimisation process, based on field observations of LAI development, was used to estimate a basal buds factor (BBF; % of LAER) with a value of 0.2 (20% of potential LAER) estimated. For the prolonged 84-day regrowth periods, canopy senescence was most apparent. Observed shoot biomass data (Figure 1) were used to fit and test a senescence function in APSIM NextGen, which improved model prediction of LAI and biomass for the HH treatment (Yang et al. 2022a).

Biomass accumulation, remobilisation and partitioning

For crops in Experiment 1, the growth rate of alfalfa increased linearly with temperature, but the rate was 20-30 kg DM/ha/d higher in an increasing than decreasing Pp (Moot et al. 2003). This prompted shoot and perennial organ (root+crown) biomass to be measured in Experiments 3 and 4 (Figure 2). Results showed a systematic seasonal pattern of root biomass decline in winter/spring, followed by an increase in mid-summer/autumn. This signal overrode changes within regrowth rotations and was apparent under different defoliation regimes (Moot et al. 2021). Thus, modelling shoot biomass required an accurate representation of these changes in perennial biomass, which are less relevant when modelling annual crops. Carbon assimilation in the APSIM NextGen model uses Radiation Use Efficiency (RUE) as a summary parameter, rather than photosynthesis and respiration. This simplification is appropriate for annual crops as the focus is on above ground biomass growth because root biomass curvilinearly increases across the vegetative stages. For alfalfa, to account for root biomass as a significant carbon sink, we used the concept of total radiation use efficiency (RUE_{total}). This includes biomass dynamics both above and below ground. Based on field data, RUE_{total} increased from negligible values at 8 °C to a maximum value of 1.6 g DM/MJ/m^2 at 18 °C, regardless of the fall dormancy rating of genotypes (Yang et al. 2022b). The study also includes a detailed investigation of the allocation of biomass among alfalfa organs. For example, leaf biomass demand was calculated from a simple linear function of LAI while stem dry matter was allocated to the organ based on an allometric power function in relation to shoot biomass.

The root biomass dynamic across seasons was characterised by a minimum in mid-summer and a maximum in late-fall, before it declined slowly over winter. The amount of root biomass lost in winter was used to estimate the rate of root turnover (i.e. respiration, translocation and senescence), which enabled a structural root component to be estimated as 2500±500 kg DM/ha. This was common to all genotypes based on the assumption that the structural component is not consumed by respiration. In contrast, the parameters for remobilization and partitioning were affected by both season of the year and fall dormancy class of genotypes. For example, FD2, FD5 and FD10 showed the same remobilization rate of 0.01/day across the year. However, the duration of the remobilization period was lower (200 °Cd) for FD2 compared with FD5 (250 °Cd) and FD10 (300 °Cd).

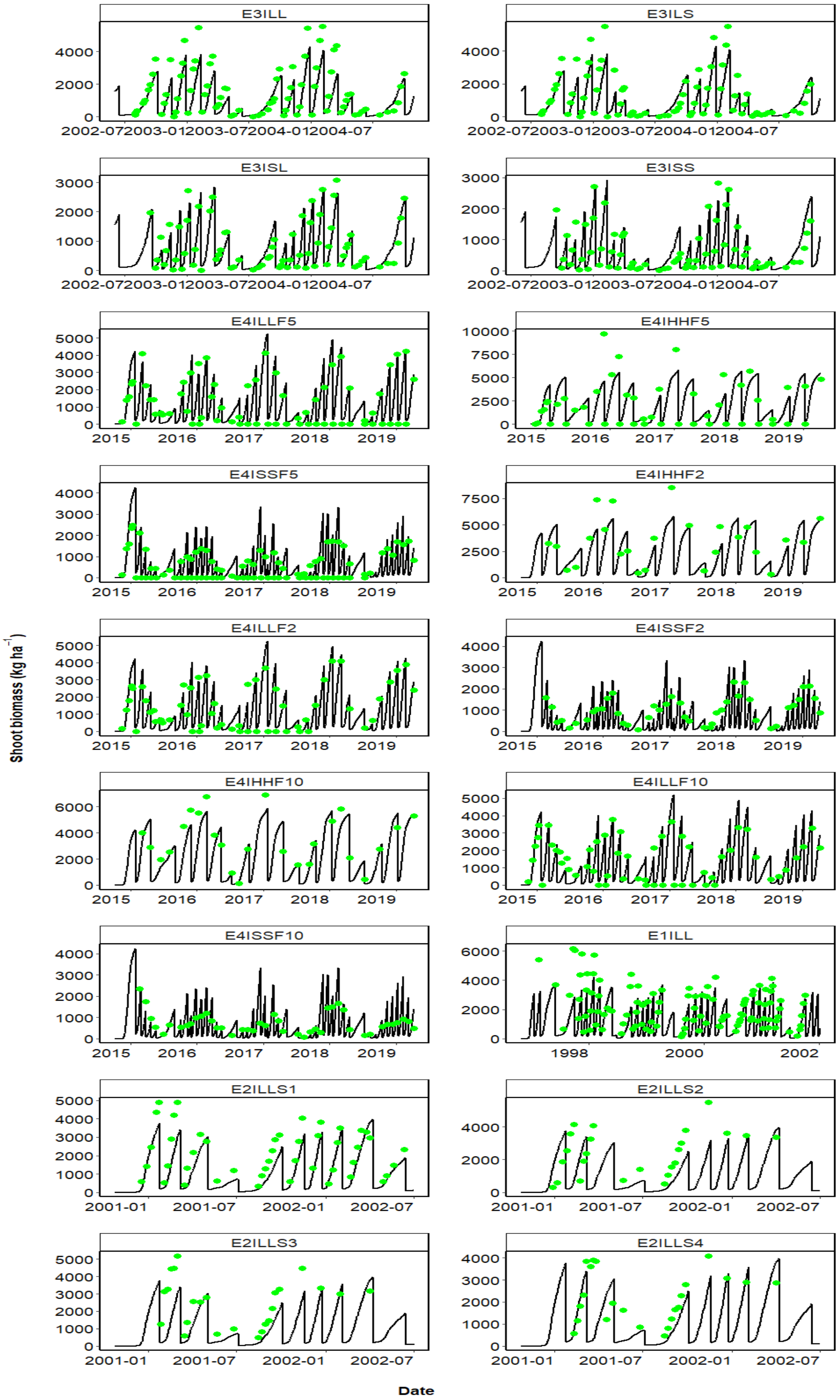

Figure 1. Time-series of predicted (−) and observed (●) shoot biomass. Datasets were from four irrigated (I) field experiments (E1-E4) with three defoliation treatments [HH (84 day), LL (42 day) and SS (28 day)] and two fall dormancy treatments (F5, F2 and F10) classes conducted in 2014-2019 at Iversen field, Lincoln University, Canterbury, New Zealand. F5 alone was sown for E1-E3. For E2 data for four different sowing dates (S1-S4) are shown.

N dynamics

For all treatments, alfalfa leaf N concentration ranged from 3.6% to 6.8% and decreased as leaf biomass increased, although this change was lower than for stem. Leaf N concentration was not affected by defoliation or genotype FD (data from Experiments 2 and 4). Stem N concentration ranged from ~1% to 6% and showed an allometric relationship with stem biomass. Root N showed a similar seasonal pattern as root biomass. To model these processes in the PMF, N supply was estimated as 2.5% of total biomass, whereas N demand was built from N concentration functions for each organ. To capture the seasonal pattern of root N, a N remobilization coefficient (% storage root N per day) was set at 2.0 for FD5 and 0.5 for FD2 and FD10) as Pp increased. However, from mid-summer to mid-winter when Pp decreased, an increase in taproot N concentration was driven by N partitioning to roots. Thus, the model was parameterized to have a maximal root N demand with no remobilization. As a result, the model had poor to fair prediction on leaf N, stem N and root N for all treatments. Applying the N module also improved shoot biomass predictions, especially for the 28 day defoliation treatment (SS).

DISCUSSION

The extensive experimental programme over a 25-year period has enabled the parametrization of the APSIM NextGen_Lucerne model. The experimental data highlighted several physiological aspects that need to be considered when modelling alfalfa which had major implications for on-farm management. Specifically, flowering was shown to be Pp dependent which implied that management decisions based solely on phenological stages were inappropriate. Improved management has encouraged greater use of alfalfa in New Zealand. Farmers are now encouraged to initiate spring grazing when the crop is 10-15 cm tall in spring and apply a rotational grazing system (Moot et al. 2016). Applications of the calibrated model indicated that a rotation length of about 350 °Cd (~ 10 main-stem nodes) is appropriate for New Zealand conditions. Similar management concepts have also been validated in an Argentinian beef grazing context (Berone et al. 2020). The analyses using APSIM-NextGen also highlighted the lack of difference in phenological development across genotypes with different fall dormancy classes in this temperate environment. Further model development requires testing of these responses with other genotypes and from other environments.

An implicit challenge when direct grazing alfalfa stands is that the herbage is usually removed over a long period (~3 to 10 days), depending on stocking rate. Thus, the time of basal bud emergence, which has implications for the development of leaf area in the following rotation, requires further investigation. To overcome the lack of experimental observations, the lag phase and a basal bud factor were developed in the current model. These functions need to be validated with field measurements and a mechanistic determination of basal bud initiation is required. Despite this, the model showed acceptable accuracy when estimating phenological development (Yang et al. 2021), leaf area expansion and canopy development (Yang et al. 2022a) and biomass partitioning (Yang et al. 2022b). A feature of the biomass modelling was the need to cope with seasonal biomass allocation differences, the effects of remobilisation within regrowth periods and differences among genotypes with different fall dormancy. An initial modelling approach to account for these dynamics considered changes in the length and rate of biomass remobilization. For instance, the FD10 genotypes remobilized taproot reserves for a longer period than FD2 and FD5 within each regrowth rotation. This may explain poor stand longevity of FD10 under intensive grazing (Harvey et al. 2014).

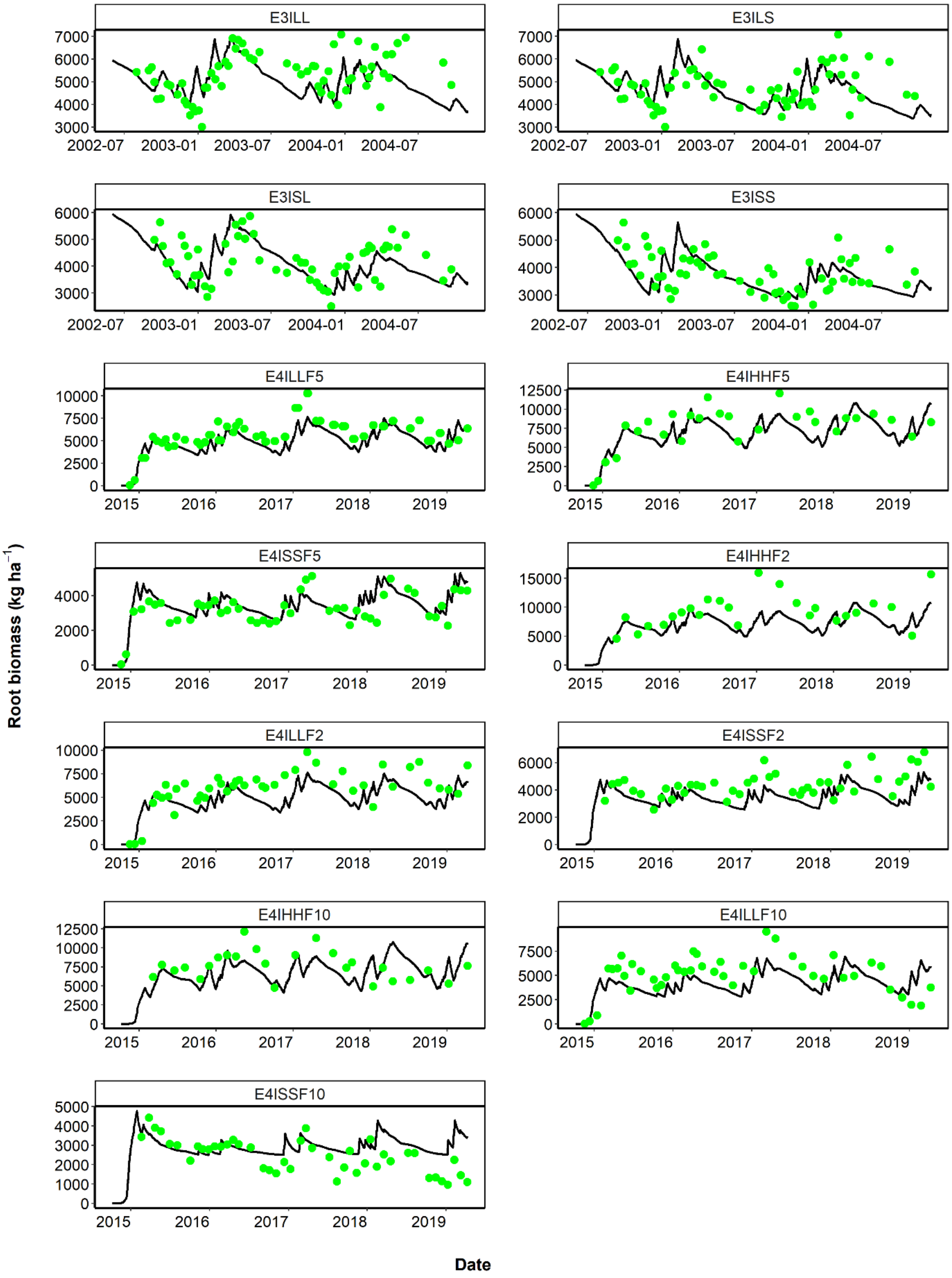

Figure 2. Time-series of predicted (━) and observed (●) root (taproots + crown) biomass. Datasets were from two irrigated (I) field experiments (E3 and E4) with multiple defoliation treatments [HH (84 day), LL (42 day), LS (42, 28 day), SL (28, 42 day), and SS (28 day)] for fall dormancy FD5 (E3 and E4) and FD2 and FD10 (E4) classes conducted in 2002-2019 at Iversen field, Lincoln University, Canterbury, New Zealand.

The combination of targeted field experimentation and biophysical modelling provided new insights that gave NZ farmers greater confidence to change on-farm management of alfalfa. For example, the previous management guideline to wait until 10% of flowering before grazing alfalfa is gone. It has been replaced by an emphasis on forage quality and utilization of the feed in spring when biomass and N remobilization from roots to shoots is enhancing spring growth rates. In autumn farmers are encouraged to let the crop flower to allow increased C and N partitioning to recharge root reserves, especially for an FD10 genotype.

SUMMARY

The APSIM NextGen_Lucerne model has been calibrated to capture alfalfa growth and development under non-limiting conditions, based on an extensive experimental programme. The model has been calibrated to represent field results but equally, in the absence of experimental data, model optimisation has proven effective to estimate model parameters. The combination of field research and modelling have unveiled new areas for future research and, importantly, underpinned changes in on-farm management for greater productivity, profitability and farm resilience, particularly in the summer dry regions of New Zealand.

ACKNOWLEDGEMENTS

We thank Drs Hung Ta, Jose Jáuregui, Sarah Hoppen and numerous casual staff and students for field measurements. Funding for this manuscript preparation was provided by Beef + Lamb New Zealand, MBIE, Seed Force New Zealand and PGG Wrightson Seeds under the "Hill Country Futures" research programme (BLNZT1701).

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SIMULATING ALFALFA GROWTH DYNAMICS OF FALL DORMANCY CLASSES ACROSS ENVIRONMENTS

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ABSTRACT

The CROPGRO-Alfalfa model, released with DSSAT V4.8 software (available at *dssat.net*), simulates daily growth processes of alfalfa (*Medicago sativa*), including herbage harvests, herbage protein, and re-growth over multiple harvests and multiple seasons. The model includes a storage organ (taproot, crown) with carbohydrate and N storage pools that provide the ability for re-growth despite zero leaf area index caused by complete shoot harvest or freeze-loss of all leaf tissue. Intensive defoliation and aggressive management can cause poor recovery of re-growth. The model includes rules for fall dormancy (FD), freeze thresholds, partitioning as a function of growth stage and daylength, re-fill of storage pools, along with mobilization of carbohydrate and N from storage pools to drive re-growth. Varying these parameters allows genetic variation among cultivars and dormancy classes. The CROPGRO-Alfalfa model has been evaluated with growth and yield data from FD-types 3, 4, 6, and 9 grown in contrasting environments in Arizona, Montana, Canada, and Spain. Daylength is the most important variable affecting the FD simulations, using a critical daylength of 9.8 hr at which allocation to storage taproot is most rapid (and less to shoot) and the opposing critical daylength (14.2 h) at which allocation to storage is least rapid (more to shoot). The relative "strength" of daylength-driven partitioning to storage (RDRMT) varies with FD class, with RDRMT of 0.500, 0.320, and 0.140 for FD 3, 6, and 9, respectively. These features (daylength effect and its strength), along with variation in leaf photosynthesis (per FD) and rate of leaf appearance allow productivity to vary across FD classes 3 (Rugged), 6 (Cisco II), and 9 (CUF 101), as observed in the growth and herbage yield of three FD-class cultivars in Arizona and Montana. Simulated yield response of FD classes is affected by environment (sites differing in daylength-temperature) and cutting management.

Keywords: crop modeling, regrowth, fall dormancy classes, daylength effects

INTRODUCTION

In this paper, we introduce the CROPGRO-Alfalfa model, its capabilities, its sensitivity to weather factors, and give examples of how it simulates daily regrowth and herbage production. Alfalfa is a productive perennial legume forage crop that is important for livestock feed, particularly for dairy animals because of its high protein and high fiber composition. Production practices include three to four harvests in the Midwestern USA, with up to eight or more harvests in warmer winter conditions in Arizona and California. Alfalfa is almost clear-cut at each harvest, leaving very little amounts of residual leaf area to drive regrowth recovery. The regrowth depends on carbohydrate and N reserves from taproot storage tissue to drive new leaf area growth. The speed of regrowth is also dependent on daylength and the cultivar's fall dormancy classification. Shortening daylengths in fall cause increased allocation to taproot reserves and less to shoot growth especially for the lower FD classification (FD 3 or 4), but much

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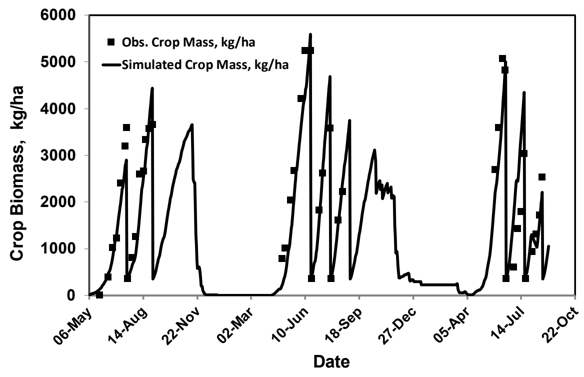
less so for higher FD classes (FD 8 or 9). Weather factors of temperature, solar radiation, rainfall, and daylength influence productivity. We describe how those affect regrowth and herbage production simulated by CROPGRO-Alfalfa.

RESULTS AND DISCUSSION

The CROPGRO-Alfalfa model is part of the Decision Support System for Agrotechnology Transfer (DSSAT) software (Hoogenboom et al., 2021). Its development originated with work by Rymph (2004) who modified the code of the annual CROPGRO model for grain legumes (Boote et al., 1998) to simulate perennial forage crops that regrow after multiple harvests (often harvested to near zero leaf area index (LAI) and over-winter and persist for multiple seasons. This required adding state variables for reserves in storage tissues (such as taproots), along with rules to grow those tissues, to use the reserves for regrowth, and to refill the reserves after cutting harvest. This became the CROPGRO-Perennial-Forage model, which has been adapted for several perennial tropical grasses including *Brachiaria brizantha* (Pedreira et al., 2011), *Panicum maximum* (Lara et al., 2012), and *Cynodon dactylon* (Pequeno et al. 2018). CROPGRO-PFM model was first adapted for alfalfa by Malik et al. (2018) and then evaluated with multiple data sets on FD 3 and FD 4 cultivars in Canada (Figure 1) by Jing et al. (2020). These experimental data were used to solve for cardinal temperature effects on photosynthesis, growth, N-fixation and other processes. The model has since been evaluated against experimental data on multiple FD class cultivars collected in Arizona and Montana (unpublished paper in progress). Simulated results from the sites in Canada, Arizona, and Montana are shown to illustrate how the fall dormancy class effects were calibrated.

Figure 1. CROPGRO-Alfalfa simulation of CFIA (FD4) during 2014, 2015, 2016 at Ottawa, Canada (Jing et al., 2020)



CROPGRO-Alfalfa simulates leaf photosynthesis hourly for sunlit and shaded classes of leaves resulting in hourly canopy assimilation that is integrated to a daily rate. The daily growth dynamics include accumulation of thermal units, leaf appearance rate, partitioning of assimilate to leaf, stem, root, and taproot storage based on vegetative stage. The N dynamics include uptake of inorganic soil N as well as growth of nodules and N-fixation when root N uptake is not sufficient to meet growth demand for N. The soil organic matter dynamics are simulated using the daily CENTURY module which handles residue contributed from senesced roots and surface residue. The soil-crop-water balance operates on a daily step with tipping bucket water balance, with evapotranspiration computed based on Penman-Monteith (FAO-56). If root water uptake is insufficient, the model computes two water-deficit signals, one which reduces canopy assimilation and a more sensitive one that reduces expansive growth sooner than photosynthesis. The model requires Class A weather inputs, soil water-holding traits for soil layers, irrigation and other management inputs. The management inputs include cutting harvest dates, amount of living stubble after harvest, and fraction of leaf. Daily model outputs include LAI, leaf, stem, taproot, root, V-stage, vegetative N concentration, as well as the herbage and herbage crude protein at cutting harvest dates.

Figure 2 illustrates how the CROPGRO-PFM-Alfalfa model simulates LAI for three FD class cultivars in Arizona. Observed LAI was greater for CUF101 (FD9) than Cisco II (FD6) than Rugged (FD3), especially during shorter days of spring/fall. The model was able to capture that response with the modifications of the strength of daylength effect on fall dormancy, along with small differences in photosynthetic rate. Figure 3 illustrates the biomass growth dynamics over time, which like the response of LAI, shows that the model modifications succeeded in capturing the greater biomass accumulation of CUF101 (FD9) compared to Cisco II (FD 6) and Rugged (FD 3).

Figure 4 illustrates the main-stem node number which also differs with FD class (the rate of node appearance set at 0.21, 0.24, and 0.27 per photothermal day for FD 3, 6, and 9). Faster leaf appearance also leads to taller plants for higher FD (data not shown).

Figure 5 shows the model-simulated dynamics of total nonstructural carbohydrate (TNC) reserves in taproot during seven regrowth cycles (where sharp drop of shoot mass reflects herbage harvest) for Cisco II (FD6) in Arizona. While there were no measurements of taproot mass or carbohydrates, the pattern does mimic limited published literature on alfalfa with a 7-14 day depletion of TNC followed by refill of TNC. The taproot and root growth reflect these cycles with slower growth during the 7-14 days after harvest followed by enhanced growth after LAI recovers.

Figure 2 - Simulated (lines) and observed LAI (symbols) for three fall dormancy (FD) alfalfa cultivars grown in Arizona in 2018 (Ottman et al., 2018).

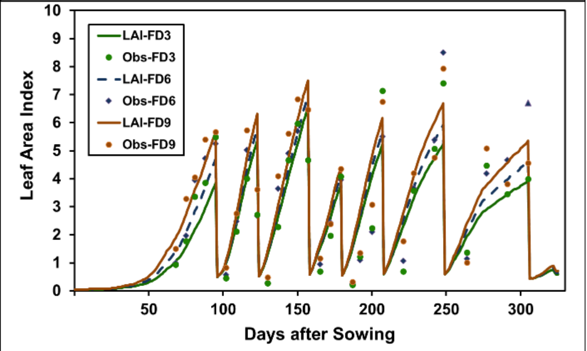


Figure 3 - Simulated (lines) and observed crop biomass (symbols) for three fall dormancy (FD) alfalfa cultivars grown in Arizona in 2018 (Ottman et al., 2018).

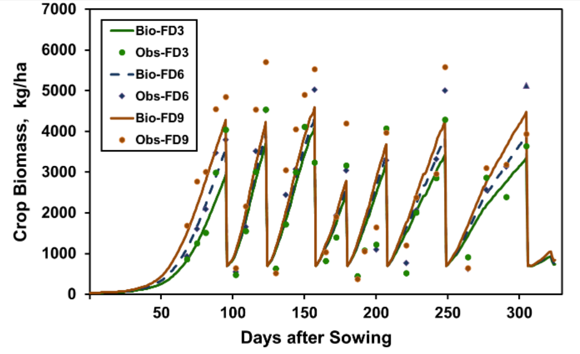


Figure 4 - Simulated (lines) and observed main stem leaf number (symbols) for three fall dormancy (FD) cultivars grown in Arizona in 2018 (Ottman et al., 2018).

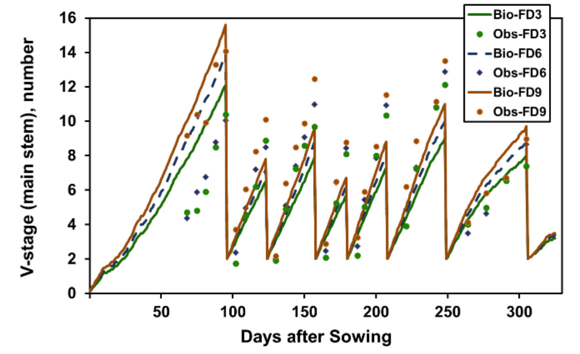


Figure 5 - Simulated taproot, root, and shoot mass, taproot TNC, and shoot mass during 7 harvest cycles of FD6 cultivar in Arizona in 2018 (Ottman et al., 2018).

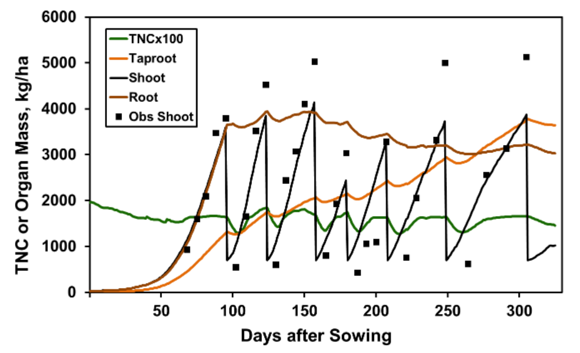
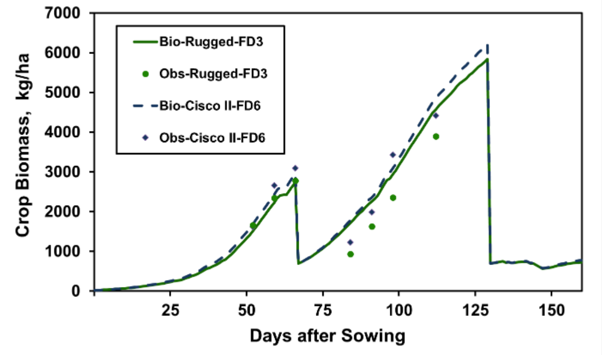


Figure 6 shows biomass growth dynamics over time for two cultivars, Rugged (FD3) and Cisco II (FD6) grown over two harvest cycles in Montana.

The CROPGRO-Alfalfa model is presently available in DSSAT V4.8 (*dssat.net*). The model presently simulates crude protein and percent leaf of herbage. To enhance this as a management tool for alfalfa producers, we hope to add capability for simulating forage quality aspects including digestibility, neutral detergent fiber, acid detergent fiber, relative feed value, and total digestible nutrients.

Figure 6 - Simulated crop biomass of Rugged (FD3) and CIsco II (FD6) during two harvest cycles in 2018 establishment season in Montana (Torrion et al., 2018).



ACKNOWLEDGEMENT

This work was supported in part by USDA NIFA Grant # 2017-70005-27191

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ECONOMICS OF ALFALFA FERTILIZATION UNDER INFLATED HAY AND FERTILIZER PRICES

Steve Norberg[1], Don Llewellyn[2], Jon Paul Driver[3], Steve Fransen[4], and Joe Harrison[5]

ABSTRACT

Knowing critical alfalfa nutrient levels in-season improves recommendations and applications, while at the same time saves producers time, expense and effort since many growers take samples for hay quality. Inflation has doubled hay and fertilizer prices which brings into question how current fertility decisions are made. From 2019-2020 detail information on phosphorus and potassium response was conducted. Two experiments were designed as follows: 1) Phosphorus (P) rate study with differing rates of P_2O_5 using monoammonium phosphate (MAP); including: 0, 30, 60, 120, 240 lb P_2O_5 acre^{-1} on a low testing P soil <10 ppm (Olsen P method); 2) Potassium (K) rate study with differing rates of K_2O using potassium sulfate: 0, 40, 80, 160, 240, 320 lb K_2O acre^{-1} on an <100 ppm K soil (ammonium acetate method). The second and third years of production (2019-2020) were used for determining P and K rates and yields. Alfalfa was harvested at mid-bud stage for all cuttings. Fall phosphorus soil tests levels were 6.7 and 5.7 ppm at the beginning of 2019 and 2020, respectively. Spring soil test levels for potassium study were 86 and 79 ppm at the beginning of 2019 and 2020, respectively. Failing to apply fertilizer in this experiment reduced yields by 15% for phosphorus and 11% for potassium. The lb P_2O_5 acre^{-1} that maximized gross income after fertilizer costs varied from 166 to 69 lb P_2O_5 acre^{-1} and from 307 to 0 lb K_2O acre^{-1} depending on price of hay and fertilizer. The optimum P level in the harvested hay was 0.41% prior to 2020. Potassium tissue levels were not found to be helpful recommending K rates as dilution of the nutrient occurred as yields increased. Optimized fertilizer rates guidance must consider both hay value and nutrient costs and adjustment values are provided for inflation.

Keywords: Alfalfa, Phosphorus, Potassium, Yield, Fertilizer Economics

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In: Proceedings, 2022 World Alfalfa Congress 'Profitable Alfalfa Production Sustains the Environment.' November 14-17, San Diego, California. UC Cooperative Extension, Plant Sciences Department, University of California, Davis, CA 95616. (See http://alfalfa.ucdavis.edu for this and other Alfalfa Symposium Proceedings.)

OBJECTIVE

To develop and calibrate phosphorus (P_2O_5) & potassium (K_2O) nutrient recommendations for irrigated bud stage alfalfa in the PNW using tissue testing for maximum profit and yield influenced by prices of fertilizer and hay.

STUDY DESCRIPTION

Plot Layout: Two alfalfa research studies (P Study, K Study) were grown near Prosser, WA in South Central WA in initial low P (add test and P ppm) & K (add test and K ppm) testing soil from 2019-2020.
P Study: Differing rates of P_2O_5 using MAP; including: 0, 30, 60, 120, 240 lb. acre^{-1}.
K Study: Differing rates of K_2O using potassium sulfate: 0, 40, 80, 160, 240, 320 lb. K_2O/acre
Analysis: Dry matter analyzed for yield, P or K content (ICP method).
Funded: Three years of funding was received from National Alfalfa and Forage Alliance and one year of funding from Washington State Hay Growers Association.

RESULTS FOR PHOSPHORUS AND POTASSIUM STUDIES

Fall phosphorus soil tests levels were 6.7 and 5.7 ppm at the beginning of 2019 and 2020, respectively (Figure 1a and 1b). Spring soil test levels for potassium study were 86 and 79 ppm at the beginning of 2018 and 2019, respectively. Failing to apply fertilizer in this experiment reduced yields by 15% for phosphorus and 11% for potassium (Figure 1a & 1b). Results were similar for both years, so they were combined over years for each nutrient.

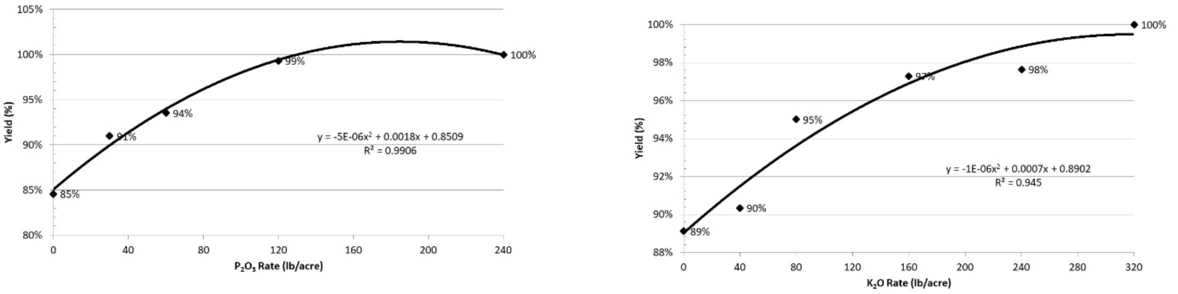


Figure 1a and 1b. The influence of P_2O_5 (Fig 1a) and K_2O (Fig 1b.) on yield of alfalfa averaged over the 2nd and 3rd years (2019 & 2020) of production at the Irrigated Research and Extension Center located near Prosser, WA.

The lb P_2O_5 acre^{-1} that maximized gross income after fertilizer costs varied from166 when P_2O_5 acre^{-1}when hay prices were \$300 ton^{-1} and fertilizer was \$0.54 lb P_2O_5 to as low as 69 lb P_2O_5 acre^{-1} when alfalfa hay was \$150 ton^{-1} and fertilizer was \$1.56 lb P_2O_5 (Table 1). This shows that in the new world of inflation prices for both hay and fertilizer need to be put into fertilizer recommendations.

The increased price of fertilizer can be so high when hay prices low that no amount of potassium would pay for itself, even in this responsive soil, which is the situation is when alfalfa hay is \$150 ton^{-1} and the price of potassium is \$1.28 lb K_2O (Table 2). Return on fertilizer is even more difficult if your goal is to maximize yield or replace nutrients removed (Table 3). When 0-0-60 price is increased from \$0.37/lb of K_2O to \$1.27/lb of K_2O the increased cost of the application over the optimum return on fertilizer went from \$34 to \$307 acre^{-1}. Farmers are already struggling so this increased cost may make it economically unsustainable for fertility to replace all the nutrients harvested and hauled off the field. Only the 120 and 240 lb P_2O_5 acre^{-1} treatments maintain or increased P fertility and only the 320 lb K acre^{-1} rate maintained the K soil fertility (data not shown).

Table 1. Influence of price of phosphorus fertilizer price on optimal economic rate (P_2O_5) and optimal phosphorus concentration of second cut harvested alfalfa forage at Prosser, WA from 2019-2020.

Fertilizer Price Of MAP (11-52-0)	**Hay Price \$150 per Ton**	**Hay Price \$225 per Ton**	**Hay Price \$300 per Ton**
Opt. Fert. Rate (lb P_2O_5/acre) / % of Base Price / Opt. % P Conc.			
Base Price \$ 560/Ton of MAP (\$0.54 lb P_2O_5)	146/(100%)/0.41	159/(100%)/0.42	166/(100%)/0.43
95% increase in Fert. Price \$1090/Ton (\$1.04 lb P_2O_5)	107/(73%)/0.38	134/(84%)/0.40	147/(89%)/0.41
189% Increase in Fert. Price \$1620/Ton (\$1.56 lb P_2O_5)	69/(47%)/0.34	109/(69%)/0.38	129/(78%)/0.40

Table 2. Influence of potassium fertilizer price on optimal economic rate of K_2O based on research at Prosser, WA from 2019-2020.

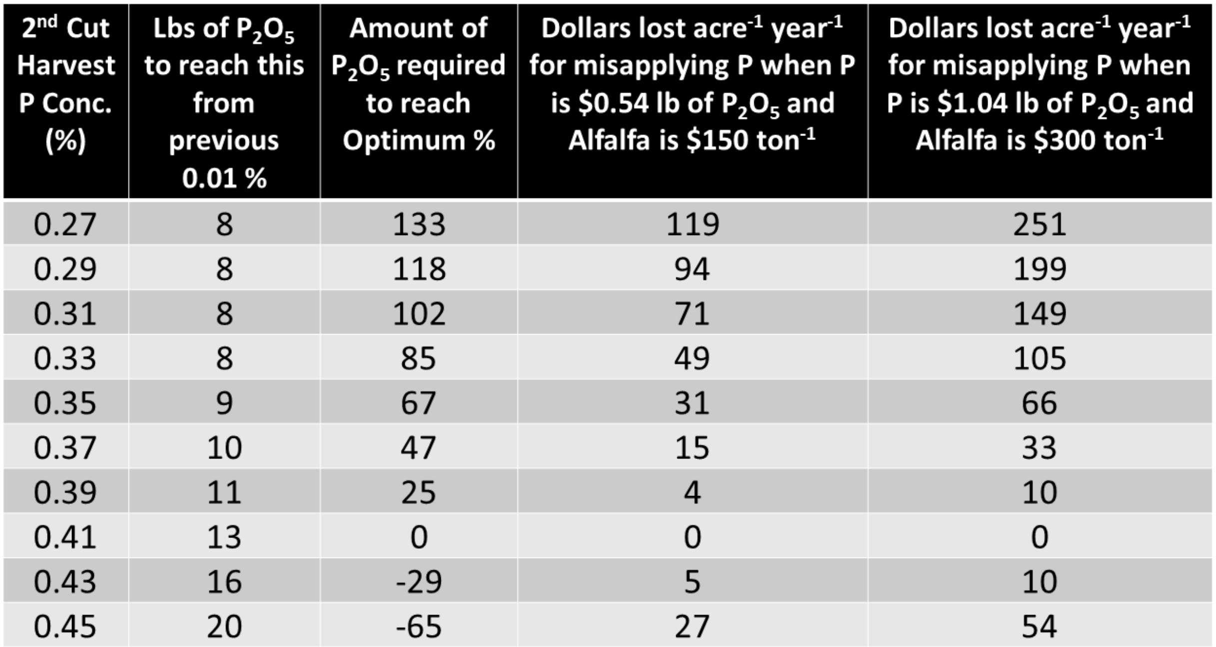
Fertilizer Price Of KCl- (0-0-60)	**Hay Price \$150 per Ton**	**Hay Price \$225 per Ton**	**Hay Price \$300 per Ton**
	Optimum Fertilizer Rate (lb K_2O/acre) / (% of base price rate)		
Base Price \$ 446/Ton KCl^- 0-0-60 Or \$0.37 lb K_2O	204/(100%)	246/(100%)	265/(100%)
122% increase in Fert. Price \$990/Ton KCl^-, \$0.83 lb K_2O	44/(22%)	144/(59%)	191/(72%)
244% Increase in Fert. Price \$1534/Ton KCl^-, \$1.28 lb K_2O	0/(0%)	43/(17%)	116/(44%)

Of the yearly increase in yield by fertilizer by type, the percent of the yield increase for the year by applying the fertilizer primarily occurred in the first two cuttings with it accounting for 79% P yield increase and 80% K yield increase, with first cutting providing 55% P and 54% K of the yield increases (data not shown).

Table 3. Impact of fertilizer price on optimum potassium fertilizer rate and cost per acre depending on the agronomic goal.

Goal	**Optimum Fertilizer Rate with Fertilizer Price (0-0-60)**		
	$446/ton of Fert. ($0.37/lb of P_2O_5)	$990/ton of Fert. ($0.83/lb of P_2O_5)	$1,534/ton of Fert. ($1.27/lb of P_2O_5)
Optimizing Annual Profit	265 lb $acre^{-1}$	191 lb $acre^{-1}$	116 lb $acre^{-1}$
Total K Replacement Rate <u>or</u> Maximizing Yield	356 lb $acre^{-1}$	356 lb $acre^{-1}$	356 lb $acre^{-1}$
Increased Fert. Cost $/acre	$34 $acre^{-1}$	$137 $acre^{-1}$	$307 $acre^{-1}$

Table 4. Impact of misapplying phosphorus to alfalfa at two scenarios, before inflation and after inflation. Different levels of second cut alfalfa tissue phosphorus concentration with 0.41% being optimum.



2nd Cut Harvest P Conc. (%)	Lbs of P_2O_5 to reach this from previous 0.01 %	Amount of P_2O_5 required to reach Optimum %	Dollars lost $acre^{-1}$ $year^{-1}$ for misapplying P when P is $0.54 lb of P_2O_5 and Alfalfa is $150 ton^{-1}	Dollars lost $acre^{-1}$ $year^{-1}$ for misapplying P when P is $1.04 lb of P_2O_5 and Alfalfa is $300 ton^{-1}
0.27	8	133	119	251
0.29	8	118	94	199
0.31	8	102	71	149
0.33	8	85	49	105
0.35	9	67	31	66
0.37	10	47	15	33
0.39	11	25	4	10
0.41	13	0	0	0
0.43	16	-29	5	10
0.45	20	-65	27	54

Recent global inflation has more than doubled the cost of misapplying phosphorus from both under and over applying fertilizer (Table 4). Interestingly, since both hay price and fertilizer price has increased the optimum of 0.41% P concentration in the harvested hay at second cut mid bud stage remains the same. Second cutting was used as the data was less variable in the samples taken. Table 4 also shows the amount of P_2O_5 needed to increase forage content by 0.01%. This amount will likely vary based on yield potential in other fields. Potassium tissue levels were not found to be helpful recommending K rates. This may have occurred as dilution of the nutrient occurred as yields increased. In the new inflationary times, we must adjust fertilizer rates to consider both hay and nutrient costs.

MANAGEMENT RECOMMENDATIONS FOR ADJUSTING FERTILZER RATES:

Phosphorus

- First, gather any hay tests that you have taken for second cut hay that has a % P of the hay. If you have no P contents from hay tests, use adjustment factor in Table 5 and multiply this number to your soil test number to get an adjusted soil test for inflation.
- Second, do your best to estimate the cost of P fertilizer and value of alfalfa hay and determine the box in table 1 that best matches your condition.
- Third, determine if your hay tests % P are similar to the suggested P concentration and determine the difference.
- Fourth, use table 4, second column, to add or subtract lb. P_2O_5 to get to the desired P concentration in the hay in table 1. Remember the number in each row is for a 0.1% increase or decrease for that tissue content. For instance, to get from 0.35 to 0.41% P. The difference is 0.6 increase needed. On average it takes about 11 lb per 0.1% increase (Avg of 10,11,13). So 6 times 11 would be an increase of 66 lb. **Add or subtract this amount to last years application amount.**

Potassium

- Do your best to estimate the cost of K fertilizer and value of alfalfa hay and determine the box in table 2 that best matches your condition and use the rate in the box in Table 6. For instance, you think at your next application you will have fertilizer price at \$990 Ton^{-1} KCl^{-} (0-0-60) which is \$0.83 lb K_2O and alfalfa hay will be \$300 ton^{-1}. That box has 0.94 in it.
- Take your recommended soil test rate from your soil sample and multiply it by 0.94 and this is your new adjusted rate for inflation.

Alternative - Request an excel spreadsheet that you can put the numbers into and get a recommendation based on our results. Contact Steve Norberg at s.norberg@wsu.edu .

Table 5. Adjustment factors for phosphorus fertilizer rates for different hay and phosphorus prices.

Fertilizer Price Of MAP (11-52-0)	**Hay Price $150 per Ton**	**Hay Price $225 per Ton**	**Hay Price $300 per Ton**
Opt. Fert. Rate (lb P_2O_5/acre) / % of Base Price / Opt. % P Conc.			
Base Price $ 560/Ton of MAP ($0.54 lb P_2O_5)	1.00	1.09	1.14
95% increase in Fert. Price $1090/Ton ($1.04 lb P_2O_5)	0.73	0.92	1.01
189% Increase in Fert. Price $1620/Ton ($1.56 lb P_2O_5)	0.47	0.75	0.88

Table 6. Adjustment factors for potassium fertilizer rates for different hay and phosphorus prices.

Fertilizer Price Of KCl^- (0-0-60)	**Hay Price $150 per Ton**	**Hay Price $225 per Ton**	**Hay Price $300 per Ton**
	Optimum Fertilizer Rate (lb K_2O/acre) / (% of base price rate)		
<u>Base Price</u> $ 446/Ton KCl^- 0-0-60 Or $0.37 lb K_2O	1.00	1.21	1.30
122% increase in Fert. Price $990/Ton KCl^-, $0.83 lb K_2O	0.22	0.71	0.94
244% Increase in Fert. Price $1534/Ton KCl^-, $1.28 lb K_2O	0.00	0.21	0.57

Alfalfa response to phosphorus and potassium in association with calcium and magnesium and harvest time

M. Anowarul Islam and Michael M. Baidoo[1]

ABSTRACT

Phosphorus (P) and potassium (K) combination can provide alfalfa (*Medicago sativa* L.) with essential nutrients to improve production. However, fertilizing alfalfa with a balance of P and K (P × K) alone may not warrant their availability for effective plant uptake until other interrelated factors (e.g., levels of exchangeable calcium [Ca], magnesium [Mg], and harvest time) are considered. The experiment was conducted at the University of Wyoming James C. Hageman Sustainable Agriculture Research and Extension Center from 2019 to 2021 to determine alfalfa's response to P and K in relation to Ca and Mg levels along with harvest time. Treatments were 10 selected combinations of three P (0, 34, and 67 kg P_2O_5 ha^{-1}), three K (0, 168, and 336 kg K_2O ha^{-1}), two Ca (0 and 560 kg CaO ha^{-1}), and two Mg (0 and 56 kg MgO ha^{-1}); and two harvest times (early harvest, late bud to early [10%] bloom; late harvest, 7 days after early harvest) arranged in randomized complete block with three replications. Alfalfa fertilized with P × K generally produced higher forage accumulation than the unfertilized alfalfa. This trend was generally observed for treatments with and without the association of Ca and Mg ($Ca_{560}Mg_{56}$). On average of two years, the $P_{67}K_{336}$ and $P_{67}K_{336}Ca_{560}Mg_{56}$ treatments produced the greatest (>11 Mg ha^{-1}) annual forage accumulation, whereas P_0K_0 produced the lowest (8.1 Mg ha^{-1}) annual forage accumulation. Harvest time affected ($P < 0.05$) forage accumulation such that higher forage accumulation was produced at late harvest (12.7 Mg ha^{-1}) than at early harvest (11.7 Mg ha^{-1}) in 2020, and the opposite was observed in 2021. Overall, the study results suggest that high rates of P and K are needed irrespective of amounts of K along with Ca and Mg present in the soil for maintaining high alfalfa productivity.

Key Words: Balanced nutrition, calcium, magnesium, harvest time, alfalfa response

INTRODUCTION

In production areas of the western United States, most soils have sufficient levels of essential plant nutrients, especially potassium (K). Reports by soil fertility and forage extension specialists therefore suggest that applying K to crops (e.g., alfalfa) is not often recommended in these areas (Blaylock et al., 1996; Koeing and Barnhill, 2006). As a result, alfalfa-fertility works have often been conducted on soils that are responsive to applied fertilizers (e.g., ≤150 mg K kg^{-1} initial soil test). Studies have investigated the relationship between cationic soil nutrients and their availability to plants, and found that the relative proportion of multiple cations (Ca^{+2}, Mg^{+2}, K^+, Na^+) ought to be considered rather than a single cation (Loide, 2004; Haliu *et al*., 2015; Laekamariam *et al*., 2018). Phosphorus and K have been shown to have a positive relationship with high alfalfa production (Berg *et al*., 2005; Burayu and Mostafa, 2021). Alfalfa's high requirement of P and K often leads to the removal of significant amounts of these nutrients from the soil following harvest and baling. Thus, to sustainably increase crop productivity, replenishing P and K to be readily available for effective uptake by alfalfa can depend on the threshold of soil cationic nutrients. Harvest time, an important management decision in alfalfa forage systems, is also crucial to the plant's ability to take-up nutrients for enhanced growth, due to the duration of plant growth prior to harvest. There is limited information available on alfalfa's response to P and K in relation to high levels of soil Ca and Mg under different harvest regimes. It is, therefore, necessary to explore alfalfa's response to P and K in association with high levels of soil Ca and Mg, and harvest management.

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METHODS

The experiment was conducted at the University of Wyoming James C. Hageman Sustainable Agriculture Research and Extension Center (SAREC) from 2019 to 2021 under irrigated conditions. The site has a semiarid climate and most of the precipitation is received in the month of May. After the final land preparation, 3 cores of soil were sampled (0-15 cm depth) from the experimental field and they were analyzed to determine the initial soil fertility status, following standard soil testing procedures (ASA, 1982; NCR, 2000). Treatments consisted of 10 selected combination rates of three P (0, 34, and 67 kg P_2O_5 ha^{-1}), three K (0, 168, and 336 kg K_2O ha^{-1}), two Ca (0 and 560 kg CaO ha^{-1}), and two Mg (0 and 56 kg MgO ha^{-1}); and two harvest times (early harvest, late bud to early [10%] bloom; late harvest, 7 days after early harvest). The treatments were arranged in 10 × 2 factorial under randomized complete block design with three replications. The combinations of P (triple superphosphate, TSP), K (muriate of potash), Ca (calcium oxide), and Mg (magnesium oxide) (Table 1) were broadcast on their respective experimental plots at constant rate before planting. Pre-inoculated (alfalfa specific Rhizobium bacteria) seeds of Hi-Gest 360 were planted (September 3, 2019) on all plots at a seeding rate of 22 kg pure live seeds ha^{-1}, 1.2 cm depth, and 18 cm row spacing by using a 9-row tye driller. All plots were irrigated (25 mm irrigation water) every 7 days (from June to September) based on the available soil moisture. Manuel weeding by hoeing of each plot was done during the seedling and establishment phase of the plant to reduce weed pressure. Plants were sampled by mechanically harvesting (in 2020 and 2021) two quadrats of alfalfa and leaving a stubble of about 8-10 cm. The remaining herbage were mowed and raked from the plots to mimic harvesting and baling. Harvested plant samples were oven-dried in a forced draft oven at 60°C for a minimum of 72 hrs. Dry weight of the samples was measured and recorded as weight per unit quadrat area. This was used to estimate forage accumulation per hectare as dry matter basis. Data was analyzed by using the mixed effect procedure (PROC MIXED) and the MEANS option in Statistical Analysis System. Post-hoc mean separations were conducted by using Fisher's protected least significance difference (LSD).

Table 1. Treatment combinations of phosphorus, potassium, calcium, and magnesium used for the study at SAREC

T_1: $P_0K_0Ca_0Mg_0$	T_6: $P_0K_0Ca_{560}Mg_{56}$
T_2: $P_{34}K_{168}Ca_0Mg_0$	T_7: $P_{34}K_{168}Ca_{560}Mg_{56}$
T_3: $P_{34}K_{336}Ca_0Mg_0$	T_8: $P_{34}K_{336}Ca_{560}Mg_{56}$
T_4: $P_{67}K_{168}Ca_0Mg_0$	T_9: $P_{67}K_{168}Ca_{560}Mg_{56}$
T_5: $P_{67}K_{336}Ca_0Mg_0$	T_{10}: $P_{67}K_{336}Ca_{560}Mg_{56}$

P source: Triple superphosphate (TSP, $Ca(H_2PO_4)_2 . H_2O$); K source: Muriate of potash (KCl); Ca source: Calcium oxide (CaO); Mg source: Magnesium oxide (MgO).

RESULTS AND DISCUSSION

The soil's pH (8.31) was alkaline with high exchangeable K (243 mg kg^{-1}), Ca (3526 mg kg^{-1}), and Mg (328 mg kg^{-1}) levels, which is common with soils in the state of Wyoming. This is associated to the higher amount of potential evaporation than average annual precipitation in the region. Typically, when the soil pH approaches 8.0 or higher, the availability of some plant nutrients is constrained, and management strategies might be beneficial to unlock these nutrients and make them plant available (Norton, 2020). Alfalfa's high nutrient demand therefore necessitates nutrient build-up and downscaling of interrelated factors critical to the nutrient's availability to be taken-up by plants for adequate growth. In this study, applying P × K to alfalfa generally produced higher yield response (annual total forage accumulation) than the unfertilized alfalfa (Table 2) which is an indication that the initial high levels of P and K (control plots) was not enough to meet alfalfa's nutritional needs for an increased forage accumulation. Compared to the unfertilized alfalfa, the general higher forage accumulation of alfalfa fertilized with P × K suggests that the increased P × K levels was responsible for a possible nutrient availability and uptake by the plant with a resultant higher yield response. This finding could be elucidated by a possible constraint of the P and K by other interrelated factors (such as the relative levels of soil Ca and Mg) and rendered the nutrients not to be readily available and taken-up by alfalfa for higher yield response. The positive impact of P × K on forage accumulation and persistence of alfalfa have been shown in previous studies (Lissbrant *et al*., 2009; Burayu and Mostafa, 2021). Thus, upon their availability for uptake by the plant, the absorbed nutrient interacted to cause a synergistic effect through their physiological roles to influence the crop's performance. Over the two production years, the 2-yrs total annual total forage accumulation was greatest when alfalfa was fertilized with high rates of P × K ($P_{67}K_{336}$) with the $Ca_{560}Mg_{56}$ association (23.1 Mg ha^{-1}; 41% increase over the control) and without $Ca_{560}Mg_{56}$ association (22.7 Mg ha^{-1}; 43% increase over the control) (Table 2). Depending on their relative levels, cationic nutrients such as Ca^{2+} and Mg^{2+} are critical to the availability of P and K in the soil for plant uptake (Mallarino *et al*., 2013; Jeschke, 2017). The roles of P and K are interdependent; therefore, a blend of both nutrients interact to form strong bond that can interact with other nutrients and impact their relative thresholds in the soil (Lissbrant *et al*., 2009; IPNI, 1998). As observed from the results of this study, the high P and K levels interacted (synergistic effect), and their interaction effect might have caused P and K levels to dominate the exchange sites and soil space at the expense of soil Ca and Mg levels, which probably became readily available to be absorbed by alfalfa for higher yield response. This explains the higher yield response of alfalfa fertilized with $P_{67}K_{336}$ in a soil with high Ca and Mg levels. Harvest time had a significant effect on forage accumulation in 2020 and 2021. Late harvest produced higher forage accumulation than early harvest in 2020, and the opposite was observed in 2021 (Table 2). The decline in forage accumulation at late harvest in 2021 could probably be due to the prolonged biotic/abiotic stress suffered by the plants under late harvest system and the influence it has on the plant growth processes as the stand ages (Undersander *et al*., 2015). This suggest that alfalfa's productivity under early harvest or late harvest schedule is dependent on the stand age.

Table 2. Forage accumulation (dry matter [DM] yield) of alfalfa (Hi-Gest 360) treated with phosphorus and potassium in association with calcium and magnesium, and harvest time at the SAREC in 2020 and 2021

Treatment (kg ha^{-1})	2020	2021	2-yrs total	2-yrs avg	Percent yield increase†
	---------------------- DM yield (Mg ha^{-1})			---------------------	(%)
P_0K_0	9.6 g¶	6.5 d	16.1 f	8.1 f	-
$P_{34}K_{168}$	12.2 d	8.6 a	20.8 cd	10.4 cd	29
$P_{34}K_{336}$	13.0 c	8.7 a	21.7 bc	10.9 bc	35
$P_{67}K_{168}$	12.5 cd	8.7 a	21.2 c	10.7 c	32
$P_{67}K_{336}$	13.8 b	8.9 a	22.7 a	11.3 a	41
$P_0K_0Ca_{560}Mg_{56}$	11.4 e	7.2 c	18.6 e	9.3 e	16
$P_{34}K_{168}Ca_{560}Mg_{56}$	10.7 f	8.0 b	18.7 e	9.3 e	16
$P_{34}K_{336}Ca_{560}Mg_{56}$	12.1 d	8.0 b	20.1 d	10.0 d	25
$P_{67}K_{168}Ca_{560}Mg_{56}$	12.4 d	8.5 ab	20.9 cd	10.4 cd	30
$P_{67}K_{336}Ca_{560}Mg_{56}$	14.5 a	8.6 a	23.1 a	11.5 a	43
Average	12.2	8.2	20.4	10.2	--
Harvest time					
Early harvest‡	11.7 b	8.5 a	20.2 a	10.1 a	-
Late harvest§	12.7 a	7.8 b	20.5 a	10.3 a	2
Average	12.2	8.2	20.4	10.2	--

† Percent yield increase = ([Treatment yield – control yield]/ control yield) x 100.

‡ Early harvest (late bud to early [10%] bloom stage.

§ Late harvest (7 days after early harvest).

¶ Within each column, means followed by the same lower-case letter are not significantly different at 0.05 probability level.

CONCLUSIONS

Alfalfa's forage accumulation potential increased when it received P × K nutrition in soils with high levels of exchangeable Ca and Mg. The levels of soil exchangeable Ca and Mg relative to levels of P and K have great potentials to limit the availability of P and K to be taken-up by alfalfa for high yield response. Forage accumulation of alfalfa under early harvest and late harvest schedule changed with stand age. To maintain higher alfalfa productivity for sustainable production, growers and other stakeholders ought to check the current nutritional status of their soil and consider fertilizing an improved alfalfa cultivar with high rates of P and K (even in a soil with high K levels), and make harvest schedules decisions based on stand age.

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QUANTIFYING N CREDITS OF ALFALFA IN ROTATION

Kim Cassida[1]

ABSTRACT

In addition to its value as a forage and soil improver, alfalfa is noteworthy as one of the most effective sources of N credits for succeeding crops in rotations. When fertilizer N is expensive, these credits can add considerable value to an alfalfa rotation. However, quantifying the exact amount of legume N to credit to the next crop is challenging because it is affected by many environmental factors like soil texture, local climate conditions, and soil N mineralization rate, as well as by management factors like stand density, age, or height at termination, time since termination, irrigation, and use of manure. States and commercial soil testing laboratories rarely agree on the amount of N to credit after an alfalfa rotation, with values ranging from 0 to 190 lb/acre. This variability reduces producer confidence in N credits, who then often err on the side of caution and apply more fertilizer N than they need, reducing profitability and increasing N leakage into the environment. This paper will present an overview of the current situation.

Key Words: alfalfa, nitrogen credit, fertility, crop rotation

THE IMPORTANCE OF N CREDITS IN CROP PRODUCTION

Alfalfa is noteworthy as one of the most effective rotation sources of N credits and this increases the value of alfalfa when N prices are high. Nitrogen credit is defined as the fertilizer N replacement value of a rotation crop for the next crop in the sequence. Many, but not all, states and commercial laboratories take this credit into account when making fertilizer application recommendations. Use of legume N credits can considerably enhance the economic value of an alfalfa rotation when fertilizer N prices are high. When fertilizer N is priced at US$1/lb (US$2.20/kg), the greatest N credits from the table can add up to US$240/acre (US$593/ha) saved over two years of succeeding crops.

Yost reviewed hundreds of site years of data for corn following alfalfa (Yost et al., 2012; 2013; 2014a; 2014b; 2014c; 2015) and concluded that alfalfa can usually provide all the N needed by corn grain or silage in the first year after alfalfa, and often makes a large contribution in the second year. An exhaustive review is past the limits of this paper but alfalfa is also documented to provide significant fertilizer replacement value to crops other than corn.

Factors Influencing Soil N Availability after Alfalfa Termination

The amount of alfalfa N that enters the soil is dependent on the total biomass of alfalfa at termination. This is controlled by the stand density and forage mass at termination. Therefore,

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many recommendations for N credits take into account stand density either as crown counts per unit area or simply as estimated percentage of legume. Wisconsin research established 5 crowns/ft^2 (53.8 crowns/m^2) as a threshold density for termination of alfalfa stands so many recommendations focus on this number to evaluate stand density. However, recommendations based solely on stand density or proportion may be misleading because there are many other factors that can influence N credits. Allowing alfalfa top growth to grow back before termination or skipping the last cutting altogether will increase total biomass and N added to soil, assuming that the top growth is incorporated. This also ensures that sufficient top growth is present to absorb herbicide for an effective chemical termination.

Soil texture influences N credits. Nitrogen credits are generally greater on fine- or medium-textured soils than on coarse-textured ones (Yost et al., 2014b).

Age of the alfalfa stand influences N credits but results are inconsistent. Yost et al. (2015) reported that alfalfa stands in Minnesota did not provide enough N to supply the needs of a first-year corn rotation until alfalfa stands were at least three years old, even when the stand density of the younger stands was excellent. In contrast, Fernandez et al. (2019) indicated that one year of alfalfa was enough to provide credits for organic corn.

The timing of N availability is a key factor influencing the usefulness of N credits. When the alfalfa crop is terminated, most of its N is tied up in the plant tissues of leaf, stem, root, and nodules. This N is not available to the next crop until the alfalfa residues have been recycled into mineralizable N by soil microbes. Nitrogen mineralization takes time and is influenced by all factors that enhance soil microbe activity such as soil moisture, temperature/ growing degree days, and C/N ratios (Clark et al., 2020). Moreover, the timing of crop N need must match the rate of N release from the residue. If the N is released before the crop is ready to capture it, it may leach out of the root zone. This is both a financial loss of a valuable nutrient and an environmental cost if the N makes its way into ground water. Nitrogen credits are usually only given to the first year after legume termination but Yost et al. (2014a) demonstrated that alfalfa can sometimes provide significant N to succeeding crops even in the second year after termination, but others have reported that legume N was gone by the second year (Schmidt et al., 1996).

Methodology For Quantifying N Credits

Nitrogen credits are not equivalent to total biological N fixation (BNF). There is much literature quantifying the impressive amounts of BNF that are possible during growth of a leguminous crop and greater BNF undoubtedly provides greater potential N credit than less BNF. However, that nitrogen will not all be available to the succeeding crop due to immobilization and losses, and therefore methods for determining BNF are not appropriate for calculating N credits.

There are three methods commonly used for estimating N credit values: traditional, difference, and soil N tests. The first two were compared by Lory et al. (1995). The traditional approach compares the yield of the crop grown after a legume rotation to a N response curve from the crop grown with fertilizer only to determine the amount of N provided by the rotation. The problem with this approach is that it assumes N is the only benefit provided by the legume. This assumption is not correct because it ignores the simultaneous non-N rotation effects, such as pest control, changes to soil physical properties, improved soil health, improved water retention, and others. By attributing all improvement in subsequent crop yield to N, the traditional method overestimates N credits.

The difference method was developed to discriminate between N and non-N rotation effects (Lory et al., 1995). With this method, N response curves are determined for both the crop grown after legumes and the fertilizer-only crop. The post-legume curve includes both N and non-N rotation effects while the fertilizer-only curve determines pure response to N. The difference in the economic optimum N rate between the two curves is the N credit. Local optimum N recommendations for the fertilizer-only crop may be used if available instead of making a new response curve for the fertilizer-only crop. Economic optimum N rate is defined as the point where marginal N cost equals marginal value of increased crop yield and is therefore dependent on market fluctuations.

Measurement of actual soil N during growth of the post-legume crop seems like a logical approach to quantifying N credits. Sadly, tests like basal stalk nitrate test and pre-sidedress N test have proven to be poor predictors of crop performance after legume rotations (Yost et al., 2013; 2014c), possibly because they only give a snapshot of the moment in time when the soil sample was collected and do not provide amounts or release rates for the reservoir of potentially mineralizable N that is still immobilized in SOM and alfalfa residues. Some soil testing labs are now offering potentially mineralizable N tests that attempt to predict how N might be released from SOM over the growing season. This approach shows promise to provide better estimates of N availability from rotations but it is relatively new. Unfortunately, the predictions are not yet sufficiently validated against real crop performance to be widely incorporated into state fertilizer recommendations.

Producer Confidence in N Credits

Yost et al. (2014c) compared state extension recommendations for N credits in corn following alfalfa across the Midwest. At that time, the main consideration was alfalfa stand density at termination. Since then, little has changed. There is still little agreement across states and most states still do not give N credit past the first year. Some states do not provide any N credit at all. Shifting to the soil test approach instead of book values for N credit will not help producer confidence if the N test results do not lead to predictable corn performance.

The disagreement in recommendations reduces producer confidence in the accuracy of N credits. Producers in Minnesota were more likely to ignore generous N credits than low credits and this resulted in more excess N being applied after good alfalfa stands than after poor ones (Yost et al., 2014c). This probably occurs because producers want to make sure there is enough N and are more willing to err on the side of excess than deficiency. However, this is likely costing them money as well as contributing to nitrate loading of water sources.

WHERE DO WE GO FROM HERE?

In order for producers to believe N credit values, they need to be able to see concrete positive results from adopting them. Current N rate recommendations for corn after corn or soybeans are largely based on data from multiple site-years and frequent updates. We do not have such a database for corn or other crops after alfalfa. We also do not have a clear understanding of all the factors influencing N availability from rotation crops like alfalfa. Disparate state recommendations for N credit and the shift towards non-standardized soil tests for measurable residual N and mineralization rates instead of book values suggest that new coordinated research is needed to assess how test values relate to crop yields.

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Facing the Realities of Water Limitations in Western US for Forage Crops

Dan Keppen, P.E[1].

ABSTRACT

Water is the key to the American West. Food security is as vital to our homeland security as our nation's other strategic interests, and the production of food and fiber on Western irrigated lands is critical to our nation's ability to feed itself.

The Global Agricultural Productivity Report in 2022 quantified the difference between the current rate of agricultural productivity growth and the pace required to meet future world food needs; that report found that current efforts to accelerate global agricultural productivity growth are inadequate. In July 2022, the State of Food and Nutrition in the World report showed that after years of seeing global hunger numbers drop, it is back at record levels and rising. World leaders fear global price spikes in food, fuel and fertilizers will lead to widespread famine, prompting global destabilization, starvation and mass migration on an unprecedented scale.

In the U.S., a bewildering set of forces appear to be aligned against keeping domestic agricultural lands in production, even as our country is now importing more agricultural products than it exports. Arizona and California are paving over and compromising productive farmland at the fastest rate in the U.S.

The U.S. is facing yet another record-breaking drought year in the West. Undoubtedly, the Western drought has reduced the amount of water for many users, including irrigated agriculture. However, in places like California and Oregon, much of the water that once flowed to farms and ranches is currently being re-directed by the federal government for environmental purposes. In other words, federal water policy is shutting down water availability for hundreds of thousands of acres of productive farmland. In the Colorado River Basin, competing interests have mounted a sustained campaign on agricultural water use, and often point to alfalfa as an example of one crop that uses too much water and should no longer be produced.

At a time when the future of Ukraine and other countries' ability to help feed the outside world is at risk, our ability to increase productivity is being further curtailed – due in part, to our own government and competing demands. The grim global hunger conditions we once expected to encounter in 2050 may now hit us decades sooner. This paper seeks to explain this critical issue further, and provides recommendations intended to protect irrigated agriculture as a growing number of faraway critics downplay and even criticize the importance of using water to produce affordable and safe food and fiber.

Key Words: agriculture, alfalfa, California, climate change, Colorado River, conflict, food insecurity, forage crops, inflation, irrigation, policy, water, Western United States.

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INTRODUCTION

The multiple-year drought we are facing in many parts of the U.S. – coupled with other domestic and global developments– is already affecting the availability and price of food for many Americans. Rising food prices and global hunger are linked to the war in Ukraine, extreme climate events like the Western U.S. drought, and other global stressors.

Putin's war in Ukraine has decreased and destabilized worldwide agricultural commodity production and availability. Rising input costs, combined with the ongoing energy and supply chain crises, continue to impact food supply and demand. Those Western producers who do have water have seen production costs increase by as much as 25%, because of rising fuel prices and transportation costs. The fertilizer input costs are going through the roof right now, too – in most places, at least two to three times more expensive than it was last year.

Numerous experts predict a recession in the next 12-18 months. Consumer prices rose 0.4% in September, up 8.2% from a year ago, and more than expected despite federal rate hikes. Excluding food and energy, the core consumer price index accelerated 0.6% and 6.6%, respectively. This is the largest yearly gain since August 1982.

All of these factors have combined to cause significant inflation and global food shortages that loom on the horizon.

FAMILY FARM ALLIANCE BACKGROUND

The Family Farm Alliance is a grassroots organization of family farmers, ranchers, irrigation districts and allied industries in 16 Western states. The Alliance is focused on one mission: To ensure the availability of reliable, affordable irrigation water supplies to Western farmers and ranchers. We are also committed to the fundamental proposition that Western irrigated agriculture must be preserved and protected for a host of economic, sociological, environmental and national security reasons – many of which are often overlooked in the context of other policy decisions.

A PERFECT STORM: WESTERN DROUGHT, INFLATION, WAR IN UKRAINE AND GLOBAL FOOD INSECURITY

A. Global Hunger Crisis

At the global level, hunger is on the rise, and the world community is not prepared to address this looming crisis. The 2022 *State of Food Security and Nutrition in the World* report[2] prepared by the United Nations Food and Agriculture Organization found that an unprecedented count of up to 828 million people went hungry in 2021, an increase of 46 million from the previous year, and a leap of 150 million people since the start of the COVID-19 pandemic. Even before the latest inflationary woes hit us and after years of seeing global hunger numbers drop, global hunger is back at record levels and rising.

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[2] https://data.unicef.org/resources/sofi-2022/

Our organization has been tracking the Global Agricultural Productivity (GAP) Report since 2010, when it first quantified the difference between the current rate of agricultural productivity growth and the pace required to meet future world food needs. That report predicted that total global agricultural output would have to be doubled by the year 2050 to meet the food needs of a growing global population. The *2022 Global Agricultural Productivity (GAP) Report* was released last month by Virginia Tech College of Agriculture and Life Sciences. The 2022 GAP Index found that total factor productivity (TFP), which increases when producers increase their output while using the same or less inputs, is at its lowest level of growth to date. The overall message of the GAP report is that vulnerable agricultural systems rest on fragile foundations. Reversing the downward trajectory of global agricultural productivity growth, the report says, demands urgent action from policymakers, leaders, donors, scientists, farmers, and others in the agri-food system. In short, the 2022 GAP report found that current efforts to accelerate global agricultural productivity growth are inadequate.

We are now seeing increased reports of world leaders sharing fears that global price spikes in food, fuel and fertilizers will lead to widespread famine, prompting global destabilization, starvation and mass migration on an unprecedented scale.

Sri Lankan President Gotabaya Rajapaksa fled the country last summer, just days after thousands of protesters stormed his residence over the nation's crippling economic crisis. Sri Lanka for months has grappled with severe food and fuel shortages and skyrocketing inflation. Domestic food production also took a hit by the government's April 2021 decision to ban the importation of chemical fertilizers and agrichemicals, in an apparent shift to organic agriculture. By the time the ban was partially reversed in November, farmers reported a 40 to 50 per cent loss in rice crops. Farmers in the Netherlands this year took to the streets in anger, protesting sweeping environmental policy change that threatens to upend the extraordinary agricultural productivity of the tiny country, which ranks second only to the U.S. in global exports.

B. War in Ukraine

When war first broke out in Ukraine in early 2022, world leaders feared that sanctions and destroyed ports could take nearly 30% of the world's grain supply out of production or off the market this year. The World Bank initially forecasted that Russia's invasion of Ukraine could drive 40 million additional people worldwide into extreme poverty and food insecurity this year.

Global cereal grain prices actually dropped this summer, due to improved production prospects in North America and Russia, and the resumption of exports from Black Sea ports in Ukraine in June. The grain deal was brokered with help from the United Nations (U.N.) and Turkey, which sought to ensure safe passage of grain from Ukraine to vulnerable nations that rely on Ukraine for grain exports. It was seen as critical for food insecure nations to avoid widespread famine and starvation, as Ukraine is a breadbasket for Europe, Africa and the Middle East. Russia in late October 2022 temporarily put the agreement brokered last June on hold, but resumed the Black Sea agreement a few days later.

Now, global grain stocks are pushing towards a decade low. Shipments were too few, and harvests from other major crop producers (U.S., France, and China) are smaller than initially expected due to poor weather in key agricultural regions. These factors are shrinking grain harvests and cutting inventories, heightening the risk of famine in some of the world's poorest nations. The bleak global economic outlook, coupled with higher fertilizer prices, “pose serious strains for global food security,” Maximo Torero, the Chief Economist for the United Nations Food and Agriculture Organization said last August.

Hunger-stricken African countries are struggling with reduced wheat imports due to Russia's war in Ukraine. However, one country - Zimbabwe - is looking to build a small strategic reserve for the first time in its history. Zimbabwean President Emmerson Mnangagwa in April described Russia's war in Ukraine as a "wake-up call" for countries to grow their own food (*Associated Press*).

C. American Farmland is Disappearing

Closer to home, the American Farmland Trust (AFT) reported in “Farms Under Threat 2040: Choosing an Abundant Future” earlier this year that Americans are paving over agricultural land at a rapid pace. From 2001-2016, our nation lost or compromised 2,000 acres of farmland and ranchland every day. “Farms Under Threat 2040” shows we are on track to convert over 18 million acres of farmland and ranchland from 2016-2040—an area the size of South Carolina.

If recent trends continue, 797,400 acres of California's farmland and ranchland in 2040 will be paved over, fragmented, or converted to uses that jeopardize agriculture. Two-thirds of the conversion will occur on California’s best land, and the top two hardest-hit counties will be Riverside and San Bernardino in Southern California. Fresno County, the nation’s leading agricultural county by gross value, is in third place, and the 17th fastest in the nation, in terms of farmland lost to other uses.

The latest study from AFT shows that Arizona and California are paving over and compromising productive farmland at the fastest rate in the U.S. According to the AFT report, Maricopa County, Arizona – which includes Phoenix and its many suburbs - is losing farmland at a faster rate than any other county in the nation.

According to recent and alarming USDA data, foreign ownership and investment in U.S. agricultural land has nearly doubled over the past decade, 2010 through 2020. As of December 31, 2020, this represents 2.9 percent of all privately held agricultural land and 1.7 percent of all land in the United States. While investors from Canada, Germany, and the United Kingdom are regularly among the top foreign investors, investors from countries such as China and Saudi Arabia have increased their investment in U.S. agricultural land. One of the largest groups of foreign investors is renewable energy companies, causing some to raise concerns that farmland will be further removed from production.

D. The U.S. Agricultural System is Importing more than it Exports

The Western U.S. is a critical part of what has long been a proud national agricultural powerhouse, where our country consistently has run an agricultural trade surplus. But in 2019, for the first time in more than 50 years, the U.S. agriculture system ran an agricultural trade deficit, importing more than it exported. The USDA forecasts the U.S. will again run a deficit in 2023 for the third time since 2019. This growing deficit is driven primarily by our dependence on imported Mexican fruits and vegetables (*Politico Pro DataPoint).* Increased reliance on foreign food has never been a policy our Nation has intentionally embraced in the past.

A bipartisan group of lawmakers from Florida in September 2022 asked the US trade agency to investigate what they called a "flood" of fruit and vegetable imports from Mexico, saying it poses a direct threat to the state's agricultural industry. Republican Senators Marco Rubio and Rick Scott, together with more than 20 representatives, filed a petition to open an investigation using the same law that former President Donald Trump used to impose tariffs on billions of dollars of imports from China (Bloomberg, September 2022). The Biden Administration responded by saying it would set up an advisory panel to suggest how to help produce farmers in the southeastern US but did not act on the request to launch a formal trade investigation into Mexican imports. (*Bloomberg*, October 2022).

E. The Western Drought Has Led to Widespread Farmland Fallowing

The U.S. is facing yet another record-breaking drought year in the West. Farmers and ranchers in some of these areas received little to no water from federal water projects this past summer. Major reservoirs in California and along the Colorado River and Rio Grande have reached or are approaching historic lows. The government has also regulatorily withheld water from producers in places like the Central Valley of California, Central Oregon and the Klamath Basin. Our farmers that are largely responsible for keeping the nation's produce aisles stocked are being forced to leave fields fallow or reduce livestock herds.

A research team from the University of California (U.C.) Merced studying the California drought found conditions between 2020-2022 to be warmer than previous dry periods. Heat waves and stress led to large crop losses. Their drought assessment revealed a 2022 water shortage in the Central Valley of 2.6 million acre-feet, which resulted in 695,000 idle acres of farmland, with more acreage impacted. The ravaging drought has left hundreds of thousands of acres of Sacramento Valley farmland unplanted this year, causing dramatic harm to people, fish, waterfowl, shorebirds, and other wildlife. Researchers at U.C. Davis published a report entitled ''Continued Drought in 2022 Ravages California's Sacramento Valley Economy", which projected that the 2022 drought impacts on farm production are likely to cause a loss of about 14,300 jobs and about $1.315 billion in economic value added in the Sacramento Valley.

Central Arizona Project (CAP) irrigators - due to operating guidelines on the Colorado River - expect that about 100,000 acres of farmland will be fallowed in 2023. Most of these lands (approximately 40,000 acres) currently produce cotton, but a significant portion – roughly 20,000 acres, according to CAP producers - will be alfalfa fields.

Undoubtedly, the Western drought has reduced the amount of water for many users, including irrigated agriculture. However, in places like California and Oregon, much of the water that once flowed to farms and ranches is currently being re-directed by the federal government for environmental purposes. In other words, federal water policy is shutting down water availability for hundreds of thousands of acres of productive farmland.

At a time when the future of Ukraine and other countries' ability to help feed the outside world is at risk, our ability to increase productivity is being further curtailed – due in part, to our own government.

THE DEMONIZATION OF ALFALFA AND WESTERN IRRIGATED AGRICULTURE

Water developed for Western irrigated agriculture is often eyed by other competing water demand sectors as the default "reservoir" to meet other needs, such as sustaining urban growth. Alfalfa is a favorite target of some in academia, journalists, critics of irrigated agriculture like anti-animal agriculture extremists, and Western cities, who use varying levels of sophistication to justify their criticisms of growing a forage crop in the West, particularly in times of drought.

For example, the journal "Nature Sustainability" published an article in 2020 titled, "Water scarcity and fish imperilment driven by beef production", which concluded that long-term water security and river ecosystem health "will ultimately require Americans to consume less beef that depends on irrigated feed crops". This article was led by Brian Richter (the president of Sustainable Waters, a global organization focused on water scarcity challenges) and Dominique Bartak with Water Asset Management (whose investment team uses private, institutional capital to target water scarce regions and promote "regenerative farmland" in the U.S. Southwest), with a cohort of academic support.

A. Colorado River Crisis Puts Forage Crops in the Crosshairs of Critics

The critical focus on alfalfa has intensified in the wake of U.S. Bureau of Reclamation (Reclamation) Commissioner Camille Touton's June 14, 2022 appearance before a Senate committee, where she called on water users across the Colorado River Basin to take actions to prevent Lake Powell and Lake Mead from falling to critically low elevations that would threaten water deliveries and power production.

When the states failed to meet the mid-August deadline set by Commissioner Touton for them to propose 15% to 30% cuts to their water use, critics of irrigated agriculture ramped up their focus on the perceived easy "fix" to the complicated challenges facing the Colorado River: stop growing crops that use lots of water….like alfalfa.

The "shot across the bow" against alfalfa production was fired by the witness who testified immediately after Commissioner Touton at the June 14th Senate hearing. The general manager of the Southern Nevada Water Authority (SNWA), whose member agencies serve more than 2.2 million residents in Southern Nevada, summarized the impressive urban efforts to reduce per-capita water use and further suggested that farmers reconsider growing crops like alfalfa. The solution, he said, is working toward "a degree of demand management previously considered unattainable."

He also noted that SNWA is planning to serve a population that will swell to 3.8 million by 2072.

In August, SNWA followed up with a strongly worded letter to the Biden administration, demanding action on several fronts, including creating "beneficial use criteria for Lower Basin water users, eliminating wasteful and antiquated water use practices and uses of water no longer appropriate for this Basin's limited resources".

In the following weeks, a steady stream of media coverage, including a 1,600-word essay in *High Country News,* have carried a similar message: Growing less hay is the only way to keep the Colorado River's water system from collapsing.

Some in academic circles and the media like to play the role of social engineer and suggest that alfalfa production be abandoned in favor of "higher value" crops, or ones that use less water. Simplistic examinations of alfalfa in terms of water demand vs. supply must be enhanced and balanced with discussion of productivity, economic return, food production, and the environment to be truly productive. A former Imperial Irrigation District (IID) board member once said that the definition of a low-value crop is one that's grown with the water someone else wants.

B. "Exporting water" to Asia via Alfalfa Sales

In recent years, some journalists have also advanced the message that the field crops grown in California's Imperial Valley are exported to Asia, implying that precious water is being shipped overseas through these crops to foreign countries. This issue is also one that is more complicated than it might initially appear to be.

According to Jay Lund of the University of California at Davis Center for Watershed Sciences, the concept of virtual water is misleading in the overall discussion of global trade and the water needed to support economic activities throughout the world. "Talk of virtual water distracts from serious discussion of economic, environmental and hydrological objectives and processes important for real water and environmental systems to function," said Dr. Lund. "Virtual water discussions are all the more counterproductive coming in the midst of a very real and serious drought."

Still – alfalfa producers continue to be subjected to public criticism in media outlets.

"$880 million – the value of hay shipped overseas last year from Colorado River Basin states, most of which went to China, Japan and Saudi Arabia," the *High Country News* opinion piece recently claimed.

The National Geographic reported in 2012 that 12% of Colorado River Basin hay is exported, which implies that 88% of Basin hay was sold for domestic use, for a jaw-dropping $2.147 billion. In the Imperial Valley, that value can be higher; generally, between 20% - 30% of the hay that is produced there is exported to other countries. The remaining 70% - 80% of the hay that's grown in the Imperial Valley is for domestic use for dairies and livestock all over the United States, especially in California.

Recent state level hay export data is made available from USDA Foreign Agricultural Service (FAS)[3]. This data indicates that Colorado, New Mexico and Wyoming are not significant exporters

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[3] It is important to note that the FAS state-level export data is fraught with asterisks. This is because sales of commodities to and from international trade partners are recorded at the national border, so the exact amount of a product produced by a State and then exported is difficult to track with absolute accuracy. Although a State's actual

of hay. Export values for the first six months of 2022 are up for the U.S. at large (up 11%), as well as the states of California (up 11%) and Arizona (up 41%). This is the result of higher per unit prices – export volumes are down 1% for both the U.S. at large and California. Export values for the first six months of 2022 are down in both value and volume for Utah (-44% and -50%, respectively) and Nevada (-46% and -52%, respectively).

It should be noted that exports occur less from inland regions – like Colorado, Idaho, Utah and Wyoming – because of the proximity of states like Arizona, California and Nevada to outbound ports.

There are certainly other products made in the Colorado River states that are exported to other countries. America's five biggest export products by value in 2021 were refined petroleum oils, crude oil, petroleum gases, cars and electronic integrated circuits. Taiwan Semiconductor Manufacturing Company (TSMC), headquartered in Taiwan and which makes chips for Apple Inc. and other customers, announced plans last year to invest $3.5 billion in its second U.S. manufacturing site in the Phoenix, Arizona area. Intel Corp., the only major U.S. producer of microchips, announced plans in March 2021 to build two chip factories in Arizona at a cost of $20 billion. The company has had another facility in Arizona since 1980. U.S. semiconductor manufacturing has long been established in Arizona, and the state has more than 200 production facilities in addition to Intel and the new TSMC plant.

It takes a lot of water to run a plant that manufactures electronic integrated circuits. Roughly 10 gallons of water are needed to make a single computer chip. That may not sound like much, but multiply it by the millions of chips made each year, and the result is a large and rapidly growing demand for water. It's difficult to determine exactly how much Colorado River water is going to support chip manufacturing in the Southwest, but the volume is not insignificant.

What is disturbing is that no one seems to be decrying the "export" of Colorado River water to other countries via these products. Regardless of whether cars, computer chips, or alfalfa is sold to another country, water is required to produce all of them. The economic benefits associated with the production of these items is enormously important to the American workers who create them. It also matters to their communities, which benefit from the economic "ripple effect" of these production activities.

POLITICAL REALITY CHECK?

Unfortunately – until very recently - few in the media have taken the time to inform their readers on the consequences of drought and downsizing Western agriculture—namely water shortages, devastation to rural communities and lifestyles, food insecurity and higher prices at the supermarket.

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agricultural export value cannot be measured directly, USDA's Economic Research Service estimates State exports of total and selected commodities based on U.S. farm cash receipts data. State shares of U.S. farm receipts are updated annually in calculating State-level international export values. This means that sometimes a state may be assigned exports based on their production that may not have actually come from their state. The moral of the story - perhaps - is that USDA data doesn't always give us a perfect picture and so everyone needs to be careful when they talk about it.

Ironically, perhaps it's because Western irrigated agriculture has been so adaptive and successful at providing plentiful, safe and affordable food that it is now jeopardized. Most policy makers and media pundits believed there could never be a problem with food production in this country. The last Americans to experience real food shortages were members of the so-called Greatest Generation and their parents. For the most part, they have left us, taking with them the memories of empty supermarket shelves and Victory Gardens.

When the issue has never been personalized, it's easy to be complacent. However, that may soon change, and it already has for millions of people living in other countries.

The grim global conditions we once expected to encounter in 2050 may now hit us a decade or more ahead of schedule. It would seem logical that a top global priority should be ensuring the ability of world food producers – especially those in the American West - to meet the future food demands of the U.S. and the world. While the state of the economy remains the top concern of 38% of American voters (with inflation and the cost of living the #1 concern), few of our political leaders and most in the media are not connecting the dots between these concerns and our own government's policies that are directing water away from some of the world's best producers.

The Biden administration in September 2022 hosted a hunger conference and released a 44-page report outlining a national strategy to improve food access and affordability, integrate nutrition and health, and empower consumers to make healthy food choices. Unfortunately, the strategy ignored the deeper issues of rising food costs, global hunger, and the role of American producers in tackling these challenges. The only mention of "inflation" was in reference to the "Inflation Reduction Act" recently signed into law by President Biden. No mention was made of the Western drought and its impacts on agriculture. There was no discussion as to why water that was originally developed to support farming and ranching in parts of California and Oregon has been redirected to questionable environmental needs, in the midst of unprecedented drought.

Current world events are leading more Americans to reconsider their priorities and ponder just how safe and stable we really are. Political reality is starting to set in, as average Americans – already battling increased inflation, higher gas prices, and soaring food costs – are resetting their priorities on issues that likely have a much more substantive impact on their daily lives….like safe, affordable food.

Fallowing U.S. farmland means increased reliance on food production in other countries with lesser production standards. A clear sentiment of the urban public is locally sourced foods. Fallowing any land during a time of crisis should be temporary, or we risk losing control of our reliable and safe U.S.-grown food supply. The expulsion of Sri Lanka's president from his country in July and the downfall of Britain's prime minister in October should, as the *New York Times* recently reported, "serve as a warning to all of the political peril that awaits those who fail to address the erosion of living standards, no matter the cause".

WESTERN DROUGHT POLICY CONSIDERATIONS

Americans are facing rising food costs and the potential for global famine looms on the horizon. The recent national infant formula shortage has further underscored the importance of a strong national domestic food supply system. Meanwhile, our own government has regulatorily withheld water from producers in places like the Central Valley of California, Central Oregon and the Klamath Basin. Many producers in the Southwestern U.S. are bracing for yet another year of severe drought and unprecedented water shortages.

The Western drought continues with no real federal policy action other than to limit irrigation supplies to farmers and residents. We need to prepare for future droughts, and not simply react to current hydrologic shortages. In the Rio Grande Basin, New Mexico's Elephant Butte Reservoir was only 7.1% full at the beginning of this month. Major reservoirs in California and along the Colorado River have reached or are approaching historic lows, threatening the ability to generate hydropower, particularly at Lake Powell, behind Glen Canyon Dam. Our farmers and ranchers that are largely responsible for keeping the nation's grocery store aisles stocked are being forced to leave fields fallow or reduce livestock herds.

There are things that the federal government can do to alleviate this disaster and better prepare and manage for future droughts. Federal investments in improving and building new water supply infrastructure – partnering with the Western states and non-federal water users – can help prevent or reduce the impacts of future droughts. Moving away from flow-based single species management to collaborative watershed-based approaches that respect all uses will help prepare Western water stakeholders for a more predictable and secure future. We need to act, and act now, to accomplish these tasks.

Western irrigated agriculture has been dealing with changes in climate and hydrology for over a century. But the prognosis for water supplies in the future is not positive and will continue to negatively impact this important source of our Nation's food supply, the economic engine for most of our rural Western communities. Coupled with the growing demand for existing water supplies from burgeoning cities and the environment, irrigated agriculture is fast becoming a target for one thing – water. We must look to several solutions in order to maintain food security for the nation and economic wellbeing of the Western landscape:

- Invest in Western water infrastructure – new water storage and improved conveyance facilities, groundwater recharge, water conservation, water management improvements, water reuse and desalination can all help alleviate the stress on our existing water supplies, especially for agriculture in the growing West;
- Invest in technology – we must manage our water supplies better through more efficient and effective use of technology to improve the modeling and predicting of weather patterns, snowpack, and runoff forecasting, as well as using technology to manage our water storage and distribution to improve efficiencies in utilizing our precious water resources; and,
- Improve regulatory processes at the federal level to expedite permitting and get these new water projects to construction within a reasonable period of time at a reasonable cost, as well as create collaborative partnerships between federal, state and local entities interested in finding solutions to our water-climate problems through adaptive strategies that can work on the ground.

Perhaps the only silver lining is that this unprecedented drought crisis will hopefully draw public and political attention to Western agriculture's critical role in providing a safe and reliable food supply, boosting the national economy, and continuing the country's stature as the world's premier food basket. Certainly, the drought helped drive Congressional action in the past year, where the Infrastructure Investment and Jobs Act signed into law in November 2021 by President Biden included $8.3 billion for Western water infrastructure. The Inflation Reduction Act signed into law this year included another $4 billion to address the Western drought, with priority placed on Colorado River challenges.

We can only hope that further political attention leads to necessary, reasonable policies that support farmers and investment in rural communities, including water infrastructure and increased water-storage capacity. The Family Farm Alliance and other Western agriculture and water organizations believe the drought underscores the urgent need to take immediate action to help better manage impacts to water resources from drought in the West.

COLORADO RIVER BASIN WATER MANAGEMENT POLICY CONSIDERATIONS

In the Colorado River Basin, there are many tiers of control. The Upper Basin includes the states of Wyoming, Colorado, Utah and New Mexico. The Lower Basin incorporates Arizona, California and Nevada. The Basin states work within the "Law of the River" to address their water supply issues, with the Lower Basin managed by a federal Watermaster (the Secretary of the Interior through Reclamation), separate from the Upper Basin, where that responsibility falls on the Upper Colorado River Commission. Additionally, every Basin state has its own unique water rights system based on the prior appropriation doctrine.

Reclamation obviously has a critical role to play throughout the Basin, and it will continue to play that role well, in a manner that will not preempt the states' roles.

The Family Farm Alliance over the past year has helped organize a group of Basin agricultural water users from the headwaters to the Mexican border to come together to present key principles and expectations that are critical to sustainable and durable operation of the Colorado River (River) into the future. These parties include Central Arizona Project agricultural interests, Colorado River District, Dolores Water Conservancy District, Imperial Irrigation District, Little Snake River Conservancy District, Palo Verde Irrigation District, Welton-Mohawk Irrigation & Drainage District, Yuma County Agriculture Water Coalition, and Yuma County Water Users Association, among others.

We believe this group can play a major role as the seven Colorado River Basin States and Basin stakeholders engage to replace the 2007 Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead. These 20-year Interim Guidelines are set to expire at the end of 2026.

The challenges and associated solutions facing the River are complex and nuanced. However, the unified message of Basin agriculture is simple: Agricultural production in the Basin is an irreplaceable national resource that is vital to U.S. food security, the ecosystem, and overall drought resilience. It must be protected by ensuring water remains on-farm.

Last March, the Family Farm Alliance board of directors adopted a policy document that articulates these key principles. This is essentially a summary of a policy update to a Colorado River white paper developed by the Family Farm Alliance in 2015. Later in the year, many of the organizations listed above also took formal action in support of these principles. These agricultural water purveyors believe that Colorado River Compact decision-makers must update the new operating guidelines to incorporate the following principles:

1. Recognize that Western irrigated agriculture is a strategic and irreplaceable national resource.
2. Provide certainty to all users and interests with Compact equitable apportionment decisions made from a foundation of common sense and fairness.
3. Address critical data gaps to facilitate the trust needed to make fair operational and legal decisions related to the next set of Interim Guidelines.
4. Manage Lake Mead to provide the Lower Basin's share of the Colorado River Compact water to Lower Basin users. Manage Lake Powell to meet both the Colorado Compact obligations to the Lower Basin and protect the Upper Colorado River Compact entitlement of the four Upper Basin states.
5. Expand water supply augmentation opportunities as options for meeting growing water demands, at a time when River supplies appear to be diminishing.
6. Emphasize that future urban growth cannot be encouraged without locking in sustainable and diverse water supplies.
7. Recognize and address the impacts of drought and Colorado River management on Federal hydropower, its customers and related programs, and the resiliency of the power grid.
8. Include substantive measures to minimize and mitigate any anticipated negative economic, environmental and cultural impacts to rural communities due to reduced irrigated agriculture and more efficient irrigation practices.

These expectations will require visionary leadership and a firm commitment to a balanced, workable policy. Collaborative opportunities do exist, and if we are prepared to seize them, conflict will be reduced and certainty for all water uses increased.

The myriad of diverse Colorado River Basin interests can and will successfully work through future droughts and water shortages in a collaborative and effective way. The future of millions of people in urban areas, millions of acres of farms and ranches and the food and fiber they produce, and the many rural communities that dot the landscape in the Basin rest on this belief.

Solutions can be found that do not pit urban and agricultural users against each other. Once those solutions are identified, these competing users can resolve any differences and develop collaborative solutions to the Basin's complex water problems.

ALFALFA PRODUCTION AS A WATER MANAGEMENT TOOL

Alfalfa production forms the foundation of rural agriculture in many Western rural communities. Alfalfa is not only a food source for livestock, it also has important environmental and soil health attributes. The attributes of alfalfa are further detailed in "Alfalfa 101 – The Importance of Alfalfa

Production in the American West", a 2022 white paper co-authored by the Family Farm Alliance and the California Farm Water Coalition.

Alfalfa fields use between 30 inches (2.5 acre-feet) and 80 inches (6.7 acre-feet) of water per year depending upon climate, soil type and topography. The wide range of alfalfa's reported consumptive use of water is due in part to the number of cuttings (harvest operations) that a single field of alfalfa can generate in a year. In many parts of the West, alfalfa producers are lucky to generate six cuttings per year. In the Intermountain West, only three to four cuttings are made per year due to the cooler weather and shorter growing season. However, in the agricultural areas of California's Imperial Valley and around Yuma, Arizona - where the weather permits year-round agricultural production - farmers can get 9-10 cuttings per year.

The tremendous yield in these areas as compared to national alfalfa yield is reflected in Table 1.

TABLE 1: Alfalfa Hay Yield for Colorado River Basin States

	Average Alfalfa Hay Yield (Tons / Acre)						
	2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
ARIZONA	8.6	8.4	8.3	8.3	8.5	8.3	8.2
CALIFORNIA	7	6.8	6.9	7.1	7.2	7.4	7.1
NEVADA	4.4	4.3	4.7	4.9	4.4	5.1	4.9
Lower CO River Basin*	6.9	6.7	6.9	7.0	7.0	7.2	7.0
COLORADO	3.5	3.7	3.4	3.7	3.4	4	2.9
NEW MEXICO	4.6	5	4.7	4.9	5.3	5	5.3
UTAH	4.2	4.2	3.7	4.3	3.8	3.7	4
WYOMING	2.7	2.8	2.7	2.7	3.1	2.8	3.2
Upper CO River Basin*	3.6	3.7	3.4	3.6	3.5	3.7	3.4
Colorado River Basin*	4.9	4.8	4.6	4.8	4.6	4.9	4.7
National Average	3.4	3.3	3.2	3.3	3.3	3.2	3.2

% of National Average

Lower CO River	202%	205%	216%	212%	215%	222%	222%
Upper CO River	104%	113%	106%	111%	108%	114%	109%

*- Calculated from Production/Acreage NASS Data

In 2022, Arizona's and California's average per acre yield on alfalfa hay & haylage was 8.2 tons/acre and 7.1 tons per acre, respectively, compared to the national average of 3.2 tons/acre, which is extremely consistent with the national tonnage per acre median for the preceding 13-year time frame.

Importantly, alfalfa has a variety of roles to play in a water-uncertain future due to its high flexibility during times of both insufficient and excess water. Eliminating its production doesn't have to be one of them.

Putnam et al. explain this in detail in a paper that was included in the proceedings of the 2021 Western Alfalfa & Forage Symposium, parts of which are reiterated here.

Alfalfa has several important biological features that make it an important component to consider as farmers adjust to a water uncertain future. Its deep roots can tap into residual moisture. Those roots can survive summer dry-downs and regrow when re-watered. Farmers in California's San Joaquin Valley have implemented summer dry-down as a practice to temporarily free up water supplies for other crops in the region. By temporarily ceasing to irrigate alfalfa, that water can be used by other farmers when it is needed most during water short years.

Because it is harvested in several cuttings, alfalfa can provide partial economic yields when irrigation ceases. Alfalfa fields can also be flooded in winter to recharge aquifers.

Buildup of soil salinity is an unwanted consequence of drought. Contrary to some published accounts, alfalfa is actually highly tolerant of salinity. This would enable alfalfa to be grown utilizing degraded water, such as treated municipal wastewater, drainage water, and the like, which provides another avenue to extend water supplies.

Alfalfa has proved to be highly flexible and resilient in surviving droughts while sustaining productivity, even when as little as half the water requirement is applied. Deficit irrigation is the application of water below full crop evapotranspiration requirements during stress-tolerant growth stages. The practice has been shown to conserve water while maintaining yield in several crops grown in the Colorado River Basin, including alfalfa (Cohen *et al.* 2013). It is one of the most cost-effective and most easily applied methods available, yet remains counter-intuitive to many, including some farmers. Perhaps the critics of alfalfa farming would consider assisting with developing policy that educates both decision makers and farmers and incentivizes the practice, which could reduce future water demand.

Under highly variable water supplies, alfalfa cropping systems offer tremendous flexibility due to its ability to be deficit irrigated and recover from droughts to yield normally. Alfalfa should be considered an important element of future irrigated cropping systems designed for highly variable water supplies in the Colorado River and elsewhere in the West.

CONCLUSION

Finding solutions to complex problems, like the Colorado River's dwindling supplies, requires working together, not divisive attacks. Fallowing productive farmland should be a last resort when it comes to America's food supply.

The problem is, there isn't enough water in the Colorado River to meet its current demands, thanks to the ongoing drought in the Western United States and uncontrolled growth of urban areas. The situation is bad enough that Reclamation is seeking 2 million to 4 million acre-feet of water reductions and additional conservation by users in the river's seven basin states. That is a significant amount and will put a strain on everyone, but we can make it less painful by working together.

Growers across the West are stepping up, at their own expense, to provide solutions for the viability of their basins and the communities those basins serve. In many cases, that means senior water rights holders are voluntarily making water supplies available to junior water users, preventing cuts otherwise required. There are other collaborative efforts underway to fund on-farm conservation projects that are helping reduce demand. Urban, agricultural, and environmental water users would all benefit from such efforts in the short and long term.

What is not helping is the relentless finger-pointing by non-agricultural water agencies and critics of agriculture, saying that farmers aren't doing enough. Critics of irrigated agriculture continue to shame farmers for growing crops, such as alfalfa, saying they should fallow their fields or switch to crops that use less water, which fixes nothing.

Farmers only grow crops that other people buy. Current vegetable and value-added farm products are subject to the same supply and demand of American manufacturers. Planting a crop simply because it uses less water ends up being a complete loss for the farmer and society if nobody is willing to buy it.

The Western agricultural system was built on local supply of feed and food. Shifting alfalfa production to other states adds additional food miles, greenhouse gas emissions from transportation, and ultimately higher costs and/or emptier shelves at the grocery store. Locally grown food for humans, dairy and animal proteins results in lower costs to producers and consumers.

Worse is the impact on communities that depend on agriculture for their economic well-being. California's Imperial Valley has no suitable groundwater or alternative water supply other than the Colorado River. With the largest irrigated district in the United States, it is an agricultural region that doesn't have an economic base that can absorb additional unemployment, business closures, and the loss of tax revenue that come with fallowing. Agricultural regions, such as the central valleys of California and Arizona, are facing a future of dwindling and unsustainable groundwater supplies as they look to replace potential shortages from sources like the Colorado River. Entire communities are at risk of closing, bankrupting their populations.

IID General Manager Enrique Martinez said it best in a recent interview with the *Desert Sun*: "You've got to . . . keep listening to the farmers, because ultimately, you don't want to get to the point of creating a food crisis to solve a water crisis."

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OPPORTUNITIES FOR EXTRACTION OF PROTEIN FROM ALFALFA

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ABSTRACT

There is a growing demand for protein due to increased population and affluent countries demanding protein rich foods. The majority of plant-based proteins on the market are storage proteins extracted from seeds. These types of proteins are stable prior to extraction and easily extracted with current technologies. However, the most abundant type of plant-based protein resides in plant leaves and stems as the functional protein RuBisCo. When this and other functional proteins are extracted and condensed, they form leaf protein concentrate (LPC). Current methods of LPC extraction include either pulping or juicing the material to release the proteins and then either coagulation, acidification, fermentation, or ultrafiltration to concentrate the soluble proteins. Recovered LPC yields in alfalfa range from 15 to 43% of the original amount of protein found in the plant. These yields are higher than other leafy plants making alfalfa a prime candidate for cultivation for LPC. Unfortunately, alfalfa contains high levels of endogenous proteases which could impact the LPC recovery rates. Proteases breakdown proteins into small subgroups that change protein solubility and the ability to be filtered at a specific size. Our lab is testing how harvest management changes protein size and extraction yields. Three commercial varieties were harvested then either immediately dried, immediately juiced, or air dried after cutting. Crude protein extractions were visualized on an acrylamide gel compared with a molecular weight marker standard. The juiced samples had the highest concentration of bands approximately 55 kda in size, supporting previous studies that indication most of the proteins within alfalfa leaf tissue are RuBisCo; its subunits are approximately 55 kda in size. Immediately dried alfalfa had protein bands at 55kda and smaller with some protein smearing. While aired dried samples showed no protein bands, with extensive protein smearing, suggesting that little or no proteins remained intact. To further investigate harvest impacts on protein stability we tested seven different harvest including freeze drying and spray drying alfalfa for protein extraction. Our experiments conclude that the harvest method of alfalfa for protein is important for the overall extraction yield.

Key Words: Leaf protein, RuBisCo, harvest management

POTENTIAL OF LEAF PROTIENS FOR FOOD VS FEED

The increase in the human population and affluent countries demand protein rich foods has caused a renewed interest in alternative protein sources. The focus in plant-based proteins has occurred due to the comparatively lower carbon footprint than animal-based proteins. Most plant-based proteins on the market are from storage proteins extracted from seeds. These types of proteins are stable prior to extraction and are easily extracted with current technologies.

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In: Proceedings, 2022 World Alfalfa Congress, San Diego, CA, November 14–17. UC Cooperative Extension, Plant Sciences Department, University of California, Davis, CA 95616. (See http://alfalfa.ucdavis.edu for this and other alfalfa conference Proceedings.)

However, the most abundant type of plant-based protein resides in plant leaves and stems as the functional protein known as RuBisCo. When this and other functional proteins are extracted and condensed, they form leaf protein concentrate (LPC).

Utilizing LPC as a protein source is not new. During World War II there was a push to extract leaf protein to address food shortages. Money and time were invested into research to extract usable protein from leaves of various crops. A pilot refinery using the Pro-Xan II method of extraction was even built in California to extract and process alfalfa protein in the 1970's. Today many countries have pilot, demo, and industrial scale biorefineries that process leaf tissue to extract proteins that are utilized for the animal feed industry (Fiorentini & Galoppini, 1981).

However, LPC has not made it into the mainstream plant-based protein food markets for various reasons. Originally the plant-protein market was small and technologies for extracting proteins from seeds like soy surpassed the leaf extraction technology. The gap was further widened due to the cost benefit ratio of the inputs and low LPC extraction yields compared to seeds. Current methods of LPC extraction include either pulping or juicing the material to release the proteins and then either coagulation, acidification, fermentation, or ultrafiltration to concentrate the soluble proteins. Recovered LPC yields range from 15 to 43% of the original amount of protein found in the species of plant. The remaining insoluble proteins can be recovered and utilized in the feed market.

Alfalfa has the highest yields than other leafy plants ranging from 20 – 43% making it a prime candidate for LPC cultivation. The amino acid profile of alfalfa is similar to soy and meet the FOA requirements for a complete protein. Additionally, the functionality characteristics of alfalfa LPC is similar to egg whites with no adverse flavors (Knuckles & Koler, 1982). Unfortunately, there are numerous challenges that need to be addressed before alfalfa LPC can become a mainstream protein source.

A MAJOR CHALLENGE TO ALFALFA PROTEIN

The one of the major challenges with marketing alfalfa LPC is the variability in protein yield. Alfalfa contains high levels of endogenous proteases which could impact the LPC recovery rates. Proteases breakdown proteins into small subgroups that change protein solubility and the ability to be filtered at a specific size. They proteases are active across a wide range of pH's suggesting there are pH specific classes of proteases within alfalfa (Scalet et al. 1984). Our lab began investigating protein extraction, by comparing juiced alfalfa with hayed alfalfa. While the crude protein levels measured by NIR were the same, crude protein extractions visualized on an acrylamide gel compared with a molecular weight marker were not. Field dried hay samples showed no protein bands, but had smearing, suggesting that no intact proteins remain. Juiced alfalfa had protein bands at 55kda and smaller with some smearing at less than 3 kda. RuBisCo subunits are approximately 55 kda. We additionally tested immediately dried alfalfa at 140°F for three days. Those samples also showed clear bands at 55 kda. To determine if there was a possible genetic component to the degradation of the proteins, we tested three modern cultivars. All cultivars responded the same to post harvest treatments of juicing, air and field drying. The break down in protein during harvest is not a problem for ruminants as they can still utilize the amino acids to create microbial proteins. Monogastrics, however, require some intact proteins for digestion to maintain nitrogen use efficiency and balance within the gut (Eugenio et al, 2022).

Protein yields were still low and variable when the material was moved to the concentration step. All commonly used methods of concentrating soluble proteins require the proteins to be incubated in water sometime during the process (Hadidi et al 2019). Dried crude protein alfalfa samples that showed strong bands previously were exhibiting degraded protein smears after concentration steps. We hypothesized that reconstituting alfalfa in water reactivated the proteases at both high and low pH. We found the longer the sample was incubated in aqueous solution the more protein was degraded irrespective of pH. Inhibiting degradation during concentration is important to maintaining protein yield.

Finding ways to maintain alfalfa LCP structure and size before emulsification is also a challenge. While heating of the sample aggregated and stabilized the protein, it did not improve the solubility of the protein and therefore, preventing the protein from being used in any clear liquid final product. Stability and consistency of the protein needs to be investigated along with the development of end products. Solubility of the protein might not matter if the end product requires a curd instead of the solubilized form of protein.

Our lab continues to evaluate how harvest management changes protein size and extraction yields with additional types of methods to prevent protease degradation during protein concentration.

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CLIMATE CHANGE AND FORAGE PRODUCTION

C. Alan Rotz[1]

ABSTRACT

Historical records show that average annual temperatures are increasing in most parts of the world along with changes in precipitation patterns. These changes are affecting the production of alfalfa and other forage crops in many regions. Climate changes are primarily driven by increasing carbon dioxide concentrations in the atmosphere due to the burning of fossil fuels. Models that predict future climate trends indicate that ambient temperatures will continue to increase. Precipitation may also change with the general trend of wetter regions getting more rain and dry regions getting less. Increased carbon dioxide levels in the atmosphere can stimulate the growth of many crops including alfalfa. This increase along with other climate changes are predicted to increase alfalfa yields from 10 to 30% in most regions if adequate water is available to maintain that production. Management changes such as earlier harvests and additional cuttings will be needed to adapt to the changing climate. The greatest threat to long-term sustainability of alfalfa production is the availability of water, particularly in dry regions where production is dependent upon irrigation. Other challenges of changing climate may include increased weed and insect pressure. Although the future offers challenges, with proper adaptation, alfalfa can remain and perhaps improve as a sustainable crop for current and future generations.

Key Words: Alfalfa, climate, greenhouse gas

INTRODUCTION

Climate change has become a sensitive political issue. The media has contributed to the polarization on this issue by sensationalizing both sides of the issue. We know much about the science surrounding climate change, but real science is often ignored by both those promoting and denying the issue. Let's set aside preconceived opinions and look at the scientific evidence and potential effects on forage production. We will look at historical changes that have occurred in the recent and distant past. We will also look at what is likely to occur in the future and how that may affect forage production. By preparing for the future, steps can be taken to adapt to the change providing a productive and sustainable future for alfalfa and other forage crops.

HOW IS OUR CLIMATE CHANGING?

Climate changes are slow and difficult to observe over time. Weather varies considerably from day to day and year to year, masking the change that is occurring. Only through long-term measurements can we quantify changes in temperature and precipitation. Temperature measurements across the United States (U.S.) since 1991 have documented a 1-2°F increase in average annual temperature in the west with little change in the southeast (Melillo et al., 2014). Measures of global temperature have shown about a 1°F increase over this 30-year period and

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In: Proceedings, 2022 World Alfalfa Congress, San Diego, CA, 14-17 November, 2022. UC Cooperative Extension, Plant Sciences Department, University of California, Davis, CA 95616. (see http://alfalfa.ucdavis.edu for this and other alfalfa conference proceedings.)

almost a 2°F increase since 1900. This may not seem like much change, but this is a substantial change over this relatively short period.

Precipitation patterns are also changing, but the magnitude and direction of change varies greatly among locations within the U.S. and throughout the world. In general, drier regions are getting drier and wetter regions are getting wetter. Within the western U.S., there has been little change in annual precipitation since 1991 (Melillo et al., 2014). Some local regions have seen 10-15% increases while others have seen 10-15% decreases. The driest region is Arizona where much of the state has seen 10-20% decreases in long-term annual precipitation. Much of the Midwest and Northeast have experienced 10-20% increases in precipitation. This change has occurred primarily through more intense storms. Extreme rainfall events have increased by about 40% in the Northern U.S. with little change in the southwestern states (Melillo et al., 2014).

One of the challenges in the western states is a decrease in winter snowpack in the mountains. With increasing temperature and changes in precipitation, less snow is accumulating and thus less is available through summer snowmelt (Melillo et al., 2014). This is of particular concern for those that rely on this water source for irrigation of crops.

These changes are well documented, but the cause is often questioned. Scientific evidence strongly supports that the cause is increasing carbon dioxide (CO_2) concentrations in the atmosphere. Measurements have documented about a 30% increase in this concentration since 1960 (Melillo et al., 2014). Measurements made through ice bores in the Antarctic indicate that current levels far exceed anything that has occurred throughout human history and beyond. There is a high correlation between global temperature and atmospheric CO_2 concentration.

Carbon dioxide and some other gases in the atmosphere, including methane, trap heat radiated from the sun. This is a good thing, because without this heat-trapping blanket around our planet, temperatures would be too cold for us to survive. The problem is that these increasing gas concentrations are thickening the blanket and causing temperature rise. The primary cause is the release of CO_2 through the burning of fossil fuels. For each gallon of fuel consumed, about 20 pounds of CO_2 are created and emitted to the atmosphere. This is taking carbon that has been stored in the earth for many years and adding new CO_2 to the atmosphere much more rapidly than it can be absorbed in vegetation, soil, and ocean water.

Methane from cattle also receives blame for global warming. Cattle produce a lot of methane (with more warming potential than CO_2), but this is part of a natural cycle. Methane from cattle oxidizes in the atmosphere transforming that carbon back to CO_2. Since that carbon originally came from CO_2 in the atmosphere through fixation by feed crops, this completes a natural cycle. Methane emission from cattle has a short-term impact but does not create a long-term accumulation in the atmosphere such as we are experiencing from the CO_2 created through fossil fuel combustion.

HOW WILL CLIMATE CHANGE AFFECT FORAGE PRODUCERS?

To look into the future, we must rely on models. Many global climate models have been developed throughout the world. These models use mathematics to represent the complex physical, biological, and chemical relationships and interactions between the land, ocean and atmospheric processes that drive our weather and climate. As these models develop, they become more sophisticated and accurate in their predictions.

We have selected nine of these models to study future climate and daily weather patterns for regions of the U.S. throughout the rest of this century (Rotz et al., 2016). Similar climate data were not available for locations for other countries, but these U.S. data can illustrate the anticipated effects for other parts of the world. A worst-case scenario was modeled, where the international consumption of fossil fuels continues at its current rate. Predicted weather data were summarized for recent (1996-2015), mid-century (2040-2059) and late-century (2081-2100) periods. The mean and variation among models were considered.

Figure 1 shows predicted seasonal temperatures for dry regions in the western U.S. to more humid regions in the east. Similar increases in temperature are predicted throughout the year. Based upon the current rate of greenhouse gas emissions, average annual temperatures are predicted to increase by 3 to 4°F by mid-century and 8 to 10°F by the end of the century. In general, temperature increases are a little greater in more northern locations relative to southern locations. The 'error bars' on the graph show the variation in prediction among the climate models. As would be expected, the uncertainty in model predictions increases as we get further into the future. All models are consistent though in predicting increases in temperature.

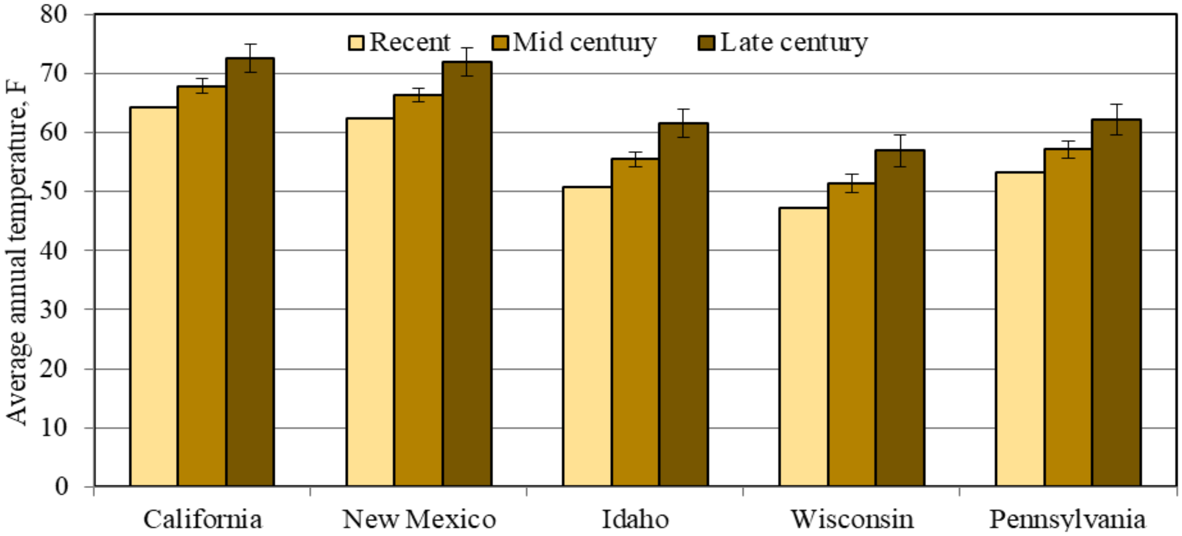

Figure 1. Recent and predicted future average annual temperatures for selected locations of the United States.

As stated above, these predictions are for a worst-case scenario where little is done to reduce our current CO_2 emission rates. Steps are being taken though to reduce fossil fuel consumption and related emissions. Therefore, temperature increases may begin to slow by mid-century with a smaller increase by late century.

Figure 2 indicates that annual precipitation is projected to have little change in the dry western regions while increases are anticipated in the wetter eastern regions. Precipitation patterns will also vary throughout the year. Predicted changes in precipitation for California show a substantial (up to 25%) increase during the winter season with little change during the rest of the year. In Wisconsin, most of the increase comes in the spring with little change in the summer. In Idaho and Pennsylvania, most of the increase comes in the winter with smaller increases throughout the remainder of the year. Compared to temperature, there is more variability among models in predicting future precipitation, but the trends tend to be consistent.

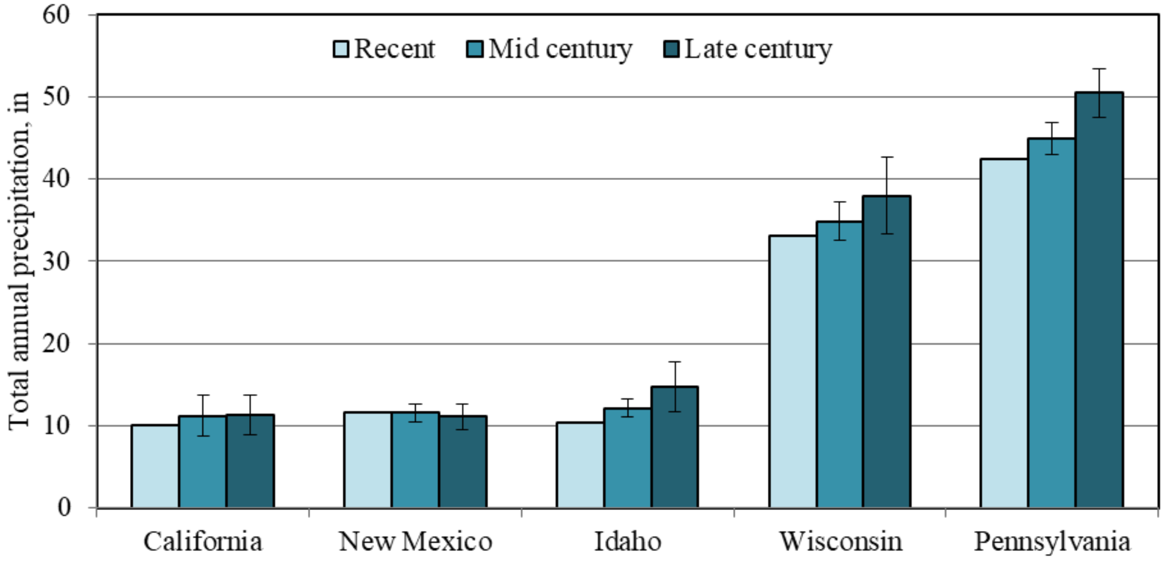

Figure 2. Recent and predicted future total annual precipitation for selected locations.

Precipitation patterns and amounts don't tell the complete story. With increasing temperature, evapotranspiration from the crop will also increase. Figure 3 shows the difference between the projected increase in precipitation and the increase in evapotranspiration. In the dry regions, there is a projected annual deficit of 2 to 4 inches by mid-century. In the wetter eastern regions, there is a small increase in water available. Since most of the increase in precipitation occurs in the winter and spring periods and most of the evapotranspiration occurs in the summer, summers will get drier.

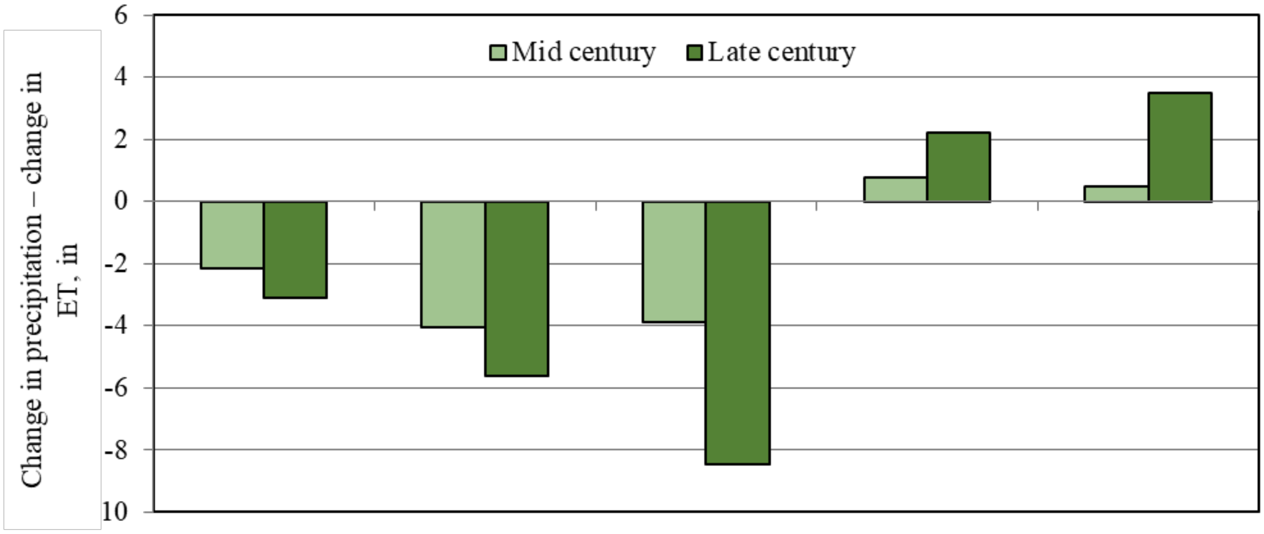

Figure 3. Difference between predicted future precipitation and predicted evapotranspiration for alfalfa crops at selected locations.

Atmospheric and climate changes will have varying effects on forage production. An important benefit comes from the increasing CO_2 levels in the atmosphere. More available CO_2 stimulates growth of most forage crops including alfalfa. Increasing temperatures also increase the growing season, particularly in northern locations, which can lead to more harvests per year. Changes in precipitation patterns will affect field curing and harvest of forage crops in some parts of the country, but this is not anticipated to have much effect since most of the increase in precipitation occurs outside the harvest season.

By linking crop and global climate models, we can study predicted impacts on crop production (Rotz et al., 2016). The Integrated Farm System Model was used to simulate alfalfa growth and harvest under weather patterns predicted by each of the nine climate models. Harvested alfalfa yields were predicted to increase at each of the locations by mid-century with less change during the remainder of the century (Figure 4). This increase primarily came from “carbon fertilization” through the increase in atmospheric CO_2. For the northern locations, the longer growing season allowed an extra cutting of the alfalfa, further increasing yield.

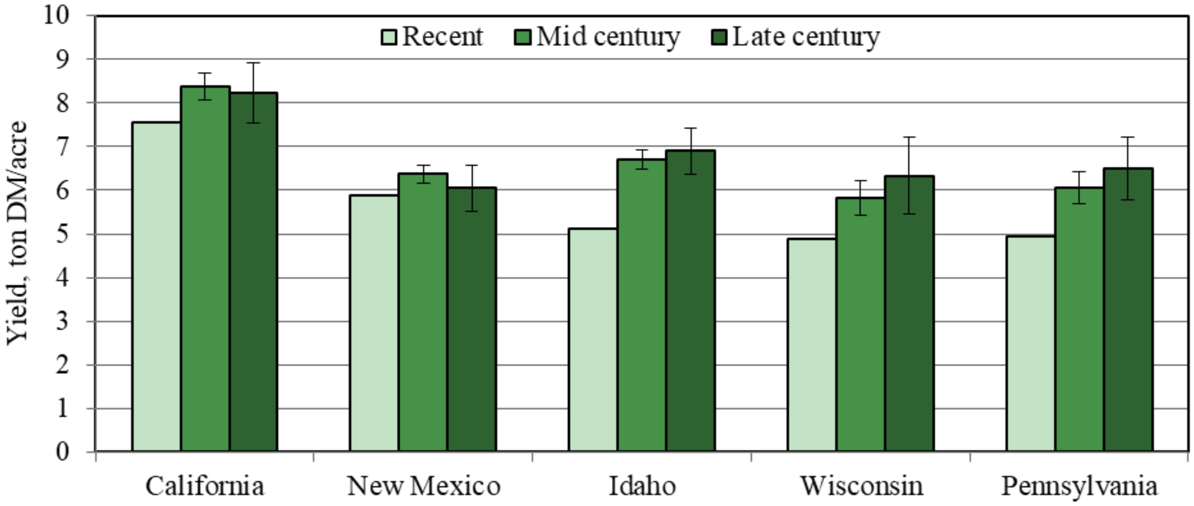

Figure 4. Recent and predicted future alfalfa yields as influenced by increased atmospheric carbon dioxide concentration and climate change at selected locations.

These projections were based upon the assumption that increased irrigation water would be available to support the increased growth in the dry western regions. With increasing limitations on water availability and use in crop irrigation, this may be an optimistic projection for the dry regions. In general, alfalfa yield is about proportional to the amount of water applied to the crop (Lindenmayer et al., 2010). If irrigation water becomes more restricted, the loss of production may be substantial.

Changes in temperature and rainfall can also affect nutrient losses from farms, but for forage producers this impact should be minimal. Our model predicts a 20 to 60% increase in phosphorus runoff across these five locations due primarily to more intense storms. The prediction for recent weather is less than 1 lb of phosphorus per acre, which is very little compared to other crops and particularly those grown in the eastern states. Therefore, the increased loss from alfalfa fields is still little loss. A similar prediction was found for nitrogen losses with most of the loss coming in the form of nitrate leaching to groundwater.

Other concerns that were not addressed in our simulated production systems are that of weed (Jugulam et. al., 2019), insect and disease (Trebicki and Finlay, 2019) control. Milder winters, longer growing seasons and increased atmospheric CO_2 will likely promote weed growth as well as crop growth. More and different insect infestations and diseases may also develop. These can also affect future yields and management practices that were not considered in this analysis.

CONCLUSIONS

Increases in atmospheric CO_2 and related changes in climate may increase alfalfa yields as long as adequate water is available to maintain production.

Gradual changes in management (planting dates, harvest dates, number of harvests, crop genetics and pest control) will be needed to adapt and perhaps take advantage of future climate.

The greatest challenge for sustainable forage production in dry climates will be access to adequate water for irrigation.

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ALFALFA GRAZING SYSTEMS IN ARGENTINA

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Key Words: alfalfa, grazing systems, grazing pressure, forage quality, beef, dairy.

Relative to confined systems, direct grazing has some advantages, particularly lower operational costs, better use of alfalfa quality compared hay or silage, and healthier animal products for human consumption compared to feed-lots (lower total cholesterol content, less intramuscular fat content, and higher unsaturated fatty acids omega-3/omega-6 relationship). However, there are some disadvantages: risk of bloat, longer fattening period, and lower milk production on an individual cow basis.

Correct alfalfa grazing management that complements high animal production with high levels of pasture yield and persistence, must be based upon the growing pattern of the plant in which new stems arise in series that come from axillary as well as crown buds, keeping a balance between active and dormant buds. From the grazing viewpoint, alfalfa has two important features: i) it can reach high values of leaf area index (LAI) without losing photosynthetic capacity in the lower leaves; and ii) speed regrowth after grazing depends primarily on reserve carbohydrate and protein content on crown and root rather than on remnant leaves. Based on the previous remarks, the best way to use alfalfa is under **rotational grazing** in which the main objective must be to combine adequate levels of grazing intensity with appropriate resting time. Alfalfa can tolerate intensive grazing periods as long as they are not frequent. Repeated interruption of the reserves cycle leads to loss of stand and the subsequent decrease in animal production.

Forage quality also plays a very important role in animal performance. Grazing alfalfa at 10% blooming integrates acceptably high forage yield with adequate levels of forage quality and root and crown carbohydrate reserves. For those months in which temperatures and day length are not high enough to allow blooming, alfalfa should be grazed when the regrowth from the crown is about 5-cm tall. More recently, research results in Argentina (3, 7) suggested to initiate grazing -during periods of pasture active growth- when the main stem has 8 to 10 nodes. As an alternative, the same authors proposed the utilization of cumulative number of grade-days [which is estimated as mean daily temperature – base temperature (5° C)] to define grazing frequency: 350-450° C in spring/summer and 550-600° C in fall/early winter.

When implementing a rotational grazing system, three fundamental issues must be defined: 1) **Grazing Frequency (GF)**, also defined as pasture resting period. GF depends on environmental conditions (season, temperature, moisture, etc.) and fall dormancy (FD), i.e. the more non-dormant the shorter the resting period. In general terms, across the Pampa Region, GF ranges from 23 days (FD 7-10 in spring/summer) to 42 days (FD 4-6 in middle-fall/winter); 2) **Grazing Period (GP)**, or number of days in which animals graze on a particular strip of pasture. GP

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depends on the type of operation (dairy or beef) and fall dormancy (the more non-dormant the cultivar the shorter GP in order to avoid consuming regrowth from crown buds). For the Pampa Region GP goes from 1 day (dairy production) to 7 days (beef production on FD 4-6 cultivars); and 3) **Degree of Pasture Utilization (PU)**, a concept related to grazing pressure that results from the interaction between forage availability and stocking rate, which –in turn- produces different levels of animal intake. The combination of all of the above three factors impacts on beef or dairy production on an individual as well as per area-unit basis.

GRAZING SYSTEMS

Beef production - As mentioned before, the most important parameters that define a rotational grazing system are GF and GP. For the FD grades (5 to 10) of alfalfa cultivars used in the Pampa Region (temperate climate and no irrigation), many studies conducted by INTA for beef production stated an average GF from 35 to 42 days and an average GP of 5 to 7 days. The negative effect of continuous grazing on pasture productivity and persistence were pointed out by Romero *et al*. (6). Under the appropriate GF for each time of the year, using an optimal stocking rate is critical in determining individual live weight gains and/or beef production per unit area.

In the Pampa Region the most popular alfalfa grazing system for beef production is the so called "**7x35**" because it results from a combination of an average of 7 days of grazing (GP) and 35 days of resting (GF), which means a total grazing cycle of 42 days. The 7x35 system is simple, effective and cheaper than others that are based on higher number of paddocks. To organize the system, the pasture is divided into 6 grazing strips o paddocks, which are grazed in turns, following a regular schedule. During spring and the beginning of summer, when alfalfa is growing very rapidly, succession of paddocks can be altered in order to maintain forage quality sufficiently high. The escaped paddocks are generally used for hay production.

There are also some other systems based on the use of slightly different combinations of GF and GP, like for instance **2**GP **x 34**GF (18 paddocks) or the one called "**leaders**" (L) and "**followers**" (F), in which two groups of animals are formed in order to alternatively graze the same paddock: group L enters first and consumes the upper half of the canopy, after which enters group F and grazes the remaining forage in the paddock. In spite of some eventual and slight increases in beef production, these alternative systems did not produce any consistent improvement over the 7x35 system that compensates the higher labor intensity they require.

Whatever the chosen combination between GF and GP, the main goal for any grazing system must be to reach a high degree of forage utilization (PU) through an adequate grazing pressure. As a general rule, systems that include high stocking rates produce more beef per unit area, and very often justify the decrease on individual live weight gains. However, losing some degree of individual gains may delay the fattening process and negatively influence the profitability of the operation and/or the returning speed of investment.

Dairy production - When formulating diets for dairy cows, especially for those with high milk potential, the first criteria to be considered should be animal intake (AI). Total amount of consumed DM depends upon animal characteristics (weight, age, level of production, lactation time, etc.) as well as forage nutritional value. Under grazing conditions, three other components

must be included: i) pasture structure (height, stand density, etc.); ii) environmental conditions; and iii) grazing management (forage allowance, grazing system, level of supplementation, etc.).
In dairy operations solely under direct grazing, forage allowance (FA) has a direct effect on milk production. In operations in which pasture is just one of the diet components, like in the vast majority of dairy farms in the Pampa Region, FA also has incidence on addition and substitution effects among feeds in the diet. Even though FA can be expressed as g DM kg live weight^{-1} or as % or live weight. Comeron *et al.* (2) concluded that the minimum level of FA in order to obtain maximum values of AI and milk production is equivalent to 1.75*MEI (maximum expected intake, expressed as kg DM cow^{-1} day^{-1}). The value of MEI can be calculated from the equation proposed by Neal *et al.* (4):

$$MEI\ (kg\ DM\ cow^{-1}\ day^{-1}) = (0.025 * live\ weight) + (0.2 * liters\ of\ milk\ cow^{-1})$$

Using this equation, a cow of 550 kg of live weight that produces 25 liters of milk day^{-1}, would have a MEI value of 18.75 kg DM day^{-1} (or 3.4% of its live weight). So, FA for that particular cow should be 1.75*18.75 = 33 kg DM day^{-1} (or 60 g DM kg of live weight^{-1}).

If the goal is to maximize animal response under grazing conditions alone, the best way to achieve it is to use high levels of FA, i.e. low stocking rates. In such a context, pasture use efficiency (PUE = AI/FA) will be low, with values no larger than 50-55% (5), implying wasting a large amount of forage and, consequently, obtaining low milk production per unit area. If the objective is to increase individual cow productivity under high PUE, some level of supplementation with conserved forages and/or concentrates must be used. In obtaining a compromise between milk production per cow and milk production per unit area, results in Argentina (1) indicate that FA should be around 20 to 22 kg DM cow^{-1} day^{-1} (or about 4% of the live weight) with an average PUE $\geq$ 70% (with a range of >80% in winter to 55% in spring or <50% in summer).

The most popular system for dairy production is the use of **daily grazing strips** (daily paddocks) with a resting period (GF) of 35 days. An alternative is the utilization of **paddocks with variable time of grazing**, where the main objective is to improve alfalfa persistence through the reduction of the instantaneous stocking rate but without reducing the average stocking rate. Another one is the use of **daily strips with sectors of restricted access**, which basically consists in subdividing the daily strips into sectors so that cows can have access to a new one throughout the day. However, none of these alternatives were more effective than the daily strips. There has also been some research on adapting the **leaders and followers** (LF) system to dairy production. The key point is how both groups (L and F) are conformed. When group L was formed by cows in the first third (40 days) of their lactating period and the F group was composed by cows in the second third (160 days), Romero & Comeron (1) did not detect differences in average milk production between both groups because the decrease in the F group could not be compensated by the increase in the L group. As an alternative, Comeron *et al.* (3) proposed a system in which the L group was composed by milking cows and the F group was composed by dry cows, each group having sequentially access for 1 or 2 days to the same grazing strip.

To keep a balance between milk production and operational costs, it is recommended a combination of direct alfalfa grazing and strategic supplementation. By doing so, it is possible to obtain >10,000 liters of milk ha^{-1} year^{-1}, as a consequence of individual production levels of

7,000 to 7,500 liters cow^{-1} lactation^{-1} and stocking rates of over 1.7 cow ha^{-1}. Direct grazing of alfalfa reduces both operative costs and losses of quality due to forage conservation.

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INTEGRATED SYSTEMS FOR HARVEST MANAGEMENT

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While alfalfa was once the dominant perennial legume species used in the southern region of the US, the harsh environment and elevated insect pressure soon eliminated many productive alfalfa (*Medicago sativa*) stands (Lacefield et al., 2009). The success and adoption of alfalfa in the North and Midwest US is in part due to improved variety development for these regions, providing higher yields and improved quality potential. While the increase of alfalfa acreage in other regions of the US has been relatively flat in recent years (USDA NASS, 2017), there is a measurable increase in alfalfa educational efforts, plantings, and adoptions in the Southeast US. Based on reported seed sales in Georgia, greater than 28,000 acres of alfalfa have been planted in the region (America's Alfalfa and Athens Seed Company, personal communication, 2019). Although alfalfa is considered a minority crop in this part of the US, potential for integration into existing forage systems is high as newer alfalfa varieties have been developed with improved adaptation to hot, humid growing conditions of the South. This includes varieties with dual-use purposes (hay and grazing) that better fit the management opportunities for forage-livestock farmers in the southern US.

The increasing acreage in the South coincides with regional research and Extension efforts focused on engaging forage-livestock farmers in on-farm demonstrations with alfalfa. Rather than focusing on monoculture alfalfa hay production, these demonstrations have primarily been through the integration of alfalfa into perennial, warm-season grass systems (i.e. bermudagrass (*Cynodon dactylon*)). Regional research efforts have shown the success of integrating alfalfa into these existing systems because it complements the seasonal growth, production characteristics, and management requirements of bermudagrass (Beck et al., 2017 a,b,c, Hendricks et al. 2020, Burt et al. submitted). This integrated system has wide potential application as it does not require 1) complete pasture renovation, 2) expensive infrastructure such as irrigation, and 3) as much cost of establishment when compared with pure stand alfalfa production. Further, the addition of alfalfa into bermudagrass decreases the need for nitrogen fertilizer, increases forage quality, decreases financial risks, and extends the forage production season from summer only to spring through fall production.

The development of grazing tolerant, dual-use alfalfa varieties has changed the alfalfa game in the Southeast US.

Dual-purpose alfalfa varieties have proven to work well in both monoculture and mixtures, including in combination with warm season perennial grasses. Integrated alfalfa-bermudagrass systems provide Southern US producers with a viable option to include alfalfa in their existing systems once again.

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In: Proceedings, 2022 World Alfalfa Congress, San Diego, CA, November 14–17. UC Cooperative Extension, Plant Sciences Department, University of California, Davis, CA 95616. (See http://alfalfa.ucdavis.edu for this and other alfalfa conference Proceedings.)

Recent work from Georgia has demonstrated that alfalfa-bermudagrass mixtures provide a high yielding, quality feed source for livestock as stored forage such as hay or baleage (Hendricks et. al. 2020). Previous grazing work with alfalfa-bermudagrass under rotational stocking found that adding alfalfa can improve forage production, nutritive value, and animal performance in beef cattle systems while reducing the need for synthetic nitrogen fertilization when compared to bermudagrass monoculture systems (Beck et al., 2017 a,b,c; Burt et al. submitted).

Next steps for expansion of alfalfa acreage and increased forage yields in the region are to adjust best management practices and integrate alfalfa into dual-purpose systems for hay and grazing for forage-livestock producers. Frequent rainfall and fluctuations in temperature (high daily and relatively low night temperatures) require forage-livestock producers to have flexibility in terms of forage use decision making (i.e. choosing between cuttings for hay or grazing). USDA NASS data reports land used for both hay and pasture separately, but many producers in the South use the same unit of land for both purposes (hay and grazing). For these reasons, evaluation of the use of alfalfa-grass systems for both hay and grazing within the same growing season is warranted to increase potential alfalfa acreage and application in the region. The opportunity to adjust within-season harvest management from primarily hay to potentially grazing enhances the adaptability and desirability of this crop to southern livestock producers.

***Recent evaluations of alfalfa-bermudagrass mixtures and defoliation strategies in the Southeast US have shed light on alternative uses and developing best management practice to enhance alfalfa-based system sustainability in the region*.**

Figure 1. Aerial photo of harvest management evaluation at UGA-Tifton Campus Better Grazing Program. (2021) Tifton, GA

Building from the previous work in Georgia, follow-up evaluations were initiated in Alabama and Georgia to define grazing parameters and compare defoliation strategies (via mechanical harvesting or grazing) on alfalfa-bermudagrass mixtures in the region. A two-year study was conducted to evaluate forage and animal responses to varied harvest management strategies in alfalfa-bermudagrass mixtures across two locations. Treatments evaluated included 1) cut only, where material was mechanically harvested as hay or baleage throughout the season depending on weather; 2) graze only, where material was rotationally grazed on a 7 day interval allowing for 28 day paddock rest with grazing initiation occurring 20 days post clean off harvest in spring and continuing until forage availability became limiting in the fall; and 3) an integrated cut and graze system, which allowed for intermittent harvest management of cutting and grazing, concluding with a fall grazing of stockpiled material. (*Complete data results from this evaluation are in preparation for publication in 2023).*

The integrated dual-purpose cut-and-graze system in this evaluation was harvested for conserved forage production early in the growing season, followed by rotational grazing, allowed to rest during the stressful summer months (July-August), harvested and then stockpile grazed from October to November/December depending on location. While this system did not provide the greatest animal live weight gain or harvestable yield, it was able to optimize the utilization of the mixture, in that it resulted in greater alfalfa stand persistence than grazing only, and required less mechanical harvesting, labor, and associated costs than the cut only system. Further, it allowed for harvesting options during wet periods when hay harvests would have been delayed, provided a forage rest period during stressful drought months, and allowed for use of the area well into the winter months without negatively impacting persistence of the alfalfa integrated into bermudagrass.

This dual-purpose system provides strategic allocation of high-quality forage resources during times of need in the calendar year for southeastern livestock systems. Early-season harvests of alfalfa-bermudagrass for conserved forage allows producers to capture that higher-quality feed resource and preserve this product for a time of later use, typically the winter months in the Southern US when grazable high quality forage availability is limiting. Mid-to-late season grazing of alfalfa-bermudagrass offers improved quality compared to bermudagrass alone, which begins to decline rapidly late in the growing season. The addition of alfalfa to bermudagrass also extends the grazing season by two to three months per year annually, and during a time of year where availability of grazeable forage is typically low. Another notable observation from the evaluation after late season grazing was a lower annual weed presence, quicker spring green up, and a cleaner first season cutting on dual-purpose cut-and-graze treatments when compared to cut only or graze only treatments (Figure 2).

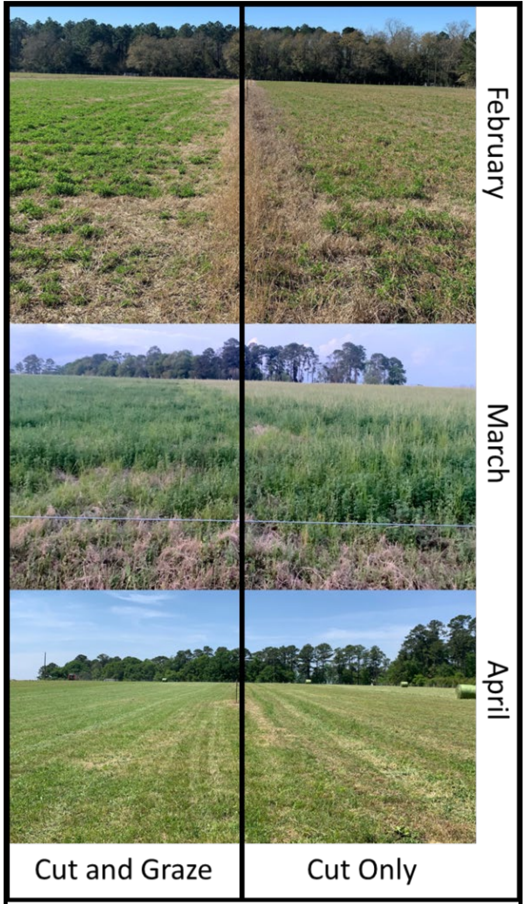

Figure 2. Visual observation of Cut-and-Graze and Cut only defoliation strategies on alfalfa-bermudagrass mixtures post first year utilization in Tifton, GA. (2021)

While certain components of each harvest management strategy evaluated were better within a single parameter or as a "snapshot" of the forage growing season, overall system performance (forage component yield, quality, estimated live weight gain, etc.) indicates that an integrated harvest management method best optimizes the use of the land unit. This system provided a similar alfalfa stand density to mixtures harvested as baleage and a higher animal average daily gain compared to the grazing only of alfalfa-bermudagrass mixtures. Further the integrated system allowed for the grazing season to be extended into the late autumn/early winter months when grazed as a stockpiled forage option. With continued climatic changes occurring in the region, the flexibility to adjust harvest management to best utilize the mixture through an integrated system without significant detriment to the overall stand performance provides producers with another strategic tool for their forage toolbox.

Acknowledgments

Funding for the work mentioned provided by USDA-NIFA-Alfalfa Forage Research program. Additional thanks for the donation of alfalfa seed evaluated (‘Bulldog 805’) by Athens Seed Company (Watkinsville, GA), and the sponsors of the Better Grazing Program at UGA Tifton.

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INTERCROPPING ALFALFA WITH CORN SILAGE

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ABSTRACT

Alfalfa is often grown in crop rotations with corn silage to provide forage for dairy cattle and other livestock in northern regions of the United States, but the performance of this system is hampered by low establishment year yields of spring-seeded alfalfa and excessive loss of soil and nutrients during corn production. Over the last decade, scientists in Wisconsin and other states have developed improved methods for interseeding and establishing alfalfa with a corn silage companion crop. When proper management practices are used, establishment of alfalfa by interseeding into corn has the potential to double first year yields of alfalfa, increase overall forage production and profitability, and decrease soil and nutrient loss from cropland compared to conventional alfalfa-corn silage rotations. Key management steps for intercropping alfalfa with corn include choosing suitable field sites, properly amending soil, selecting suitable alfalfa varieties and corn hybrids, applying herbicides and other agrichemical treatments, and using appropriate planting and harvest management practices. Further research is still needed, however, to improve alfalfa establishment during wet growing conditions and to enhance nutrient uptake and yield of the corn silage companion crop.

Key Words: alfalfa, corn, forage, intercropping, management

INTRODUCTION

In the northern USA, establishment-year yields of spring-seeded alfalfa are low, often being one-half that of subsequent full-production years. Planting small grain, grass, or legume companion crops with alfalfa can improve forage yields in the establishment year, but the yield benefit is limited and often results in reduced forage quality. One way to bypass the low-yielding establishment year of alfalfa and to increase farm profitability would be to interseed alfalfa into corn silage. In this system, corn silage serves as a high-quality and high-yielding forage companion crop, while alfalfa initially serves as a cover crop to reduce soil and nutrient loss from cropland during and after corn production. With proper management, full production year yields of alfalfa established under corn are comparable to solo seeded stands. A primary focus in this production

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system should be to establish alfalfa at stand densities of 12 to 20 plants per square foot following corn harvest to maximize subsequent forage production. Our current recommendations for obtaining good establishment of alfalfa intercropped with corn silage are described below.

SELECTING A FIELD SITE

Growers should try alfalfa interseeding on a smaller field for several years while learning to properly implement and adapt the practice for conditions on their farm. Field sites must be suitable for good alfalfa production, with a soil pH of 6.6 or greater and good drainage. The soil should have a good water holding capacity or be irrigated if prone to drought. The site also must have a seedbed that is relatively smooth, firm, and free of excessive surface residues that would interfere with seeding alfalfa into corn. Interseeding should not be carried out in fields that are routinely wet and prone to soil compaction or rutting during corn silage harvest.

SOIL FERTILITY

Total available nitrogen from manure and commercial fertilizer should be at the upper end of rates permitted by nutrient management plans for corn silage. Based on soil test results, apply lime, phosphorus, potassium, boron, and sulfur to meet the crop nutrient needs for both corn silage and seeding-year alfalfa. Alfalfa seedlings will take up some applied nitrogen, so applying a high proportion of nitrogen in starter fertilizer (or possibly in deep-banded manure or fertilizer under the corn row) may help to favor nitrogen uptake by corn. For example, apply a starter fertilizer at corn planting to provide 50-20-20 lbs per acre of nitrogen, P_2O_5, and K_2O in a 2 x 2 placement. Growers should be prepared to sidedress additional nitrogen along the corn row, particularly if lower rates of available nitrogen are applied before or during planting or if nitrogen is lost due to excessive rainfall. After corn harvest, fertilize alfalfa according to soil test recommendations to support stand persistence and high forage yields. Alfalfa will readily take up any residual nitrate in the soil profile after corn harvest. Further research is, however, needed to refine fertilizer management for corn grown with interseeded alfalfa.

PROPER TIMING FOR CORN PLANTING AND ALFALFA INTERSEEDING

Alfalfa can be established under early or late planted corn. Interseeding within three days of corn planting will give the best establishment of alfalfa. If corn is planted early and exposed to prolonged cool conditions at or below 50°F, then consider delaying alfalfa interseeding until corn emergence (VE stage). This timing will reduce alfalfa competition with slow-growing corn and often improves corn silage yield while providing good establishment of alfalfa. Seeding alfalfa several days or weeks before corn planting is not advised because alfalfa will be too competitive with corn and reduce silage yield. Interseeding should not be attempted if the soil profile is excessively dry unless ample rainfall is expected or cropland can be irrigated. Under prolonged dry soil conditions, alfalfa establishment will be uneven, or if established, alfalfa seedlings will be too competitive with corn for soil moisture. In this case, producers should focus on growing corn without alfalfa, and then plant alfalfa in a conventional manner the following spring.

CORN SILAGE HYBRID, SEEDING RATE, AND HARVEST

The hybrid used for intercropping should have good to excellent agronomic traits, including protection from corn rootworm. Some light must penetrate the corn canopy from July until corn harvest to help sustain alfalfa growth. Harvesting corn in late August or early September is also necessary to allow interseeded alfalfa adequate time to regrow and improve winter survival. To accomplish this, growers should plant short season, moderate stature hybrids in rows spaced 30 inches apart at a target harvest density of 25,000 to 30,000 plants per acre. Our work in southern

Wisconsin and southern Idaho suggests 100- to 102-day hybrids work well if planted in early May. The combined effects of moderate population and early harvest of corn, along with modest reductions in corn growth due to competition from alfalfa, will likely reduce silage yield by about 10 to 15% compared to high density solo-seed corn harvested in mid to late September. Although planting corn in widely spaced rows (e.g. 60-inches apart) may improve light penetration and alfalfa establishment, this must be balanced against further reductions in corn silage yield. Conversely, narrow-row corn (e.g. 20-inch spacing) should be avoided because it allows less light penetration to sustain alfalfa growth. Avoid harvesting corn silage if fields are wet as compaction will damage or kill alfalfa plants. Our current research is aiming to identify specific hybrid traits that are associated with improved yield of corn silage grown with interseeded alfalfa.

ALFALFA ESTABLISHMENT

Proper seeding is critical for good alfalfa stand establishment and the suppression of weeds under corn. Plant alfalfa about ¼ to ½ inch deep in corn inter rows using a drill with press wheels, a seeding rate of 16 lbs per acre of pure live seed, and a row spacing between 6 to 10 inches. Adjust seeding rates to account for coatings, low germination, and high proportions of hard seed. Alfalfa can be drilled across corn rows as long as care is taken to ensure that germinating corn is not disturbed. If a corrugated roller seeder must be used, plant alfalfa first into a properly tilled and smoothed seedbed and then immediately plant corn. Our studies in Wisconsin have shown the following alfalfa varieties establish relatively well under corn: 55H94, 55H96, Hybriforce 3400, Hybriforce 3420, Hybriforce 4400, 54Q14, 54Q29, 55V50, FSG403LR, FSG329, Spredor 5, WL359RR.LH, RR Vamoose, FSG430RR.LH, 431RRLH, 55VR08, 54VR10, L-457HD+, and L-451APH2+. Alfalfa varieties with high resistance to multiple races of Aphanomyces should be used in areas where this disease is common. Our most recent work suggests alfalfa can be bred for improved establishment under corn and hopefully varieties specifically developed for interseeding will soon become available.

AGRICHEMICAL TREATMENTS TO AID ALFALFA ESTABLISHMENT

We recommend applying micro-encapsulated acetochlor (e.g. Warrant® 1.5 qt/a) just after alfalfa emergence. Postemergence weed control will vary depending on the alfalfa variety and corn hybrid used. For Roundup Ready® systems, glyphosate is highly effective when weeds are 4 to 6 inches tall, and our experience suggests only one application is needed. If conventional alfalfa or corn is planted, we recommend bromoxynil (e.g. Moxy 2E®) applied when broadleaf weeds are 1 to 2 inches tall and after alfalfa has four trifoliate leaves. Pendimethalin (e.g. Prowl H_2O®) may be used as a pre-emergent herbicide after alfalfa reaches the second trifoliate stage and before it is 6 inches tall to provide some control of germinating annual grass and broadleaf weeds. The Roundup Ready® system should, however, be used on fields where summer annual grass weeds are routinely a problem unless glyphosate-resistant weeds are present.

Numerous studies in southern Wisconsin have found superior establishment of interseeded alfalfa is obtained by applying prohexadione-calcium (e.g. Kudos®) followed by fungicide (e.g. Priaxor®) and, if needed, insecticide (e.g. Warrior® II). These agrichemical treatments are required if corn silage yields are high (over 7 tons of dry matter per acre) and wet growing conditions favor foliar disease on alfalfa (Figure 1 and 2). Kudos® is registered for use in Wisconsin and Pennsylvania and should be applied at 12 oz per acre with labelled adjuvants in early- to mid-June when interseeded alfalfa is 4- to 12-inches tall, and corn is 1.5- to 2.5-feet tall. Kudos® application requires a nozzle spacing on conventional booms (or drop nozzles) to direct the spray onto alfalfa in the interrow area and away from corn. In Wisconsin, initial top growth of interseeded alfalfa dies back prematurely in late summer due to heavy disease pressure underneath higher yielding corn. Recent research has shown that Priaxor® fungicide applied at 4 fl. oz per acre when corn is about 4 to 6 feet tall is effective for lessening foliar disease of interseeded alfalfa. A drop nozzle may work best for this application, but it is not required if the spray penetrates through the corn canopy to provide good coverage of alfalfa. If potato leafhopper nymphs are present in fields this suggests impacts may be high from this pest. In these cases, research has found insecticide applications such as Warrior® II eliminated impacts from this insect. Research suggests that if Kudos® cannot be applied, good stands can often be obtained by applying fungicide and insecticide if potato leaf hoppers are present.

Recent studies suggest treatment of interseeded alfalfa with prohexadione, fungicide, and insecticide is not needed in arid irrigated regions (e.g. Idaho) if other management practices described above are closely followed. The use of these agrichemicals may be reduced or omitted in eastern rainfed regions if pressure from disease or insects and yields of corn silage are low (e.g. less than 6 tons of dry matter per acre), or if wide row corn is grown. Further work is, however, needed to clearly define thresholds and scenarios where these agrichemical treatments are needed to ensure establishment of alfalfa intercropped with corn.

SUMMARY

Alfalfa can be successfully established in a corn silage companion crop to improve overall forage yields, profitability, and environmental outcomes if management practices described in this paper are closely followed. These practices include choosing fields well-suited for alfalfa production, properly amending soil, preparing a good seedbed, and planting corn at moderate populations for harvest in early September. A well-adapted alfalfa variety should be planted at normal seeding rates with a drill at or before the VE growth stage of corn. Good weed control, application of prohexadione, fungicide, and insecticide and efforts to minimize wheel traffic damage during corn silage harvest are also key factors favoring good alfalfa establishment. Additional research is underway with the aim of further improving alfalfa establishment, especially during wet growing conditions, and to improve fertilizer management and yield of corn silage in this system.

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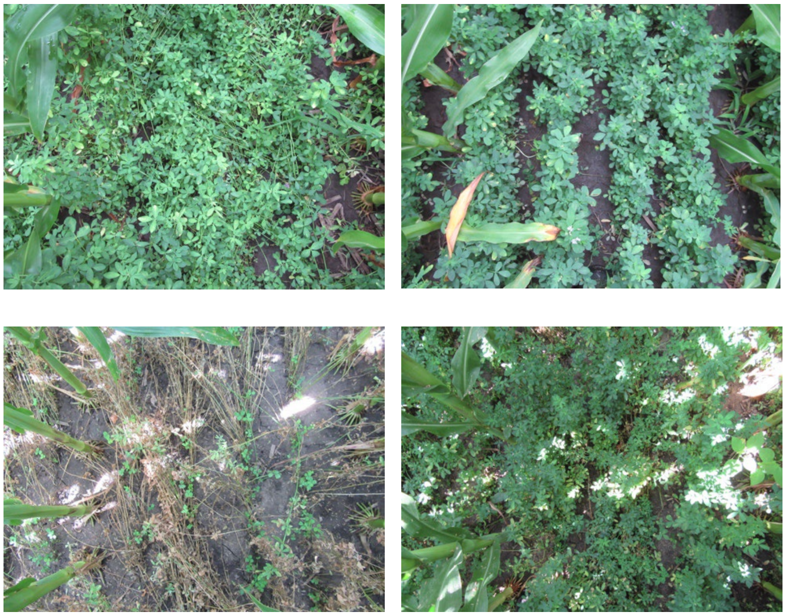

Figure 1. Normal appearance of interseeded alfalfa in July (top photos) and August (bottom photos) under corn. Alfalfa seedlings grown without agrichemicals have tall stems, weak roots, and die back due to disease and insect pressure (left photos). Alfalfa treated with Kudos® followed by fungicide and insecticide has improved survival due to more compact, healthier top growth and larger roots (right photos). Penetration of light through the corn canopy also favors alfalfa survival.

Figure 2. Typical appearance of interseeded alfalfa in late fall when established during near- normal growing conditions (top photos) or wet conditions that favored aggressive corn growth, alfalfa disease, and wheel traffic damage at corn harvest (bottom photos). Alfalfa undergoes substantial or complete stand loss when established without agrichemicals (left photos). Establishment was greatly improved by applying Kudos® followed by fungicide and insecticide (right photos).

ALFALFA BREEDING PROGRAMS FOCUS ON GRAZING AND SUSTAINABLE SYSTEMS

Federico Sciarretta[1]

INTRODUCTION

Alfalfa is a perennial forage legume grown over 32 million hectares worldwide (Cash, 2009). Nowadays in Argentina about 3.7 million hectares are stablished in a wide range of environmental and soil conditions. About 60% corresponds to alfalfa sown in pure stands and the last 40% in mix with different temperate grasses. Generally alfalfa in pure stands is mainly used in dairy farms, hay or silage systems; on the other hand when it´s mixed with grasses is mostly used in beef cattle production. (Basigalup, 2017). When the system of alfalfa utilization is analyzed the data shows that 75% is used in direct grazing by animals and the 25% rest (nearly 900.000 hectares) are under cutting system.

Alfalfa provides herbage of consistently high nutritive value (Gierus, 2012). These characteristics result in higher quality and stability of herbage production compared to other perennial species (Mills,2015). Lucerne crops also support a series of additional agroecosystem services. They provide significant nitrogen (N) inputs via biological N2 fixation. At a rate of 20–25 kg N t DM, depending on soil fertility (Lüscher, 2000), Alfalfa crops can fix up to 500 kg N ha yr1 (Berenji & Moot, 2015). The alfalfa root system is also known to increase soil organic carbon content and the size and stability of soil aggregates (Angers, 1992).

Since the alfalfa introduction in the region, there has been important advances in breeding programs and local selections of cultivars with better environmental adaptations and outstanding disease profile, being the last characteristic the most important one that was able to achieve better dry matter productions and good persistence. However traditional breeding programs are focus on targets related to higher yields and good disease profile under cutting systems. In this case alfalfa is harvested with machinery under a frequency (depending on the season) of 10% flowering or 5 cm basal regrowth from the crowns in order to achieve good balance between dry matter production, and quality; and to not compromised root reserves (Carbon and nitrogen). In such situations the alfalfa plants are always in comfort (energy balance and optimal photo assimilates partition to all plant´s structures) reason why persistence is not been challenge.

The current situation of Argentinian dairy systems that graze alfalfa in the country tend to enter into the paddock in early stages of the crop development to maximize animal product and avoid higher cost due to mowing residuals after grazing. Something similar happens in the beef cattle production, perhaps in lesser degree when animals graze the same paddocks for long periods of time (more than 7 days) so a reduction of persistence and productivity can be expected (Basigalup et al., 2007), particularly in subtropical regions where the growing rates are high. This is because regrowth from the crown (new growth) can be removed by the animal, forcing

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the mobilization process to restart and depleting root reserves (Moot et al., 2003). Another important example of animal´s negative interaction is plants looses due to animal traffic and the damage done by hooves. These specific field conditions results in lower alfalfa´s persistence and the paddock is usually used during 2 years and over sown in the third year with alternative grasses as bromus sp to maintain productivity. An important solution to this problem can be approach by implementing adequate management practices: (frequent grazing during spring and summer to optimized live gain weight and proper rest in autumn to replenish crown and root reserves to guarantee stand persistence). However, this management should be supported from breeding programs to maximized global result of genetics interactions between environmental conditions and used conditions to achieve productive and sustainable alfalfa stands (or pastures). (We need to consider that management practices are not always easy or practical to implement for all the farmers due to specific conditions (scale, knowledge, climate conditions, etc). In the light of the aforementiones reasons, Argentinian´s breeding programs should be focused on developing grazing tolerant alfalfas.

MATERIALS AND METHODS

In our research and breeding stations placed in three contrast environmental condition of Argentina (Pergramino (PE), Pozo del Molle (PM) and Trenque Lauquen (TQ) alfalfa´s population are sown in dense swards plots and in a spaced plant block nursery . After 4 years of frequent and heavy grazing (8-10 nodes development stage in the main stem after regrowth and no residuals left during the hole year around) survival plants are collected under a selection pressure of 1,2% (i.e. 60 plants of an initial number of 5000 spaced plant block). These recurrent phenotypic selections are also based in data recorded during the years (% of persistence, total forage yield KgDM/ha, environmental adaptation and disease profile) that allows to synthetize new cultivars with improved agronomic traits. Selected genotypes are included in the polycross cage (Syn 0) and harvested seed are proportional bulk to participate in agronomics trails or to be part of another selection cycle (i.e. to roguing out of type, phytosanitary selections or improve forage yield in a specific season of the year).

Two main projects currently working:

- Grazing tolerant Non dormant Varieties: mainly focused to develop cultivars in central region ofArgentina (Santa Fe, Cordoba, San Luis and north of Buenos Aires provinces)
- Grazing tolerant Dormant Alfalfa varieties: mainly focused to develop cultivars in Central andsouthern regions of Argentina (Buenos Aires, La Pampa, San Luis and Rio Negro provinces). In this case wehave to highlight the importance of selecting genotypes that grow and persist well in competition withdifferent grasses (tall fescue, phalaris, orchadgrass, etc).

IMPORTANT TRAITS UNDER GRAZING SELECTIONS

Long term persistence: Important genes that codified for survival under heavy animal grazing. Large and deep crowns with adequate reserves partition to root.

Long term yield: data analyses must show excellent forage potential yield when is compared in the first and second year since establishment compared to top cultivar on the market, regardless the selection genotypes maintain yield through the remaining years of the pasture.

Plant structure: short and many grown up points that guarantee constant photosynthesis under frequent and heavy grazing to depend less on constant carbo hydrates metabolism coming from the root and crown. Leafy plants from the bottom of stem and fast recovery after grazing.

Grazing phenotype: compact strata, shorter internode length to improve leaf/steam ratio. Higher number of stem per plant to maximize dry matter production in a shorter and dense canopy. Genotypes with this plant structure could improve dry matter intake when grazing management is not adequate (i.e. 10% flowering development stage to enter in the paddock or more than 3 ton dry matter availability).

RESULTS AND DISCUSSION

To evaluate the new selection in non-dormant alfalfa's varieties agronomic trials were sown in 2018 and 2019 in two different sites in Argentina, with 3 replicates each in a Randomized complete Block Design. Frequent defoliation management was applied at all sites (grazing starting at 8-10 nodes per stem year-round); PE site was defoliated with sheep and Pozo del Molle (PM) with dairy cows. Soil Cover (%), Dry matter production (Kg/ha), and plant height (cm) were registered. ANOVAs was used to analyze differences in dry matter production (yearly and total production) and soil cover percentage. Tukey tests were used to determine the extent of variation between different levels of a factor when the ANOVA was significant (α = 0.10).

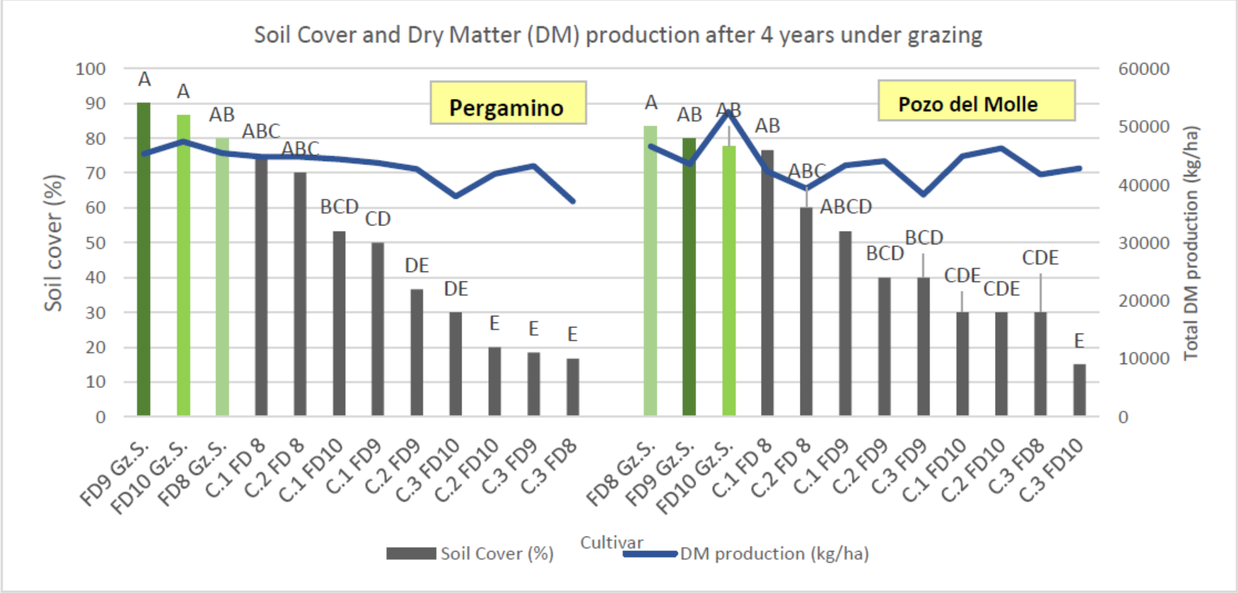

Figure 1. Soil cover () after 4 years in two localities in Argentina and total dry matter production (), 38 cuts in each site. Different letter means significant differences between varieties. Gz.S: Grazing selections. C: commercial checks. Fall dormancy (FD) 8, 9 and 10.

CONCLUSION

High differences in persistence under frequent and direct grazing were observed on the Gz.S, maintaining or increasing forage yield. After four years of experimental data, alfalfa lines which had been selected under frequent and direct grazing had higher persistence (85%) than those without grazing selection. This highlights the importance of breeding programs conducted under grazing when that is the ultimate use that will be given to such cultivars. For Argentinian´s grazing system is more relevant to reach a productive fourth or fifth year rather than a small increases of forage yield in the first or second year (economically, productively and environmentally). Combining breeding programs and proper management practices is a way to increase productivity and utilization of grazed alfalfa farms that may offer an opportunity for more sustainable, productive and financially resilient beef and dairy farms.

ALFALFA BREEDING WITH IMPLEMENTATION OF MOLECULAR TOOLS

Bernadette Julier[1], Marie Pégard[1], Camille Gréard[2], Philippe Barre[1]

ABSTRACT

Genome-wide, high throughput, cost-effective molecular markers have been developed for less than a decade in alfalfa. Their use for breeding this autotetraploid, heterozygous species is not straightforward but highly promising. We propose to browse through their main uses with an emphasis on results from the European project EUCLEG (www.eucleg.eu) and to highlight the interest of using allele frequencies directly estimated on pools of individuals from a population. A first use is the description of genetic resources. With a large set of markers (>100.000), a continuum among the European – American accessions was evidenced but clearly separated from the Chinese accessions. A second domain is the use of markers to identify genes or locus associated to valuable traits and explaining a substantial part of the variation: QTL. Genome wide association studies on a highly diverse panel of alfalfa populations (varieties, landraces, breeding populations) revealed QTL for yield and quality traits such as protein and ADF contents, explaining up to 15% of the variation. Despite the great advantage of dealing with a high level of diversity, a drawback is that the detection of some QTL could be hampered by the genetic structure within the panel. Another possibility to seek QTL is reverse genetic with allele mining in candidate genes. We used this method to find potentially interesting alleles involved in plant growth or digestibility. A third use is genomic selection based on all available markers to predict the phenotype of an individual from its genotype with a calibration set up on a training population. Within a highly diverse panel and a training set of about 270 populations, we obtained predictive ability ranging from 0.50 to 0.66 for yield, protein and ADF contents measured at two locations for two years. These values are relatively high compare to other studies with less diversity and seem promising. The use of genomic selection within breeder plant material has to be demonstrated but the expected genetic gain per year is huge (more than six times compared to phenotypic selection) especially regarding the decrease of selection cycle duration. We conclude that these different uses of molecular markers could renew alfalfa breeding programs for any trait of current and future interest.

Key Words: Association genetics, genetic diversity, genomic selection, *Medicago sativa*, marker

INTRODUCTION

Molecular markers have been proved to be useful tools to speed up genetic progress in many breeding programs as for dairy cows or maize. Their implementation in alfalfa breeding is lagging behind because of still recent development of genome-wide cost-effective genotyping methodologies and because of the genome complexity of this autotetraploid species. The first complete genomic sequence has been released in 2020 only (Chen et al., 2020). We propose to

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In: Proceedings, 2022 World Alfalfa Congress, San Diego, CA, November 14–17. UC Cooperative Extension, Plant Sciences Department, University of California, Davis, CA 95616. (See http://alfalfa.ucdavis.edu for this and other alfalfa conference Proceedings.)

go through three main applications of these now available markers. (1) The description of genetic diversity with molecular markers to manage the genetic diversity within the breeding programs and decipher alfalfa expansion history in the world. (2) The use of markers to identify genes or locus that explain a substantial part of the variation (at least 10%) for quantitative traits. This could be obtained by association studies (correlation between genetic and phenotypic data) and/or by allele mining in candidate genes (reverse genetics). (3) The genomic selection based on all available markers to predict the phenotype of an individual from its genotype with a calibration set up on a training population. We emphasize the advantage of studies carried out at the population level that ease the phenotyping steps while allele frequencies are estimated on pooled DNA. Examples are mainly taken from the results of the European project EUCLEG (www.eucleg.eu) to illustrate the findings.

PANELS OF POPULATIONS AS A KEY MATERIAL

As alfalfa varieties, breeding materials, landraces and wild materials are heterogeneous populations, most studies aiming at analyzing genetic diversity are based on populations. Genotyping at the population level, with pools of individuals, have been successfully established in alfalfa with the GBS (Genotyping By Sequencing) methodology (Julier et al., 2018). This protocol has been optimized with a selection of two restriction enzymes that further reduce genome complexity and limit the number of missing data (Julier et al., 2021). Such a genotyping was cost-effective compared to the genotyping of a minimum of 30 individuals required to represent each population.

In addition to the knowledge obtained on genetic diversity, breeders are looking for molecular tools that could increase the genetic gain. Genome-wide association studies (GWAS) and genomic selection (GS) are dedicated methods to identify markers associated to phenotypic variation and to build prediction equations, respectively. The markers are then used to select individuals that either carry the best alleles and / or have the best genetic prediction. Up to now, specific populations are produced, they are mainly progeny of polycross from chosen parents (Annicchiarico et al., 2015; Li et al., 2015). If well chosen, this panel of individuals directly composes the breeding material on which the selection is applied. However, as most breeding traits are quantitative traits and require repeated measurements, offspring of each progeny must be obtained for phenotypic evaluation in dense swards. Instead, the panel for GWAS and GS can be composed of populations, so that seeds are directly available to conduct phenotypic evaluation in dense swards. Such a panel of populations offers the possibility to directly conduct both diversity and genetic analyses. An additional aspect is to consider the possibility to extend the diversity of the population. When choosing a panel of individuals, the extension of diversity requires new crosses that may be complex to connect to the initial progeny. With a panel of populations, the addition of new accessions is straightforward. If the same genotyping method is applied and if the phenotyping experiments are connected with control populations, the datasets may be joined. In addition, when the panel of populations is large enough, subsets of populations on targeted diversity can be sampled. A drawback could be the population substructure hampering the detection of QTL co-segregating with the kinship. In that case, crosses are needed to obtain linkage disequilibrium only based on physical links and not on substructure.

Below, we are reporting experiments conducted with panels of populations that we hypothesized to be efficient for genetic analyses.

A NEW VIEW OF ALFALFA GENETIC DIVERSITY

On a set of 400 cultivated populations, the GBS markers revealed a significant structure with continuous variation among European and American origins (Figure 1). The accessions from China were clearly different from the Western origins and from the two populations with ssp. *falcata* genetic background (Pégard et al., 2021). The breeding material of five European breeders has been plotted on the graph. Depending on the breeders, the range of diversity they provided for this study was either narrow (Figure 1 B) or more diverse (Figure 1 A) but in no case their material was close to North American nor Chinese diversity. Our aim is now to genotype the whole range of *M. sativa* species complex including natural populations in order to draw the history of alfalfa expansion in the world, from ancient until recent times.

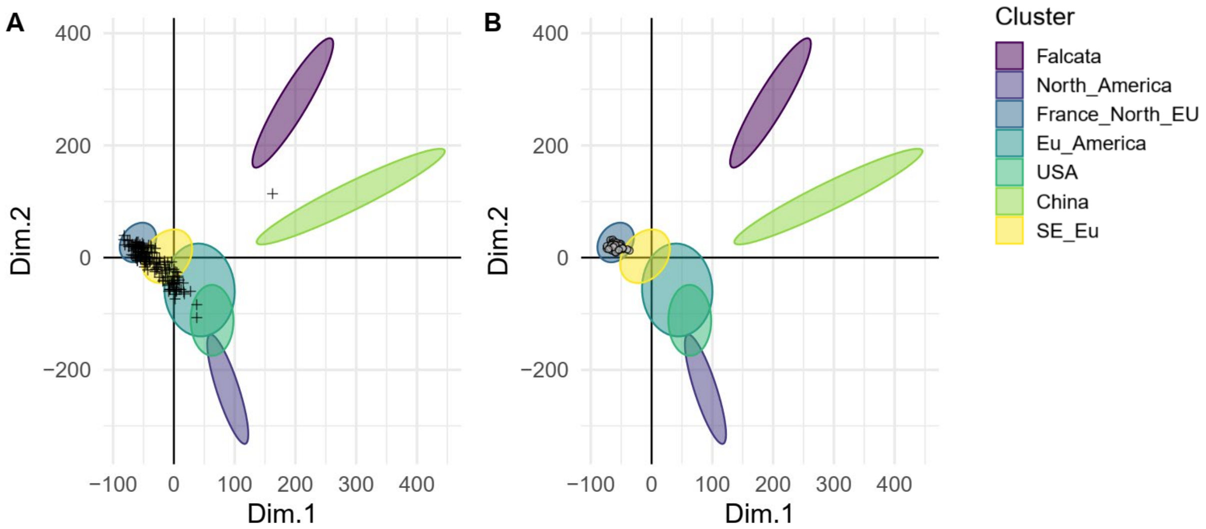

Figure 1. Graphical representation of the first two dimensions of a principal component analysis (PCA) for 400 alfalfa populations genotyped with ~ 100 000 GBS markers. Dim.1 and Dim.2 explained 4.9% and 3.3% of total genetic variation. The ellipses clustered populations after a Discriminant analysis on principal components and the clusters were mainly related to the geographical origins of the populations. Materials of European breeders were plotted on this PCA (black symbols), the cases of two breeders are represented (A) relatively large diversity, (B) narrow diversity of the breeding pools.

MARKERS ASSOCIATED TO TRAIT VARIATION: QTL

The panel of 400 populations was evaluated in field plots in two locations from 2018 to 2021 for forage yield and quality traits. More than 200 000 GBS markers (less than 5% missing data) were used for the analyses. With Genome Wide Association Studies (GWAS), significant QTL were observed for some but not all traits, each explaining up to 15% of the phenotypic variation. This results highlight that a few major loci act at explaining a part of the genetic variation, in addition to many markers with minor effects. The high genome coverage contributed to identify such major loci in this forward genetic strategy.

Another interesting strategy for seeking QTLs is to use previous knowledge in particular from model species in which gene effects on the phenotype have been demonstrated. These genes are perfect candidates for further investigation in other species. A reverse genetic strategy is to mine natural allele diversity for these genes in plant material. Such an approach was conducted in five genes involved in lignin pathway, growth and stress resistance (Gréard et al., 2018). Nonsynonymous variants were detected, more often in wild than in cultivated material. These variants could be used in breeding programs to select promising individuals. The huge advantage of this strategy is that once a variant is identified, it is highly probable that the mutation is the causal one so the linkage between the allele variant and the causal mutation cannot be broken.

GENOMIC SELECTION

The potential of genomic selection can be evaluated from the predictive ability that is the correlation between the true genetic values and the predicted values by using a genomic predictive equation. On our panel composed of 400 populations, with a large training subset of 270 populations, the predictive ability ranged from 0.50 to 0.66 depending on the trait (Table 1). These values of predictive ability were higher than those already published on panels of individuals.

The potential of using predictive equations established on population panels for the selection of individuals was proved to be relevant (Cericola et al., 2018). In these conditions, renewed versions of alfalfa breeding schemes can be conceived, in which the duration of a breeding cycle drops from 10 years in phenotypic selection to 2 years in genomic selection. Considering moderate trait heritability measured in the design and the phenotypic standard deviation, the genetic gain per year could be about 6 times higher in genomic selection than in phenotypic selection (Table 1). This calculation did not take into account the necessity to update the predictive equation which could be done in parallel with a short delay at each cycle.

Table 1. Predictive ability estimated for dry matter yield, ADF and protein contents combined over multiple cuts in Lusignan (France) and Novi Sad (Serbia)

Trait	h^2	Phenotypic standard deviation	Predictive ability	Genetic gain per year with phenotypic selection	Genetic gain per year with genomic selection
Dry matter yield (t/ha)	0.26	1.1	0.58	0.01	0.09
ADF content (%DM)	0.22	39.8	0.50	0.46	2.87
Protein content (%DM)	0.29	40.9	0.66	0.62	3.89

CONCLUSION

Promising results have been obtained with molecular markers in alfalfa. A new overview of genetic diversity offer prospects to better exploit untapped genetic resources in breeding programs in all the regions of the world. Anonymous markers or variants in candidate genes that explain a part of genetic variation can be used to select promising individuals. Genomic prediction, based on a panel of populations, reached high predicting ability. Genetic gain per year is expected to be improved by 6-fold in renewed breeding schemes. This concept still has to be proved, with the measure of achieved genetic grain. Implementation of genomic selection in breeding schemes also requires to optimize its cost efficiency. Two components are important, (1) production of genomic predictive equations and identification of major QTL for all breeding traits, (2) lowering of genotyping costs.

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ACKNOWLEDGEMENTS

This project has received funding from the European Union’s Horizon 2020 Program for Research & Innovation under grant agreement n°727312. We thank the seed companies and institutes that provided us with seeds of their accessions (AgriObtentions, Alforex, ART, Barenbrug, Cérience, CGS Sementi, CREA, DLF Seeds, Forage Genetics, Foratec Argentina, IFVCNS, IKBKS, INTA, INRAE-CRG Prairies, Lantmännen, NordGen, RAGT-2n). The staffs of INRAE (URP3F, FERLUS and GeT-PlaGe) and IFVCNS (Djura Karagić, Dragan Milić, Miroslav Zorić) are thanked for their deep investment to collect genotyping and phenotyping data.

BREEDING FOR ALFALFA COMPATIBILITY WITH CORN

Heathcliffe Riday, John H. Grabber, Wenli Li[1], Nicolas Enjalbert[2], Steve Wagner[3], and David Mickelson[4]

ABSTRACT

Alfalfa is the primary forage legume grown in the United States. Research and demonstration projects have shown that alfalfa can be successfully interseeded during its establishment year with corn grown for silage. This practice can increase overall system profitability and sustainability. The alfalfa establishment environment in this system is, however, very challenging due to shading, interspecies competition, and humid conditions under corn and this often results in poor stands of alfalfa during wet growing seasons. Studies carried out during 2015 and 2016 demonstrated considerable differences among alfalfa varieties in their ability to establish under corn. A subsequent study under corn in 2019 found one cycle of selection improved stand density of five alfalfa synthetics by an average of 35% over their parental base germplasms (105 vs. 78 plants m^{-2}). Based on these results further cycles of selection for alfalfa establishment under corn silage were initiated in 2020 and 2022. During 2022, fall ground cover of cycle-2 and cycle-1 selected intercropped alfalfa germplasms after corn harvest averaged 91% and 67% respectively compared 39% for non-selected germplasms. In another study, alfalfa RNA was isolated in July from leaf and root tissue after corn canopy closure from several selected germplasms and their non-selected base germplasms. Using an RNAseq approach comparing selected and non-selected germplasms, 345 differentially expressed genes (DEGs) were identified in leaves and 250 DEGS were identified in roots with 18 DEGs identified in both tissues simultaneously. Based on our results we anticipate further selection gains for alfalfa established under corn silage, possibly accelerated by DNA-based molecular markers. Ideally with enough selection, alfalfa varieties could be developed that successfully establish under corn silage without the need of pesticides or growth regulators. Such varieties would improve the reliability, profitability and sustainability of this intercropping system.

Key Words: alfalfa, corn silage, intercropping, breeding

INTRODUCTION

Alfalfa is the primary forage legume grown in the United States (USDA NASS, 2021). Corn silage in dairy systems is another major feed source that can often compete with alfalfa for dairy feed acreages on dairy farms (Russelle, 2013). Spring established alfalfa has less yield than alfalfa stands in post-establishment years. Fall established alfalfa prevents a full growing season of corn silage or soybeans in northern climates. Therefore, it is of interest to establish alfalfa stands while simultaneously being able to grow a high yielding forage such as corn silage. Extensive research studies and demonstration projects have shown that alfalfa can be successfully interseeded during its

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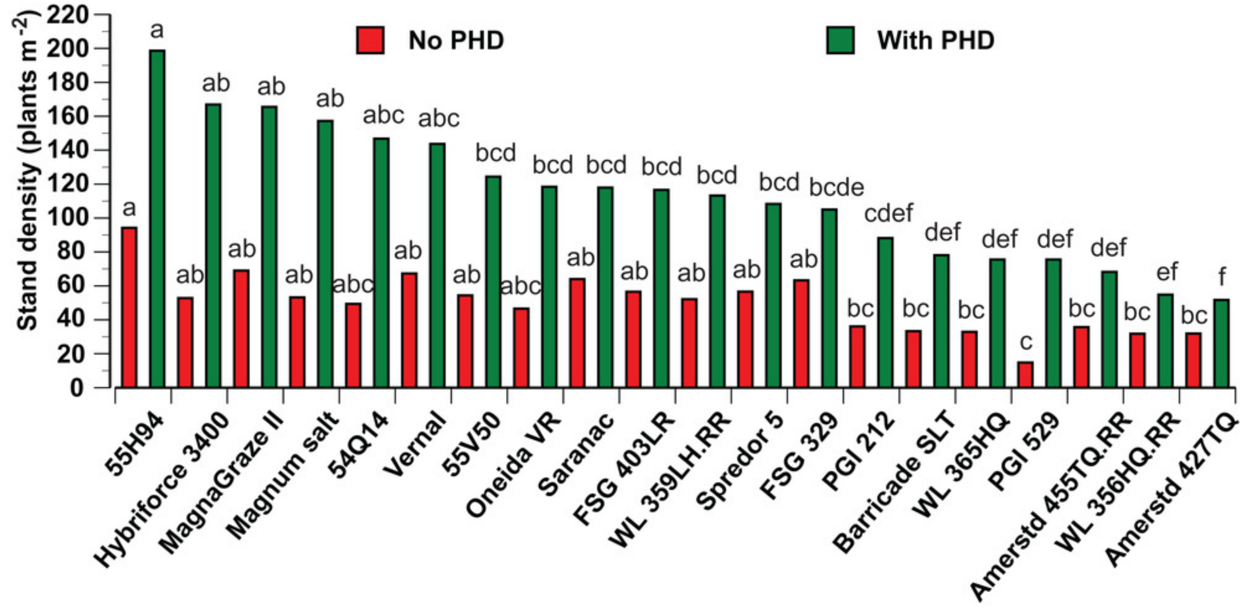

Figure 1. Final stand density of interseeded alfalfa varieties following corn silage harvest in 2015 as influenced by prohexadione (PHD) treatment. (Grabber et al., 2021b; Fig. 4)

establishment year with corn grown for silage and that this practice increases profitability and sustainability of the system (Grabber, 2016; Osterholz et al., 2019; Osterholz et al., 2020; Grabber et al., 2021a). This newer intercropping system maintains corn silage yields during alfalfa establishment while simultaneously producing dense alfalfa stands during alfalfa's establishment year. Keys to this system's success is applying a growth regulator (prohexadione) and fungicides to the alfalfa prior to corn canopy closure. Based on this work Grabber et al. (2021b) planted an alfalfa variety trial in 2015 and evaluated alfalfa stand establishment among varieties when intercropped with corn silage. Among the 20 varieties tested they observed a 282% and 527% performance differential depending on if the alfalfa stands were treated with a growth regulator or not (Fig. 1). These observations were indicative of substantial genetic variation for the alfalfa establishment ability under corn silage trait.

INITIAL SELECTION STUDY

Based on the results of the alfalfa variety trials (Grabber et al., 2021b) we decided to conduct a selection study for the alfalfa establishment ability under corn silage trait. In autumn 2017 parents of five synthetics were selected out the surviving alfalfa plants from variety trials established in 2015 and 2016 as part of the Grabber et al. (2021b) study. During 2017 and 2018 seed of the five synthetics was produced. The five synthetics were designated S&W-1 (109 parent), Alforex-1 (40 parent), Alforex-2 (47 parent), DFRC-1 (54 parent), and DFRC-2 (68 parent). In May of 2019 the five synthetics selected for increased alfalfa establishment ability under corn silage were planted along with each of the five synthetic's unselected parental base germplasms. The ten entries were planted in replicated trials along with a corn silage companion. In the study only alfalfa plots that were treated with the growth regulator prohexadione and fungicides had sufficient alfalfa stand for analysis. On average the five selected alfalfa synthetics had 35% greater alfalfa plant establishment density compared to the average of the unselected parental base germplasms (105 vs. 78 plants m^{-2}) (Fig. 2).

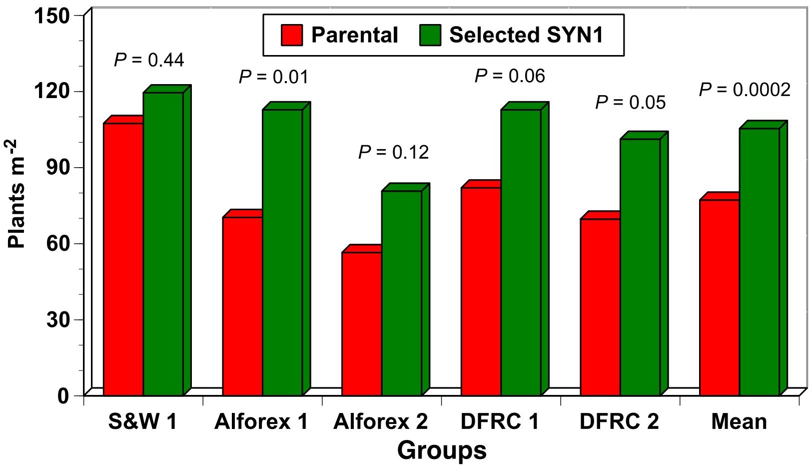

Figure 2. Final stand density of five selected alfalfa synthetics compared to their unselected parental base germplasms following intercropped corn silage harvest in 2019.

CONTINUING BREEDING EFFORTS

After observing consistent and marked selection gains for the alfalfa establishment ability under corn silage trait we decided to conduct additional selection for this trait. A second round of selection was made in spring of 2020 from alfalfa plots that had been planted in 2019 and intercropped with corn silage. These plots had very few surviving plants and 26 plants mostly DFRC-1 plants were recovered and intermated during summer of 2020 to form IntAlf20 syn1 which is a cycle-2 population. During summer of 2021 syn2 seed was increased on IntAlf20. In spring 2022 IntAlf20 (cycle 2), DFRC-1 (cycle 1), DFRC-2 (cycle 1), and 11 unselected germplasms were planted intercropped with corn silage. No growth regulator or fungicide was applied to the plots to maximize selection pressure. After corn silage was harvested in October 2022 plots were visually evaluated for percent ground cover. IntAlf20 (cycle 2) had 91% ground cover, while the cycle 1 entries averaged 67% ground cover, and the unselected germplasms averaged 39% ground cover. These observation show that repeated rounds of selection improve the alfalfa establishment ability under corn silage trait. Surviving superior alfalfa plants were selected out of the 2022 plots to further improve this alfalfa establishment trait.

RNAseq ANALYSIS TO IDENTIFY ALFALFA INTERCROPPING GENES

After determining that alfalfa's establishment ability under corn silage had a genetic component we conducted a study to identify potential genes associated with this trait. Using the 2019 study we chose two selected and unselected-base germplasm pairs from among the five germplasm pairs, one pair's base germplasm had superior alfalfa establishment ability under corn silage while the other had inferior establishment ability. In July 2019 alfalfa RNA was isolated from leaf and root tissue after corn canopy closure at the onset of increased alfalfa plant stress. Comparing selected and non-selected germplasms, 345 differentially expressed genes (DEGs) were identified in leaves and 250 DEGs were identified in roots with another 18 DEGs identified in both tissues simultaneously.

CONCLUSIONS

We anticipate further selection gains for alfalfa established under corn silage, possibly accelerated by DNA-based molecular markers. Ideally with enough selection, alfalfa varieties could be developed that successfully establish under corn silage without the need for pesticides or growth regulators. Such varieties would improve the reliability, profitability and sustainability of this intercropping system. Grabber et al. (2021a) found that an alfalfa stand's first autumn plant density should be around 200 plants m^{-2} or more to have good stands the following years. We anticipate with repeated rounds of selection that this target plant density will be achieved.

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UTILIZING GENESYS TO IDENTIFY WILD RELATIVES OF ALFALFA WITH ADAPTATION TO DIVERSE CLIMATES

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ABSTRACT

From its centers of origin, alfalfa (*Medicago sativa* L.) and wild relative populations have evolved to survive in highly diverse environments, with extremes that include the Arctic Circle, the desert areas of Kazakhstan and Western China, and the arid, Mediterranean areas of South Europe and North Africa. Alfalfa has further been disseminated anthropogenically, initially by ancient armies as a fodder source for horses, and in later European conquests to support emerging agriculture.

Here we demonstrate the use of Genesys, an online platform for housing information on global plant genetic resources, to identify a subset of alfalfa accessions collected from environments with bioclimatic variables linked to extreme drought, heat, and cold tolerance. The subset includes 28 alfalfa accessions originating from environments with an average monthly temperature range of -44–46 ºC, 0–3,414 m elevation, up to 68.25 ºN latitude and as low as 153 mm average annual precipitation (checked with satellite imagery to confirm no obvious supplementary water). The *M. sativa* subsp. represented in the subset include 14 subsp. *sativa*, 4 nothosubsp. *varia*, 1 subsp. *caerulea* and 9 subsp. *falcata*. The subset also contains 2 *M. sativa* subsp. *falcata* accessions collected from the extreme mildest winter temperature for this sub species, where the minimum temperature of the coldest month was at least 3 ºC. The alfalfa climate adaptation subset, which is available for request from https://www.genesys-pgr.org/subsets/0367d084-95c8-4d26-85d1-c14b98ebbb7b, will now be characterised for key phenotypic traits and molecular diversity. The alfalfa and wild relatives assembled in this subset provide important unique diversity for a range of abiotic traits that can be introgressed into alfalfa to support carbon neutral farming and extend or maintain the range of alfalfa production for environments with changing climates.

GENESYS

Genesys, https://www.genesys-pgr.org, is an online platform for managing information on global plant genetic resources, assembling databases from individual genebanks at one location. The mapping feature of Genesys displays the global distribution of collection origins for accessions that are georeferenced, proving excellent information on the known geographical distribution of a species (Figure 1). This feature allows the user to refine their search for accessions based on latitude, longitude, and elevation. The georeferenced data is also overlayed onto www.worldclim.org datasets, which further allows accession lists to be refined using a range of bioclimatic variables (rainfall, temperature, seasonality etc.).

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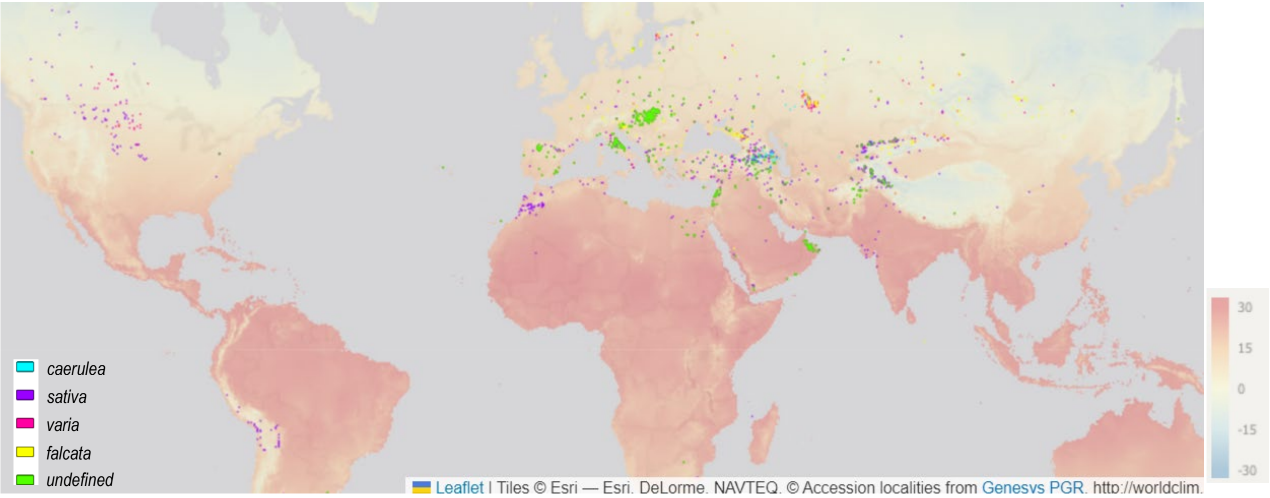
We used Genesys to summarize the geographical and climatic adaptation of *M. sativa* based on collection origins, and identify individual accessions collected from the most extreme environments. The accessions are available as a subset, hereafter 'alfalfa diverse climate adaptation subset' and can be viewed and requested as a group through https://www.genesys-pgr.org/.

ALFALFA ACCESSION DIVERSITY BASE ON COLLECTION ORIGIN

There are 19,736 alfalfa accessions held in international genebanks, with 2,494 of these accessions georeferenced (i.e., have latitude and longitude information, Table 1, Figure 1). The United States Department of Agriculture, National Plant Germplasm System (USDA NPGS) houses the largest collection of alfalfa germplasm (Irish and Greene 2021) , followed by the Vavilov Institute of Research (VIR) and Australian Pastures Genebank (APG). Some duplication exists between the three genebanks (because of germplasm exchanges), with for example, 638 of the APG accessions being known duplicates with Plant Introduction (PI) or Western Regional Plant Introduction Station (W6) numbers. The introduction of Digital Object Identifiers (DOI) numbers, being considered by several national genebanks, will identify further duplication.



M. sativa* subspecies	**NPGS**	**VIR[+]**	**APG**	**Other**	**Total**
caerulea	97 (41)	67 (0)	182 (122)	86 (9)	432 (172)
sativa	3,372 (920)	2,470 (0)	1,165 (161)	879 (49)	7,886 (1,130)
varia	437 (202)	714 (0)	412 (223)	676 (53)	2,239 (478)
falcata	457 (297)	335 (0)	303 (205)	301 (108)	1,396 (610)
glomerata, tunetana, viscosa	33 (13)	53 (0)	57 (27)	37 (0)	180 (40)
undefined	8 (0)	0 (0)	576 (32)	7,019 (32)	7,603 (64)
Total	**4,404 (1,473)**	**3,639 (0)**	**2,695 (770)**	**8,998 (251)**	**19,736 (2,494)**

*Current Germplasm Resources Information Network (GRIN) taxonomy. [+]Classified as species not subspecies: *M. caerulea*, *M. sativa*, *M. falcata.* VIR accessions are not referenced on Genesys. *M. sativa* was used as *M. sativa* subsp. *sativa* for RUS001, consequently no accessions remain undefined. Information collated from Genesys-PGR and GRIN-Global databases. Background displays annual mean temperature.

Figure 1. The number and distribution of *Medicago sativa* L. subsp. accessions held at the NPGS, APG and other international genebanks, listed on Genesys (November 2022). Numbers in parenthesis indicate number of georeferenced accessions.

The adaptation of the *M. sativa* complex to a range of geographic and bioclimatic variables, based on the collection origin of georeferenced accessions, is shown in Figure 2. The subsp. *sativa* has the greatest range of adaptation, but these results are also skewed by the higher representation in genebanks.

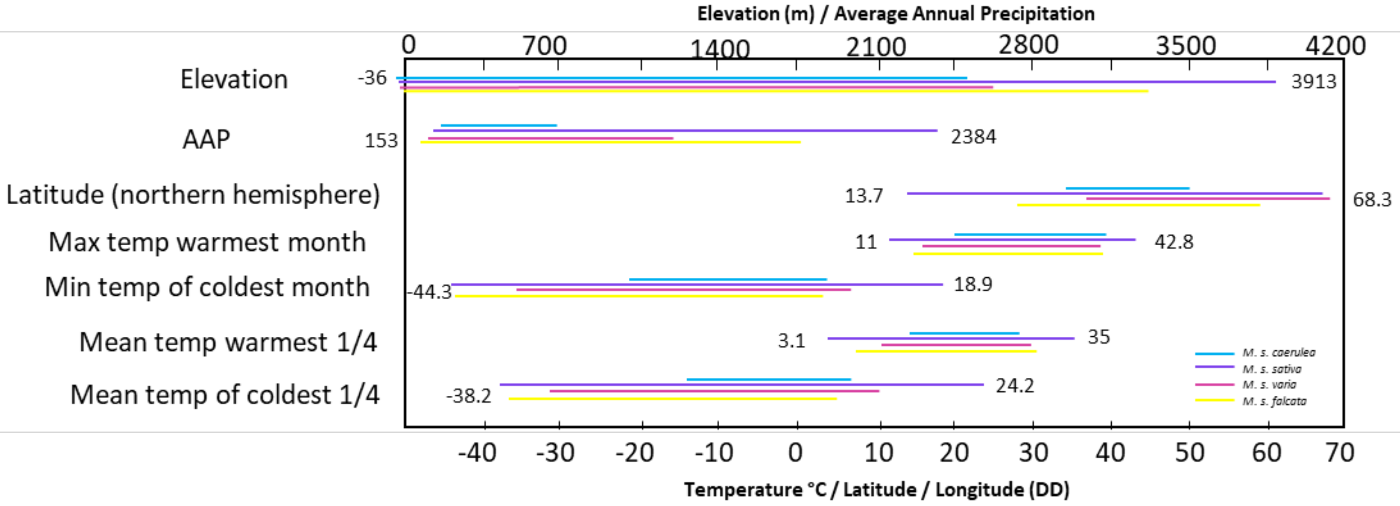


Figure 2. Adaptation of *Medicago sativa* L. subsp. accessions [wild, (natural, semi natural), traditional landrace and unclassified] to different environments based on elevation, average annual precipitation (AAP), northern hemisphere latitude, and bioclimatic variables that include the maximum temperature of the warmest month, minimum temperature of the coldest month, mean temperature of warmest quarter, and mean temperature of the coldest quarter. Extreme values at species level shown for each variable.

ALFALFA DIVERSE CLIMATE ADAPTATION SUBSET

The alfalfa diverse climate adaptation subset contains 28 accessions including 14 subsp. *sativa*, 4 nothosubsp. *varia*, 1 subsp. *caerulea* and 9 subsp. *falcata*. (Table 1). The subset has been developed to allow users to easily identify and request seed of accessions that represent extremes in adaptation of the species.

The success of the subset in achieving the goal of identifying accessions with extreme adaptation relies on the accuracy of the recorded georeference, which is known to have a degree of uncertainty. This uncertainty is particularly relevant when using this method to identify drought tolerance, because rainfall is inherently variable over short distances. We used Google Maps satellite imagery to identify accessions with low average annual precipitation that weren't obviously receiving supplementary water from irrigation or waterways, and this relies on a relatively accurate georeference. For this reason, we identify several accessions to represent extreme variability for each geographic and bioclimatic trait.

The APG is regenerating seed of the subset, and there are plans to have the whole subset available for distribution by June 2023 from both the APG and NPGS.

In addition, the climate adaptation subset will be evaluated for phenotypic and agronomic traits as well as molecular diversity. Data and results from all evaluations of this subset will be available at Germinate 3, https://ics.hutton.ac.uk/cwr/alfalfa/#/home and from GRIN-

Global. It is hoped that the climate adaptation subset is used together the original alfalfa core collection (Basigalup 1995) and any future core collections developed using modern genomic sequencing methods.

Table 1. Alfalfa (*Medicago* sativa) diverse climate adaptation subset.

Selection Criteria	OS	APG	NUMB	SUB-SP	CTY	LAT	LONG	ELV	AAP	ATR	TWM	TW 1/4	TCM	TC 1/4
1. Northern Latitude (LAT)	3,4, 8	85092	PI 631833	falcata	SWE	68.25	13.83		1,341	18.3	13.9	10	-4	-2
		85104	ABY-Af 1430	falcata	RUS	65.30	115.94		303	65	21	12	-44	37
		85095	PI 251692	sativa	RUS	67.62	33.65		571	34	17	10	-17	-12
		85097	PI 452469	sativa	CAN	61.17	-113.67		302	51	21	14	-30	-23
2. Max Elevation (ELEV)		43047	W6 14166	varia	IND	34.14	77.56	3257	119	37	18	10	-20	13
		85088	PI 631612	falcata	NPL	28.82	83.85	3414	402	25	15	9	-10	-3
		85101	PI 632066	sativa	PAK	35.29	75.65	3277	139	39	16	9	-23	-17
		85102	W6 23584	sativa	CHN	31.33	100.73	3060	643	34	21	14	-13	-2
3. Ave Annual Precipitation (AAP)		16453	MJM 7318	sativa	IRN	35.87	51.47	1935	182	42	30	20	-12	-5
		21565	CPI 103195	varia	LBY	31.40	15.63	40	157	26	33	27	7	13
		38309	IFMI 2362	sativa	SYR	33.53	36.35		190	34	36	24	2	8
		43145	PI 384890	sativa	IRN	36.42	55.02	1700	163	35	33	25	-3	4
		84274	VIR 50713	varia	KAZ	47.84	59.62	173	183	51	32	23	-18	-12
		84837		caerulea	KAZ	47.72	56.06	85	195	49	33	24	-16	-10
		84976	PK-CWR-0035	varia	PAK	35.77	75.39	2534	162	39	26	18	14	-8
		35189	PI 499663	falcata	CHN	44.09	88.51		197	50	30	22	-20	-13
4. Annual Temp range (ATR)	1,8	85103	W6 40005	sativa	RUS	61.92	129.66		249	70	26	16	-44	-38
5. Max Temp warmest month (TWM)		38231	IG 101387	sativa	IRQ	36.35	43.12		466	41	43	31	2	9
		6742	PI 202824	sativa	SAU	24.23	47.37		87	33	43	34	10	17
	6	85094	PI 145202	sativa	SAU	21.43	39.82		69	25	42	35	17	24
6. Mean Temp warmest ¼ (TW1/4)		38322	IFMI 2427	sativa	OMN	23.67	57.83	0	75	24	40	34	16	21
		85096	PI 380916	sativa	IRN	27.27	53.60		156	28	37	31	9	16
		85100	PI 516841	sativa	MAR	29.82	-5.72		39	41	46	35	5	14
		85093	W6 39982	falcata	RUS	22.65	39.76		72	27	38	31	11	19
7. mild climate falcata		36133		falcata	GRC	39.16	23.49	56	497	28	32	26	4	9
		85085	PI 631584	falcata	ITA	45.65	13.78		1,077	24	28	23	3	6
8. Min Temp coldest month (TCM)	3	85091	PI 631679	falcata	MNG	49.86	92.07		144	61	25	17	-36	-28
		85089	PI 631676	falcata	MNG	49.50	94.35		244	58	21	14	-37	-29

OS = other selection criteria accession matches in first column, APG = Australian Pastures Genebank number, Numb = other numbers, SUB-SP = M. sativa subspecies, CTY = country of origin, Lat = latitude, LONG = longitude, ELV = elevation, AAP = average annual precipitation, ATR = Temperature annual range (bio5-bio6) [°C], TWM = Max temperature of warmest month [°C], TW1/4 = Mean temperature of warmest quarter [°C], TCM = Min temperature of coldest month [°C], TC1/4 = Mean temperature of coldest quarter [°C]

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ACKNOWLEDGEMENT

This work was undertaken as part of the initiative "*Biodiversity for Opportunities, Livelihoods and Development*" (BOLD) which is supported by the Government of Norway. The project aims to strengthen food and nutrition security worldwide by supporting the conservation and use of crop diversity. BOLD is managed by the Global Crop Diversity Trust and implemented in partnership with national and international genebanks and plant breeding institutes around the world. For further information, go to the project website: https://www.croptrust.org/work/projects/the-bold-project/

CHALLENGES WITH DRYING ALFALFA AND OTHER FORAGES

Edward J Shaw[1]

Since the beginning of modern-day agriculture, farmers have had the challenge of getting the right moisture to achieve optimum yields and best quality without spoilage.

A. Wet weather problems.
1. All too often, farmers cut their forage crops, have it almost ready to bale; yet the moisture is still too high for it to keep, and a heavy rain comes in. The results are additional loss of color and quality.
2. In many places in North America and around the world, high yield forages can be grown but due to humidity, dews, etc., it is impossible to get the last 5 to 10% moisture out to reach an acceptable preservation level to be baled. Processing the crop as haylage or silage is the solution, however operation costs rise, reduces the potential market to local area, restricting distance transport and eliminates export opportunities.

B. Extreme dry conditions
1. Every farmer has experienced the disappointment of loss of income when there is leaf loss due to baling hay when it is at the moisture level required for it to keep. Often, by the time the stems are cured, the potentially over dried leaves can break from the stems and/or disintegrate during the baling process. The results are stemmy skeleton hay with low RFV and reduced yields.

   A solution to this challenge is a steamer, that potentially will maintain color, increases quality and yield.

Moisture problems affect Hay Growers around the world and each area has its own harvesting challenges. The art and science of drying hay can become complex very quickly with so many variables, however it can be simplified into two categories: either the hay is too high moisture to be baled and appropriately preserved or the moisture is too low and quality, yield and profit decrease.

History of the Agri Green's development of the AG Maximizer Hay Dryer

Emil Gulbranson and Sons of Vanderhoof, British Columbia Canada, a farmer, logger, and world hay exporter experienced ongoing difficulties drying hay in 2016. The challenges faced due to extreme wet harvesting conditions initiated a search of alternative hay drying methods.

Emil researched hay dryers around the world; travelling to access and evaluate bed dryers, barn dryers and spike dryers, some of which were successful in Europe. The dryer that he was most satisfied with, as far as drying efficiency, was stationary, costly and did not meet his needs as it would only dry two 3X4 bales at a time.

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In: Proceedings, 2022 World Alfalfa Congress, San Diego, CA, November 14–17. UC Cooperative Extension, Plant Sciences Department, University of California, Davis, CA 95616. (See http://alfalfa.ucdavis.edu for this and other alfalfa conference Proceedings.)

He researched lumber dryers and over time designed a unique compressor/fan combination to give the volume and pressure required to create heat and be large enough to dry at least twenty (3X4X8) bales/hour. A prototype was created, and testing began. When he ran out of fresh baled hay to dry in Vanderhoof, he contacted me to see if there was hay to dry in Southern Alberta. We arranged for him to come to the Lethbridge area and dry wet bales at the Hay Exporter facilities, Green Prairie.

We were drying 3rd and 4th cut and some of the samples had an RFV of 212 and increased protein to 21 % I took a pressed sample to a trade show in the Middle East, and the USA alfalfa exporters could not believe 1) it came from Canada and 2) after pressing the leaves were attached to the stem.

We have sold units in 5 countries, including South Africa, Poland, two into the UK, six in various states and eight across Canada.

How it works

The technically designed fan/compressor in combination with a Tier 4 or Stage 5 400 HP diesel engine captures all the radiant heat from the engine (approx. 50 degrees F) in addition to the friction of the air in the compressor (another 50-degree F). This combined heat increase of 100 degrees F over ambient is available at no added cost. For example, if ambient air temperature is 80 degrees F, the heat produced by the unit will increase the temperature of the air blown through the spikes into the bale to 180 degrees F. The AG Maximizer dries hay from inside out. This process can reduce moisture levels from 25% to 15%. The bales are then stored on edge, three high with a space between the bales and over the next 24 to 96 hours the bales will lose another 3 to 5%. As the heat comes out of the bales, it also takes out this moisture.

What this means to a farmer.

1. A farmer can bale in the 25% moisture range and retain a greater crop yield and quality (minimum leaf loss), then dry the bales to the desired moisture level. This approach widens the window that enables farmers to produce consistent moisture levels and retain leaf, adding value to their product.
2. A farmer in wetter climates can bale earlier and dodge the storms and retain color, quality, and quantity.
3. The AG Maximizer enables a farmer to start baling earlier in the day and later in the evening when moisture levels are above 15% (better for leaf retention). Baling can continue through mid-day, processing fully sun-cured hay that does not require drying. The AG Maximizer extends baling hours considerably and as a result can lessen the need of an additional tractor and baler.

Cost of operating

1. Fuel used is approximately fifteen gallons/hour. Averages .83 gallons/bale.
2. One operator.
3. One telehandler, skid steer or loader unit.

Since the prototype was developed in 2017, Agri Green has sold eighteen units (including one round bale unit) worldwide to dry areas, high humidity locations and regions in which rain conditions are challenging.

Some of the findings.

1. Alfalfa can be baled at 25% and we have had increases in RFV, protein and even yield increase by two hundred pounds per acre.
2. Round Bermuda bales (baled after second day after cutting) had 111 pounds of weight (water) removed by AG Maximizer Hay Dryer from a 1300-pound bale.
3. Grass and or mixed hay dries the best, higher density bales talk more time to dry.
4. Some producers have been able to reduce one tractor and baler by starting earlier, going later, and having the balers bale dry hay in the middle of the day.
5. One customer had a section pivot of timothy and he baled ½ the field with high moisture in the morning and processed through the dryer and waited for the rest to dry naturally and then bale. When a major pet food company looked at the hay, they bought all the hay processed through the dryer and not the sun-dried hay, as the hay through the dryer was softer and not shattered and dusty.
6. On two tests, one in Alberta and one in Arizona, forty% moisture hay was dried down to 25%. Several weeks later the hay still had the same color, no smell, and had kept. We are continuing research to verify and conclude what occurred.
7. Our first client has his 17-year-old daughter load, dry, unload and reload the dryer and in a 10-hour day will do more than two hundred bales.
8. Fuel used is less than one gallon per bale.

Background to support the anecdotal findings in the development of the Agrigreen Maximizer Hay Drier

1. Loss at baling, pick up and chamber Source Pitt. R.E 1990 Silage and hay preservation Ithaca NY
    a. Yield and leaf loss at 25% is 4% yield loss and 4% leaf loss
    b. Yield and leaf loss at 20 is 6 % yield loss and 4% leaf loss
    c. Yield and leaf loss at 12 % moisture is 6% yield loss and 8% leaf loss

Yield and leaf loss	Moisture %	Yield loss in %	Leaf in %
	25	4	4
	20	6	4
	12	8	8

Both yield loss and leaf loss doubles when going from 25% to 12 %

2. Hay loss barn dried to Field cured Source Michael Collins - Forage and Research Department of Agronomy University of Kentucky, Lexington
    a. Barn dried % of barn dried harvest losses is 10% to 18%
    b. Field cured hay is harvest losses is 18 to 24%

Barn dried to field Suncured losses	
Barn dried	Suncured losses
10 to 18%	10 to 24%

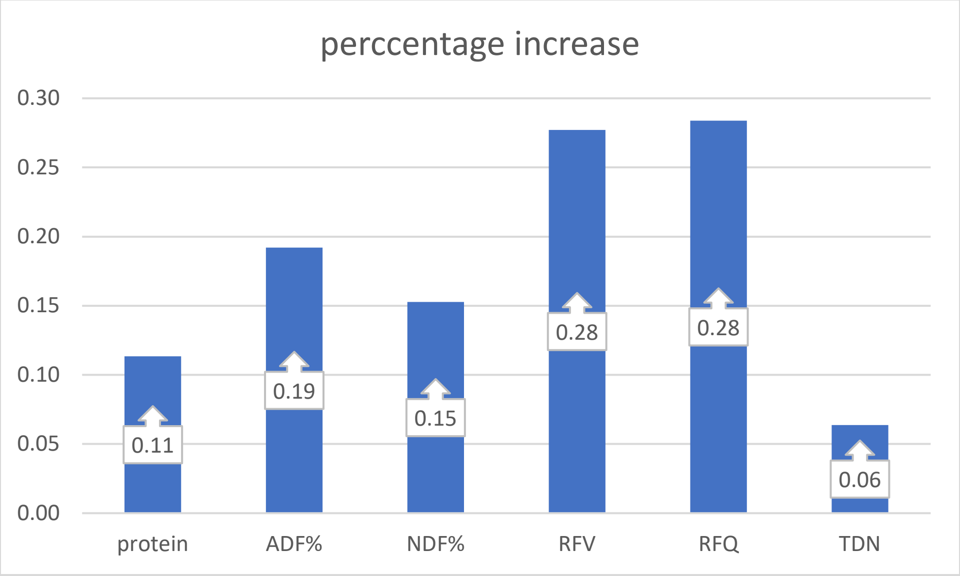
3. Leaf retention loss source Doug Rich High Plains Journal updated 6/21/21 and Jeff Roberts Farm Tec Inc. Hudson, Wisc.
    a. Baled alfalfa at 20% moisture has 20% leaf loss
    b. Baled alfalfa at 10% moisture had up to 50% leaf loss

Leaf loss from 10% to 20% moisture	Leaf loss
20 %	20%
10%	50%

4. Potential value from leaf loss Dr. Dan Undersander
    a. Consider hay at $210 per ton, and $1 per point of RFV (relative feed value) for a two ton per acre yield for every one percent leaf loss equals $14 per acre
5. Quick test and trial done in Tonapah in 2020

Agrigreen sent a test unit to Tonapah in 2020. The field was had both bales were both dried at over 20% and then the bales from the same field and cutting were allowed to dry down and be baled with out drying. The table is an average of both types of bales evaluated* Note   This test was for twenty-one bales of both Suncured and dried. Lab tests were sent out to a lab. We did not weigh the bales

	moisture	protein	ADF	NDF	RFV	RFQ	TDN	
Average Suncured	9.43	20.7%	27.35	33.08	190	182	61.83	
After drying with dryer	14.23	23.05	22.10	28.03	242.67	233.67	65.77	
% change		11.35%	19.19%	15.26%	27.72%	33.33%	6.37%	



From the above research and tests, it is obvious that the higher moisture you can bale, the higher the yield and the higher the quality

With the Agrigreen Maximizer Hay drier, farmers can bale earlier,

1. Reduce weather risk
2. Bale to keep more yield and more quality. This increases more dollars per ton and dollars per acre
3. Use this in high humidity area
4. Use this in dry desert conditions to reduce leaf loss

Advantages of Agrigreen Maximizer hay Drier

1. Only portable stand alone drier in the market
2. Can be made fully portable or stationary. In portable model can be driven to field/shed and be fully operational in 10 minutes
3. Only requires one person to operate
4. Is stand alone, does not need hook up to power, gas, biogas, or external heat supply
5. Has been sold and proven into UK, Europe, South America, USA, and Canada

USING A DEWPOINT STEAMER TO MINIMIZE LEAF LOSS DURING HAY BALING

Logan Staheli

ABSTRACT

Staheli West, located in Cedar City, Utah, manufactures 2 versions of hay steamers. The DewPoint 331 hay steamer is used in the 2-tie, 3-tie, and round bale markets. The DewPoint 6210 is used in the large square bale market. Both machines use a boiler and diesel fired burner to turn water into steam. The steam is applied to the cured hay during the baling process through a series of distribution manifolds mounted onto the baler. The steam is injected into the hay at the pickup of the baler and further as the hay passes through the feed chamber. Steam application during baling significantly reduces leaf loss compared to baling with natural dew. Researchers at the University of Wisconsin conducted field experiments on the effects of steam on hay during the baling process. They found that compared to dew rehydration, steam re-hydration reduced baler leaf loss by an average of 58% for large square balers and 43% for 3-tie balers. In another study from the University of Wisconsin, leaf percentage was shown to account for 71% of the variation in alfalfa quality. Reducing leaf loss is important and baling with steam is proven to be very effective.

Key Words: hay baling, baling hay, steaming hay, hay steamer, dewpoint steamer, alfalfa, alfalfa leaves, rfq, forage quality, hay quality

INTRODUCTION

Leaf loss is one of the major factors negatively impacting harvested alfalfa forage quality. University of Wisconsin research has shown that leaf percentage accounts for 71% of the variation in forage quality. Leaves have a relative forage quality (RFQ) of approximately 550, while stems have an RFQ of only 70 to 80 (Weakly and Rodgers, 10). The DewPoint hay steamers have been proven to effectively reduce leaf loss. In studies done by both the University of Wisconsin and INTA out of Argentina, hay baled with steam is shown to contain more leaves, have a higher bale density, and better appearance. Why is steam so effective at softening the hay and reducing leaf loss? Why is leaf retention in hay so important? What do the studies say about the DewPoint hay steamer? We will discuss these questions in our presentation at the World Alfalfa Congress and in these proceedings.

WHY USE STEAM?

Steam is the hot gas that forms from water when it boils. 1 Gallon of Water Produces Around 1,700 Gallons of Steam. Unlike particles in the solid or liquid state, gas (steam) particles are widely separated and are free to move randomly and can therefore penetrate into the tiny pores of hay easier than water or even natural dew.

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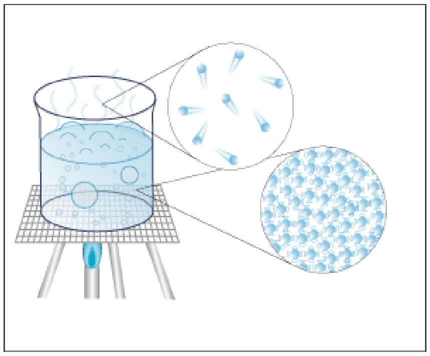
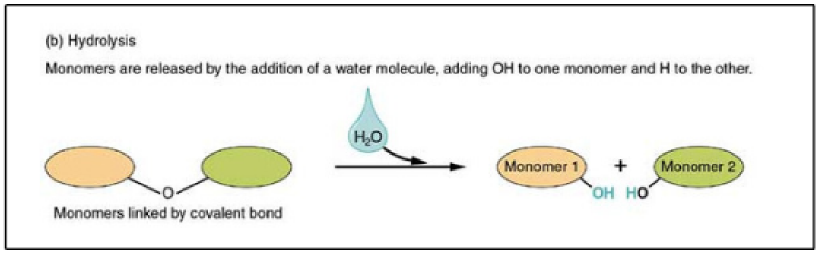


Steam breaks down and softens the hay through a process called Hydrolysis. Hydrolysis ("hydro" = water and "lysis" = break) involves adding water to one large molecule to break it into multiple smaller molecules (Bio Explorer.net).



BALER HARDWARE DESIGN

The treatment of the hay is accomplished by injecting steam through a series of distribution manifolds mounted in the baler. These manifolds are designed to reduce leaf loss. Moisture is monitored by a moisture sensor and adjustments to the steam rate are made by the operator in the cab.

UNIVERSITY OF WISCONSIN STUDY

In 1998, Researchers at the University of Wisconsin conducted field experiments on the effects of steam on hay during the baling process. Two experimental conditions were evaluated in all tests. Baling at night when dew re-hydration was apparent (natural dew) and baling in the day with steam rehydration when the hay was less than 12% moisture. The study states:

> Compared to baling with dew rehydration, steam re-hydration significantly reduced baler losses by an average of 58% (1.2% to 0.5%, respectively) for large square balers and 43% (0.7% to 0.4%, respectively) for 3-tie balers. Although not quantified, visual observation of steam re-hydrated alfalfa bales indicated that leaf retention on the stems was superior to that of bales formed with dew rehydration. Compared to bales formed with dew re-hydration, steam re-hydration increased bale density by an average of 20% and 30% for large and 3-tie bales, respectively (Shinners and Schlesser).

INSTITUTO NACIONAL DE TECNOLOGIA AGROPECUARIA (INTA)

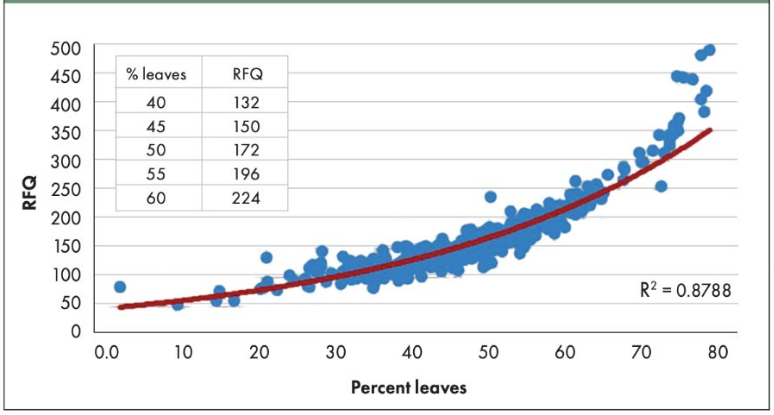
In another study performed in Argentina, INTA learned of the benefits of the DewPoint steamer. They found that the steamer adds 5% of moisture to the windrow. So, if your hay is bone dry, you can bring it up to an optimal moisture range. They also found that after 15 days from the time of baling, the steamed hay bales returned to the initial windrow moisture. This is important for operations storing hay and exporting hay in shipping containers. INTA also found a 41% reduction of dry matter loss during baling. So, there is a significant reduction of leaf loss when baling with steam. They also found a 15% increase in bale weight and density of the big bales, which is important for hay transportation and exporting. Their study also covers the increased efficiency of operations with steamers, and an increase in quality of life of all those involved. They state that steamed hay looks and holds together better, and that crude protein was 1.1% better in the steamed hay. Lastly, they found that the DewPoint hay steamer provides predictability by being able to control moisture conditions (Zavalia).

LEAF (LEAVES ENHANCE ALFALFA FORAGE)

In a study by David Weakley and Charlie Rodgers, they discuss how leaves impact the quality or RFQ of hay. They found that for every 1%-unit change in leaf percentage, there was a corresponding rise or drop in RFQ of 4.6 units. Further research by Dan Undersander found that a 1%-unit loss of leaves drops the value of the hay or haylage by $7 per ton (Undersander). That loss encompasses both yield loss from losing the sheer weight of the leaves, and quality loss, with quality making up the highest percentage (Weakley and Rodgers). So, losing leaves means losing tonnage and quality. Typically, when an operation purchases a steamer, their big bales weigh 100-150 lbs. more than they did before and it's not water weight. It's more leaves in each flake of the bale.   These studies show that reducing leaf loss has a huge effect on the profitability of an operation.

Other takeaways from the study show that the average leaf percentage of standing alfalfa is around 50% and according to LEAF baled hay or haylage with 45% leaf percentage is ideal, 40-45% leaf percentage leaves room for improvement, and if leaf percentage falls below 40%, significant leaf loss has occurred (Weakley and Rodgers). With proper harvest practices and barring rain and other significant weather events, most farms running steamers correctly are making ideal hay all the time.

Figure 3. Influence of percent leaves on RFQ



TWO HARVEST OPERATIONS THAT ARE CRITICAL

Raking

The DewPoint steamer can do some pretty amazing things, but one thing it can't do is make leafy hay bales when there aren't any leaves in the windrow to begin with. Raking is a critical process that has to be done right if you want to make ideal hay. A lot of leaves can be lost during the raking process. Many new DewPoint steamer customers become more conscientious about their raking practices after they purchase a steamer. They invest a lot of money in the steamer, so they increase their focus on their other harvest practices to get the largest ROI. A lot of money can be lost raking without proper moisture conditions.

When someone buys a DewPoint steamer, we train them to rake before the hay gets too dry. This allows the leaves to stay intact and gives the steamer the most potential to pay for itself quickly. As mentioned previously, the steamer reduces leaf loss by over 58%, so the more leaves that are in the windrow, the more leaves the steamer can preserve (Shinners and Schlesser).

Baling

Baling hay too dry to beat storms, or because of a lack of dew is another way farmers can leave a lot of leaves and money on the ground. Farmers can't always rely on mother nature for proper moisture conditions. The DewPoint steamer allows the operator to apply the optimal amount of moisture in the form of steam to reach the target moisture percentage in each bale.

AN EXAMPLE OF WHAT THE STEAMER CAN "DEW" FOR YOU

Let's say you bale conventionally with dew and lose 3-5% of leaves conservatively, so you're still making good hay, maybe even ideal hay as defined by the LEAF study. However, a 3-5% loss of leaves equates to a $21-$35 per ton loss according to Undersander's research. By baling with steam, a farmer can reduce their leaf loss by 58% and make an extra $12-$20/ton due to increased bale density and quality. Do the math on your operation. How many tons of baled hay do you produce each year and times that by $12-20 per ton? Suddenly the steamer isn't viewed as a cost but rather as an investment and an investment that will pay for itself repeatedly (Undersander).

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