Alfalfa, Wildlife & the Environment

SECOND EDITION

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Alfalfa, Wildlife & the Environment

American farmers harvest about 18 million acres of alfalfa annually, making it the fourth most widely grown crop in the country behind only corn, soybeans, and wheat. Its value in 2018 reached nearly $10 billion, exceeding even wheat to make it the third most valuable crop nationwide. However, mention the word "alfalfa," and most people would think about the sprouts used on their salad—a minor use. Very few would recognize the important role alfalfa plays in their lives in the form of milk, cheese, ice cream, honey, leather, or wool. Fewer still would recognize the roles that alfalfa plays in maintaining a diverse farm landscape and a healthy environment. This publication was developed to allow readers to become more familiar with alfalfa's importance as a crop, and its contributions to broader social goals.

In the two decades since the first edition of *Alfalfa, Wildlife, and the Environment* was published, environmental activists and organizations have come to understand working farmland as a vital part of natural ecosystems, with exciting potential to contribute to biodiversity, water quality, soil health, and wildlife conservation. Promoting perennial crops and nitrogen-fixing legumes like alfalfa is now an integral aim of the environmental movement and connections are being built between wildlife conservation advocates and farming and crop production organizations.

At the same time that this shift has taken place, however, the proportion of farmers in the U.S. population has continued to decline, and it is safe to say that very few in the general public have an in-depth appreciation of crop production. A public disconnected from agriculture is particularly a problem for alfalfa, which is two steps removed from the dinner plate, but important for human nutrition nonetheless. Each section of this document introduces concepts that must be understood in order to accurately assess the impact and value of alfalfa as a crop:

- **Alfalfa is vital to our food system.** Alfalfa's primary end use is as a feedstuff for cattle and other livestock, which makes it a crucial part of the production of beloved dairy foods like ice cream and cheese. It is also a valuable horse feed, and new uses are also being developed for alfalfa protein in foods for pets, fish, and even humans.

- **Alfalfa builds and protects soil.** Alfalfa offers unique benefits as a perennial crop, including building organic matter for structure, stability, and water holding capacity. By providing year-round living cover, it nourishes healthy soil biological activity and offers physical protection from wind and water erosion.

- **Alfalfa benefits our insect friends.** Alfalfa plays an important role as a food source and habitat for pollinators, predators of crop pests, and other beneficial insects. This makes it a valuable resource for the honey industry, as well as a tool for the conservation of native pollinator diversity.

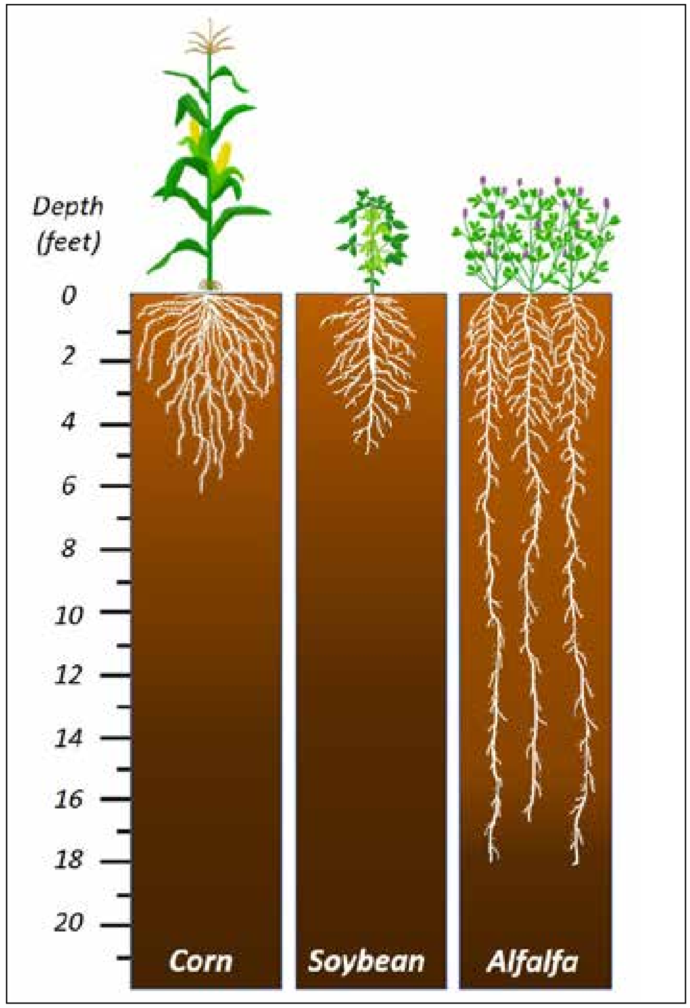
- **Alfalfa feeds and shelters wildlife.** Alfalfa is used by game and nongame wildlife, including nesting and migratory birds. The insects and small mammals feeding on alfalfa fit into a greater food web in the ecosystem, supporting birds and larger carnivores. Wildlife organizations help to advise farmers on harvest practices and schedules that can ensure the safety of nesting birds.

Alfalfa research supports sustainability and productivity. A successful alfalfa crop relies on the skilled attention of the farmer. Farmers apply research-based recommendations and personal experience to choose management practices that will maximize the productivity of their stands, optimize winter survival, control pests, and make efficient use of water resources.

Alfalfa supports the whole farm. Alfalfa can boost the yield of other crops in a farm's rotation, and can even reduce the need for chemical inputs. It is particularly known for its benefit to corn, which draws on the nitrogen fixed in the alfalfa's roots. This nitrogen contribution, as well as alfalfa's weed- and pest-suppressive abilities, make it an especially valuable crop for farmers using integrated pest management or organic practices.

Alfalfa provides ecosystem services. The benefits provided by alfalfa within the cropping system extend off the farm to provide a wide range of services to society at large. These include food production, water protection, soil conservation, biodiversity, aesthetic value, and economic resiliency.

Despite its many benefits, alfalfa is often overlooked in agricultural research and education. The amount of research funding dedicated to alfalfa is far below what would be proportional to the value of this productive and environmentally friendly crop in the American agricultural system. We hope that this document can be a step forward toward building a broader understanding of alfalfa's value on the farming landscape and in the food system. As farmers and researchers work toward building more diverse and resilient cropping systems that feature year-round living cover and biological fertility sources, the future of this time-honored crop looks bright.



Alfalfa roots commonly extend up to 16 feet into the soil, much deeper than other crops. The deep root system holds soil in place and creates channels that promote water infiltration, biological activity in the root zone, and improved nutrient cycling.

Did you know?

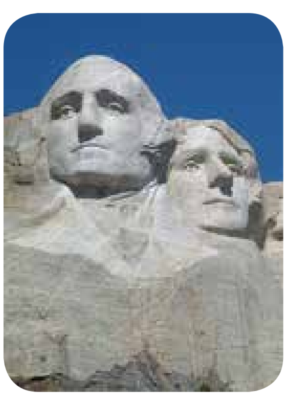
Alfalfa produces its own nitrogen fertilizer by partnering with a soil bacterium to "fix" nitrogen from the air. This nitrogen contribution extends to the following crop, saving farmers thousands of dollars on fertilizer for their corn!

One-third of the honey in the U.S. comes from alfalfa fields.

Alfalfa is considered the premier forage for dairy cows, making it an essential component of milk, yogurt, ice cream, and cheese. Yum!

Protein Power:
alfalfa produces more protein per acre than any other crop. This protein is important in the diets of livestock like horses and cattle.

Alfalfa can be used for remediating environmental contamination—most famously, at the "Erin Brockovich" site in Hinkley, CA, where it is used to contain the spread of carcinogenic Chromium-6 in groundwater: alfalfa irrigated with the contaminated water takes up Chromium-6 and converts it to the plant nutrient Chromium-3.



George Washington and Thomas Jefferson grew alfalfa.

Photo from Imperial Valley, CA, 1903.

As a high-quality horse feed, alfalfa powered transportation and farm operations in the U.S. for nearly a century. Early growers marveled at the vigor of alfalfa.

1. What is alfalfa?

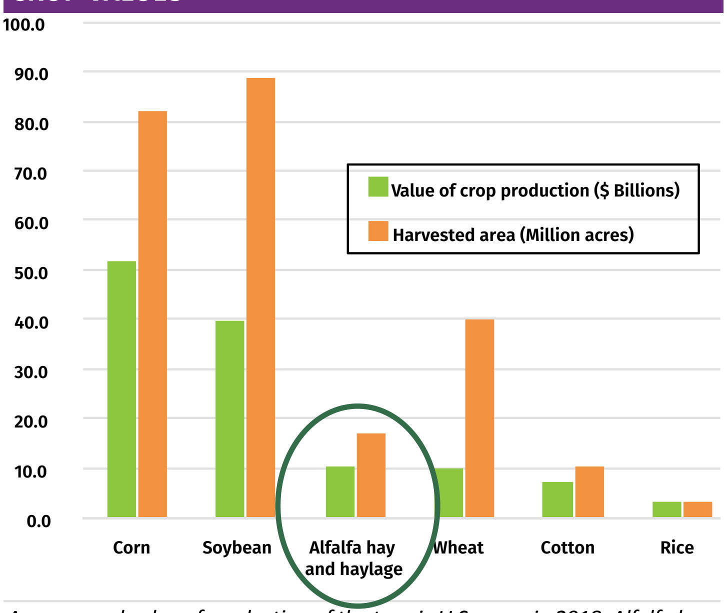
Alfalfa is a perennial forage crop that has been a mainstay of U.S. farms and ranches for more than a century. Nationwide, about 18 million acres of alfalfa are harvested annually for hay or haylage (fermented forage). Their economic value is estimated at more than $9 billion annually, making it the third most valuable crop in the US, behind only corn and soybean. Farmers admire alfalfa for its high yield, wide adaptation, disease resistance, and excellent feeding quality to a variety of livestock.

Alfalfa's unique contribution to the world's livestock systems arises from its biology. The alfalfa plant is a deep-rooted herbaceous perennial, capable of surviving extreme cold and drought and continuing to produce for several years without needing to be replanted. Alfalfa's deep perennial roots allow it to draw water from far below the soil surface, making it resilient to droughts. With an effective rooting zone of 4 to 6 feet and the potential to reach 20 feet, alfalfa is capable of extracting nearly 70% of the available water in the soil. The alfalfa plant responds to fall temperatures and shortening days by entering a dormant state in which

What is forage?

Forages are animal feeds that consist of the vegetative parts of plants, including stems, leaves, and immature grain. In comparison with grain feeds (sometimes called concentrate feeds), forages are higher in fiber and lower in energy.

CROP VALUES



Acreage and value of production of the top six U.S. crops in 2018. Alfalfa hay and haylage was the third most valuable crop, behind corn and soybean.

Fertilizer from the air: the legume-*rhizobium* partnership

Alfalfa is a member of the legume family, which also includes peas, beans, clovers, lentils, and vetches. These plants share a unique ability to form symbiotic partnerships with a type of soil bacteria called rhizobia.

Alfalfa roots showing nodules

Rhizobia have an unusual metabolic capability: they can convert nitrogen, the most abundant element in the Earth's atmosphere, from its inaccessible dinitrogen (N2) gas form into water-soluble compounds usable by plants. When legume roots come in contact with a compatible strain of rhizobium, the roots form structures called nodules, which are then colonized by the bacteria. Inside the nodules, the rhizobia enjoy a protected environment and are provided with energy-rich carbon compounds produced by the plant's photosynthesis. In return, the rhizobia provide the plant with nitrogen, which it uses to build proteins. This process is called biological nitrogen fixation.

it survives the winter. It then regrows in the spring from buds located on the crown. Stems and leaves readily regrow following cutting, allowing from two (in northern regions) to ten (in the Southwest) cycles of harvest and regrowth during the growing season. Alfalfa can live up to 10 years in drier regions, if not stressed by disease or frequent harvests.

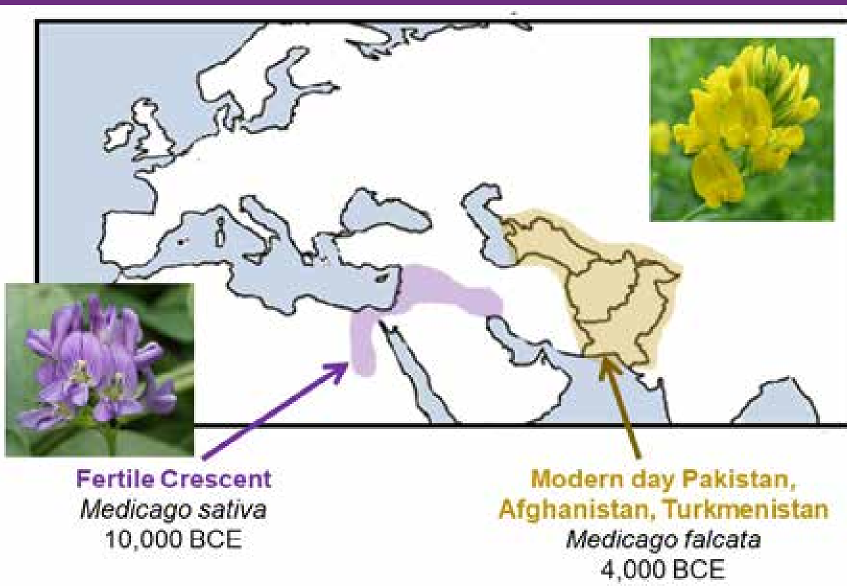
Alfalfa is a member of the legume family. Legumes have the unique ability to provide their own nitrogen fertilizer by associating with soil bacteria to "fix" nitrogen from the air into water-soluble forms that the plant can use for its growth. This biological partnership contributes to the high protein content that makes alfalfa so nutritious to livestock. Alfalfa can produce up to 4,000 pounds of protein per acre per year—more than any other crop.

A field of alfalfa being irrigated.

Agronomically, alfalfa is one of the world's most versatile crops. It is grown in environments ranging from the continental climate of Minnesota to the Mediterranean valleys of California. Alfalfa can grow on soils ranging from sands to heavy clays, as long as they are not too acidic or saline. It is grown as an intensive cash crop under irrigation, or as a lower-intensity rainfed crop in forage mixes. However, it has poor tolerance to excess moisture, and tends to succumb to root disease and winter-kill in wet soils.

Alfalfa stems regrow from the crown following cutting or winter dormancy. Typically, alfalfa plants grow about 20 stems of 2 to 3 feet in length, which grow alternating compound leaves of 3-5 leaflets. Flowers can be purple, yellow, or variegated, and produce ample sugar-rich nectar that attracts insect pollinators.

CENTERS OF ORIGIN FOR ALFALFA



Alfalfa was one of the earliest domesticated crops. From its origins as a deep rooted, drought-resistant perennial legume growing wild on the steppes of Asia, alfalfa has spread throughout Asia, Europe, Australia, Northern Africa, and North and South America. Domesticated alfalfa has two distinct centers of origin: Medicago sativa (purple flowered alfalfa) originated near Iran in the Fertile Crescent, while Medicago falcata (yellow flowered alfalfa) originated near modern day Pakistan and Afghanistan. In these areas, alfalfa was likely used as forage for livestock and the seed was also used in human diets. The oldest written reference to alfalfa is from Turkey in 1300 BC. It was important to the early Babylonian cultures, as well as to the Persians, Greeks, and Romans. As a valued feed for horses, alfalfa contributed to the might of military empires from the Mediterranean to China. The Spanish and Portuguese later spread alfalfa to the New World during the conquest of Mexico, Peru, and Chile.

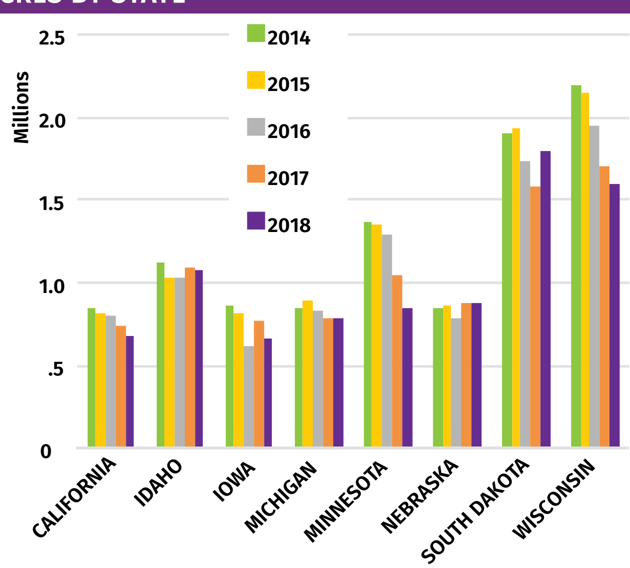
Alfalfa became an important crop in the U.S. during the 19th Century. Early attempts to introduce alfalfa into the Eastern colonies were not successful, likely due to weather, acidic soils, and plant diseases. It was not widely adopted in the U.S. until its introduction in the 1850s from South America into the sunny western states. Significant introductions of alfalfa were made into the U.S. Midwest in the late 1800s by a German farmer, Wendelin Grimm. Grimm brought seed of a winter-hardy alfalfa from Germany and planted it on his farm in Minnesota. After several years of selecting seed from surviving plants, he had developed a persistent winter-hardy alfalfa landrace. Grimm's work and other introductions by N.E. Hansen of South Dakota, the USDA's first plant explorer, led to significant increases in alfalfa acreage throughout the Midwest, where less winter-hardy western varieties of alfalfa could not persist.

As the use of animal power for farming and transportation declined, fossil fuels took the place of alfalfa as a source of draft power—but its importance to livestock farmers has persisted. These days, the top alfalfa-producing states are in the West and Midwest; it can also be grown in the South on well-drained soils. Because alfalfa can be used as feed in various fresh, dried, and preserved forms, it can be used both as a pasture or hay crop by dairy farmers and other livestock producers, and as a cash crop by farmers who do not raise livestock themselves. In recent years, alfalfa has become increasingly important as an export crop, feeding the growing dairy and meat industries overseas.

It is no accident that the two top dairy states, California and Wisconsin, are also leading states in alfalfa production. When harvested near the early-flowering stage of maturity, about half of the forage is nutrient-rich leaves, high in the protein and fiber needed by dairy cows for milk production. Alfalfa is not as easily recognizable on the dinner table as are major grain crops such as corn or wheat, but its importance to the dairy industry places it at the forefront of the U.S. food system.

Until the 1940s, horses provided most of the draft power on U.S. farms.

ACRES BY STATE



Alfalfa variety development

Agronomists and plant breeders have made great improvements in alfalfa productivity, persistence, and nutritive value over time. Early variety development focused on increasing winter-hardiness and resistance to diseases, insects, and nematodes. In the 2000s, application of genetic engineering technology to alfalfa resulted in development of herbicide-tolerant Roundup Ready® alfalfa to facilitate weed control, and reduced-lignin alfalfas with higher nutritive value to livestock, known as forage quality. Breeding and agronomic research continues to focus on traits and growing practices to expand alfalfa's usefulness for livestock, human food, and industrial purposes.

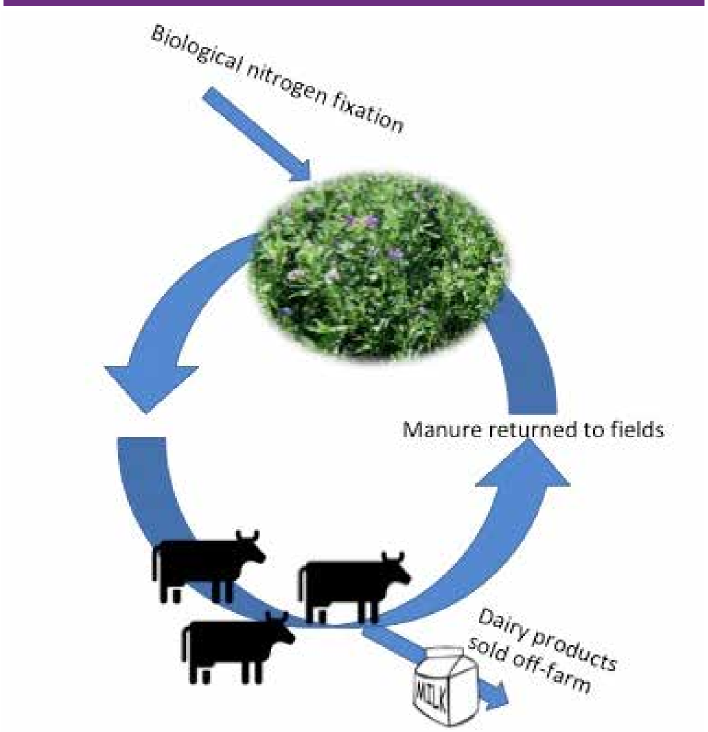
TIMELINE OF THE DEVELOPMENT OF ALFALFA VARIETIES WITH NEW OR IMPROVED TRAITS

TIME PERIOD	MAJOR TRAITS
1900s-1950s	Winter-hardiness; resistance to bacterial wilt
1950s-1990s	Resistance to insects, nematodes, and diseases
1995	Grazing tolerance
2005-2011	Herbicide tolerance (Roundup Ready®); Aphanomyces resistance
2010	Salt tolerance
2014	Reduced lignin (improved digestibility)

2. CONNECTING THE DOTS
Alfalfa and food

A big, crunchy bowl of alfalfa stems and leaves might not be a very good food for humans, but it is an excellent feed for ruminants—grazing animals with an extra fermentation chamber in their digestive systems, which include cattle, sheep, goats, and horses. And ruminants are exactly the animals that we rely on for some of our favorite foods: dairy products.

NUTRIENT CYCLING



On a farm that integrates crop and livestock production, nutrients like nitrogen and phosphorus are recycled through a "closed-loop" system: for example, alfalfa grown on the farm nourishes cattle, whose manure is then used to fertilize the alfalfa fields.

Ruminants' unique digestive process allows them to extract energy from fibrous plant materials that would be indigestible to other animals. Alfalfa is not only high in fiber, but also rich in protein, making it a valuable component of a healthy diet for ruminant livestock. Modern dairy cattle are amazingly productive—the average U.S. dairy cow now gives about 23,000 lbs of milk per year! And making that much milk requires a lot of protein. Meanwhile, the fiber in alfalfa and other forages helps prevent ulcers, abscesses, and other health problems associated with modern-day grain-heavy diets. A lactating dairy cow can consume 14 to 16 lbs/day of alfalfa hay as a part of a mixed ration, or higher amounts on a more forage-intensive diet. That's why feeding dairy cattle is the #1 use of alfalfa in the U.S.

Many advocates for sustainable agriculture have called for the re-integration of crops and livestock in our farming systems. Alfalfa is an important crop for this strategy. Crop farmers who raise alfalfa as a feed for their own livestock can enjoy the benefits that this perennial legume provides to their farm's soil health, water quality, and the productivity of other crops in their rotations. Meanwhile, they are obtaining a high-quality feed at cost, and "closing the loop" of nutrient cycling by generating manure that can, in turn, be used for fertilizing the alfalfa and other crops. In some areas, alfalfa is grazed directly by ruminant livestock, decreasing costs associated with hay cutting and returning manure directly to the field.

NUTRIENT CONTENT OF ALFALFA AND GRASS HAY

	Total Digestible Nutrients	Crude Protein	Crude Fiber	Phosphorus	Calcium	Magnesium	Potassium
	PERCENT OF FEED DRY WEIGHT						
Alfalfa hay (dairy quality)	60	18.0	23.0	0.22	1.41	0.33	2.52
Average grass hay	53	8.4	31.4	0.19	0.54	0.12	1.66

Consolidation in the dairy industry has resulted in more dairies raising large herds on limited land area and relying on purchased feeds, including hay. In recent years, exports of alfalfa hay have also increased, driven by low domestic dairy prices and increased demand for feeds in the growing dairy industries in China and the Middle East. These shifts have expanded the role of alfalfa as a trade commodity, which has opened new markets for alfalfa farmers, but also carries the risks and complexities associated with global trade and intensifies environmental challenges. U.S. alfalfa farmers will need strong research and policy support to navigate these changes and build strong, sustainable farming systems.


Farmer Kirsten Jurcek of Brattset Family Farms gives a hayride talk about the importance of alfalfa as a component of diversified pastures, and how to properly graze it.

In addition to its central role in the dairy industry, alfalfa is used in many foods for livestock, pets, and even humans. Alfalfa is an important crop for beef cattle and sheep, which thrive on more mature, lower-protein hay and alfalfa-grass mixes. It continues to be an excellent and widely used feed for horses, just as it was when horses powered farms and transportation systems in centuries past. It is included in feeds for guinea pigs, rabbits, and other small pets, and is sometimes an ingredient in dog and cat foods. Recent research has even explored the use of alfalfa protein concentrate as a low-cost substitute for fish meal in aquaculture systems. Alfalfa also makes an appearance in nutritional supplements for human consumption, in addition to its more familiar use as a salad sprout.

Horses still love alfalfa

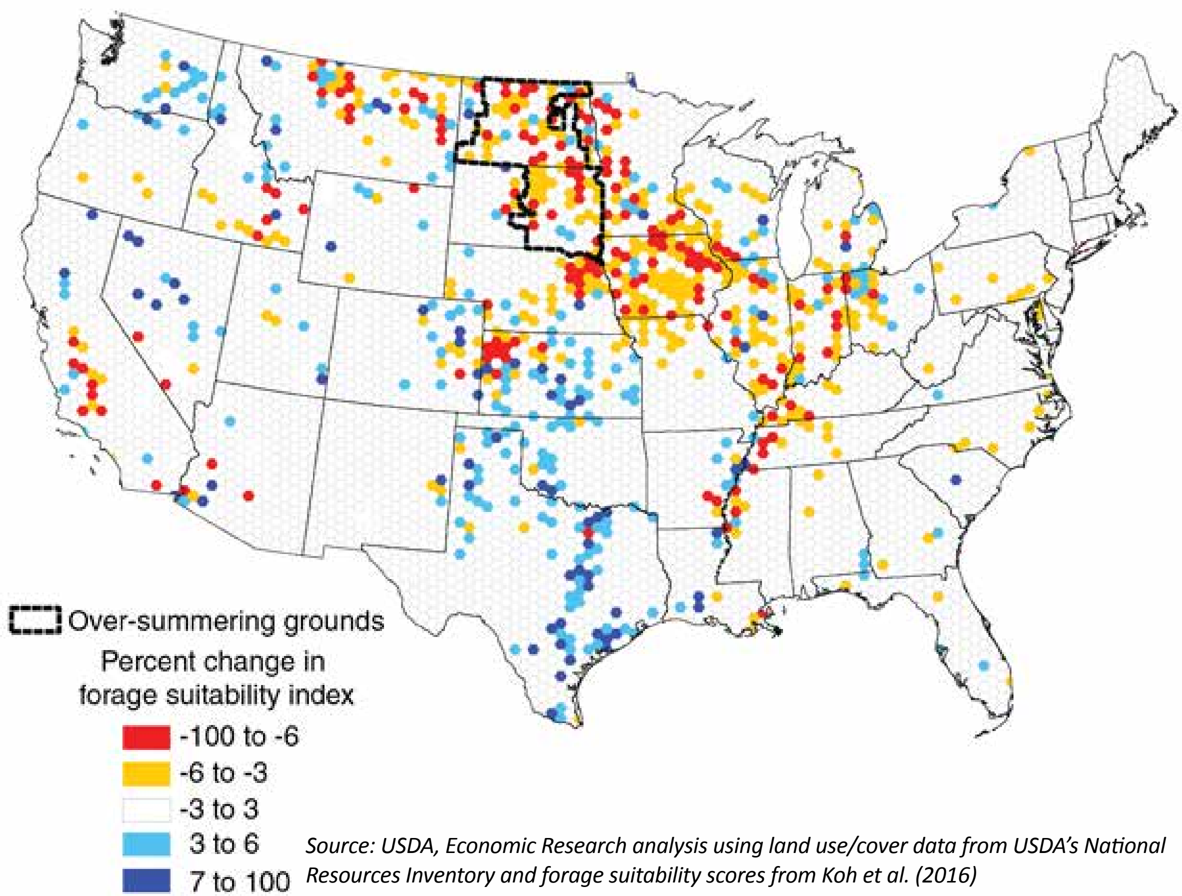

A horse enjoys a meal of alfalfa.

Horses may no longer be the engines of transport and mechanical power in our society, but they are still beloved companions to millions of Americans, and they still eat a lot of alfalfa. Working horses need the high protein and energy content that alfalfa can provide—even though, these days, their work is more likely to be racing than pulling a plow. Horses kept primarily for pleasure have lower energy requirements, but alfalfa hay is still a valuable component of the diet for them. For less-active horses, lower-quality (less nutrient-dense) alfalfa hay harvested at a later maturity stage, or a mixed alfalfa-grass hay, is a cost-effective way of providing both the nutrients that horses need and the bulk (fiber) that satisfies their hunger.

Bee forage = HONEY

Flowering alfalfa is an excellent source of nectar for honeybees, producing a delicious honey that is light, mild, and versatile. Alfalfa fields managed for flowering in Midwest farming regions have long been a summer home to many of the traveling commercial honeybee colonies that pollinate the fruit and nut orchards of California. In fact, alfalfa and clover are the main sources of nectar for honey production in the Midwest. Recently, increases in land planted to corn and soybeans have resulted in less alfalfa available for honeybees. This is likely one of the stresses contributing to the high rates of overwinter colony loss that threaten the production of fruit and nut crops and the livelihood of commercial beekeepers. Honeybees need a varied and abundant diet of nectar and pollen to maintain strong immunity to the pathogens that damage the health and productivity of their colonies. Reversing the decline in agricultural diversity, particularly bringing back more bee-forage crops like alfalfa, sunflower, canola, and mixed pastures to the Northern Great Plains, is an important step toward protecting the livelihoods of beekeepers and orchardists.

DECLINE IN POLLINATOR FORAGE SUITABILITY BETWEEN 2002 AND 2012



Source: USDA, Economic Research analysis using land use/cover data from USDA's National Resources Inventory and forage suitability scores from Koh et al. (2016)

3. Growing alfalfa

Profitable and environmentally sustainable long-term alfalfa productivity is dependent on all aspects of crop management including establishment, fertilization, harvest scheduling, weed control, and irrigation. Alfalfa thrives on well-drained soils with a neutral pH. It also requires adequate supplies of essential soil minerals. If those needs are met, alfalfa can be grown under a wide range of climatic conditions and management practices.

To capture the long-term perennial benefits of alfalfa and realize returns on establishment costs, a farmer's aim is to maintain stands for several years. Successful establishment of adequate populations of plants is a key element influencing long-term productivity over a 3- to 5-year stand life. Alfalfa seeding times vary regionally to take advantage of favorable soil moisture and temperature conditions for germination and seedling growth. Spring seedings using herbicides for weed control allow for harvests during the seeding year, while late summer or fall seedings allow the alfalfa to be planted after another crop has been harvested and generally result in high production in the first full year of the stand.

Seed is often coated with *Rhizobium* inoculum to promote biological nitrogen fixation as well as fungicides for control of seedling diseases. Most fields with a history of alfalfa production usually contain enough rhizobia to satisfy the needs of a new alfalfa crop; nonetheless, inoculation of a new seeding is typically inexpensive and is recommended to ensure good alfalfa-*Rhizobium* relationships from the beginning of the stand, for high levels

STAGES IN THE LIFE OF AN ALFALFA STAND

Stage	*Management considerations*
Seedbed preparation	• Mineral nutrients (P, K, S, and B) should be applied based on preplant soil testing • Soil pH should be near-neutral; may be adjusted by liming • A firm seed-bed should be prepared to enhance seed-soil contact
Establishment	• Seed can be drilled, broadcast, or aerial seeded, and is typically incorporated to only ¼ to ½ inch deep. • Seed may be treated with Rhizobium inoculant and/or fungicide • Herbicide and/or companion crop can prevent weed competition during establishment • Established stand density should be at least 55 stems/ft^2 for pure alfalfa or 40 stems/ft^2 for alfalfa/grass mixtures
Stand maintenance	• Insect pests should be monitored and controlled using chemical and cultural methods • Irrigation is usually necessary in arid areas
Harvest	• Harvest is timed based on producer goals to optimize forage yield, forage quality, and stand persistence • Cut forage is dried in windrows in the field • Forage can be harvested as hay (<20% moisture) or haylage (65% moisture), or can be grazed.
Termination	• Stand is plowed when plant populations and yields decline • Conservation tillage and no-till reduce soil and carbon loss. • Alfalfa provides residual nitrogen and improves soil tilth for following crop

of nitrogen production throughout the stand life.

Planting alfalfa in mixtures with grass crops can provide advantages over planting in monoculture. Alfalfa is often planted in mixture with perennial grasses adapted to the farmer's climate and harvest regime. This promotes faster drying of the cut forage, reduces weed invasion and reduces the risk of bloat in grazing livestock. It also protects the farmer against complete forage loss if the alfalfa plants are affected by winter-kill or flooding. However, long-term maintenance of the desired ratio of alfalfa to perennial grass is challenging, as alfalfa and grasses compete for resources.

A traditional practice in northern regions, frequently used by organic farmers, is to plant spring-seeded alfalfa along with an annual companion crop such as oat. The small grain companion crop emerges and produces aboveground biomass more rapidly than establishing alfalfa, which invests early resources in producing roots rather than shoots. The companion crop helps the young alfalfa stand compete with weeds (reducing the need for herbicides), protects against wind and water erosion, and can be cut to provide an additional harvest of forage in late spring, or harvested for grain in summer. After the companion crop is harvested, the alfalfa stand remains in the field and can continue to produce for several years.

In the Midwest, orchardgrass and meadow fescue are popular perennial grass companions for alfalfa. Planting alfalfa in a mixture with grass can reduce the risk of bloat to grazing livestock.

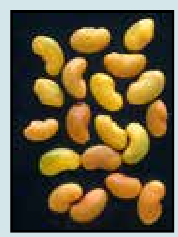
Alfalfa farmers tailor their harvest practices to the needs of the livestock that will consume the forage. Especially in the Midwest and Northeast, some livestock producers let the animals graze the alfalfa fields for some portion of the year—they harvest their own food! For storage or transport, alfalfa and mixed forages are dried and baled to make hay. They can also be fed when freshly harvested (as green chop), or fermented into haylage (also called silage) for long-term on-farm feeding. In a normal

Raking of cut alfalfa before baling. Typically, an alfalfa stand that is being grown for hay will be cut 3 to 4 times per year in northern zones, 4 to 7 times per year in the southeast and central Western regions of the U.S., and sometimes up to 10 to 11 times in areas of the Southwest.

Alfalfa seed production

Alfalfa seedpods

In forage production systems, alfalfa plants never have a chance to produce seed because they are cut before they finish flowering. But farmers need a reliable supply of seed for planting, so specialized seed production occurs in the Western states of California, Idaho, Nevada, Oregon, and Washington. Most alfalfa seed is grown under irrigation, and the production practices for seed are quite different from those for hay. Alfalfa for seed is produced as an annual crop. It is generally planted in rows at rates of only 1 to 3 lbs per acre, usually in the fall (though early spring planting is also used), and cut once in the spring to spur flowering. Alfalfa flowers are insect-pollinated, generally by honeybees, alfalfa leafcutter bees, or alkali bees (see Section 5). When the bloom is complete, irrigation is stopped so that seed will mature and the plant will begin to dry down. The drying is completed either by swathing the plants and allowing them to dry in windrows, or by applying a chemical desiccant. When the seed is dry, it is harvested with a combine. Alfalfa seed production fields are an important resource for wildlife. The flowers yield nectar for native pollinators, while the vegetation provides cover and nesting sites for birds, which benefit from the lack of repeated cutting. Well-managed alfalfa fields can yield an average of 700 lbs/acre of seed, and total annual seed production in the U.S. is over 80 million lbs.



Alfalfa seeds

regrowth cycle, as alfalfa matures from vegetative to flowering stages, forage yield increases while nutritive value decreases. Farmers can cut alfalfa at different maturity stages for feeding livestock with different nutritional needs. For milking dairy cattle, alfalfa is often cut in the bud stage, before blooming, to ensure high digestibility and protein content, while alfalfa for beef cows is cut during bloom, when digestibility and protein is lower but yield is higher. In general, the best balance between yield and quality can be obtained when the alfalfa is harvested around the 10% bud growth stage. At times when weather limits flower development, farmers harvest based on calendar date.

Grazing cattle harvest their own feed.

Hay in large round bales

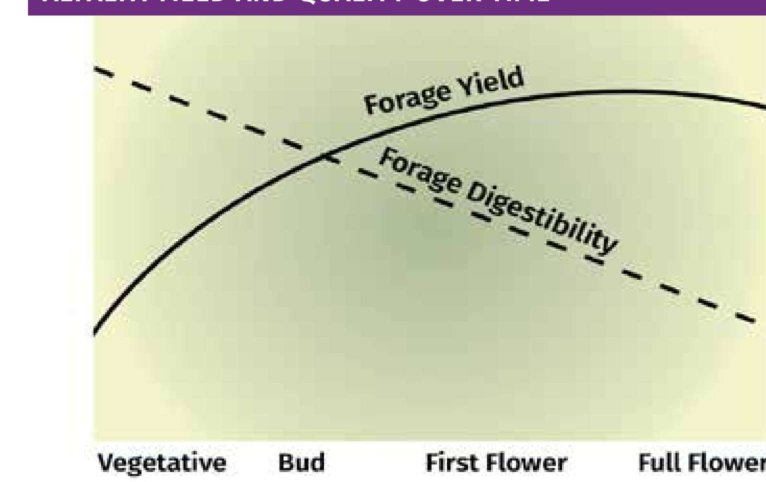
Making haylage, or fermented hay. Haylage can be stored in upright tower silos or in large plastic bags.

Alfalfa in humid regions is rarely irrigated, but irrigation is used in drier Western environments to maintain yield. Farmers are sometimes criticized for growing alfalfa in arid or droughty areas, because its long growing season, dense canopy and deep rooting system make it a crop with relatively high water demand. Water use ranges from 4 to 7 inches for each ton/acre of forage produced and total irrigation applications can range from 2 to 7 acre-feet per year. However, because the whole plant is harvested, alfalfa actually has a high water-use efficiency, or ratio of dry matter harvested to water used. Alfalfa's water-use efficiency is 30 to 50%, a range that is comparable with other forages like corn silage. Alfalfa also offers important flexibility compared to some other irrigated crops, because a well-established stand can survive severe reductions in watering by entering a dormant state during times when water is scarce, while remaining alive and ready to resume active growth when water supplies increase. This may serve as an environmental benefit in drought-prone areas, where farmers sometimes fallow fields (take them out of production) in reaction to drought. Unlike bare-ground fallow, dormant alfalfa provides ground cover and keeps living roots in place, preventing soil loss from wind erosion during droughts.

Alfalfa can suffer from a variety of disease, weed, and insect pressures. Although herbicides and pesticides are commonly used, cultural methods are also helpful in controlling these problems. Weed infestation can be reduced by ensuring a strong initial stand and planting grass companion crops. Diseases are kept in check by crop rotation and resistant varieties, and insect pressure can be managed by adjusting cutting schedules and maintaining vegetative field borders that harbor natural predators of common alfalfa pests.

Over time, alfalfa stands tend to become thinner as damage accumulates from winter injury, disease, and/or herbivory. Gaps in the stand provide opportunities for weeds to invade, and forage yield and quality decline. Research across the U.S. has shown that yields and quality

ALFALFA YIELD AND QUALITY OVER TIME



As alfalfa matures, its forage yield increases, while the quality of the forage declines.

typically decline below an economically sustainable level after 3 to 5 years. At this point, the stand can be terminated with herbicides or tillage, or both, and the remaining foliage and the extensive underground root system become food for soil microbial communities. The dead alfalfa tissues will contribute to soil organic matter stocks, and their nutrient content will be recycled for future crops to use.

A recently terminated alfalfa field is prime ground for many crops. In much of the Midwest, alfalfa is often grown in rotation with corn, where it prepares the soil to support high yields in the corn crop, a "heavy feeder" that places high demand on soil resources. In drier areas, alfalfa is more frequently rotated with wheat, and in the West and Southwest it is used in rotation with crops from cotton to potato to tomato. In Section 4, we will explore the unique contributions of alfalfa as a rotation crop.

ALFALFA STANDS AT VARIOUS STAGES OF MATURITY

Vegetative stage

Bud stage

Flowering stage

Efficient irrigation

Because it is costly and uses a limited resource, irrigation must be managed to promote efficiency, maximizing the amount of irrigation water that is taken up by the crop and minimizing losses to evaporation. The most common approaches to irrigation are gravity systems (flood and furrow irrigation), which have lower capital and operational costs but tend to be less efficient, and sprinkler systems (center pivot, linear, and traveling gun), which cost more but provide a higher efficiency of application. In recent years, research has increasingly focused on strategies for making maximum use of limited water supplies, by adjusting the amount, timing, and placement of irrigation to ensure that as much as possible of the applied water is available to the crop. Farmers may irrigate in the spring, when water-use efficiency is highest, and reduce irrigation applied and forgo harvests in the summer. Some farms have even adopted sub-surface drip irrigation systems that deliver water directly to the roots of the crop, reducing the loss of water to evaporation from the soil surface.

An alfalfa seed production hayfield under flood irrigation.

An alfalfa seed production field under center pivot irrigation.

Siphons direct water from an irrigation ditch into the furrows of an alfalfa field.

4.

PERENNIAL BENEFITS

Building soil health with alfalfa

As a perennial crop, alfalfa offers many benefits to farms and ecosystems. Perennial crops build and protect soil, promote healthy and active soil microbial communities, and interrupt annual tillage cycles by adding a no-tillage phase to crop rotations. In the northern U.S., where annual crop fields are bare in the late fall and early spring, perennial crops can use solar energy and water resources that would otherwise be wasted.

Organic matter is crucial to the water holding and nutrient cycling capabilities of soil.

The foundation of healthy soil is organic matter: the carbon-based materials derived from the deposition and breakdown of plant, animal, and microbial biomass. Alfalfa increases soil organic matter compared to grain-only cropping systems, and perenniality is the key to this benefit. In order to persist over multiple years, perennials invest energy in building deep, extensive root systems. Living roots contribute to soil organic matter by releasing exudates, carbon-based compounds that help to defend the plant from competitors and pathogens. Small roots are constantly growing, dying, and decomposing. This turnover accelerates when alfalfa is cut; resources are withdrawn from the root system to regrow above-ground leaves and stems, resulting in "sloughing" of root tissues to the soil. The dead root material isn't wasted—it becomes a part of the soil organic matter, and is a feast for a diverse and active soil microbial community. A recent study from California found that the root zones of alfalfa plants had 46% more microbial biomass, containing over twice as much nitrogen, than the root zones of corn plants.

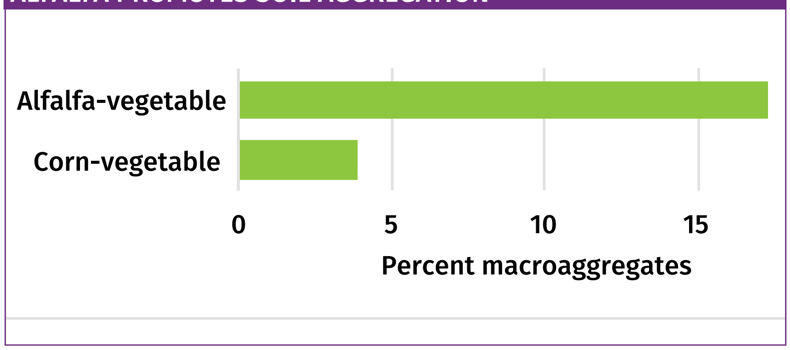
A diverse perennial mixture of grasses, alfalfa, and other legumes

Because of their ability to deposit organic matter deep into the soil, perennial plants are an important strategy for carbon sequestration—the removal of climate-warming CO_2 from the atmosphere. When plants photosynthesize, they take in CO_2 and build it into the larger carbon compounds that form their leaves, stems, and roots. By the second year of the stand, alfalfa roots can be 10–12 feet deep, much deeper than corn roots and well below the depth reached by tillage equipment. The carbon compounds deposited in these deeper soil layers are therefore protected from being released back into the atmosphere following tillage when the field is rotated out of alfalfa. Many scientists believe that increasing perennial land cover is a promising avenue for reducing greenhouse gas concentrations and stabilizing the global climate.

Reducing tillage is another perennial benefit. Farmers till the soil to prepare a smooth seedbed for new plantings, to control weeds, and to incorporate crop residues into the soil. But tillage also disrupts soil structure, reduces populations of important soil microbes (especially fungi), causes soil carbon to be lost to the atmosphere, and leaves soil vulnerable to erosion. By planting a perennial crop that will stay in place for 3 to 5 years, farmers offer the soil a reprieve from the disturbance of tillage, giving the soil a chance to rebuild strong microbial communities, organic matter stocks, and aggregate structures that will help it stay resilient through future disturbances.

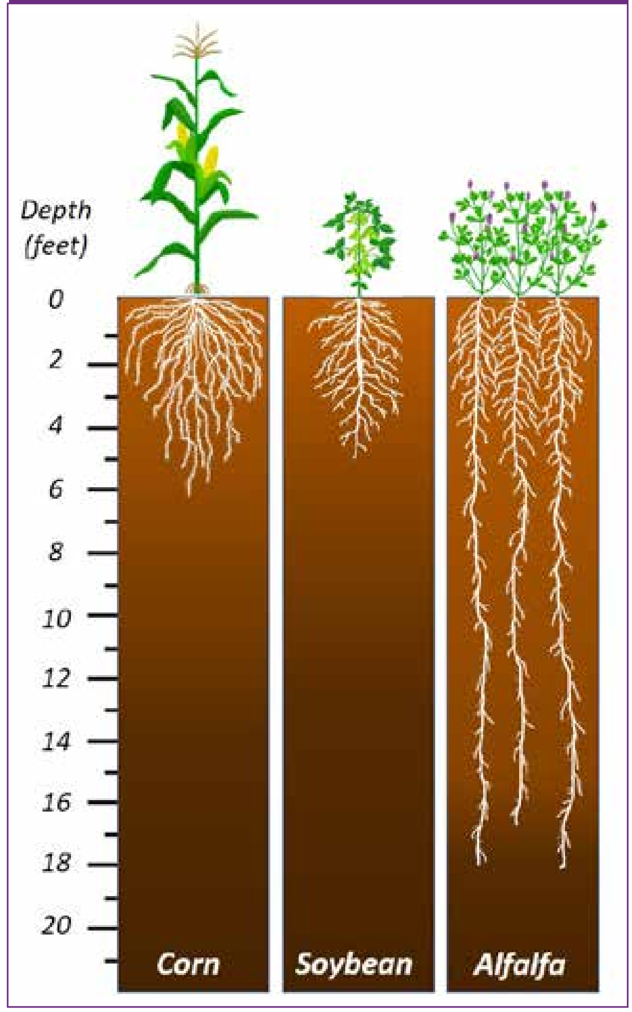
In addition to building soil, alfalfa and other perennials help to protect soil from erosion. During the late fall, winter, and early spring, when grain-crop fields are typically bare in northern regions, soils are vulnerable to rain and wind, which can carry away soil particles. Erosion is a big problem in the

ALFALFA PROMOTES SOIL AGGREGATION



Alfalfa promotes the formation of soil macroaggregates (large groups of bonded soil particles), which increase soil aeration, create paths for water, and are important habitats for beneficial soil microorganisms. Increased macroaggregates in soils also contribute to resistance to erosion and compaction. A California study found over four times as many macroaggregates in soil from vegetable fields using alfalfa as a rotation crop than those using corn as a rotation crop.

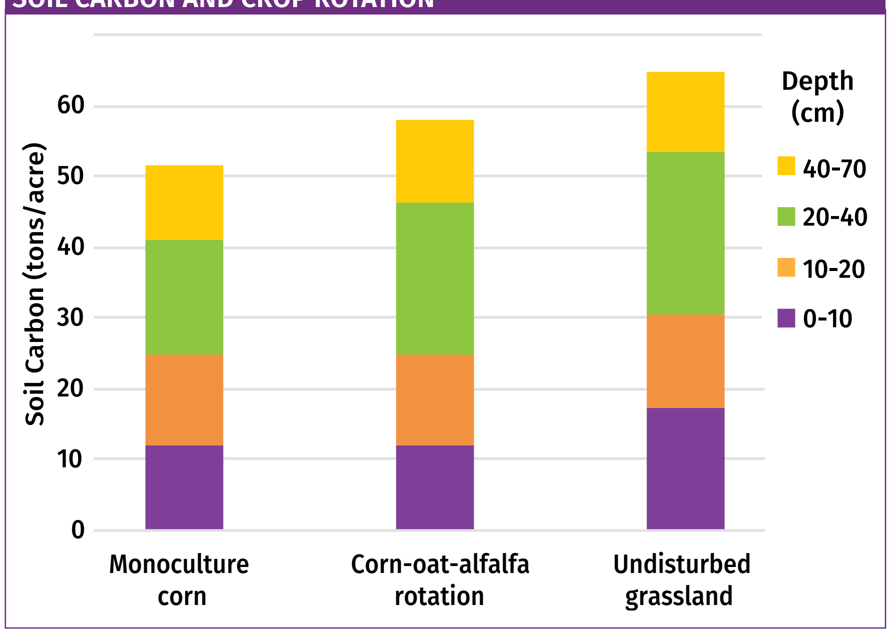
ROOT COMPARISONS



Alfalfa roots can grow to 10-12 feet by the second year, and may ultimately extend up to 20 feet into the soil--in contrast with corn and soybean, whose roots reach 4 to 6 feet and are heavily concentrated in the top foot of the soil.

Unprotected soil is vulnerable to erosion from rain or wind.

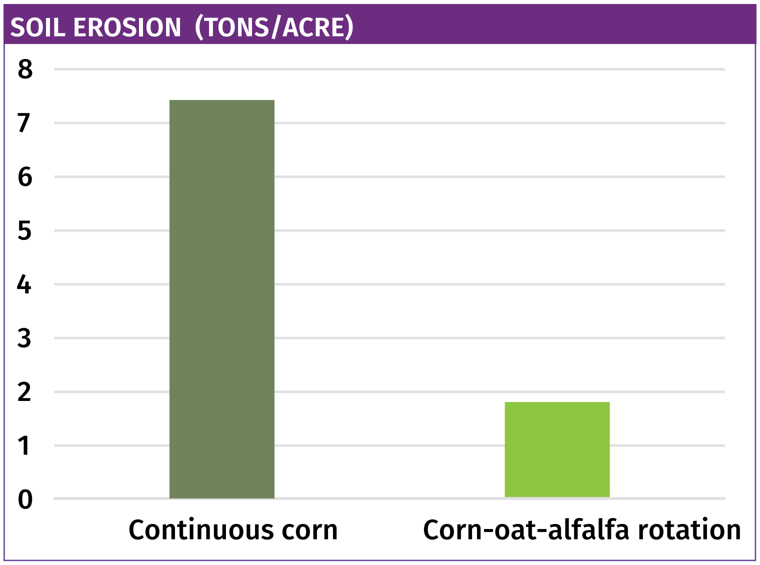
SOIL CARBON AND CROP ROTATION



An experiment in Iowa showed that rotating corn with alfalfa results in an increase in soil carbon, particularly at greater soil depths.

U.S.—about 1.7 billion tons of soil are lost to erosion every year, mostly on prime cropland. But when a field is planted to a perennial crop like alfalfa, there is no bare period. Aboveground plant cover protects the soil surface from the impact of raindrops and the scouring of wind, while roots form a matrix holding the soil in place. Alfalfa's extensive root structure also improves water infiltration into the soil, helping to absorb, store, and filter rainwater and reduce surface runoff.

Another advantage to eliminating the bare-soil period with alfalfa is that perennial crops can take advantage of the full growing season and the abundant sunlight and rainfall resources that are inaccessible to annual crops. By the late spring, when the first small shoots of corn or soybeans are beginning to show in the fields, an established alfalfa stand already has months of growth behind it, capturing solar energy for photosynthesis, taking up nutrients that could otherwise be lost to waterways, and using soil moisture stored from fall rains and snow-melt that could otherwise have been lost to evaporation or even contributed to spring flooding.

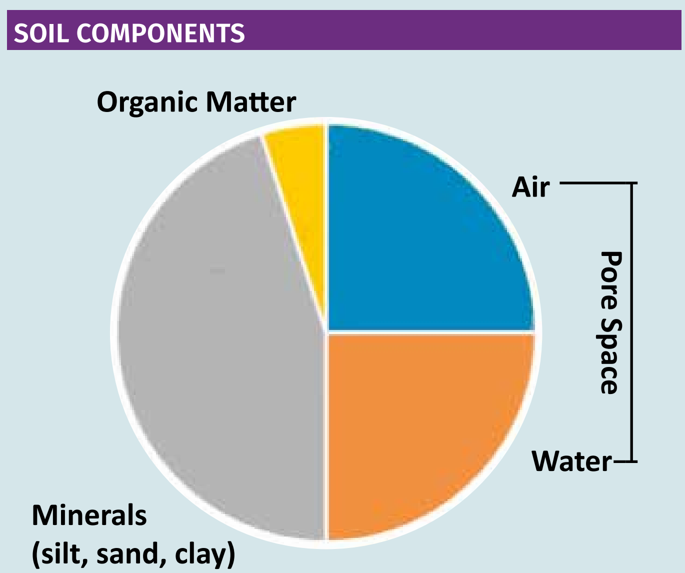


An alfalfa field and a cornfield in early summer. The alfalfa has taken full advantage of spring sunshine and soil moisture and is providing excellent soil protection, while the corn is just beginning to grow.

What's the big deal about soil organic matter?

Soil organic matter makes up a relatively small portion of the total soil, generally about 1 to 6%, but it is incredibly important for the soil functions that crops depend on. Soil organic matter consists of both labile (readily decomposable) and recalcitrant (stabilized) forms. Labile organic matter feeds the microbial communities that carry out crucial functions like residue decomposition, nutrient cycling, and aggregate formation, and serve as the basis for diverse soil food webs of earthworms, nematodes, arthropods, and others. Stabilized organic matter contributes to soil structure, and serves as a long-term reserve of fertility, slowly releasing nutrients to plants.

Soils with higher levels of organic matter are more able to absorb and hold water, and less vulnerable to erosion and nutrient loss. As farmers strive to sustain high crop yields while reducing the need for costly chemical fertilizers and irrigation, building soil organic matter is key!



5. Food and shelter for beneficial insects

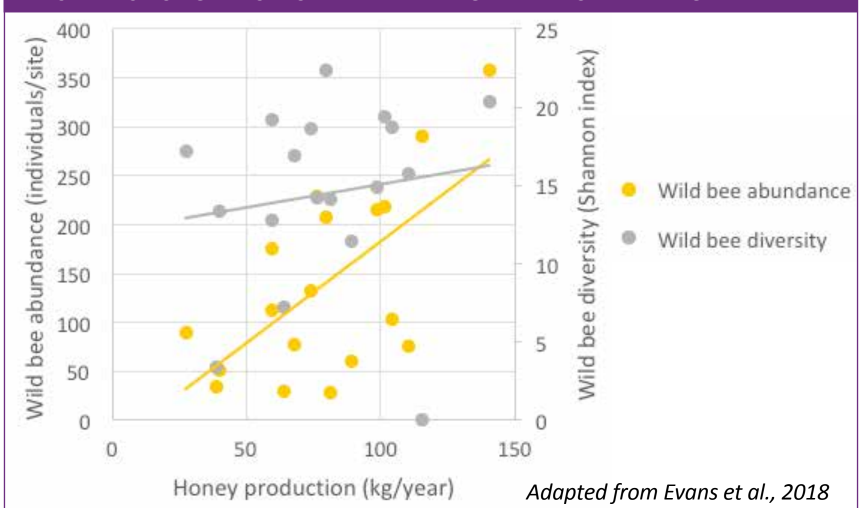
Alfalfa is a perfect habitat for an enormous diversity of insect species. Scientists have observed over 1000 species of insects and other arthropods (including mites, spiders, etc.) living or feeding in alfalfa fields. If we're used to thinking about insects as pests to be controlled in row crops, a field full of bugs might not sound like such a good thing. But in fact, the insect communities found in alfalfa fields bring benefits to wildlife and surrounding crops.

Alfalfa adds plant diversity to the rural landscape, and in particular, it can add flowers. Many of the country's agricultural lands used to be covered in prairies containing a mix of grasses and flowering species, which supported an abundance of native North American insects. However, these ecosystems have been replaced mostly with grain crops like corn and wheat, which do not have flowers useful for insects and have resulted in large declines in insect populations and biodiversity. When grown for seed or managed for honey production, alfalfa produces abundant floral nectar, which is excellent forage for domesticated honeybees as well as native bees and other pollinators.

The pollinators that are attracted and supported by the alfalfa flowers will also provide pollination services to neighboring crops. Native bees, in particular, are drawing increasing attention from conservationists. Many of the estimated 4000 species of native bees in North America are threatened by an increasingly simplified rural landscape, in which monoculture fields of corn and soybean may be virtually the only plant life for miles. When farmers add alfalfa to their rotations and manage it to allow flowering, they ensure that the agricultural landscape can feed the local bees.

Having an alfalfa field nearby, with its rich diversity of insects, can benefit other crops in many ways. An abundance of insects attracts birds and bats, which will eat pests in nearby fields of other crops. Predatory insects and arthropods raised in the alfalfa stands can also eat pest

NECTAR CROPS PROMOTE WILD BEES AND HONEYBEES



Adapted from Evans et al., 2018

Cropland that includes bee forage crops like alfalfa promotes the success of both wild bees and honeybees. A 2018 study found that sites where higher abundance and diversity of wild bees were also sites where honey production was highest.

Pea aphid on alfalfa leaf.

insects in neighboring crop fields. For example, alfalfa, like many other crops, is eaten by aphids. Natural predators can significantly reduce the number of aphids, but these beneficial insects need a winter habitat in order to maintain their populations. Because alfalfa is a perennial, it provides a refuge where the predator species can spend the winter before dispersing to eat aphids in the neighboring fields in the following season. A study in Australia found that melon fields had almost a 50% reduction in aphids per plant when there were a high proportion of alfalfa fields planted nearby, and attributed the difference to early arrival of predators from the alfalfa fields.

Some farmers even intersperse alfalfa strips among their other crops, such as cotton or strawberries, to help with pest control. Organic strawberries are a high-value crop for California farmers, but they face a high risk of damage from the lygus bug, a common pest. Lygus bugs like alfalfa even more than they like strawberry plants, so organic strawberry farmers have adopted an ingenious method of using alfalfa to control lygus bugs—they plant strips of alfalfa between the strawberry rows, to attract the bugs out of the strawberries. Then they use tractor-mounted vacuums to clean the bugs from the alfalfa strips.

Maximizing the insect benefits of alfalfa requires careful management. As insecticide use and typical cutting frequencies have increased in recent years, farmers and researchers have also called attention to the need to

A SAMPLING OF BEAUTIFUL AND BENEFICIAL ARTHROPOD SPECIES FOUND IN ALFALFA FIELDS

ODONATA (DRAGONFLIES AND DAMSELFLIES)

·Ruby Meadowhawk

·Twelve-spotted skimmer

LEPIDOPTERA (BUTTERFLIES AND MOTHS)

·Eastern Tailed Blue

·Red Admiral butterfly

HYMENOPTERA (BEES, WASPS, AND ANTS)

·Rusty patched bumblebee

·Paper wasp

ARANEIDA (SPIDERS)

·Marbled orb-weaver

·Banded garden spider

make space for pollinators and pest predators. As we will see in the next section, researchers are working with farmers to develop management practices that balance forage yield and quality with the needs of insects and wildlife, including Integrated Pest Management protocols to reduce unneeded spraying and incorporate cultural controls on pest insect populations, and harvest schedules that maintain high-value yields while allowing the alfalfa stand to mature to flowering during critical times for wildlife use.

Alfalfa's other pollinators

Honeybees are the most familiar visitor to alfalfa flowers, but in fact, they are not the most efficient pollinators of alfalfa. Typically, when an insect probes an alfalfa flower for nectar, the flower will "trip", or spring open to knock pollen from the stamen onto the insect, where it can be carried to other flowers. Honeybees don't like being hit by the flowers, so will avoid tripping them, sometimes learning to approach the flower's nectaries from the side. Farmers producing alfalfa seed for planting need the flowers to be tripped for good pollination, so they often rely on alfalfa leafcutter bees or alkali bees, efficient pollinators who don't seem to mind being bopped by the flowers. Alfalfa leafcutter bees are a domesticated species of gentle, solitary, ground-dwelling bees, which farmers purchase and provide with nesting tubes. Alkali bees, which also nest in the ground, are native species. When alfalfa seed growers in eastern Washington realized that the alkali bees were vulnerable to common tillage and insecticide spraying practices, they organized to protect and encourage native alkali bee populations, by building nesting beds, diversifying their farmland with earlier-blooming crops, and carefully managing pesticide applications. Their successful campaign of research, education, and outreach will ensure that these native pollinators will continue to thrive and support the local alfalfa seed industry for many years to come.

PERCENT OF ALFALFA FLOWERS TRIPPED BY VISITING BEES

Honeybee	22
Alfalfa leafcutter bee (female)	78
Alkali bee (female)	81

Adapted from Cane, 2002

Alfalfa seed growers often purchase alfalfa leafcutter bees, which are highly effective pollinators.

Seed producers in eastern Washington have taken wide-ranging action, including reducing traffic speeds, to protect native alkali bees.

Alkali bee

6.

Alfalfa and wildlife

Alfalfa fields provide food, shelter, and breeding grounds to an enormous diversity of game and non-game wildlife, from small to large. As the only perennial crop in major U.S. farming systems, alfalfa provides abundant year-round vegetation, a key resource for wildlife in farming landscapes. Alfalfa fields, when carefully managed, provide a more stable, less disturbed environment where wildlife can forage, nest, and breed. We have already seen how alfalfa fields support diverse soil microbial communities and an impressive range of insects. Many larger animals also find food and shelter in alfalfa fields.

After the insects, the most numerous, and perhaps most familiar, residents of alfalfa fields are mice, voles, and gophers. We may think of insects or rodents in an alfalfa field as pests, but they are also an important part of the food web in farmland ecosystems, supporting birds, bats, and larger carnivores. Even the much-maligned pocket gopher has a role to play in this ecosystem, not only because it is important prey for several endangered or threatened raptor species, but also because its tunnels can shelter reptiles and amphibians. The Swainson's hawk, short-eared owl, prairie falcon, California tiger salamander, and western spadefoot toad are only a few of the species that benefit from gophers in alfalfa fields.

Hundreds of bird species use alfalfa fields as a food source and a nesting ground. The increasing dominance of row crops in agricultural landscapes, and the associated loss of wild grasslands, have made alfalfa fields a crucial element in bird conservation efforts. The white-faced ibis and long-billed curlew, native California waterbirds, have been found to depend heavily on flood-irrigated alfalfa for breeding sites. In France, a five-year program of alfalfa planting and management successfully reversed the near-eradication of the little bustard, a formerly

Tundra swans in a flood-irrigated alfalfa field in the Sacramento Valley.

widespread grassland species. Hayfields are also important habitat for many songbirds, including bobolinks, horned larks, meadowlarks, and many species of native sparrows. Some species feed on the alfalfa itself, while others come for the abundance of earthworms, arthropods, and larvae. These songbirds also serve as important prey for raptors.

Deer, elk, and antelope also love alfalfa fields! While their grazing may not always be welcome, the importance of alfalfa fields for supporting game species is well known to hunters. Completing the alfalfa food web are large predators like cougars, and a variety of scavengers, from coyotes to vultures.

Alfalfa cropping systems are more productive than ever, as advances in alfalfa breeding and agronomy in recent years have enabled farmers to harvest high-quality hay more

Little bustard.

A SAMPLING OF SPECIES USING CALIFORNIA ALFALFA FIELDS FOR FOOD, COVER, AND REPRODUCTION

	Feeding	Cover	Breeding
BIRDS			
White-faced ibis	X	X	
Snow goose	X	X	
Cinnamon teal	X	X	X
Northern harrier	X	X	X
Ferruginous hawk	X		
Ring-necked pheasant	X	X	X
California quail	X	X	X
Mountain plover	X	X	
Burrowing owl	X	X	X
Short-eared owl	X	X	X
Vermillion flycatcher	X	X	
Horned lark	X	X	
Mountain bluebird	X	X	
Tricolored blackbird	X		
MAMMALS			
Pallid bat	X		
Black-tailed jackrabbit	X	X	X
Belding's ground squirrel	X	X	X
San Joaquin kit fox	X		
Long-tailed weasel	X	X	X
Pronghorn	X	X	X
Elk	X		
REPTILES AND AMPHIBIANS			
Western toad	X	X	X
Checkered garter snake	X	X	X
California tiger salamander	X	X	X

Highlighted rows indicate species that are endangered, threatened, or of local conservation concern.

Western meadowlark perched on a haybale.

Food plots bring game

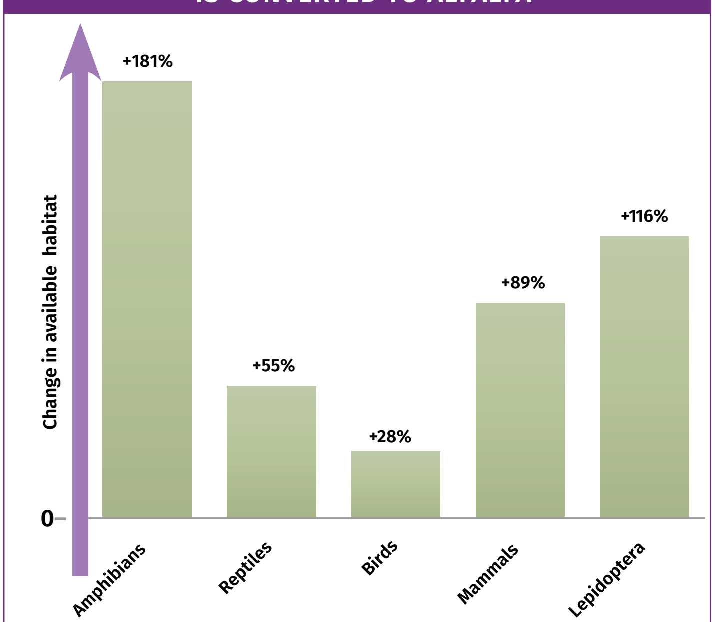
Hunters and wildlife-management agencies often plant food plots to attract game to their land and provide year-round nutrition for game species. Alfalfa is one of the most popular crops for food plots. Whitetail deer especially love alfalfa, and will choose it over most other foods. Turkeys, rabbits, quail, and elk will also use alfalfa plots. The plots also benefit songbirds and other non-game species, which take advantage of the food, cover, and nesting space provided by alfalfa mixtures.

frequently. However, aggressive harvest schedules can pose challenges for wildlife. To ensure that an alfalfa field can support the needs of the wild species it attracts, farmers must understand the ecology of the farm and the surrounding landscape. Sometimes this means changing views of species that are commonly viewed as pests. For example:

- Pocket gophers can wreak havoc in an alfalfa field, eating plants and leaving soil mounds that can damage equipment. Researchers have encouraged farmers to recognize that gophers can also bring surprising benefits, including increasing earthworm activity and channeling water deeper into the soil profile through their burrows. Farmers have learned that including predator habitat in the farmstead can help to control gopher populations effectively and ecologically.
- Many migratory and native bird species build nests in alfalfa fields. However, hay harvest can destroy nests and incubating adults, especially if the crop is cut early in the season or if cuttings are frequent. Some species will re-nest after a haying, and may successfully fledge offspring if sufficient time is allowed before the next cut. Other species may benefit from refuge areas that are left uncut until after the nesting season. Alfalfa seed production fields are especially valuable to birds, as they are allowed to grow to maturity without cutting.

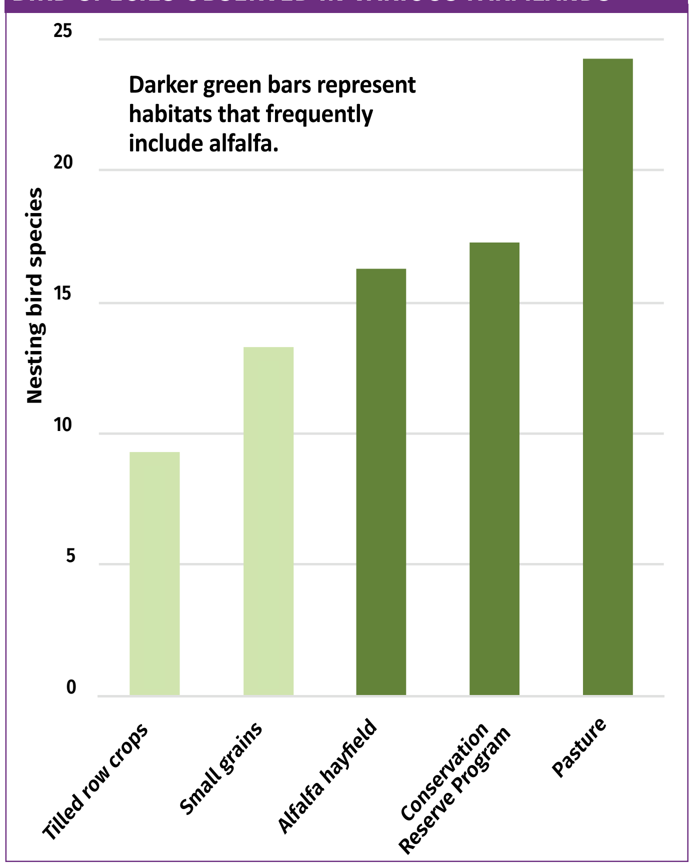
Alfalfa is most effective for promoting wildlife biodiversity and natural-enemy control of pest species when it is part of a complex landscape that includes not only diverse crops, but uncultivated areas with varied vegetation types, such as hedgerows, streambanks, wetlands, and road ditches. For example, hawks can use alfalfa fields as hunting grounds, but also need perching and nesting sites, which can be in woodlots or forest edges adjacent to crop fields. These "edge" environments are also favorable to mammalian predators like foxes and skunks, and can improve biological control of pest insects. An environment hospitable to predators enables them to control the populations of prey species that can damage crops.

WILDLIFE HABITAT INCREASE WHEN ROW CROP LAND IS CONVERTED TO ALFALFA



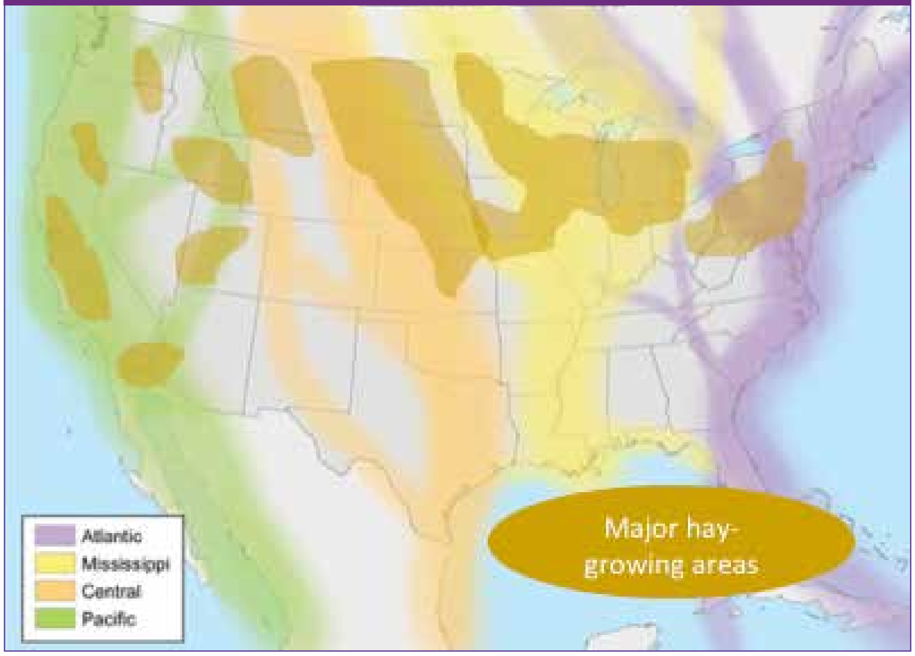
In a case study of the Walnut Creek watershed in Iowa, where current land use is almost exclusively corn and soybean cropping, researchers projected that suitable habitat for all wildlife groups would increase in a scenario where some current row crop land was converted to alfalfa production.

BIRD SPECIES OBSERVED IN VARIOUS FARMLANDS



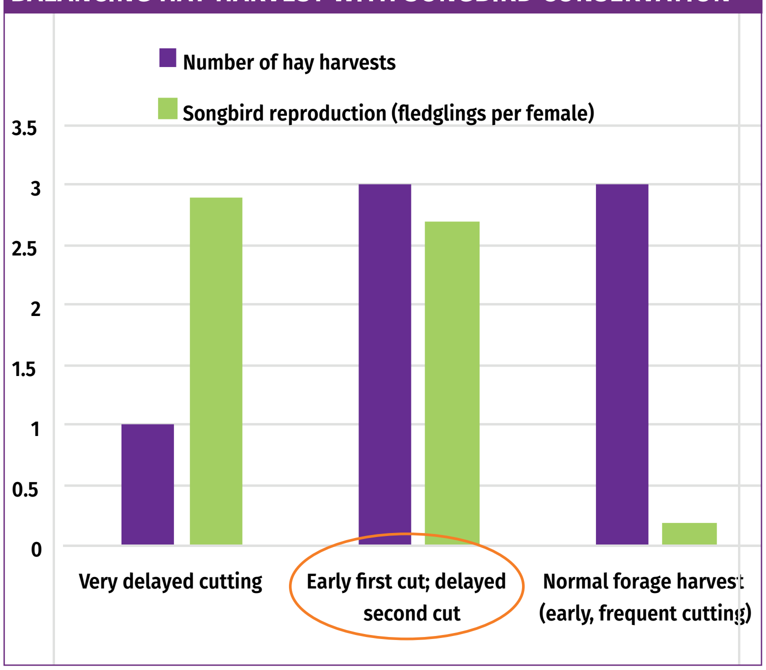
Number of bird species observed nesting in various farmland habitats in Iowa.

WATERFOWL FLYWAYS



Many of the major alfalfa growing areas in the U.S. intersect with the flyways used by migratory waterfowl. Alfalfa fields along these routes can be important resources for the birds during their migrations.

BALANCING HAY HARVEST WITH SONGBIRD CONSERVATION



Conservation programs for grassland birds have traditionally emphasized delaying haying until the nesting season is completed, which requires farmers to forgo their highest-quality hay production. A trial in Vermont found that farmers could successfully balance productivity and songbird conservation under a program of an early first harvest followed by a later second harvest. This allows farmers to obtain two cuttings of high-protein, dairy-quality hay, as well as a larger cutting of lower-protein hay.

Partnering for conservation

Realizing the potential of alfalfa fields to contribute to the success of wild bird populations requires research, policymaking, and education. The importance of flood-irrigated crops as bird refuges along the Pacific Flyway, a major through-route for migratory birds, has attracted the attention of the Audubon Society and Ducks Unlimited. Recently, these organizations have worked with California farmers to ensure that agricultural lands will be as hospitable as possible to nesting and migrating birds. These efforts include protecting farmland from urban encroachment, delaying forage harvest on some acres, and timing flood irrigations to maximize groundwater recharge as well as habitat quality.

Swainson's hawk

7. Alfalfa in the cropping system

Alfalfa has long been prized by farmers not only for its value as a crop, but for its benefits to other crops in the farming system. Alfalfa makes enormous contributions to soil fertility and tilth, boosts the productivity of the crop rotation as a whole, and can reduce the need for chemical inputs. Alfalfa is often grown in rotation with crops like corn that have high N fertilizer requirements. The increase in productivity from growing alfalfa in rotation with other crops is called the "rotation effect."

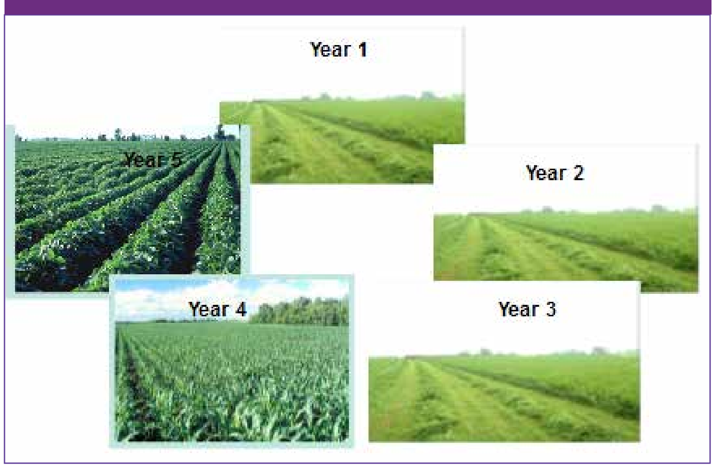
The most measurable benefit provided by an alfalfa crop is nitrogen that can be used by following crops in the rotation. Atmospheric nitrogen fixed in the alfalfa's root nodules by symbiotic *Rhizobium* bacteria (see Section 1) is returned to the soil through root exudates and sloughing, leaf litter, and residue incorporation when the crop is terminated. This serves as a slow-release reserve of nitrogen that can be used by future crops. It is particularly important for corn, a "heavy feeder" that requires large supplies of nitrogen. A third-year stand of alfalfa is capable of fixing over 400 lbs/acre of N, up to about 160 lbs of which can remain as a net nitrogen contribution to the system after forage is harvested. This can provide so much nitrogen that the succeeding corn crop will not even respond to the addition of synthetic fertilizer.

OUTCOMES OF ADDING TWO YEARS OF ALFALFA TO A CORN-SOY ROTATION

Labor needs	↑
Corn and soybean yields	↑
Fossil fuel energy use	↓
Synthetic fertilizer use	↓
Herbicide use	↓
Water quality	↑
Total system profitability	↑

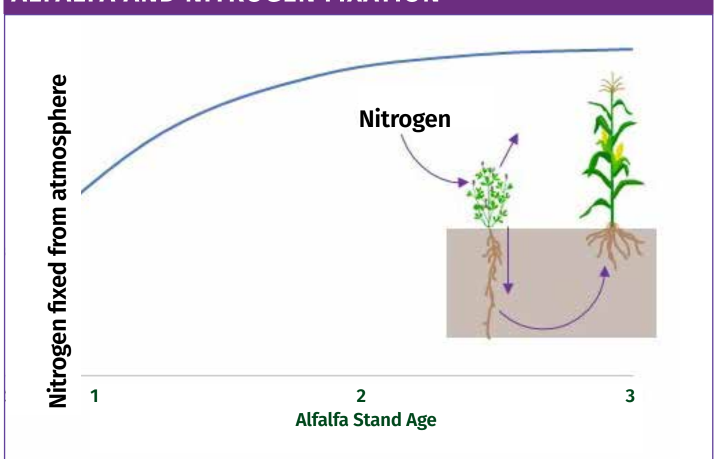
A long-term cropping system experiment in Iowa found that diversifying a corn-soybean rotation with two years of alfalfa required more labor, but improved yields, profitability, and water quality while reducing the need for fossil fuel energy and chemical inputs.

CROP ROTATION: ALFALFA–CORN–SOYBEAN



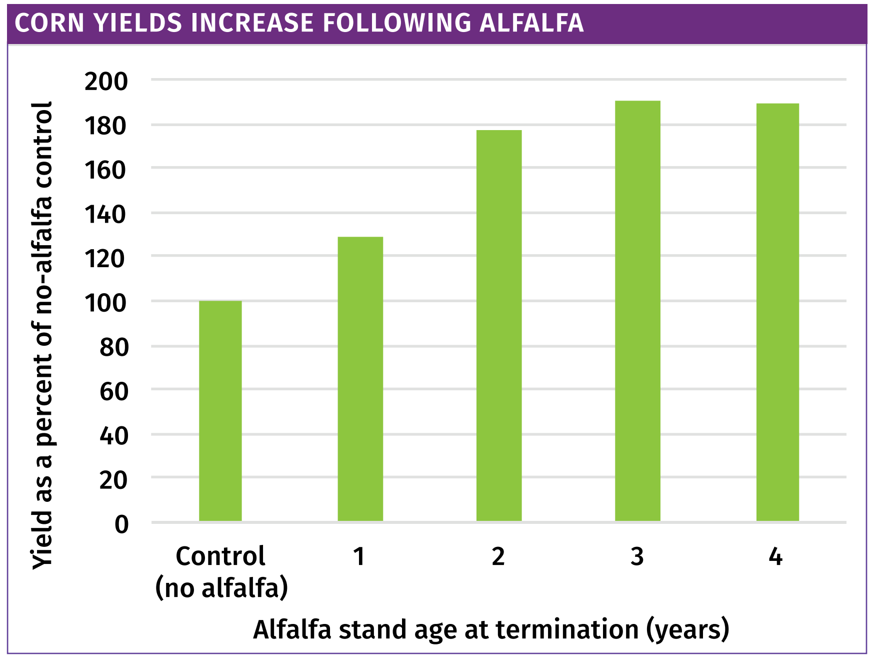
Rotations describe the sequential production of crops over time on the same piece of land. A typical Midwestern farm might use a 5-year rotation with three years of alfalfa followed by corn and soybean. After the soybean, a new alfalfa stand is planted and the rotation begins again.

ALFALFA AND NITROGEN FIXATION



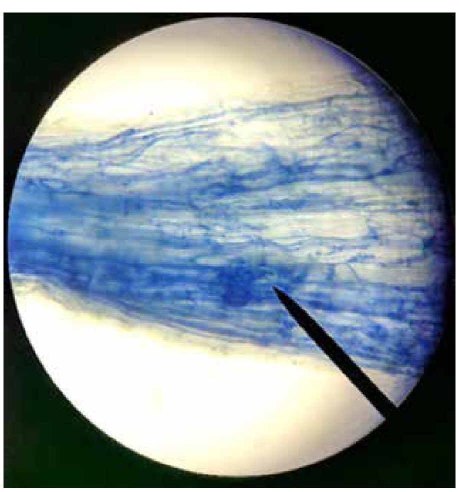
A Canadian study found that alfalfa's nitrogen fixation from the atmosphere increased over three years of the stand. Some of this nitrogen is removed with hay harvest, but much of it is incorporated into the soil, leaving a positive nitrogen balance after alfalfa harvest, which can be used by a following crop.

Alfalfa can also support phosphorus nutrition of the following crop by promoting beneficial soil fungi called arbuscular mycorrhizae. These symbiotic fungi form associations with plant roots, actually inserting themselves into the root cells and extending a network of fine hyphae, or filaments, through the soil that take up phosphorus and transport it back to the plant, which provides the fungus with carbon compounds in exchange. Alfalfa is a strongly mycorrhizal plant; it partners very effectively with the fungi and increases their abundance



Corn yields increase following alfalfa in the rotation. The longer the alfalfa stand has been in place, the greater its benefit to the succeeding corn crop.

Alfalfa herbage and roots are incorporated into the soil when the stand is terminated.



Beneficial mycorrhizal fungi (stained blue) penetrate plant root cells to facilitate exchange of nutrients. The dark spot beside the pointer is a vesicle, or storage structure, formed by the fungus inside the root tissue.

What is a nitrogen credit?

NITROGEN CREDIT RECOMMENDATION

Nitrogen credit recommendation for first-year corn following alfalfa in Wisconsin depends on the texture of the soil, the quality of the alfalfa stand, and how much regrowth was present when the stand was terminated.

	MEDIUM & FINE-TEXTURED SOILS		SANDY SOILS	
	<8 inches regrowth	>8inches regrowth	<8 inches regrowth	>8 inches regrowth
Alfalfa stand quality			Nitrogen credit (lbs N per acre)	
Good	190	150	140	100
Fair	160	120	110	70
Poor	130	90	80	40

Knowing how much fertilizer to apply is important. If a farmer puts more nitrogen fertilizer on a field than a crop can take up, it will be a waste of money and may leach into the groundwater. If too little is applied, the crop won't yield to its full potential. Farmers know that alfalfa can provide nitrogen to a following crop, but in order to make prudent decisions about fertilizer application, they must have good estimates of how much they can safely reduce their fertilizer use without compromising yields. The amount of nitrogen fertilizer that is effectively replaced by a preceding crop is called a nitrogen credit. According to university-issued guidelines, farmers planting corn after alfalfa can take nitrogen credits of up to 190 lbs/acre in the first year. The benefit can even extend into the second or third year after the alfalfa stand is terminated. However, a recent review suggested that official recommendations for alfalfa nitrogen credits to a succeeding corn crop do not always accurately reflect the field-specific factors that best predict when additional fertilizer will be needed. Ongoing practical research is needed to ensure that farmers will have management guidance that maximizes the benefits of alfalfa to the economic and environmental sustainability of their cropping systems.

in the soil so they can more effectively colonize the following crop. Alfalfa also promotes mycorrhizal benefits by decreasing the need for synthetic nitrogen fertilizers, which tend to reduce mycorrhizal abundance.

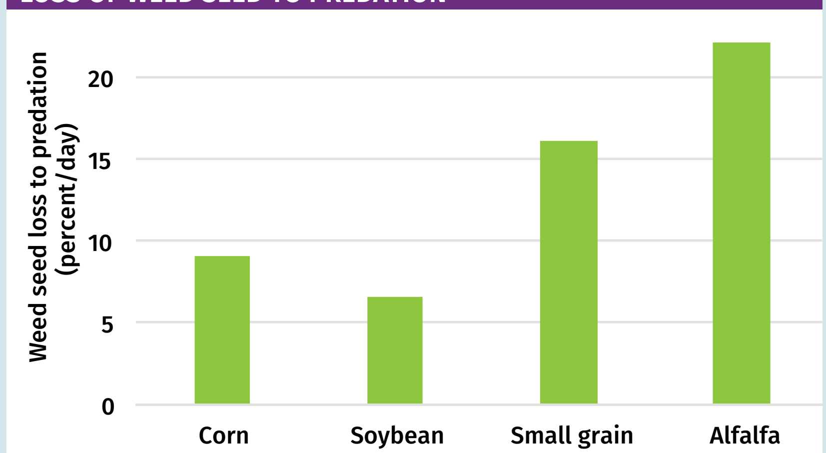
Alfalfa can help break up pest and disease cycles that reduce the yield of grain crops. Common pests that plague corn and soybean crops, such as corn rootworm and soybean cyst nematode, cannot reproduce on alfalfa roots. When crop rotations are diversified to include alfalfa and other non-corn and soybean crops, the pressure of these pests on their host crops is reduced. This makes the use of alfalfa in the rotation an important component of an integrated pest management (IPM) strategy, which incorporates scouting and cultural tools for managing pests and pathogens in order to minimize the use of expensive and potentially hazardous chemical controls. And, as we saw in previous sections, alfalfa can benefit not only the crops that come after it, but also crops growing in neighboring fields, by supporting predators and natural enemies of pests and by feeding pollinators.

Alfalfa's deep roots and its contributions to soil organic matter help to improve soil tilth, nutrient cycling, and water-holding capacity. The positive changes that alfalfa brings to the soil structure and the soil microbial community resonate throughout the cropping system, supporting yields of all the crops in the rotation. Economic analyses in the Corn Belt have found that net returns to diversified farming systems including alfalfa are greater than or equal to returns to corn-soybean systems, while sustaining long-term productivity and reducing negative environmental impacts.

Alfalfa as ecological weed control

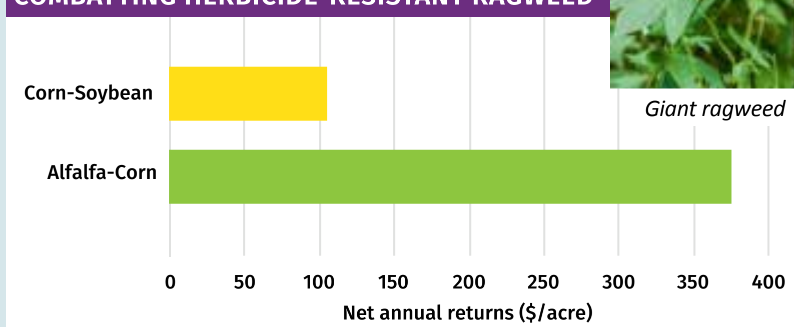
Weed control is a major challenge for organic farmers, who do not use herbicides, and who are always looking for ways to beat back weeds without relying too heavily on soil-damaging tillage. Many organic farmers use alfalfa in the rotation as a means of tackling tough weed problems without chemical inputs. When planted in a field that is heavily infested with Canada thistle, field bindweed, or other persistent perennial weeds, alfalfa's strong perennial root system and thick vegetative cover compete with the weeds for water, sunlight, and nutrients. Alfalfa's harvest schedule allows the farmer to repeatedly mow the field throughout the season, defoliating the weeds and depleting their energy reserves until they lose the ability to regrow. Alfalfa can also reduce annual weed pressure by cutting weeds before they go to seed and by providing cover to rodents, birds, and other animals that feed on weed seed. This is valuable not only to organic farmers, but to those facing the rise of herbicide resistant weeds.

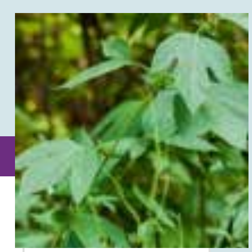
LOSS OF WEED SEED TO PREDATION



Weed seed predation is higher in alfalfa fields than in other crops. This means that many of the seeds produced by weeds in an alfalfa field are eaten by birds, rodents, or insects before they have a chance to germinate or be incorporated into the soil seedbank.

COMBATTING HERBICIDE-RESISTANT RAGWEED





Giant ragweed

In a Minnesota study of fields infested with herbicide-resistant giant ragweed, an alfalfa-corn rotation effectively controlled giant ragweed emergence and was much more profitable than a corn-soybean rotation.

8. Ecosystem services

We've seen the many benefits that alfalfa provides to farmers, including nutritious livestock forage, soil fertility, and pest control. But the effects of this perennial legume also extend beyond the boundaries of the farm. Researchers comparing different land uses and cropping systems use the concept of *ecosystem services* to look beyond the quantity of harvested crop and begin to account for the value of the many functions that society depends on the land to provide.

Ecosystem services include *provisioning services*, or the production of food and useful goods. Alfalfa's provisioning services include not only its direct production of forage for livestock, which in turn provides humans with milk and meat, but also its positive effects on the yields of other crops in the rotation. Alfalfa has also been explored as a potential feedstock for next-generation biofuel production—another valuable provisioning service.

Alfalfa is also an outstanding provider of *regulating services*, which contribute to environmental stability and quality. For example, with its perennial ground cover and soil stabilizing root systems, alfalfa regulates the quality of surface water by reducing the amount of sediment and nutrients that wash into lakes and streams. The improved water infiltration in alfalfa fields also reduces the amount of surface runoff to waterways during heavy rain, which results in the important services of flood prevention and groundwater recharge. Alfalfa, by drawing carbon from the atmosphere and depositing it deep in the soil profile, also has the potential to provide the vital and timely service of climate regulation.

Cultural services include ecosystem services that contribute to human well-being, pleasure, and spirituality. Alfalfa has much to contribute in this category as well. Many farmers describe the profound fulfillment that they derive from building farming systems that re-integrate crops and livestock, reduce chemical inputs, and support wildlife. Diverse

CATEGORIES OF ECOSYSTEM SERVICES

PROVISIONING SERVICES Food Production Water Wood and Fiber Fuel	**SUPPORTING SERVICES** Nutrient Cycling Soil Formation Primary Production Habitat Provision
CULTURAL SERVICES Spiritual Aesthetic Educational Recreational	**REGULATING SERVICES** Climate Regulation Flood Mitigation Water Purification

The concept of ecosystem services allows researchers to recognize the benefits provided by farms to society at large.

A SAMPLING OF ECOSYSTEM SERVICES PROVIDED BY ALFALFA

PROVISIONING SERVICES
- Dairy and meat products
- Honey
- Higher grain yields in rotation crops
- Emerging markets for alfalfa protein

SUPPORTING SERVICES
- Erosion prevention
- Predator habitat
- Nitrogen fixation

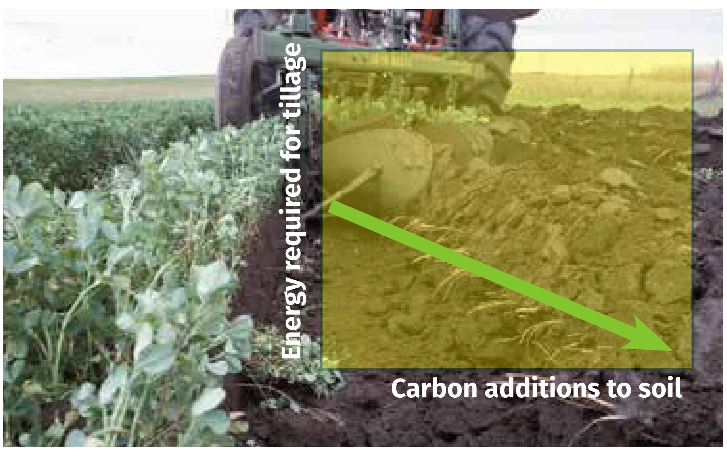
CULTURAL SERVICES
- Wildlife protection
- Landscape diversity
- Hunting and fishing

REGULATING SERVICES
- Improved drinking water quality
- Carbon sequestration
- Reduced need for pesticides

rural landscapes that integrate perennials and natural areas offer opportunities for recreation to both rural residents and urban visitors, including fishing, hunting, and agri-tourism. These can provide additional income streams and economic resiliency to host farmers and rural communities.

Many of alfalfa's benefits in cropping systems are related to its provision of *supporting services,* which build the ecosystem's functional capacities. For example, by hosting nitrogen-fixing bacteria and phosphorus-scavenging mycorrhizal fungi, alfalfa supports nutrient availability with reduced inputs of synthetic fertilizer. By improving soil tilth, alfalfa can even allow farmers to conduct field operations at lower tractor power and reduced fuel use. These supporting services bring benefits to the wider society by reducing the farm's need for fossil-fuel-intensive inputs that contribute to global climate change.

Alfalfa provides a unique balance of ecosystem services that is not matched by any other crop. Many of these services can work synergistically. For example, the regulating service of reducing sediment runoff also improves the cultural service of recreational fishing opportunities, which depend on clear, clean streamwaters. When the supporting service of habitat provision results in a higher density of predators and therefore less crop damage, it increases the provisioning service of crop yields in alfalfa and other nearby crops. Provisioning services are often seen as a trade-off with other categories of ecosystems services—in other words, the more a farm focuses on short-term productivity, the more damaging it tends to be to the agroecosystem's ability to provide supporting, regulating, and cultural services. In particular, when a farm increases its use of synthetic nitrogen fertilizer, it may boost its output of grain crop yields while undermining groundwater quality and increasing demand for fossil fuels. Alfalfa can offer farmers a way around this trade-off. Its perenniality, vigorous growth, high nutritional value, and symbiotic nitrogen fixation allow it to yield a high-value product while



With long-term additions of carbon-containing materials like alfalfa residues, soil becomes easier to till, requiring less tractor power and therefore less fuel.

A recently terminated alfalfa field is prepared for the next crop

Learning together

In Wisconsin, Minnesota, and other areas where pastured livestock are raised, farmers and educators gather regularly for pasture walks, an opportunity to build knowledge and community among graziers. Host farmers offer the group a first-hand view of their area of expertise, ranging from how to use alfalfa in grazing mixtures to how to manage cattle with moveable electric fencing. Attendees share dilemmas, suggestions, and sometimes a meal. These walks build networks of support for economically resilient, stewardship-minded farming. They represent a model for how communities of farmers can come together around perennial crops to support multi-functional farming systems that fulfill the needs of people and animals on and off the farm.

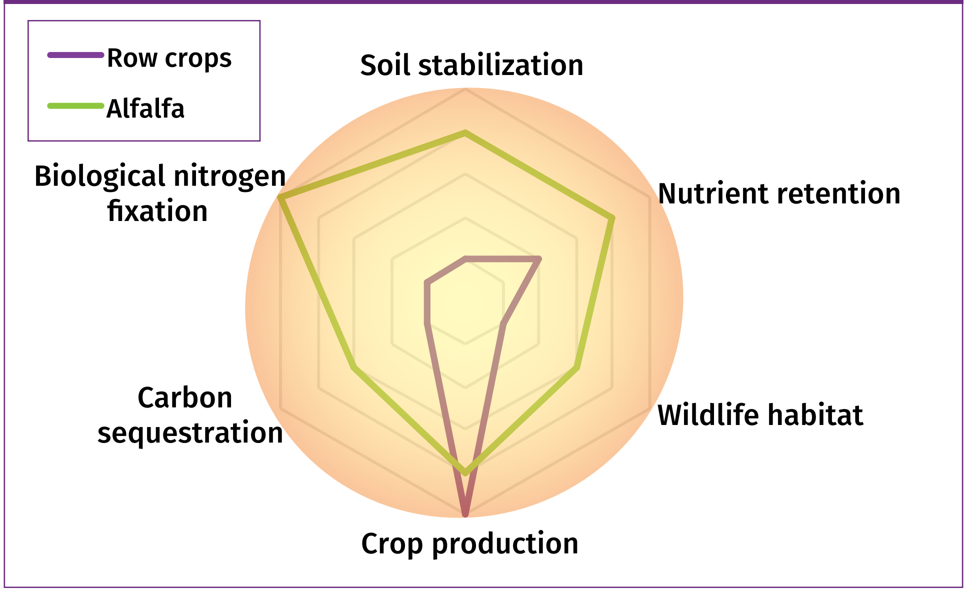
Mike Gehl, a Grazing Planner for Glacierland Resource Conservation and Development, demonstrates how to calculate forage yield from diverse swards including alfalfa using a pasture stick.

protecting the foundation of ecosystem function that supports long-term sustainability.

Ecosystem services produced by a farm benefit the broader society that surrounds it, often in ways that have monetary value. For example, farms that reduce nutrient and sediment runoff support the livelihoods of surrounding communities that earn revenue from recreational activities like fishing and boating—which depend on good water quality in local lakes and streams. Conservation incentive programs can serve as a mechanism for public agencies or private organizations to "purchase" these services from farmers and land managers, essentially paying them to implement practices that support important ecosystem functions. The Conservation Reserve Program (CRP), which pays farmers to protect sensitive waterways and highly erodible soil by taking marginal farmland out of row crop production and planting perennial cover, is one well-known example of a program of payment for ecosystem services. Alfalfa is a popular component of CRP planting mixtures.

Alfalfa helps to regulate the flow of nutrients into surface and groundwater.

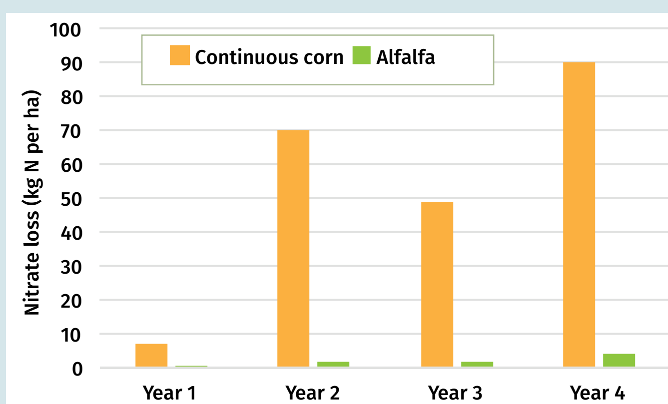
PROVISION OF ECOSYSTEM SERVICES BY ALFALFA COMPARED TO ROW CROPS



Compared with alfalfa, annual row crops offer high productivity but much lower levels of other ecosystem services.

Protecting drinking water

Many communities that depend on well water in agricultural areas face the problem of excess nitrate, the soluble form of nitrogen that is commonly applied as fertilizer, in their drinking water supplies. In drinking water, nitrate can cause "blue baby" syndrome (impaired blood oxygenation) and other health issues. Communities whose groundwater is contaminated by fertilizer nitrate leaching may have to pay millions of dollars for filtration equipment to render their drinking water supplies safe—money that could be saved if nearby farmers reduced nitrogen loss from their farms. Alfalfa provides a valuable service in regulating groundwater nitrate levels: because it fixes nitrogen and maintains living roots throughout the year, it not only does not require nitrogen fertilizer application, but can also take up excess soil nitrate, particularly in the late fall and early spring when high levels of unused fertilizer are exported from annual cropping systems. In a recent California study, levels of mobile soil nitrate observed in late fall just before winter precipitation began were 55 to 60% lower in soils with an alfalfa crop than following a corn crop.



Alfalfa greatly reduces nitrate loss through subsurface tile drainage, particularly in wetter years (years 2 through 4 in this Minnesota study), when large amounts of N may be lost from cornfields.

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Photo credits and figure sources

Introduction

Cattle on pasture; corn/alfalfa strips; irrigation Conservation Service (NRCS)

Alfalfa leaves; cattle behind fence; farmers with roots; baler: National Alfalfa and Forage Alliance (NAFA)

Root depth illustration: Kate Freund

Honey: Marco Verch (CC license at https://www.flickr.com/photos/30478819@N08/45447726491)

Section 1

Flowering alfalfa; alfalfa crown: Craig Sheaffer

Crop values figure: USDA-NASS 2019

Alfalfa leaves; horses pulling haycart: David L. Hansen

Flower close-up; Centers of Origin graphic: Kate Freund

Field under irrigation: Dan Putnam

Top alfalfa-growing states figure: USDA-NASS 2019

Alfalfa roots with nodules: Adria Fernandez

Section 2

Cattle on pasture: NRCS

Cattle in barn: NAFA

Nutrient content chart: Balliette and Torell, undated

Nitrogen loop figure: Adria Fernandez

Hayride talk: Kristen Jurcek

Pollinator forage map: Claudia Hitaj, USDA-ERS

Alfalfa flowers: Kate Freund

Horse: Devan Catalano

Section 3

Cutting alfalfa; alfalfa seeds: David L. Hansen

Alfalfa-grass mixture; silage; grazing cow; Forage Maturity figure: Craig Sheaffer

Raking cut alfalfa; large round bales; vegetative stage: NAFA

Alfalfa seedpods; center pivot: Mark Smith

Bud stage; flowering stage: Kate Freund

Siphons: Dan Putnam

Flood irrigation: Nicole Tautges

Section 4

Corn and alfalfa strips; eroded cornfield: NRCS

Soil organic matter; alfalfa and cornfield: Craig Sheaffer

Pasture mix: Kristen Jurcek

Soil aggregation chart: Nicole Tautges, unpublished data

Soil carbon figure: adapted from Gregorich et al., 2001

Soil erosion figure: adapted from Larson et al., 1997

Soil components piechart: Adria Fernandez

Section 5

Monarch; Red Admiral butterfly: David L. Hansen

Beautiful and Beneficial Insects table: adapted from Pimentel and Wheeler, 1973

Twelve-spotted skimmer: Wikimedia Commons user JD (CC license at https://commons.wikimedia.org/wiki/File:Twelve-spotted_Skimmer_(9213332677).jpg)

Ruby Meadowhawk: Melissa McMasters (CC license at https://commons.wikimedia.org/wiki/File:Ruby_meadowhawk_(25138368564).jpg)

Eastern Tailed Blue: James St. John (CC license at https://www.flickr.com/photos/jsjgeology/32072412986)

Rusty patched bumblebee: US Fish and Wildlife Service Midwest Region (CC license at https://commons.wikimedia.org/wiki/File:Rusty_Patched_Bumble_Bee_(28971822177).jpg)

Paper wasps: Carl Krucke (CC license at https://bugguide.net/node/view/126176)

Marbled orb weaver: Flickr user C Watts (CC license at https://www.flickr.com/photos/watts_photos/29866817907)

Banded garden spider: Wikimedia Commons user gailhampshire (CC license at https://commons.wikimedia.org/wiki/File:Banded_Garden_Spider_(Argiope_trifasciata)_-_Flickr_-_gailhampshire_(1).jpg)

Nectar crops chart: adapted from Evans et al., 2018

Pea aphid: Bruce Potter

Flower tripping table: adapted from Cane, 2002

Alkali bee; alfalfa leafcutter bee: Dan Putnam

Speed Zone sign: Western IPM Center

Section 6

Rabbit in alfalfa: Craig Sheaffer

Tundra swans; Swainson's Hawk; deer in alfalfa: Dan Putnam

Little bustard: Francesco Veronesi (CC license at https://commons.wikimedia.org/wiki/File:Little_Bustard_(Tetrax_tetrax),_Castuera,_Extremadura,_Spain.jpg)

Sampling of Species table: adapted from Putnam et al., 2001

Meadowlark on haybale: Andy Reago and Chrissy McClarren (CC license at https://commons.wikimedia.org/wiki/File:Western_Meadowlark_(31319234995).jpg)

Wildlife habitat increase figure: adapted from Santelmann et al., 2006

Bird species observed: adapted from Best et al., 1995

Hay harvest figure: adapted from Perlut et al., 2011

Waterfowl flyways: USFWS/Adria Fernandez/Arlene West

Section 7

Corn/soy/alfalfa fields: David L. Hansen

Outcomes of Adding Alfalfa chart: adapted from Davis et al., 2012

Crop Rotation figure: Craig Sheaffer

Alfalfa and nitrogen fixation: Adria Fernandez

Nitrogen credit recommendations: University of WI Extension, undated

Alfalfa herbage/roots/soil: Craig Sheaffer

Mycorrhizal fungi: Emily Woodward

Loss of Weed Seed figure: Iowa State Extension, adapted from Westerman et al. 2005

Giant ragweed: Melissa McMasters (CC license at https://www.flickr.com/photos/cricketsblog/17014936200)

Combatting Ragweed figure: adapted from Goplen et al., 2018

Section 8

Landscape with crop strips: David L. Hansen

Categories of Ecosystem Services: adapted from Millennium Ecosystem Assessment, 2005

Farmstead with pond: Alamy

Sampling of Ecosystem Services table: Adria Fernandez

Carbon Additions figure: David L. Hansen/Adria Fernandez/Arlene West

Recently terminated field: University of MN Extension

Calculating forage yield: Kristen Jurcek

Provision of Ecosystem Services chart: Adria Fernandez/Arlene West

Nitrate loss chart: adapted from Randall et al., 1997

Full references list available in the online PDF of this publication at https://www.alfalfa.org/publications.php

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