Redesigning Alfalfa for Use in Mixtures with Grasses

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A lush field consisting of a mixture of grass and legumes is the goal of many producers. There are many benefits to such a production system. Probably most important in times of high fertilizer prices, is the reduced need for nitrogen due to the legume's capacity for biological nitrogen fixation. Compared to grass monocultures, mixtures have higher total yields because the legume continues to be productive when grasses are less productive in the summer, and the hay produced has increased digestibility and protein leading to better animal performance. Compared to an alfalfa monoculture, a mixture is less expensive to establish, uses less water, and is more productive on sites with lower fertility. There is also increasing interest in grass-legume mixtures for disposal of manure or water from sewage treatment containing high levels of nitrogen.

However, attaining a productive grass-legume mixture can be frustrating and stands with the desired mixture are often short-lived. In the 1990s, USDA-ARS scientists located in St. Paul, MN initiated research to develop alfalfa that has increased productivity and stability in mixed species plantings. Alfalfa is an excellent legume for growth in a mixture as it is highly productive, is widely adapted, has an extensive root system that taps water and nutrients deeper in the soil, and has a canopy that allows good light penetration. However, alfalfa has been developed primarily for growth in monoculture, so it is no surprise that different traits or characteristics are necessary for growing in a mixture. For maximum productivity with grasses, a redesigned alfalfa will need to supply nitrogen to the grass component, have enhanced ability to acquire potassium (K) and phosphorus (P) from soil, and resist lodging over longer harvest intervals.

Table 1. Selection created alfalfa differing in N uptake capacity. Results from one regrowth period show a 19% difference in nitrogen uptake between cycle 2 selected populations.

Selected Populations	Forage N Concentration (%)	N Uptake from Fertilizer (lbs/ac)
High N Uptake Cycle 2	4.03	29
High N Uptake Cycle 1	3.97	27
Low N Uptake Cycle 1	3.97	23
Low N Uptake Cycle 2	3.95	24
LSD 0.05	NS*	3

**High and low types were not significantly different in N concentration.*

To develop alfalfa that has enhanced nitrogen transfer, a basic understanding of the source of nitrogen was needed. Alfalfa plants increase nitrogen in soil that can be used by other plants, but the source of the nitrogen was unknown. This information was critical to be able to maximize nitrogen transfer to grasses. 15N nitrogen gas, a naturally-occurring stable isotope of nitrogen, was delivered to alfalfa plants and traced through plants and soil. It was found that 36-46% of the nitrogen moves from roots and crown into foliage, less than 1.5% accumulates in soil, and the remainder stays in root and crown tissue. The results showed living roots do not excrete nitrogen but that a majority of the nitrogen accumulating in soil is due to death and breakdown of roots and nodules.

The next step in the research was to determine the dynamics of root and nodule growth to determine when and where root turnover occurs. Video recordings of alfalfa roots growing in the field were made using cameras in tubes buried in soil to track emergence, growth, and death of roots. An amazing 10" of roots per cubic inch of soil was found. In the first 7 weeks of growth more than half of the roots were fine hair-like roots located in the first upper 10" of soil. These roots had a lifespan of 58-131 days and by the end of the season one-half of all the fine roots had decomposed. Turnover of fine roots was the major source of N, contributing 53 lbs N/ac over one season. The study suggested that alfalfa plants with a greater density of fine roots would make more N available to a companion crop. Additionally, plants with increased fine root density might compete more effectively for P and K when grown with grasses. Both P and K are poorly mobile in soil. Phosphorus reacts with calcium and magnesium in soils of neutral to high pH and with iron and aluminum in soils of neutral to acidic pH. Potassium is absorbed or is closely associated with cation exchange sites on clays. As a consequence, P and K can be absorbed by plants only when their roots or their mycorrhizal symbionts are in close proximity of these ions. When grown in soil with lower levels of these nutrients, plants that have more roots may be able to access more P or K and may be able to produce higher yields than plants with fewer roots.

Figure 1. Development of alfalfa with highly fibrous branch roots and low fibrous taproot.

Previous research found alfalfa root system architecture is influenced by fall dormancy and geographic origin. Non-dormant types tend to have taproots with few branches and few fine fibrous roots. Dormant types tend to have many branches and develop highly fibrous roots. A selection and breeding program to develop alfalfa with highly fibrous roots started with four diverse groups of alfalfa germplasm differing in fall dormancy. In the first cycle of selection, plants with the most fibrous roots in each group were identified from plants grown in the field for 22 weeks. This growth period was necessary for the mature root structure to develop. These plants were intercrossed and their progeny used for a second cycle in which plants that had either a strong taproot or many lateral branching roots were selected. This program succeeded in developing alfalfa from each dormancy group that had branched and highly fibrous roots (Figure 1). On average, the fibrous selection has 30% more fibrous roots than typical alfalfa. Forage yield of plants selected for fibrous and lateral roots was 7-14% greater in the establishment year and 9-16% greater in the first production year than alfalfa selected for taproot production, suggesting that selection for altered root morphology is a viable strategy for enhancing yield in alfalfa. Importantly, recent research found root architecture is stable and maintained in different soil types with different P and K availability. Field trials are in progress to measure N transfer and competition for P and K when these plants are grown in monoculture and as a companion with reed canarygrass and orchardgrass.

When planted as a companion with grass, alfalfa will often out-compete the grasses for nitrate, reducing grass productivity and persistence. Could alfalfa be developed that has reduced nitrate uptake and relies primarily on N fixation? To address this question, a novel method for measuring nitrate uptake was developed. The traditional method using 15N is too expensive for testing the large number of plants used in an alfalfa breeding program. It was found that bromide, a non-essential plant nutrient, and nitrate absorption are correlated in alfalfa, and bromide concentration is easy and inexpensive to determine. Plants were identified for either high or low bromide uptake in two cycles of selection in the field. The new populations had similar amounts of N in forage and similar forage yields but differed in the proportion of nitrogen that was derived from fertilizer (Table 1). This is the first demonstration that a legume will preferentially fix nitrogen even when nitrate is present. Currently, seed of this unique alfalfa is being produced for field trials making development of the re-designed alfalfa plant one step closer to completion.