ALFALFA – SMALL GRAIN ROTATIONAL BENEFITS: IT'S WORTH MORE THAN YOU THINK

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ABSTRACT

Alfalfa in California helps fix significant amounts of atmospheric N_2 annually. Fixed N often becomes available to subsequent crops and can be included when determining N fertilizer needs. However, there is limited information on alfalfa's N contribution in semiarid irrigated cropping systems. We conducted field trials at three sites on soils ranging from clay loams to a sandy loam to help develop recommendations in California. We compared wheat's responses to N fertilization when grown after two cropping systems: continuous alfalfa (Alfalfa-Grain) and a sudangrass-wheat rotation (Grain-Grain). Forage yields, grain yields, grain protein content, and N uptake were higher in wheat following the Alfalfa-Grain treatment than in wheat following the Grain-Grain treatment. At Davis, Tulelake, and Kearney, wheat following the Grain-Grain treatment required 114 lb N ac^{-1}, 119 lb N ac^{-1}, and 82 lb N ac^{-1}, respectively, to achieve the same amount of N uptake as unfertilized wheat following the Alfalfa-Grain treatment. Depending on location, alfalfa's N contribution was likely in a range between 80 lb N ac^{-1} and 120 lb N ac^{-1}.

Keywords: alfalfa, *Medicago sativa*, wheat, rotation, N credit, N contribution

INTRODUCTION

Due to a symbiosis with N_2-fixing bacteria, legumes such as alfalfa often add plant-available nitrogen (N) to soil after they have been plowed down. Many times, subsequent crops can benefit from this nitrogen, so many cooperative extension services recommend including the preceding legume's N contribution, or its N credit, when determining subsequent crops' N fertilizer needs (1–3). Ignoring a legume's N contribution can lead to over-fertilizing, which can be costly and can negatively impact the environment (4, 5). Reducing fertilizer use to account for legumes' N contributions could reduce environmental impacts of N fertilization and could also help increase profits (6).

For alfalfa, nitrogen credit recommendations have been developed for several rainfed environments, with data from hundreds of site-years' indicating that N contributions range from 30 to 75 lb N ac^{-1} for seeding year alfalfa stands (7, 8) and up to 175 lb N ac^{-1} (9, 10) for older stands. Depending on soil and environmental factors, two- to five-year-old stands of alfalfa have also frequently been found to supply all the N needs of subsequent corn crops (11).

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In California, however, field data for determining alfalfa's nitrogen contribution are currently lacking, even though alfalfa is widely grown throughout the state. Estimates from field data in similar climates are also comparatively lacking, though a few site-years of data exist. For example, in Spain, a two-year-old alfalfa stand was estimated to supply around 140 lb N ac^{-1} to a subsequent corn crop (12), and four- to five-year-old stands were found to supply all of a subsequent corn crop's N requirements in some cases (13).

Though there are some field data for determining alfalfa's nitrogen contribution in similar climates, California's wide range of environments, soils, and management strategies could all have different effects on the amount of nitrogen alfalfa helps add to soil. Developing a nitrogen credit recommendation for California could help growers statewide reduce fertilizer input costs. Thus, to help begin developing N credit recommendations for alfalfa in California, we established field trials at three locations, repeated over two periods, or phases. The study is currently at the halfway point.

OBJECTIVES

Our overall objective is to understand the impacts of rotation with alfalfa on the N fertilization needs of a non-leguminous crop. Specific objectives are to:

1. Quantify the N available to a subsequent wheat crop provided by rotation with alfalfa.
2. Develop an N credit recommendation for crops following alfalfa.
3. Differentiate other rotational benefits or disadvantages that may be attributed to crop rotation following alfalfa, distinct from N benefits.

Figure 1. *Field trial in Parlier, CA. Photograph on left depicts sudangrass-wheat rotation treatment and continuous alfalfa treatment. Both treatments were then terminated and followed by wheat planted with different N rates (right-hand side photograph). Photograph on right depicts differences in N response of wheat to continuous alfalfa treatment and sudangrass-wheat rotation treatment.*

PROCEDURES

Locations and treatments

Field trials were established at three locations in California: Davis (UC Davis campus, Solano County), Kearney/Parlier (UC Kearney Research and Education Center, Fresno County), and Tulelake (UC Intermountain Research and Education Center, Siskiyou County). Soils at Davis and Tulelake were clay loams, with Tulelake's soil's having a high organic fraction. Soil at Parlier was a sandy loam. Locations were selected to represent a range of growing conditions under which wheat and alfalfa are commonly grown.

Trials consisted of two cropping system treatments followed by six N rate treatments in wheat, repeated over two periods (Figure 1). Cropping systems were: continuous alfalfa (Alfalfa-Grain) and a sudangrass-wheat rotation (Grain-Grain). After these treatments were terminated, wheat was planted. Wheat planted at Davis and Kearney was ‘Patwin’ hard white spring wheat. At Tulelake, the wheat variety used was ‘Tubbs’ soft white winter wheat. The wheat received six N rate treatments: 0, 50, 100, 150, 200, and 250 lbs N ac^{-1}.

Trial design and establishment

Treatments were arranged in a randomized complete block design in a split-plot, with 4 or 5 replications. Main plots were the cropping system treatments and subplots were the subsequent N rate treatments in wheat.

At each location, cropping system treatments were established in existing stands of alfalfa. For the Grain-Grain treatment, strips of alfalfa were removed and planted to sudangrass. Remaining strips of alfalfa were left in place for the Alfalfa-Grain treatment. None of the crops in either treatment was fertilized, but plants were otherwise managed according to recommended practices. In both phases, before treatments were terminated in the fall, alfalfa stands had been in production for at least 2.5 years and sudangrass-wheat rotations had been maintained for at least 1.5 years. Treatments were terminated by tillage.

After cropping system treatments were terminated, all plots were planted to wheat for determining the two cropping systems' effects on subsequent crops' responses to N fertilization. Soil samples were taken before planting to characterize soil chemical and physical properties and for determining soil total N content. To avoid excessive leaching, 50 lb N ac^{-1} of the N for each treatment except the control, which did not receive any N fertilizer, were applied as a preplant fertilizer. The rest of the fertilizer for each treatment was applied as a topdress when the wheat plants were tillering and were assumed to be assimilating N most rapidly. Phosphorus fertilizer was also applied at the Davis site to safeguard against possible P deficiencies. For all sites, plants were flood irrigated as necessary to ensure maximum N uptake. Plots were weeded as necessary.

Plot harvest and sampling

When the wheat reached the soft dough stage, whole plants were harvested from a 60 ft^2 to 200 ft^2 portion of the plot area to determine forage yields. Sub-samples were taken for determining moisture content and N content. Once the wheat grain was ready for harvest, plants were harvested for determining grain yields. Grain sub-samples were taken for determining moisture content and protein content.

Estimating alfalfa's nitrogen credit

Several methods exist for estimating N credits. In the traditional N credit method, an N response curve is developed for yields of a non-legume grown after several seasons of non-legumes (Figure 2). This N response curve is then compared to the yield of the non-legume when grown after a legume. Estimating the N credit then requires finding the N fertilization rate at which the non-legume produces the same yield as the unfertilized non-legume when grown after a legume (14, 15).

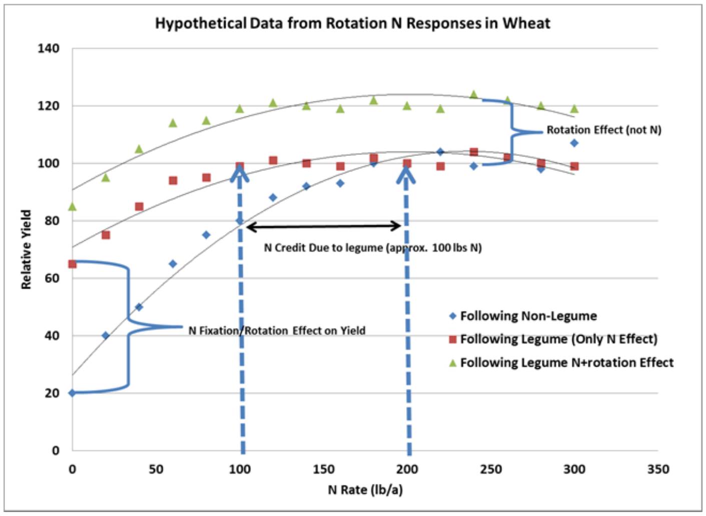

Figure 2. *Hypothetical results from a rotation study designed to estimate the N credit due to rotation with a legume.*

Another method, the difference method, requires developing N response curves for yields of non-legumes grown in sequence both after non-legumes and after legumes. These N response curves are then used to find economically optimum N rates (EONR), and the difference between the EONRs for the two treatments is the N credit (14). The difference method allows potentially differentiating between yield gains due to N contributions and yield gains due to non-N rotation effects (Figure 2).

While preliminary results will be based on the traditional N credit method, this project is designed to use the difference method, and we will develop N credit recommendations based on the difference method.

RESULTS AND DISCUSSION

Soil N content

Soil total N content ranged from 0.01% at Kearney to 0.42% at Tulelake (Figure 3). Except at Tulelake, total N content was not distinguishably different between cropping system treatments. At Tulelake, soil total N at 6 inches in the Alfalfa-Grain treatment was higher than that in the Grain-Grain treatment. A similar effect was present at Kearney, though differences were not distinguishable. However, there were differences in total N content by depth. In general, there was less total N deeper in the soil than shallower.

In terms of nitrate content, soil following the continuous alfalfa treatment had between 5 and 7 ppm NO_3^- and soil following the sudangrass-wheat rotation treatment had between 0.5 and 4 ppm NO_3^-. These differences, while small, were consistent across all sites.

Wheat yields

At all three locations, unfertilized wheat forage yields were higher following the Alfalfa-Grain treatment than following the Grain-Grain treatment, as expected (Figure 4). However, forage yield responses did not appear to be correlated with soil N content. At Davis, where differences in total N between cropping system treatments were not distinguishable, wheat forage yields did not respond to N fertilization following the Alfalfa-Grain treatment. In contrast, forage yields did respond to N fertilization for all other treatments and locations.

Interestingly, at both Kearney and Tulelake, wheat forage yields following the Grain-Grain treatment plateaued before reaching maximum forage yields of wheat following the Alfalfa-Grain treatment. These different yield maxima might indicate that the continuous alfalfa treatment at these sites provided some non-N rotation benefits or that fertilizer N was lost through leaching or volatilization. At Davis, there were no differences in maximum yields, as expected.

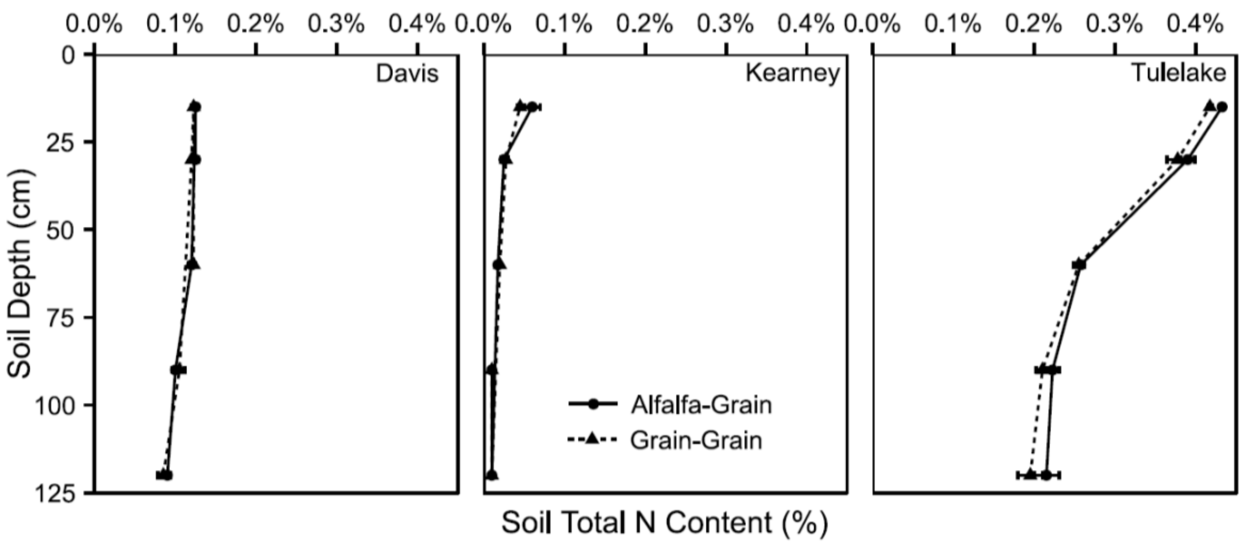

Figure 3. *Soil total N content by depth at the three locations following the Alfalfa-Grain and Grain-Grain cropping system treatments. Error bars represent standard errors of the mean.*

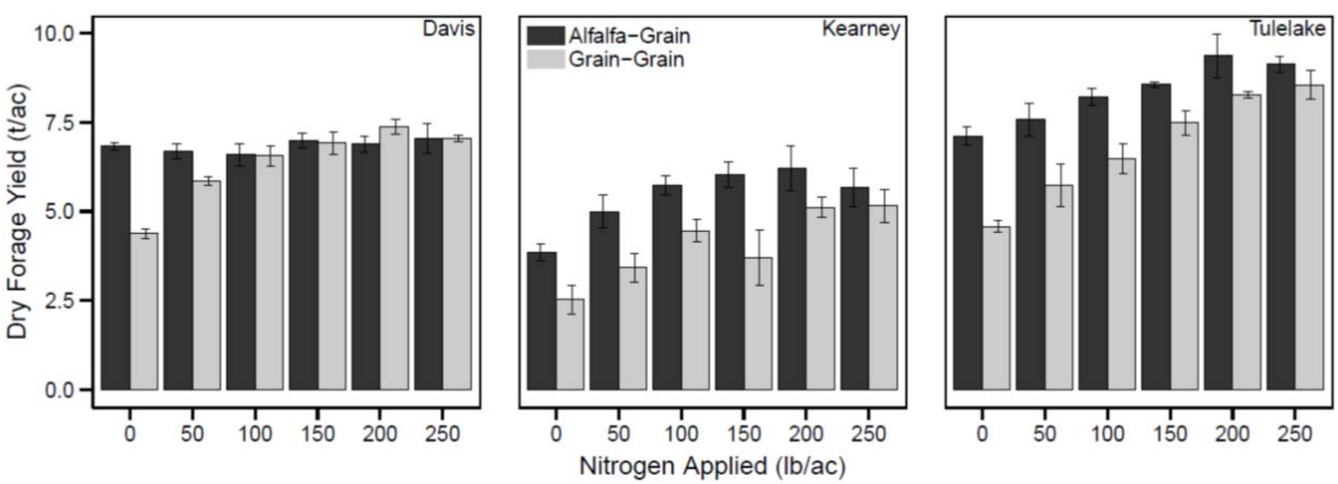

Figure 4. *Dry forage yields of wheat at the 6 N rates at the three locations following the Alfalfa-Grain and Grain-Grain cropping system treatments. Error bars represent standard errors of the mean.*

Wheat grain yield responses to the cropping system treatments were somewhat similar to forage yield responses (data not shown), especially at Davis. At Tulelake, grain yields following the Alfalfa-Grain treatment plateaued beyond the 100 lb N ac^{-1} rate, but grain protein continued accumulating (Figure 5). Unlike forage yields, maximum wheat grain yields at Tulelake were also the same following both cropping system treatments.

Wheat grain protein

While maximum grain yields were the same following both cropping system treatments at Tulelake, maximum grain protein contents were different. Grain protein also responded to N fertilization differently following the two cropping system treatments.

When supplied with 250 lb N ac^{-1}, wheat following the Alfalfa-Grain treatment at Tulelake had an average protein content of 11.3%, and wheat following the Grain-Grain treatment had an average content of 9.8%. Interestingly, grain protein content at Tulelake had a smaller response to N fertilization when wheat followed the Grain-Grain treatment than when wheat followed the Alfalfa-Grain treatment. This result could again indicate that the Alfalfa-Grain treatment provided non-N rotation benefits to this subsequent wheat crop. Previous work has also suggested that this difference in responses could be related to differences in timing of N availability to wheat following the two cropping system treatments (16).

At Davis, wheat grain protein content exhibited similar responses to nitrogen fertilization following the two cropping system treatments. However, maximum and minimum grain protein contents were different between the cropping system treatments. Wheat fertilized with 250 lb N ac^{-1} produced an average protein content of 12.9% following the Alfalfa-Grain treatment and an average protein content of 11.9% following the Grain-Grain treatment.

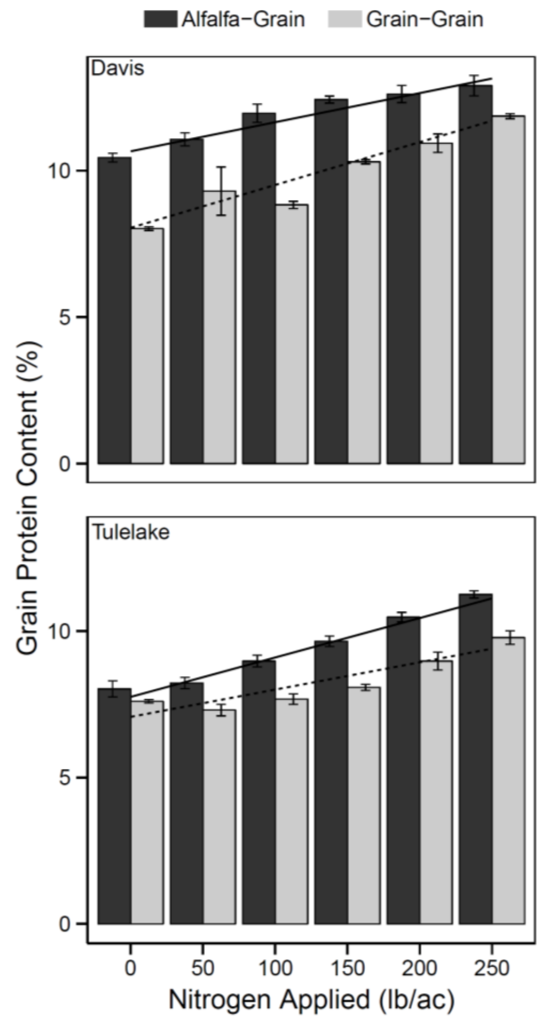

Figure 5. *Grain protein content of wheat grown with 6 N rates after the Alfalfa-Grain and Grain-Grain cropping system treatments at Davis (top) and Tulelake (bottom). Error bars represent standard errors of the mean. Regression curves represent linear models.*

Differences in grain protein content between Davis and Tulelake were likely primarily due to differences in varieties and secondarily to environmental factors.

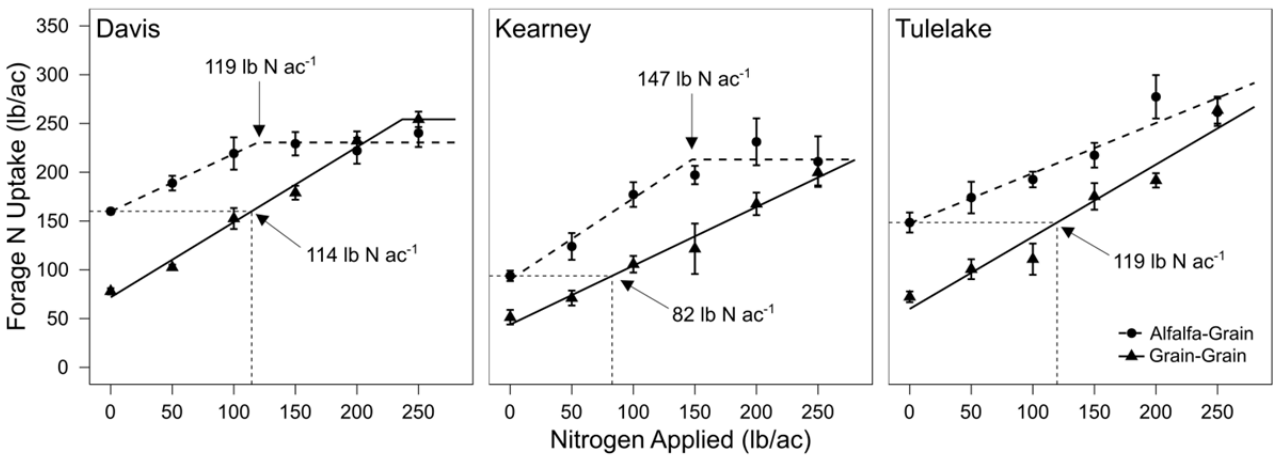

Figure 6. *Total nitrogen uptake of wheat grown with 6 N rates after the Alfalfa-Grain and Grain-Grain cropping system treatments at the three locations. Error bars represent standard errors of the mean. Regression curves (dashed and solid lines) represent linear-plateau models. Dotted lines and bottom set of arrows indicate the amount of fertilizer N required for wheat following the Grain-Grain treatment to take up the same amount of N as unfertilized wheat following the Alfalfa-Grain treatment. Top set of arrows indicates N fertilizer rate beyond which N uptake in wheat plateaued when following the Alfalfa-Grain treatment.*

Nitrogen uptake in wheat forage

Forage N uptake followed different patterns at all three sites (Figure 6). At Davis, N uptake in wheat reached a maximum of 230 lb N ac^{-1} following the Alfalfa-Grain treatment, plateauing beyond 119 lb N ac^{-1} of N applied. At Kearney, this maximum was 213 lb N ac^{-1}, plateauing beyond 147 lb N ac^{-1} of applied N, and at Tulelake, wheat took up a maximum of 277 lb N ac^{-1}.

Additionally, wheat following the Grain-Grain treatment at all sites took up similar maximum amounts of N compared to wheat following the Alfalfa-Grain treatment (Figure 6). However, at Davis, wheat following the Grain-Grain treatment also required an N application rate of 114 lb N ac^{-1} to achieve the same amount of N uptake as unfertilized wheat following the Alfalfa-Grain treatment. At Tulelake, a similar 119 lb N ac^{-1} were required, and at Kearney, 82 lb N ac^{-1} were required.

From these data, alfalfa's N contribution might range from between 80 lb N ac^{-1} at Kearney to 120 lb N ac^{-1} at Davis and Tulelake. Nitrogen contributions calculated from other metrics, such as grain protein content, grain yield, or forage yield, might be higher or lower.

CONCLUSIONS

This study is in mid-stage and should be completed in 2015-16. Remaining work includes a second year at the same sites for replication of the same treatments, in addition to analysis of the N uptake data and N yields under the different rotation and fertilization regimes. In these first-year results, alfalfa's N contribution ranged from about 80 lb N ac^{-1} at Parlier to about 120 lb N ac^{-1} at Davis and Tulelake, but there was evidence of contributions above 120 lb N ac^{-1} at Kearney and Tulelake. These results correspond well with results from previous research in Spain for irrigated plots in a climate similar to California's climates (12, 13).

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