**Rotation Study: Characterizing Alfalfa's N Benefit to Wheat following Alfalfa[1]**

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## Introduction

Row crops, such as small grains, corn, cotton, and tomatoes, can often benefit from a previous alfalfa crop. Much of this benefit can come from alfalfa's nitrogen (N) contribution. Like other legumes, alfalfa supports bacteria that convert, or fix, $N_2$ from the atmosphere into a form plants can use. Depending on alfalfa stand age, local climate, and soil type, these bacteria can fix between 350 and 800 lbs N/ac per year. While a lot of this N is harvested with each cutting, much of this N is also stored in the roots/crowns. After an alfalfa stand has been terminated, the roots decompose and their N is released into the soil. For crops following alfalfa, this N can reduce the subsequent crop's fertilizer need; crops following alfalfa have not needed N fertilizer at all in some cases.

Despite the significance of alfalfa and rotations with alfalfa in California, alfalfa's N credit has not yet been quantified in California. While N credit recommendations already exist in many Northeastern and Midwestern states, differences in how alfalfa is produced in California could affect alfalfa's N contribution to subsequent crops. For example, greater numbers of cuttings paired with different root biomass allocations might give less of an N contribution, but the generally warmer climate could allow N from the alfalfa to become available more quickly. These factors could all make N credit recommendations for California different from those reported for other regions.

## Objective

We aim to determine how alfalfa impacts a subsequent wheat crop's N fertilization needs and to develop an N credit recommendation for crops rotated after alfalfa in California.

*Figure 1: Grains rotation (left) and continuous alfalfa (right), at Kearney REC, from Phase 1 in August, 2013. Both crops were plowed under shortly after and planted to wheat.*

*Figure 2: Wheat following continuous alfalfa (right) and wheat following grains (left). The original rotation plots (seen in Figure 1) were split into six subplots each, with each of the six subplot's receiving a different N rate. N rates ranged from 0 to 250 lbs/ac, in 50 lbs/ac increments.*

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## Methods

This experiment is comparing two rotations: an alfalfa-grain rotation and a grain-grain rotation (Figure 1). It is being repeated in 2014-15 and is replicated at three sites in California: Davis (Solano County), Kearney/Parlier (Fresno County), and Tulelake (Siskiyou County). Soils in Davis and Tulelake are clay loams, and in Parlier, a sandy loam.

Prior to establishment of the wheat test crop, the alfalfa-grain rotation treatment had a 2- or 3-year-old alfalfa stand, and the grain-grain rotation treatment was managed with a wheat/sudangrass forage rotation. Both rotation treatments were managed according to recommended practices, but nitrogen fertilizers were not added to either rotation treatment. All alfalfa stands were healthy prior to being plowed under.

In the Fall of 2013, both the alfalfa and the grains were plowed under. Soil samples were taken to determine total N content following the two rotation treatments. The wheat test crop was then planted for the 2013-14 season (Figure 2). Nitrogen was applied to the wheat test crop as urea at six rates in 50 lb N increments ranging from 0 to 250 lbs N/ac. Fifty pounds of the N for each treatment were supplied as preplant fertilizer and the rest were supplied during tillering. No other nutrients were supplied. Fields were irrigated several times during the season to ensure that water was not limiting. Weeds were controlled as necessary.

Once the wheat reached the soft dough stage, plots were harvested to determine forage yields. Sub-samples were taken to determine moisture content and N content.

*Analysis*

Ideally, the wheat test crop produces the same maximum yields in both the alfalfa-grain and grain-grain rotations (Figure 3). Even if it does, differentiating between the N-related and non-N effects of rotation could be difficult. Crop rotations have been shown to increase soil organic matter, improve soil structure, alter nutrient availability, improve water-use efficiency, improve mycorrhizal associations, disrupt pest and disease cycles, and decrease yield variability, among many other effects. These effects could all benefit yields and could raise maximum yields beyond those of plants not grown in a rotation (Figure 3). Still, we hope to estimate the N credit by analyzing the wheat's responses to N supplementation under the two rotation treatments.

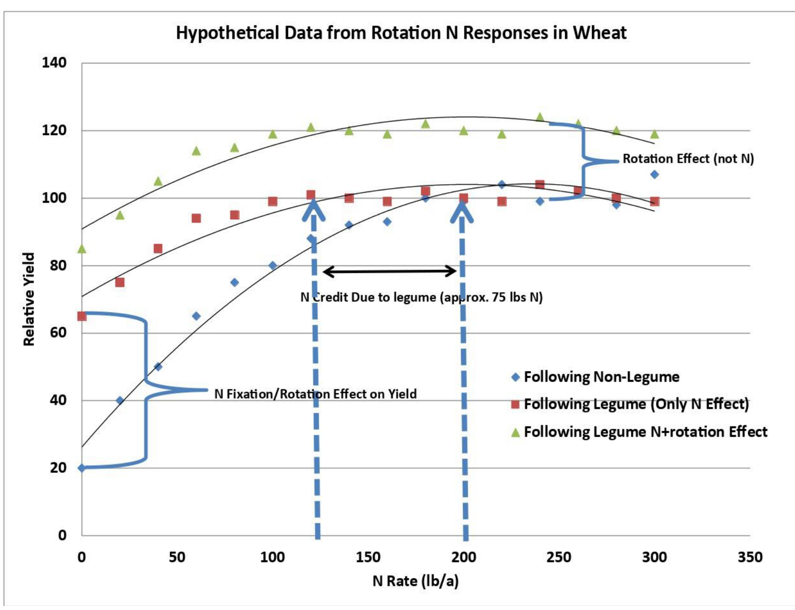


*Figure 3: Hypothetical relative yield responses of wheat fertilized at different N rates following a legume (squares) and following a non-legume (diamonds). The difference between N needed to achieve optimum yields on the two response curves (squares and diamonds) indicates an N benefit of around 75 lbs/ac. Rotation effects unrelated to N that help produce different maximum yields (triangles) could make this analysis difficult. However, even when maximum yields are similar, non-N rotation effects could still exist and possibly skew the analysis.*

## How much N did the alfalfa contribute?

Depending on the location, the alfalfa contributed between 75 and 120 lbs. N/acre, producing pronounced differences in growth and yield (Figure 2). This N contribution also affected crop maturity, but not any more than N fertilization typically would. Wheat at Parlier and Tulelake both needed N fertilization to reach maximum yields, but they needed less than would normally be required (Figure 4).

At Parlier, unfertilized wheat following the alfalfa-grain rotation yielded about the same as wheat in the grain-grain rotation fertilized with 100 lbs. N/acre (Figure 4, bottom). Extrapolating between the N treatments in the grain-grain rotation, the alfalfa may have contributed around 80-100 lbs N/acre. However, there were likely also other effects at play at Parlier, because the wheat there produced a higher maximum yield when following alfalfa than when following grains. Thus, the estimated N contribution of 80-100 lbs N/acre could be an overestimate.

At Tulelake and Davis, the alfalfa may have contributed around 100-120 lbs. N/acre.

Alfalfa's N contribution also affected maturity about as much as N fertilization did. The unfertilized wheat at Parlier was already starting to dry down while the wheat fertilized with 250 lbs. N/acre was still growing.

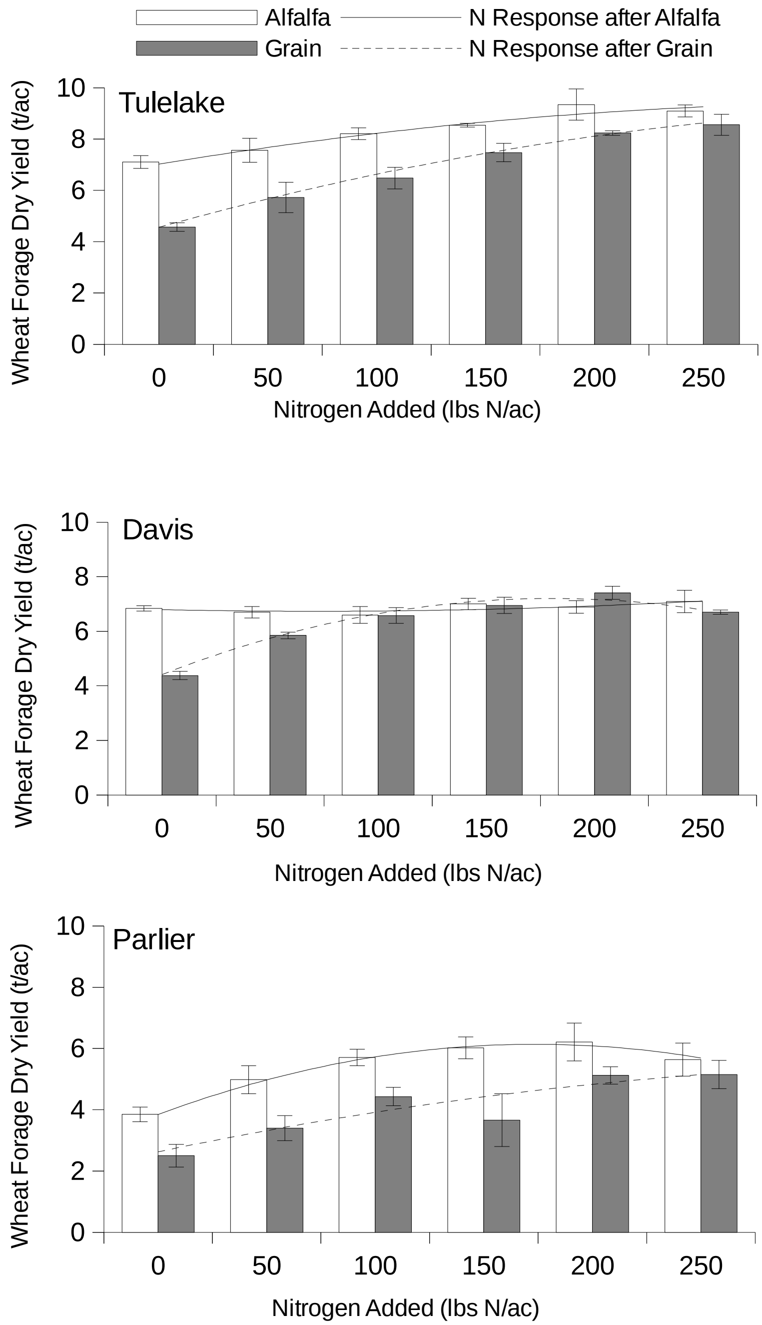


*Figure 4: Forage yields of wheat (reported as dry weights) after continuous alfalfa and after grain rotation at Tulelake (top), Davis (middle), and Parlier (bottom). Error bars represent standard errors of the mean. Response curves are quadratics.*

## How do soils and soil textures play into all of this?

Based on past research from other locations, soil texture has been found to affect alfalfa's N benefit, with alfalfa grown in coarse soils' providing the least benefit, in fine-textured soils' providing more, and in medium-textured soils' providing the most benefit. Since the Tulelake and Davis sites have finer soils than the site in Parlier (Kearney), our results are as expected.

## How much did alfalfa affect the soil's total N content?

Most soils actually have a lot of stored nitrogen, but the vast majority of this N is not accessible to plants. The only two forms of N that are generally deemed to be available to plants are ammonium and nitrate. Nitrogen in the soil must first be converted into these two plant-available forms of N before plants can use them. Unfortunately, 90% of the nitrogen in the soil cannot even be converted to these plant-available forms of N. Thus, differences between the soils' total nitrogen content between the two rotation treatments were negligible (Figure 5).

For example, at Tulelake, the 0.4% total N content in the top 6 inches (Figure 5, top) might represent 7000-8000 lbs[3]. N/acre. N contributions from alfalfa are many times less than 7000-8000 lbs. N and would be hard to notice when measuring total N. At Kearney, 0.05% total N content (Figure 5, bottom) could represent around 1000 lbs. N[2], so even in sandy soils that cannot hold a lot of N, the soil can still have a sizable total N content. Still, as shown in the results above (Figure 4), this almost negligible difference in total N content could mean big differences in yield.

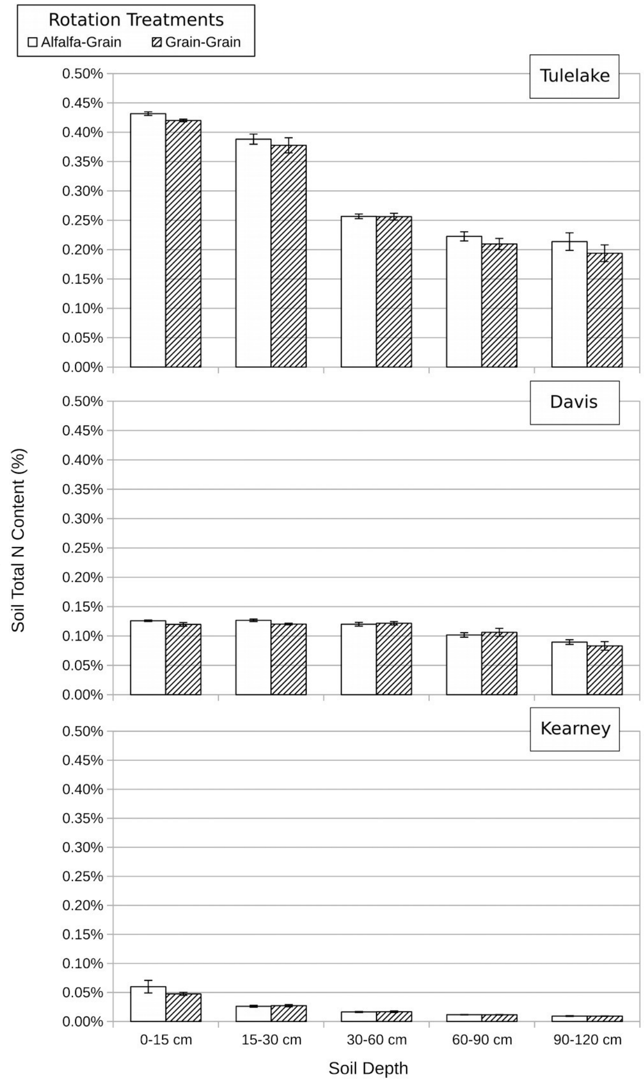


*Figure 5: Soil total nitrogen content with deeper soil depths, expressed as percentages of soil mass, at Tulelake (top panel), Davis (middle), and Kearney (bottom). Comparison of soil total N content after the two different rotation treatments (alfalfa-grain and grain-grain). Error bars represent standard errors of the mean.*

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3 Assuming an acre-furrow slice (an acre of soil, 6 inches deep) weighs 2,000,000 lbs.