A. Cover Page-CDFA FREP Proposal

Proposal: Characterizing N Fertilizer Requirements of Crops Following Alfalfa

1. **Project Leaders:**

- Dan Putnam, Cooperative Extension Forage Specialist, University of California Department of Plant Sciences, One Shields Ave., 530-752-8982 dhputnam@ucdavis.edu;
- Stu Pettygrove, CE Soils Specialist, Department of Land Air and Water Resources, University of California, Davis, One Shields Ave. 530-752-2533 gspettygrove@ucdavis.edu;

2. **Project Cooperators:**

- Khaled Bali, CE Farm Advisor, Imperial County. 1050East Holton Road, Holtville, CA 92250. 760-352-9474. kmbali@ucdavis.edu;
- Steve Wright, CE Farm Advisor, Tulare County. 4437 Laspina St., Ste. B, Tulare, CA 93274. 559-684-3315 sdwright@ucdavis.edu
- Steve Orloff, CE Farm Advisor, Siskiyou County, 1655 South Main Street, Yreka, CA 96097. 530-842-2711 sborloff@ucdavis.edu

3. **Project Supporters:**

- Aaron Kiess, Bob Ferguson, California Alfalfa & Forage Association, 36 Grande Vista, Navato, CA 94947
- JaniceCorner, California Wheat Commission, Woodland,CA

4. **Funding: Funding from CDFA is requested as follows:**

2013: $47,986

2014: $50,943

2015: $51,054

Total: $149,983

There are no other funds that are available for this project. In-kind support is provided from the PI and cooperator’s time, and in the form of reduced charges for lab and field work for ‘in house’ work. This project is coordinated with other N projects that are related including N studies on wheatcurrently funded by the California Wheat Commission, and N studies on alfalfa, examining uptake potential for high nutrient waters, funding (requested) from UC Division of Agriculture and Natural Resources.

B. **Executive Summary**

Farmers of row and field crops (corn, small grains, tomato, cotton) in California have been under scrutiny from several quarters to more accurately match the needs of the crop with fertilizer applications. It is well known that perennial legumes such as alfalfa confer benefits to the subsequent non legume crop, especially from residual soil N from N_2 fixation that can be absorbed by the following crop. This lessens the N fertilizer need of the non-legume in rotation. However, quantification of this fertilizer benefit has been largely ignored in California. Alfalfa produces between 350 and 750 lbs of N per acre per year(aboveground), greater than 90% originating from the atmosphere through N_2 fixation. Estimates of the residual N benefit (from roots, remaining plant parts, and soil microorganisms) from other regions have ranged between 30 and 200 lbs/a per year, and in some cases may satisfy the entire N needs of a subsequent crop. There are greater than 200,000 acres of alfalfa which is rotated with other crops each year in California, yet there are no research-based data from this region to guide the quantification of this benefit. This is a large gap in our technical knowledge about N management with field crops. Calculation of the N benefit of crop rotations would impact overall N management, with benefits to the environment from reduced risk of leaching from excess N applications, and benefits to farmers from reduced costs and optimization of N fertilizer use. Our objective is to determine the impacts of rotation with alfalfa on the N fertilization needs of a non-legume crop, to develop an 'N credit' recommendation for management of N fertilizers in non-legumes rotated with alfalfa. We propose to conduct N response estimates for wheat following alfalfa compared with a non-legume rotation at four locations in California. Wheat was chosen as a test crop, since wheat is grown throughout California and is an excellent indicator crop for N. Sudangrass-wheat will be used as a non-legume rotation. An existing vigorous alfalfa field will be chosen, and crop rotations established on portions in an experimental design in strips for two years before the test plots would be applied to allow alfalfa-wheat and non-legume-wheat rotation comparisons to have significant soil effects. The design will allow internal replications as well as 8 location-years, in two phases, incorporating the differences between Intermountain, Central valley, and Imperial Valley conditions. N^{15} data utilizing the natural abundance method will be used to estimate the quantity of N derived from atmospheric N_2 fixation in the alfalfa before plowdown. Soil samples will characterize N profile prior to the test wheat crop. Crop uptake data in wheat will be measured with whole plant and grain samples, and yield and quality response to N will be measured following either a non-legume (wheat/sudangrass) or alfalfa. The difference method will be used to estimate N credits ascribed to the legume—this includes non-N rotation benefits (such as soil tilth) which maybe present. This data will be used to extrapolate and estimate N credits for other crops in addition to wheat following alfalfa. The primarily audience for this data will be farmers, crop consultants, Certified Crop Advisors, Extension Professionals, and agencies. The findings from this study will be extended to farmers and others via field days,the California Alfalfa & Forage Symposium, websites, newsletters, refereed publications and blogs. Grower Associations will assist in the outreach. This study will enable the agricultural sector to promote more sustainable techniques which will reduce the risk to groundwater from excess and unnecessary N applications and better utilize the benefits of crop rotation.

C. Justification

While many growers utilize the 'recipe' approach to fertilizer applications, there are both economic and environmental incentives to more carefully calculate requirements under different soil conditions, especially for mineral N. Economic penalties for growers are incurred when imprecise estimates are used, either through yield losses from inadequate fertilization, or from excess applications which are costly. Environmental concerns from excess applications include possible effects on groundwater with N fertilizers and manure used on agronomic crops (see Harter et al. report, March, 2012, see http://groundwater.ucdavis.edu/) and impacts on air quality. Large impacts on groundwater contamination from N fertilizers are reported, particularly for the Tulare basin where corn, grains, and alfalfa are a predominant component of the landscape. An important strategy to better manage N for non-legumes, it is necessary to understand crop rotation effects from legumes which provide some quantity of N to subsequent crops. Data on this issue is available from other (lower-yielding non-irrigated) regions, and 'N credits' for better fertilizer management have been calculated, but to our knowledge no data is available on this issue for California's highly productive irrigated field crops.

Alfalfa in California is commonly rotated with wheat, corn, oats, processing tomato, cotton, and sometimes specialty vegetables. A minimum of 200,000 acres are likely rotated from alfalfa each year in California. Alfalfa is typically in place from 3 to 6 years, and almost always followed by a non-legume. Farmers value both the soil tilth benefits of crop rotations with alfalfa, as well as the weed suppression and N benefits. However, little is known about the impacts on the fertilizer N needs of subsequent crops in this rotation, and many growers do not take this into consideration when developing a fertilizer program. Under irrigation, a productive alfalfa crop fixes between 350 and 750 lbs of N per acre per year in California, totaling – 2,000 to 4,000 lbs N/acre over a 5 year alfalfa stand. While most of this N is presumably removed in the forage, some quantity of residual nitrogen remains in the soil, a portion of which may be available to subsequent crops. This is due to the stable soil rhizosphere, the sloughing off of root and nodule pieces, high quantities of soil microorganisms in a stable leguminous perennial system, the root mass itself, and the deposition of high-N containing foliage to the soil. While there have been many studies conducted in the Midwest to quantify an 'N credit' for corn or grains following alfalfa, to our knowledge there have been no studies in California to characterize this rotational N benefit under irrigated conditions. Factors such as higher temperatures, the higher alfalfa and grain yields, soil type, as well as the presence of irrigation water create conditions in California which are likely to be highly distinct from Midwestern production systems. Additionally, the wide variety of conditions (from desert to Mediterranean and mountain conditions) within California creates challenges to develop a unified recommendation for an 'N credit' for crop rotations. This is a large gap in our technical knowledge that limits our ability to improve N fertilizer management in the state.

On a statewide basis, if a modest N savings from crop rotations of 40 lbs N per acre over 200,000 acres were realized, this amounts to a potential fertilizer savings of 8 million lbs of N statewide each year, and a cost savings to California growers of $3.2 million/year (based upon a $0.40/lb of N price).

Of course, this estimate currently has a high degree of uncertainty. Rotations could be determined to have a zero N benefit, in which case ascribing an N benefit to rotations would be a management mistake, resulting in underfertilization, or this estimate could be low, in which case better estimates could increase the net cost savings to growers. We simply do not have the data to address this question.

This project clearly is in line with FREP's goal of improving N use efficiency in California Cropping systems for several large acreage crops: wheat, corn (together 1.4 million acres), and potentially cotton and tomato. It is also clearly in line with the overall objective of protecting environmental quality through the prevention of leaching to groundwater of either excess N from over-fertilization or even from the leguminous residual N remaining in the soil – this must be utilized by subsequent crops or it may itself present a threat to groundwater.

There are major incentives for growers to pay attention to the N credit coming from legumes. Most of these are economic, but environmental pressures are large as well. Many growers (through trial and error) have developed their own 'seat of the pants' estimates for N credits for wheat following alfalfa. However, often this is overridden by logistics or habit, and little thought is often given to the potential for soil residual N to provide benefits to the subsequent crop. Development of a solid, research-based dataset from the most important growing areas, along with appropriate outreach, will enable the development of these recommendations based upon science, not guesswork.

D. Objectives.

Our objective is to determine the impacts of rotation with alfalfa on the N fertilization needs of wheat, to develop an 'N credit' recommendation for management of N fertilizers in non-legumes rotated with alfalfa. Since wheat is a highly-responsive crop to N fertilizers, estimates will be made on wheat that can be extrapolated to other crops.

E. Work Plan and Methods

Crop rotation studies are by definition long-term, and thus this project is a 3-year project, but with a lead-in (unfunded) preparation year (2012). The study will take place in 2012, 2013, 2014, and 2015, but funded starting in January 2013 through December, 2015. We had debated doing this project on farmer's fields, but have decided that it would be better to place the trial on University Experiment Stations, since 1) proper controls are lacking in farmer's fields comparing cropping systems, and 2) variables (such as plant stand, tillage, and harvest schedule) can be better controlled. Because we desire comparative cropping systems (alfalfa and non-legume) over a long (at least 1.5-year) period, we will start with well-established alfalfa crops, with at least 1 year of crop history. Strips of non-legume sudangrass will be established in a split-plot experimental design in 2012 (see Figure 1). These sudangrass strips will be rotated with wheat in the winter of 2012-13, and again with sudangrass in the summer of 2013, creating a three-crop 'non-legume' rotation, compared side-by-side with the perennial alfalfa crop. The purpose is to deplete these soils of residual N (from the alfalfa or other sources) from these strips, create a cereal-cereal rotation, and to provide a 'non-legume' annual cropping system to compare with the 'legume' alfalfa cropping system. After a sufficient period of time (18 months), the test grain crop will be planted under 6 fertilizer rates to estimate the N response with an alfalfa-wheat vs. a non-legume-wheat rotation. The experimental design is a split-plot, with cropping system as main plots (df=1), and N rates as subplots (df =5). Four sites and two year (Phases) per site will be utilized.

Replication. In addition to replication in blocks (4) at each site (Figure 1), the rotation experiment will be implemented in two phases, Phase I and Phase II, to create two year's results at each location. This is for the purposes of replication over time. Phase I will begin in 2012 (without funding, in the hopes that funding will be forthcoming), to create the conditions for the test plots in 2013, when the funded project begins. This will be completed in 2014. Phase II will begin in 2013, and completed in 2015 (see Table 1). This approach enables two full location years at each site (each location year consisting of about 2 years), and 8 location/years total for the dataset, which makes for a solid basis of experimental evidence. The spread of locations from Tulelake, through the Central Valley and Desert zones guarantees the consideration of location variables (Table 1).

Locations. These are chosen for the major wheat and alfalfa growing areas of California. Wheat is chosen since it's a great test crop for N and grown throughout the state.

- **Tulelake.** This is an intermountain high elevation climate, with a high-organic matter soil, that has nevertheless been responsive to N applications in other trials. This is a 3-cut alfalfa region, where wheat is the major rotation crop.
- **Davis.** This is often considered typical or representative of the Sacramento Valley region, where wheat and alfalfa is a common rotation. These are clay loam soils with high water-holding capacity. This is a 6-7 cut alfalfa region.
- **Kearney.** This is considered to be typical of the east side of the San Joaquin valley, a Mediterranean climate, with light soils that are sandier than at Davis, with lower water-holding ability. This is a 7-8 cut region, and alfalfa-wheat rotations are very typical.
- **El Centro.** This is a true desert climate, with heavy cracking clay or loamy clay soils. Alfalfa is a major crop here, and very commonly rotation with wheat. Desert durum wheat crops are highly prized for their grain quality, and protein content is an important quality feature. This is a 9-11 cut region, and alfalfa-wheat rotations are the most common.

Wheat Test Plots. After the establishment of the two cropping systems (legume vs. non-legume) for a sufficient length of time (18 months), test plots of wheat will be established. A replicated fertilizer N-rate study with 6 treatments (zero N to very high N rates in two applications) will be instituted at each site after establishment of the non-legume rotation strips compared with the alfalfa strips. We will utilize a randomized complete block design to estimate the N effects. Crop above-ground biomass yield at two stages, agronomic traits (lodging, height) and total plant N uptake measured at harvest. Grain yields will also be measured, so that the N benefit can be estimated for both grain and forage. The benefit of the legume in rotation will be estimated using the difference method (Lory et al., 1995), which utilizes N rate data under the two systems. Comparing the optimum N fertilizer rate (the point of maximum yield) with the unfertilized control will give an indication of N credit for the legume from that study, which then can be characterized across sites. Comparison of crop N uptake with fertilization with non-fertilized controls will give an indication of the importance of residual N.

Estimating the N Rotational Benefit and N credits. Approaches to estimating the N benefit have included a comparison of the optimum yield under non-legume rotations compared with the optimum yield with legume rotations (see Figure 2). This is known as the 'difference method', which compares the economic N rate of the conventionally fertilized non-legume and of the non-legume grown in rotation (Lory et al., 1995). Analysis to differentiate between 'rotation effects' which may not include N supply, vs. N effects are possible.

Details of this plan are contained within the Tasks listed below, and in Figure 1 and Table 1.

Task 1. 2012 Preparation of Experimental designs and logistical planning (unfunded-starting summer, 2012). Work with PI, SRA, station managers and cooperators to identify sites and design field experiments. This will involve phone calls and time allocation by cooperators, and site visits in some cases.

Task 2. 2012-13 Establishment and Maintenance of Field Plots for Phase I (unfunded-starting summer, 2012). Field plots at four locations (Tulelake, Davis, Kearney, and El Centro) will be established by plowing up portions of field into strips that will be planted to sudangrass in summer, 2012, followed by wheat, fall 2012, followed by sudangrass, 2013. Each crop will be harvested as a forage, with tillage occurring between crops. This will be initiated in anticipation of receiving funding for this project, at our risk-due to the value of establishing crops well in advance to fairly test the cropping system variables. Zero fertilization used to maximize utilization of any residual N in these non-legume plots. This is necessary to avoid delays in implementing this longer-term rotation experiment (otherwise, replication would be lower, and it would have to take longer than 3 years).

Task 3. 2013 Estimation of N_2 fixation utilizing the natural abundance method (N^{15}) for Phase I. Quantification of nitrogen which may originate from atmospheric sources vs. that which might be obtained from the soil will be estimated at each of the four sites, since the legume and non-legume plant samples will be available. This will occur in late summer, 2013 near to final harvest of the alfalfa and sudangrass crops. This is coordinated with a separate project (Pettygrove, Putnam, with Fresno State University) which is characterizing N2 fixation across manured and non-manured fields in CA.

Task 4. 2013 Plow-down, soil preparation, Phase I. At an appropriate time for each location (typically fall or late summer), the last alfalfa & sudan crop will be harvested, and the entire experimental area prepared for planting, utilizing techniques (plowing, disking, soil preparation) frequently used by farmers rotating alfalfa to wheat.

Task 5. 2013 Soil Sampling, Phase I. Soil samples will be taken late summer in these plots to estimate the residual N by soil depth to characterize the N presumably available to subsequent crops. In addition, a comprehensive soil sample will be taken at each site to characterize the soil.

Task 6. 2013 Establishment of wheat N test plots, Phase I. Wheat (varieties recommended by the UCD wheat project appropriate for each region) will be established at each site, utilizing agronomic techniques appropriate for wheat, including planting time, density, depth, method of seeding, etc. N fertilizers in the form of ammonium sulfate will be applied at 6 different rates, from 0 to 250 lbs N/acre in split applications (see Figure 1), with 50 lbs N/acre applied at planting, and the remainder to be applied after approximately 4-6 weeks according to current recommendations.

Task 7. 2013 Establishment of Field Plots for Phase II. Phase II is a complete replication of Phase I, but on a different portion of the existing alfalfa field, and with treatments applied 1 year later. This enables two years experimental data at each location, resulting in 8 location-years total. Field plots at four locations (Tulelake, Davis, Kearney, and El Centro) will be established by plowing up portions of field into strips in 2013 that will be planted to sudangrass in summer, 2013, followed by wheat, fall 2013, and sudangrass in summer, 2014, in preparation for the N treatments in the wheat, to be applied fall, 2014. Zero fertilization used to maximize utilization of any residual N in these non-legume plots.

Task 8. 2014 Harvest and Plant Sampling, Phase I. Wheat Plots will be harvested at the boot stage and again at the soft dough stage to obtain a whole plant forage sample at two plant-uptake stages. 400 gram samples will be taken at each time. These also correspond to the most important time for forage harvests. Yields will be measured based upon a 4' x 15' area at the soft dough stage on one section of the plot, and grain samples taken on another portion of the plot at grain maturity. Thus, yield impacts of N rates will be estimated on both whole-plant and grain components.

Task 9. 2014 Estimation of N_2 fixation utilizing the natural abundance method (N^{15}) for Phase II. Quantification of nitrogen which may originate from atmospheric sources vs. that which might be obtained from the soil will be estimated at each of the four sites, since the legume and non-legume plant samples will be available. This will occur in late summer, 2014 near to final harvest of the alfalfa and sudangrass crops.

Task 10. 2013 Plow-down, soil preparation, Phase II. At an appropriate time for each location (typically fall or late summer), the last alfalfa & sudan crop will be harvested, and the entire experimental area prepared for planting, utilizing techniques (plowing, disking, soil preparation) frequently used by farmers.

Task 11. 2014 Soil Sampling, Phase II. Soil samples will be taken late summer in these plots to estimate the residual N by soil depth to characterize the N presumably available to subsequent crops.

Task 12. 2014 Establishment of wheat N test plots, Phase II. Wheat (varieties recommended by the UCD wheat project appropriate for each region) will be established at each site, utilizing agronomic techniques appropriate for wheat, including planting time, density, depth, method of seeding, etc. N fertilizers in the form of ammonium sulfate will be applied at 6 different rates, from 0 to 250 lbs N/acre in split applications (see Figure 1), with 50 lbs N/acre applied at planting, and the remainder to be applied after approximately 4 weeks.

Task 13. 2015 Harvest and Plant Sampling, Phase II. Wheat Plots will be harvested at the boot stage and again at the soft dough stage to obtain a whole plant forage sample at two plant-uptake stages. These also correspond to the most important time for forage harvests. Yields will be measured based upon a 4' x 15' area at the soft dough stage on one section of the plot, and grain samples taken on another portion of the plot at grain maturity. 400 gram samples will be taken at each time, and dry matter determined via oven methods, to adjust dry matter yields. Thus, yield impacts of N rates will be estimated on both whole-plant and grain yield components. Plant and grain samples will be analyzed for total N content.

Task 14. Laboratory Analysis (2013-2014-2015). Soil samples and plant samples will be dried, prepared, and submitted to the UC Davis Analytical Lab, beginning in 2013. The primary analysis will be total N concentration, but analyses for soil characteristics will be done at each site. Soil samples include 6 depths for each cropping system, at each location. Plant samples will be submitted for total N analysis. An estimate of the costs of lab analyses are provided in the budget.

Task 15. Data Analysis and Data Summary (2014-15). Data from these trials (Phase I and Phase II). Will be analyzed using SAS and other statistical programs, testing for differences between response curves for the two cropping systems at different N rates.

Task 16. Outreach (2013-14-15). Publication of these results will be at the California Alfalfa & Forage Symposium, and at the Grain Commission meetings. A peer-reviewed ANR publication on the rotational estimates for N credits will be developed by PI and co-authors. Presentation of the results at the FREP conference in 2015 is likely, if organizers would like. Field plots and current results will be presented at field days in 2013, 2014, and 2015 at the different locations. The target audience is: farmers, ranchers, CCAs and PCAs, Universities and companies who make recommendations for fertilizer use.

F. Project Management, Evaluation and Outreach.

Management. PIs Putnam and Pettygrove have primary responsibility for managing the overall field trials and research project. Pettygrove will provide expertise and implement the natural abundance method and experimental design. Putnam will set up the rotation studies, and oversee the SRA who will conduct much of the field work in cooperation with field station staff and with project cooperators. Cooperators Bali will assist in overseeing the site at El Centro, Wright the site at Kearney, and Orloff the site at Tulelake. DeBen will coordinate the harvests and sampling activities.

Evaluation. At the conclusion of the project, we will provide a cost-benefit analysis of the practices that have been evaluated. Survey of wheat and alfalfa growers will be conducted to see if they are adapting N-credit practices.

Outreach. We will feature these trials at UC Field Days once per each year of the study. An ANR publication on the N benefits and the credits that may be due to rotations will be written. This trial will be featured at the California Alfalfa Symposium. All of these outreach activities will have PCA and CCA credits available to participants. Several of the planned outreach activities are as follows:

- Davis: Field Day May, 2013, 2014, 2015
- Kearney: Field Day September, 2013, 2014, 2015
- Tulelake: Field Day August, 2013, 2014, 2014
- El Centro: Field Day, April, 2013, 2014, 2015
- Peer Reviewed ANR Article: 2015.
- Peer Reviewed National Publication: 2015
- FREP Conference (2015)
- California Alfalfa & Forage Symposium, 2014 or 2015.

G. **Budget Itemization**

This budget is modest given the statewide, multi-location, three year nature of the project. This will fund ½ of an SRA salary primarily, with funds budgeted for site charges for each project, and for laboratory analysis and travel to each of the sites, a limited number of times each year.

Table 1. Crop Sequence for the alfalfa-wheat rotation studies.

	Year 1 (unfunded)	Year 1 (2013)	Year 2 (2014)	Year 3 (2015)
Tulelake Phase 1	Establish sudan strips	Continue Rotation Strips - Fall Wheat Establishment	Measure N response in wheat	
Tulelake Phase 2	Continuous alfalfa	Establish non-legume rotation	Continue Rotation Strips - Fall Wheat Establishment	Measure N Response in wheat
Davis Phase 1	Establish sudan strips	Continue Rotation Strips - Fall Wheat Establishment	Measure N response in wheat	
Davis Phase 2	Continuous alfalfa	Establish non-legume rotation	Continue Rotation Strips - Fall Wheat Establishment	Measure N Response in wheat
Kearney Phase 1	Establish sudan strips	Continue Rotation Strips - Fall Wheat Establishment	Measure N response	
Kearney Phase 2	Continuous alfalfa	Establish non-legume rotation	Continue Rotation Strips - Fall Wheat Establishment	Measure N Response
El Centro Phase 1	Establish sudan strips	Continue Rotation Strips - Fall Wheat Establishment	Measure N response	
El Centro Phase 2	Continuous alfalfa	Establish non-legume rotation	Continue Rotation Strips - Fall Wheat Establishment	Measure N Response

Example Plot Plan: 30'

5 51	**4** 52	**3** 53	**6** 54	**5** 55	**3** 56	**6** 57	**5** 58	**5** 59	**4** 60
1 41	**3** 42	**5** 43	**4** 44	**4** 45	**1** 46	**5** 47	**3** 48	**6** 49	**2** 50
2 31	**2** 32	**4** 33	**3** 34	**3** 35	**5** 36	**3** 37	**4** 38	**4** 39	**6** 40
4 21	**6** 22	**6** 23	**5** 24	**2** 25	**4** 26	**1** 27	**2** 28	**3** 29	**5** 30
3 11	**5** 12	**2** 13	**2** 14	**6** 15	**6** 16	**2** 17	**6** 18	**1** 19	**1** 20
6 1	**1** 2	**1** 3	**1** 4	**1** 5	**2** 6	**4** 7	**1** 8	**2** 9	**3** 10

Plots: 20'x30'

Rotation:

1	Non-Legume-Wheat
2	Alfalfa-Wheat

50 increment

N Treatments:

1	0 lb N/acre
2	50 lb N/acre
3	100 lb N/acre
4	150 lb N/acre
5	200 lb N/acre
6	250 lb N/acre

Figure 1. Example plot plan showing strips of alfalfa (yellow strips) alternating with a non-legume (white strips). N rates will be superimposed on these plots after 18 months of cropping, to

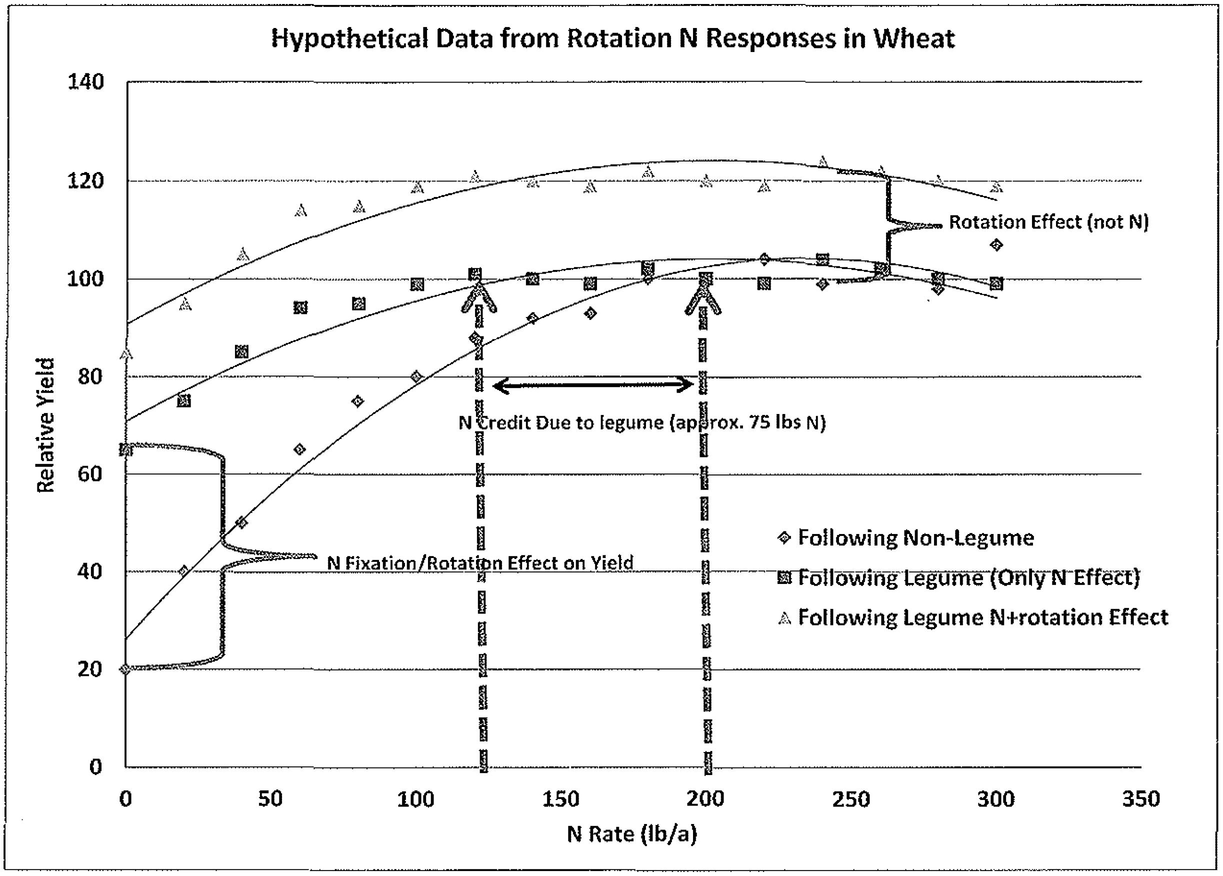

Figure 2. Hypothetical results of wheat fertilized at different rates following a non-legume (blue diamond) vs. legume crop (red squares). If rotations are beneficial, the N and rotation benefit can be seen at zero N. The difference between optimum yield without rotation vs. with rotation can be considered the N benefit, in this case 75 lbs/acre. The green triangle represents a hypothetical curve where rotation effects (beyond N) are influencing crop yield (such as soil tilth and other effects), which is often seen in rotation studies.