TITLE: Effect of N Source, rate and application time on spring Wheat Grain Yield and Protein content

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INTRODUCTION:

Montana is traditionally recognized worldwide for production of premium quality wheat. Spring wheat continues to be the key cereal crop for the state of Montana. In 2010, Montana ranked third among the spring wheat producing states in the nation (USDA, 2012) with almost 2.9 million acres, and over $730 million value. Nitrogen (N) is the most common nutrient limiting yield of wheat and other cereal crops in Montana (Engel, 1993). Nitrogen use efficiency (NUE) is currently only about 40% - 50% (Gupta and Khosla, 2012). A considerable increase from the previously estimated 33% NUE in the late 1990's (Raun and Johnson, 1999) is primarily due to development of cutting edge technologies and advances in nutrient management strategies including utilization of novel more efficient fertilizer products. The most practical and ethical solution to meet crops' nutrient needs is establishing more efficient ways to fertilize the crops (Smil, 1997). Developing an effective N management system, improving N recommendations, and increasing NUE are central issues, which should be addressed to maintain and increase the sustainability of wheat production in the future. Enhanced efficiency fertilizers (EEFs) are products that reduce loss on applied nutrients to the environment and/or increase nutrient availability compared to conventional fertilizers. Nitrogen can be lost from soil-plant systems through leaching, volatilization, runoff, and immobilization. Nitrogen use efficiency (NUE) is currently estimated at 40% - 50% in cereal crop production systems (Gupta and Khosla, 2012).Traditional nitrogen (N) fertilizers (such as urea, ammonium sulfate, and diammonium phosphate) are extremely soluble in water.

The slow release N fertilizers (SRNFs) release N at a slower rate than conventional fertilizers; they protect N by delaying N availability with protection time varying from weeks to months. Producing SRNFs entails simply decreasing the solubility by chemically binding N. Most SRNFs rely on biochemical breakdown in the soil and the rate of N release is dependent on the chemical structure/resistance to decomposition, molecular weight/degree of polymerization. Although the release time varies depending on the environmental conditions such as soil temperature and moisture, it is generally uncontrolled (Blaylock, 2007). Currently, the vast majority of SRNFs in agriculture is utilized for fertilizing specialty crops, such as vegetables, citrus and not utilized (Clapp, 1993; Ruark, 2012). Urea-formaldehydes (UFs) and urea-triazones (UTs) are some of the popular SRNFs used for N fertilization. Field trials in wheat and barley have shown that UTs can be applied to plant leaves or roots at higher rates than urea or ammonium nitrate (UAN) without causing fertilizer burn due to lower salt index. The reported climate-dependent benefits include improved NUE, comparable grain yields with reduction of N rate by 25-30%; in some cases, a single in-season foliar application was sufficient to optimize yields. Wheat studies in the Northern Great Plains demonstrated that both grain yields and protein content have been higher with UTs compared to UAN application with UT application rate 2.6 times lower than UAN. Similarly, research in North Dakota and Montana showed that higher barley yields and better quality were achieved with UTs compared to conventional fertilization using urea (Woods Whiting, 2009). Higher cost associated with the EEFs, such as slow release N fertilizers (SRNFs), and lower perceived risk of N loss (due to soil characteristics and semi-arid environment) have limited interest in SLNFs in the Northern Great Plains region. Consequently, very little independent research has been carried out so far to assess the effectiveness of SRNFs in cereal crop production (Olson-Rutz et al., 2011).

Even though supplying N in amounts lower that required for plant growth and development results in decreased grain yields and lower grain quality, over-fertilization is a much more common problem than under-fertilization. Work by Bloom (1996) showed that most plant species can sustain full growth at N concentrations that are over two orders of magnitude lower than those provided in most crop production systems. In fact, because N absorption is downregulated, high concentrations of N in the soil may result in decreased affinity of N and capacity of the transport system and inhibited root growth. Some studies showed that N application to non-deficient soils may result in luxury consumption during tillering with no consequent effect on yield (Marx and Karrow, 1999). Ignoring information about the actual need of the crop for N and temporal and spatial variability results in over-application and lower NUE.

Timing of N application has been a topic of debate among researchers and growers with application time recommendations varying greatly according to whether grain yield or grain quality is the primary goal. Spring wheat's primary value is its quality, represented by high grain protein content. Thus, when evaluating NUE in spring wheat, both grain yield and protein content must be considered. Combining yield and protein into protein yield, as proposed by Jackson (2001), makes sense because N is vital to both yield and protein production. Delaying fertilization until later in the growing season allows for more accurate determination of crop need for N to optimize yield. Late-season application of liquid N is sometimes regarded as a way to increase grain protein content – a substantial quality consideration for spring wheat. The reports that late-season applied N increases grain protein content are based on old studies, including the report by Finney et al (1957).

At present, there are no guidelines developed for effective and efficient use of liquid N fertilizers in spring wheat. This includes more traditional liquid products like UAM and LU as well as the EEFs such as UTs. A comprehensive liquid N product utilization strategy, including guidelines on the optimum N rate, time, and application method, must be developed that would focus on optimizing wheat yields and increasing grain quality. In order for wheat growers to fully benefit from incorporation of liquid N fertilizers into their operation, an extensive research must be carried out. Recent developments such as lower fertilizer manufacturing costs, higher overall N prices and premium on fertilizer use efficiency, increased awareness of environmental impact of intensified crop production, and government incentives (such as Conservation Stewardship Program) have resulted in growers' increased attention to SRNFs (Blaylock, 2007). Scientifically sound and unbiased field research is needed to evaluate the efficiency of SRNFs in cereal production. If sufficient and consistent benefits, such as maximized grain yield and/or increased grain protein can be demonstrated to growers, the adoption of SRNFs will drastically increase in the region.

OBJECTIVES

The specific objectives include:

- To compare the efficacy of 3 liquid N fertilizers – urea ammonium nitrate (UAN), liquid urea (LU), and urea formaldehyde-triazone (UFT) applied to spring wheat
- To determine the optimum N rate of liquid fertilizers by evaluating a range of N rates applied
- To identify the appropriate time of liquid N fertilizer application (early-season application - late tillering/beginning of stem elongation – Feekes 5, and late-season application - flowering/beginning of fruiting – Feekes 10.5)
- To compare 3 methods of liquid N product application: drop tubes, fan nozzles, and stream bar.

This study aims to provide high-quality research data for development of comprehensive liquid N fertilizer utilization recommendations for optimizing yield and improving spring wheat grain yield quality. Both agronomic and economic efficiency will be accessed.

MATERIALS AND METHODS

The experiment was established at Western Triangle Agricultural Research Center (near Conrad, MT) located in the center of the Golden Triangle – Montana's key spring wheat growing area, using SY Tyra spring wheat. Treatments were arranged in the Randomized Complete Block Design (RCBD) with 4 replications. Treatment structure is reported in Table 1. Consistent with current Montana State University guidelines based on the general N requirements to attain a desired yield suggest that 3 lb of N are required to produce 1 per bushel (lb N/bu) of spring wheat (Dinkins and Jones, 2007). Previously attained spring wheat grain yields averaged about 100 bu/ac at the experimental location evaluated, resulting in the recommended total N rate of 300 lb N/ac. The N fertilizer rates in Table 1 are proposed based on the assumption of 50 lb N/ac residual soil (preplant profile). The topdress N rates were adjusted according to the soil test results, keeping the total N rates of 150 and 300 N/ac. Treatment 1 was established as an N-unfertilized check plot. At seeding, N fertilizer was applied as UAN, side-banding the solution at a rate of 20 lb N/ac. The topdress N was applied as a one-time application at spring green-up (treatments 2-7) or as a split application (treatments 8 through 19). For the split topdress, fertilization at spring green-up was followed by second topdress fertilization at flag leaf emergence (Feekes 8-9) at a 30 lb N/ac rate using UFT or LU. All topdress fertilizer wias applied utilizing an ATV-mounted sprayer equipped with a stream bar. The plot size was 5'x 25' with each plot containing 5 rows. The liquid N fertilizer was applied to all 5 rows; the field data (detailed below) was collected from the 3 middle rows to avoid any possible treatment overlap due to liquid product application. One week after topdress fertilization at green-up, spring wheat crop canopy reflectance - Normalized Difference Vegetative Index (NDVI) - was measured within each plot using the GreenSeeker active-light optical sensor to estimate crop yield potential, as affected by the applied N treatments. The sensor is designed to illuminate the light in red (650nm) and NIR (770nm) bands and to detect the fraction of the emitted light returned from the canopy to the sensor. The NDVI is highly correlated with aboveground biomass, plant vigor, leaf chlorophyll content, and plant N status (Walsh et al., 2009). At flag leaf emergence (Feekes 8-9), the weight of 15 plants randomly selected within each plot. The aboveground biomass of the harvested plants was combined to produce a composite biomass samples and the subsamples were analyzed for total N content.

Grain yield by-plot was measured utilizing the Harvest Master GrainGage, by Wintersteiger. Grain protein content was determined at Western Triangle Agricultural Research Center's lab utilizing the Near-Infrared Inframatic 9500 SW Whole Grain Analyzer by Perten. Protein yield was calculated as a product of grain yield and grain protein content. The effect of liquid N source, N fertilizer rate, application time, on spring wheat grain yield, protein content, protein yield, and NDVI were evaluated using statistical procedures.

Table 1. Treatment structure.

Treatment	*Total N Rate (residual soil N plus N applied as fertilizer), lb N/ac	N Fertilizer Application					
		At Seeding		Spring Green-Up (Feekes 2-3)		Flag Leaf Emergence (Feekes 8-9)	
		N Rate, lb N/a	N Source	Target N Rate, lb N/a	N Source	N Rate, lb N/a	N Source
1	0	0	n/a	0	n/a	0	n/a
2	150	20	UAN	80	UAN	0	n/a
3	300	20	UAN	230	UAN	0	n/a
4	150	20	UAN	80	LU	0	n/a
5	300	20	UAN	230	LU	0	n/a
6	150	20	UAN	80	UFT	0	n/a
7	300	20	UAN	230	UFT	0	n/a
8	150	20	UAN	50	UAN	30	UFT
9	300	20	UAN	200	UAN	30	UFT
10	150	20	UAN	50	LU	30	UFT
11	300	20	UAN	200	LU	30	UFT
12	150	20	UAN	50	UFT	30	UFT
13	300	20	UAN	200	UFT	30	UFT
14	150	20	UAN	50	UAN	30	LU
15	300	20	UAN	200	UAN	30	LU
16	150	20	UAN	50	LU	30	LU
17	300	20	UAN	200	LU	30	LU
18	150	20	UAN	50	UFT	30	LU
19	300	20	UAN	200	UFT	30	LU

*Assuming the soil residual (preplant profile) N of 50 lbs N/ac & 100 bu/a Spring Wheat

RESULTS AND DISCUSSION

This report summarizes the results of one growing season at one location in north-central Montana. Grain yields ranged from 59.5 to 64.7 bu/a, which is only about 60% of the average grain yields for the experimental area of 100 bu/a. The lowest yield was observed for unfertilized control (trt 1), the highest yield was achieved with trt 13 (300 lb N/a total rate; 200 N/a at green-up as LU followed by 30 lb N/a as UFT) (Table 1).

Test weights ranged between 53.8 and 55.3 lb/bu; the test weights of at least 56 lb/bu are much more preferred, as growers are “docked” on the percentage basis, if the test weight is lower that the acceptable range. Excellent grain protein values between 14.5 and 15.5 % were achieved in this study (Table 1). Protein yield values ranged between 51705 to 57990 lb for trts 1 and 13, respectively.

The GreenSeeker NDVI values were relatively high and ranged from 0.73 to 0.82 (Table 2). A high NDVI value of 0.73 noted for the unfertilized control (trt 1) suggests that there was adequate amount of N present in the soil/plant system and points to even and satisfactory plant stand establishment and biomass development.

A response to applied N was observed, application of 150 lb N/a had significantly increased grain yield test weight, grain protein, and protein yield. With increase of total N rate from 150 to 300 lb N/a, only grain protein content has increased.

Nitrogen rate applied at green-up (Feekes 2-3) had significantly effected grain protein content (Table 3; Figure 1).

No significant differences in spring wheat grain yield, test weight protein yield, NDVI, biomass weight, and average leaf length associated with N rate applied at green-up.

Nitrogen source applied at green-up has significantly affected spring wheat grain yield: UFT resulted in higher yield compared to UAN and LU (Figure 2).

Furthermore, Figure 3 shows that LU and UFT had a significant advantage in terms of both grain yield production and quality – higher protein yield values were achieved with application of LU and UFT at green-up.

Nitrogen (rate and source) applied at flag leaf had no effect on any of the evaluated valuables, including grain yield and quality and biomass parameters. Previous work in spring wheat had shown that N should be applied late tillering/jointing (Feekes 5-6) in order to make a difference in grain yield production. Application of N at Feekers 8-9 (flag leaf) might have been too late to have a substantial effect.

Figure 4 shows the relationship between GreenSeeker NDVI and final protein yield. In this study, N rate applied at green-up had significantly affected leaf N content, but not NDVI or grain yield. Also, there was no relationship between leaf total N concentration and grain yield. This has been the case in several Montana studies in wheat, showing that leaf N content is not a food predictor of grain yield. GreenSeeker NDVI had a strong relationship with test weight, grain protein, biomass weight, and leaf length.

Biomass weight and leaf length were strongly correlated with grain protein content.

We recommend to repeat the study with adjusting N rate recommendations down, to see a more definite response to applied N fertilizer. Since the study will be repeated in south-west Idaho Furthermore, we recommend to adjust the application time from Feekes 8-9 to Feekes 5-6, in order to be able to have time to make a difference in yield and protein response. We anticipate that with these adjustments, a mre pronounced effect of N rate and fertilizer source might be noted in the year 2 of the study.

Table 1. Spring wheat grain yield, grain test weight, grain protein content, and protein yield, Conrad, MT, 2014.

Trt	Grain yield, bu/a	Grain test weight, lb/bu	Grain protein content, %	Protein yield, lb/a
1	59.5 (b)	55.3 (a)	14.5 (e)	51705 (b)
2	61.7 (ab)	54.5 (bcd)	15.0 (bcd)	55485 (a)
3	61.9 (ab)	54.6 (bc)	15.2 (b)	56205 (a)
4	62.0 (ab)	54.9 (ab)	15.1 (bc)	56190 (a)
5	62.4 (ab)	54.6 (bc)	15.1 (bc)	56400 (a)
6	62.8 (ab)	54.4 (bcd)	15.0 (bcd)	56265 (a)
7	63.5 (ab)	54.5 (bc)	15.2 (b)	57615 (a)
8	61.4 (ab)	54.7 (abc)	15.0 (bcd)	54990 (ab)
9	62.2 (ab)	54.9 (ab)	15.0 (bcd)	55920 (a)
10	63.8 (a)	54.9 (ab)	14.9 (bcd)	57045 (a)
11	60.9 (ab)	53.8 (d)	15.5 (a)	56745 (a)
12	62.2 (ab)	55.1 (ab)	14.9 (bcd)	55575 (a)
13	64.7 (a)	54.6 (bc)	15.0 (bcd)	57990 (a)
14	62.5 (ab)	54.7 (abc)	15.1 (bcd)	56370 (a)
15	61.9 (ab)	54.9 (ab)	14.7 (de)	54690 (ab)
16	62.6 (ab)	54.7 (abc)	14.9 (bcd)	56085 (a)
17	61.4 (ab)	54.1 (cd)	15.5 (a)	57180 (a)
18	63.9 (a)	54.9 (ab)	14.8 (cde)	56625 (a)
19	62.1 (ab)	54.8 (ab)	14.7 (de)	54885 (ab)

Means within each column followed by the same letter are not significantly different at 90% confidence level.

Table 2. GreenSeeker NDVI, aboveground biomass dry weight, average leaf length, and leaf total N content, Conrad, MT, 2014.

Trt	NDVI	Biomass weight, g	Average leaf length, cm	Leaf N content, %
1	0.73 (c)	38.8 (e)	22.7 (bc)	3.38 (abcd)
2	0.76 (abc)	47.0 (cde)	23.6 (abc)	3.48 (ab)
3	0.74 (c)	44.6 (cde)	23.8 (abc)	3.53 (ab)
4	0.78 (abc)	55.4 (bcde)	22.8 (bc)	3.39 (abcd)
5	0.74 (c)	53.6 (bcde)	23.2 (abc)	3.56 (ab)
6	0.77 (abc)	54.7 (bcde)	23.8 (abc)	3.18 (de)
7	0.80 (ab)	49.3 (bcde)	22.7 (bc)	3.43 (abc)
8	0.76 (bc)	53.9 (bcde)	24.5 (ab)	3.46 (ab)
9	0.76 (bc)	47.8 (bcde)	24.5 (ab)	3.52 (ab)
10	0.77 (abc)	43.9 (cde)	22.6 (abc)	3.43 (abc)
11	0.81 (ab)	46.4 (cde)	23.5 (bc)	3.61 (a)
12	0.82 (a)	58.2 (bcd)	25.1 (a)	3.33 (cd)
13	0.76 (bc)	50.7 (bcde)	23.8 (abc)	3.47 (ab)
14	0.78 (abc)	40.4 (de)	25.1 (a)	3.07 (e)
15	0.76 (bc)	58.7 (bc)	22.8 (bc)	3.44 (abc)
16	0.76 (bc)	55.6 (bcde)	23.3 (abc)	3.20 (cde)
17	0.75 (bc)	80.8 (a)	25.1 (a)	3.47 (ab)
18	0.77 (abc)	65.6 (ab)	22.3 (c)	3.20 (cde)
19	0.73 (c)	40.1 (e)	22.0 (c)	3.49 (ab)

Means within each column followed by the same letter are not significantly different at 90% confidence level.

Table 3. The summary of total N rate (TN), N rate applied at green-up (GUNR), N source applied at green-up (GUNS), N rate applied at flag leaf (FLNR), and N source applied at flag leaf (FLNS) on spring wheat grain yield, test weight, grain protein content, protein yield, biomass weight, leaf length, and leaf total N content, Conrad, MT, 2014.

Parameter	GUNR	GUNS	FLNR	FLNS
Grain yield	ns	*	ns	ns
Test weight	ns	ns	ns	ns
Grain protein	*	ns	ns	ns
Protein yield	ns	*	ns	ns
NDVI	ns	ns	ns	ns
Biomass weight	ns	ns	ns	ns
Leaf length	ns	ns	ns	ns
Leaf total N	**	ns	ns	ns

*, **, and *** designate significant, very significant, and highly significant effect; ns designates no significance at 90% confidence level.

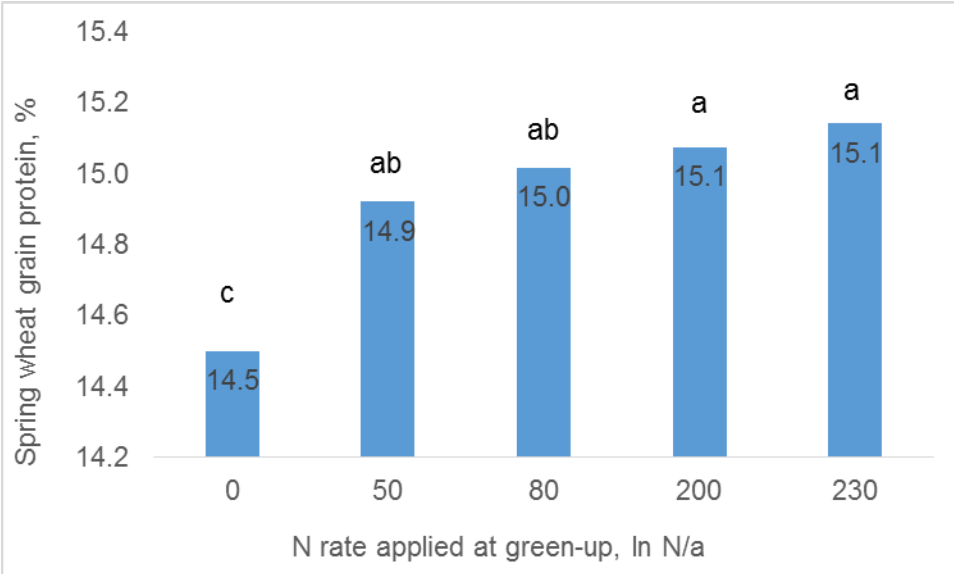

Figure 1. Spring wheat protein content as affected by N rate applied at green-up (Feekes 2-3), Conrad, MT, 2014.

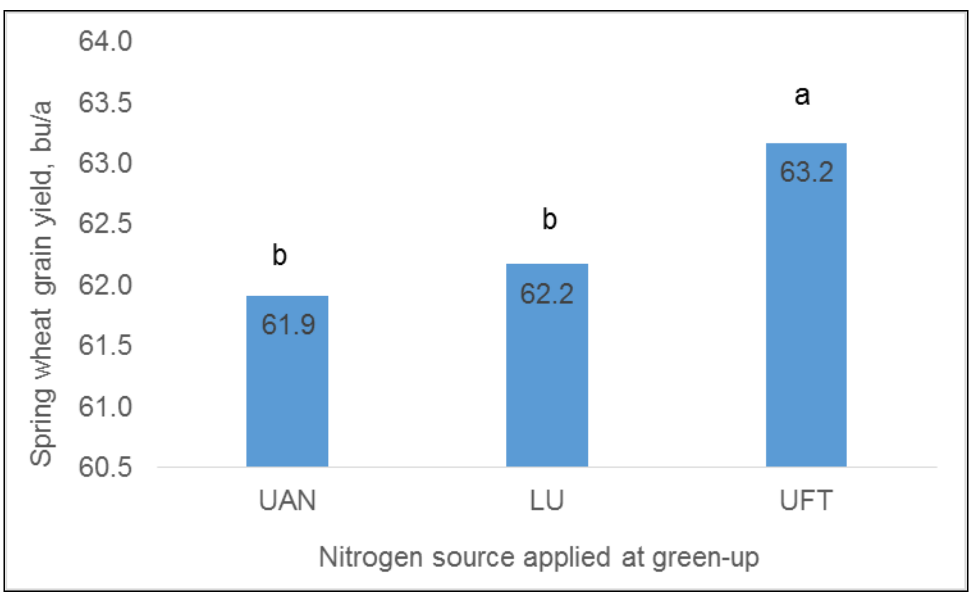

Figure 2. Spring wheat grain yield as affected by N source applied at green-up (Feekes 2-3), Conrad, MT, 2014.

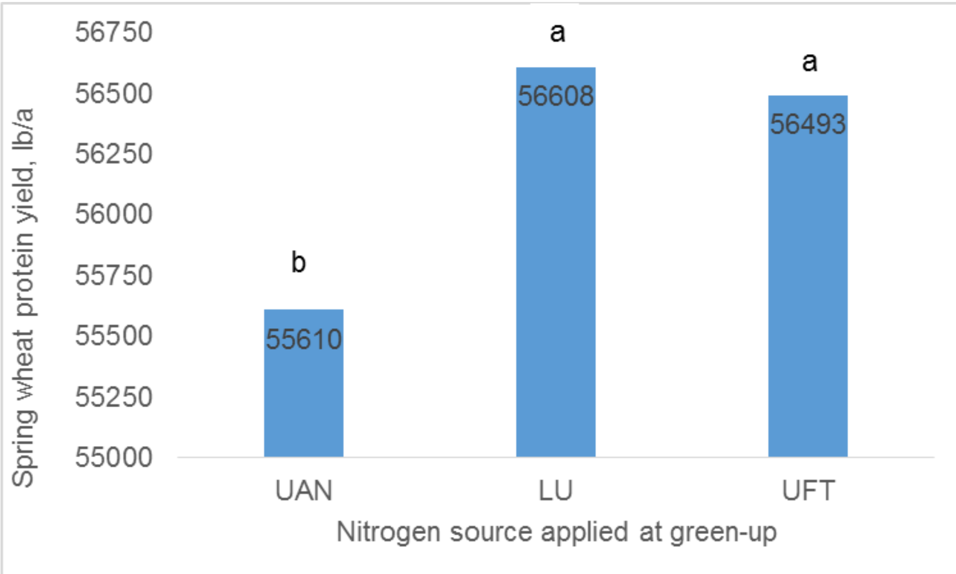

Figure 3. Spring wheat protein yield as affected by N source applied at green-up (Feekes 2-3), Conrad, MT, 2014.

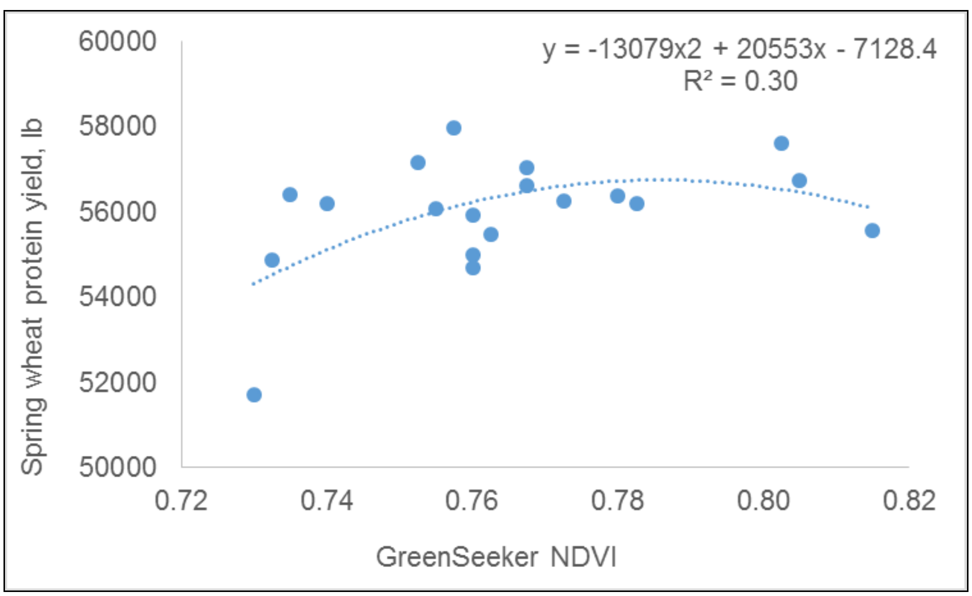

Figure 4. Relationshig between GreenSeeker NDVI and spring wheat protein yield, Conrad, MT, 2014.