IN-SEASON VARIABLE RATE N IN POTATO AND BARLEY PRODUCTION USING OPTICAL SENSING INSTRUMENTATION

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ABSTRACT

Inadequate or excess nitrogen (N) severely impacts yield and potato (*Solanum tuberosum* L.) tuber quality and malt barley (*Hordeum vulgre* L.) protein and kernel plumpness. These crops are somewhat unique in their narrow N sufficiency range. Variation across fields with residual soil N and yield potential result in large spatial differences for the optimal N fertilizer rates needed to produce high quality potatoes and malt barley. Recently developed optical sensing technology combined with variable rate spray controller hardware makes it possible to apply N in-season at an unprecedented small scale. The objective of this study is to evaluate the use of optical sensing instrumentation to help manage in-season N for potato and malt barley by correlating the Normalized Difference Vegetation Index (NDVI) with tissue nitrate, yield, and various crop quality parameters. Four potato and five barley locations were used as evaluation sites in eastern Idaho. High correlations of R^2 = 0.83-0.90 were observed in 3 of the 4 potato fields for yield compared to NDVI at two weeks prior to row closure for potato. The correlation between yield and N rate were also very high in these fields with R^2 = 0.88-0.99. Similarly, high correlations of R^2 values of 0.37-0.95 were observed in 4 of the 5 fields when comparing yield with NDVI at Feekes 6 for malt barley. The correlation between yield and N rate were also very high in these fields with R^2 = 0.50-0.99. Other yield and quality parameters were measured and recorded to further evaluate the optical sensor in potatoes and malt barley. Trends and correlations showed useful relationships between NDVI and yield and N Rate.

INTRODUCTION

Potatoes and malt barley are an important aspect of Idaho's economy and nitrogen (N) application is an essential input required for profitable and sustainable production. Excessive N in the form of nitrate is a health risk for humans and livestock, as well being a detriment to crop quality and yield (Ojala, et al, 1990). Recent surveys show that several regional ground water supplies in Idaho are above the EPA's maximum contaminant level for nitrate (Idaho Department of Environmental Quality http://www.deq.state.id.us/). These areas of high nitrate concentration tend to be along the Snake River plain across southern Idaho following the areas of major farming and livestock activities. According to this survey, the majority of nitrate contamination is attributed to agriculture. Methods for improved N management need to be implemented to alleviate this perceived problem.

Fortunately, improving N management is also beneficial for crop producers. Improved N management enhances crop yields and net returns for growers. In addition to yield increase, potatoes show improved tuber size and shape and reduced internal and external defects with optimal N management (Stark and Westermann, 2003).

Malt barley shows increased yield and, at times, increased protein as N rates increase. Malt barley can be rejected or discounted in price if protein levels are too high or too low. In order to make quality malt, barley must have a protein content of between about 11.5 and 13.5%. Although environmental conditions play a much greater role, N fertilizer application must be carefully managed to ensure that malt barley protein is in the range desired by the malting facility. In addition, excessive N applied to barley results in increased fertilizer costs and possible reduced grower income due to lodging, delayed maturity, decreased kernel plumpness and test weight, and increased incidence of pathogen infections favored by plant succulence. Fertilizer N must be carefully managed to prevent too little and too much N (Stark and Brown, 2003). All sources of N must be taken into account when making recommendations.

Recent innovations in sensing technologies (aerial imagery and optical sensors) are providing small grain and potato growers new methods to increase yield and crop quality. It is hypothesized that it is possible to create variable rate spread maps for in-season N application from an aerial image, verifying spatial differences in "greenness" via tissue analysis. Alternatively, in-season variable rate N applications may also be made by utilizing a sprayer equipped with a computerized variable rate controller and sensors that indirectly measure plant chlorophyll content. Plant chlorophyll concentration is related to many factors, but is strongly influenced by N status in the leaves. These sensors (GreenSeeker, N-Tech Industries, Ukiah, CA) interpret leaf chlorosis as N deficiency and control the amount of N applied accordingly. Research done on wheat in the Midwestern U.S. has shown significant increases in yield and protein with the GreenSeeker technology (Raun et al., 2002). Other researchers have verified these results in other regions and with other crops, including barley, corn, and wheat (2004 Crop Nitrogen Algorithm Conference, University of Nebraska, Lincoln, http://nue.okstate.edu /Nitrogen_Conference2003/Planning_Session2004.htm).

The findings of these studies with the GreenSeeker show that growers can apply reduced or no N pre-season and then "even up" the field with use of a variable rate application early in the season (Raun et al, 2001). The GreenSeeker sensors are calibrated in these crops using an "N-rich strip". As the sensor equipped sprayer travels across the field, the N rate applied is based on a comparison between the readings at each location with those in the reference strip, as calibrated with a research derived algorithm. The amount of N applied from each nozzle can be altered every 2 to 3 feet with this system. Growers are successfully adopting this technology in the Midwest where historical small grain yields are much lower than in the irrigated Pacific Northwest.

Although this technology seems to work well with many crops, an issue that arises with potatoes and malt barley is the severe negative effect of the excess N on crop yield and quality. The N-rich strip typically involves application of a double rate of N. Two potential problems exist if this strategy is employed for potatoes and malt barley. The first issue is that the effect of a double rate of N in a strip across the entire field is unacceptable for potato and malt barley growers due to the relatively severe impacts of excess N with these crops as compared to wheat, corn, and feed barley. The other problem lies with the assumption that the "greenest" plant is the one that produces the crop with greatest net return. It may be possible to solve these concerns with an N-rich strip having a rate less than double of what is applied to the rest of the field and/or altering the algorithm to apply N to target less than maximum greenness.

Although it is highly likely that this technology will also improve yield and maintain protein levels in Idaho barley fields, in-field research needs to be conducted to fine tune the algorithms for Idaho conditions. Furthermore, the usefulness of this technology for in-season variable rate N application on potatoes needs to be explored and an algorithm needs to be developed if the technology looks promising.

MATERIALS AND METHODS

Barley - Five field trials on two-row malting barley were completed in eastern Idaho near Newdale (1202), Rockford (Harrington), Idaho Falls (Merit), Osgood a (1202), and Osgood b (Merit). Six N rates (0, 35, 70, 105, 140, and 175 lb-N $acre^{-1}$) were applied immediately prior to or at planting as ammonium nitrate (34-0-0; NH_4NO_3) with four replications of 18 ft x 36 ft plots in a randomized complete block experimental design (RCBD). The N fertilizer was watered into the soil with irrigation or rainfall within one to seven days of application.

Normalized Difference Vegetation Index (NDVI) calculations were made for the vegetation every 7 to 14 days by taking readings with a hand-held optical sensing device (GreenSeeker). The GreenSeeker contains its own source for consistent light emission and photodiode detectors and interference filters for red [R] and near infrared [NIR] wavelengths at 671±6 nm and 780±6 nm spectral bands, respectively. The effective spatial resolution for the GreenSeeker when held approximately 36 in. above the canopy is 2 ft^2 (Stone et al., 1996). The NDVI is calculated by subtracting the reflected R spectrum band from the NIR band and dividing by the sum of these same two bands. The NDVI serves as a commonly used index for remotely sensing plant health (Tucker, 1979). An NDVI image was also taken from an airplane platform for comparison with the ground based sensor.

Leaf/stem tissue samples were taken at Feekes 6 (Zadoks 31) growth stage (Large, 1954). Yields were measured at maturity in a 3.3 ft^2 harvest area in the middle of each plot. Kernel size was determined after harvest by sieving the grain through Seedburo Precision Dockage Sieves (Chicago, IL) at 0.086 and 0.094 in. screen size, with the "plump" category referred to hereafter as the percentage of kernels retained on the larger screen. Protein analysis was done with a Dickey-John Instalab 600 NIR Product Analyzer (Auburn, IL). Soil samples were taken to a depth of four feet in each plot to compare pre- and post-season nitrate levels. The soil and tissue are currently in process of analysis for nitrate-nitrogen (NO_3-N) concentrations.

Potatoes - Four field trials on Russet Burbank potatoes were completed in eastern Idaho near Rexburg, Riverton, Ft. Hall, and Aberdeen, Idaho. Six N rates (0, 70, 140, 210, 280, and 350 lb-N $acre^{-1}$) were applied throughout the growing season. One fourth of the fertilizer N was applied preplant and the rest applied three times during the season with equal amounts as ammonium nitrate with four replications of plots six rows wide (18 ft) by 36 ft long in a randomized complete block experimental design (RCBD). The N fertilizer was watered into the soil with irrigation or rainfall within one to five days of application.

GreenSeeker NDVI readings were taken as described previously. Petiole tissue samples were taken twice during the season at tuber initiation and tuber bulking. Each plot was harvested at maturity by using a two row lifter and picking up the tubers in a 20 ft length approximately in the middle of each plot. Tuber yield was determined by grading for size, shape, weight, and internal and external defects. Soil samples were taken to a depth of four feet in each plot to compare pre- and post-season nitrate levels. The soil and tissue are currently in process of analysis for nitrate-nitrogen (NO_3-N) concentrations.

RESULTS AND DISCUSSION

Barley - The overall correlation between yield and N Rate was very strong with R^2 values (fitted with a second order polynomial equation) of 0.502 Osgood a, 0.996 Osgood b, 0.41 Newdale, 0.908 Rockford, and 0.585 Idaho Falls. The correlation between yield and NDVI are mostly strong with R^2 values (fitted with a second order polynomial equation) of 0.833 Osgood a, 0.954 Osgood b, 0.852 Newdale, 0.181 Rockford, and 0.374 Idaho Falls. The NDVI and yield results for each field are shown in Figure 1. Although protein values are not yet analyzed, kernel plumpness shows a similar relationship when comparing the trends in Figure 2 with the NDVI values in Figure 1. The correlation between kernel plumpness and NDVI are (fitted with a second order polynomial equation) 0.847 Osgood a, 0.177 Osgood b, 0.956 Newdale, 0.123 Rockford, and 0.888 Idaho Falls.

Most importantly, it is apparent from an examination of the data at the low N Rates (0, 35, and 70 lb-N acre^{-1}) that the Greenseeker accurately predicted a yield and/or plumpness increase in a majority of circumstances when it occurred. This is important as a grower would apply a low rate or no N fertilizer at or before planting. At the Feekes 6 growth stage, a sprayer equipped with GreenSeeker sensors would be used to apply variable rate liquid N fertilizer.

Two scenarios can be evaluated with this particular trial. The first would be if the grower applied no N in the field except 35 lb-N acre^{-1} in the N rich reference strip. In this case, the GreenSeeker effectively predicted an increase in yield in every field, as evidenced by an increase in the NDVI. The GreenSeeker accurately predicted that the Newdale and Idaho Falls fields needed N and that the Osgood b field needed a relatively higher rate of N. It also accurately predicted that the Osgood a and the Rockford fields would not show an economical response to added N.

Many growers may be uncomfortable not applying any N pre-plant and, as such, the second scenario would be more applicable to their situation, namely, if the grower applied a low rate of N (35 lb-N acre^{-1}) across the field and then applied a 2x rate in an "N rich strip" (70 lb-N acre^{-1}). In this case, the GreenSeeker effectively predicted a yield response in four out of the five fields. The only exception was the Newdale field; a yield response was observed between the 35 and 70 lb-N acre^{-1} rates, but the NDVI value obtained from the GreenSeeker showed a decrease. However, it is interesting to note that the plumpness began to decline dramatically beyond the 35 lb-N acre^{-1} rate in the Newdale field. Considering this quality factor, the GreenSeeker accurately predicted the N needed in all five fields for this second scenario.

It is also interesting to note that there was a strong relationship between the NDVI values obtained from the aerial images, especially for the Osgood b field, which had the greatest yield response (Figure 3). It is possible that an aerial image could be used to create a variable rate N spread map rather than mounting sensors on a sprayer. This option would be more economical, but further analysis of the data needs to be performed before this question can be answered.

Potatoes –The overall correlation between yield and N Rate was very strong with R^2 values (fitted with a second order polynomial equation) of 0.990 Ft. Hall, 0.909 Riverton, 0.878 Rexburg, and 0.215 Aberdeen. The correlation between yield and NDVI are mostly strong with R^2 values (fitted with a second order polynomial equation) of 0.902 Ft. Hall, 0.878 Riverton, 0.828 Rexburg, and 0.227 Aberdeen. The NDVI and yield results for each field are shown in Figure 4. The correlation between NDVI and specific gravity (Figure 5) are not as strong as the correlation with yield with values (fitted with a second order polynomial equation) of 0.470 Ft. Hall, 0.514 Riverton, 0.889 Rexburg, and 0.170 Aberdeen.

As was the case for the barley, the Greenseeker accurately predicted whether or not the crop needed additional N in all circumstances when examining a scenario of 0 N applied pre-plant with a 70 lb-N acre^{-1} N-rich strip. Similarly, the GreenSeeker accurately predicted N needs in three of four fields when examining the scenario of 70 lb-N acre^{-1} applied pre-plant with a 140 lb-N acre^{-1} N-rich strip. The only exception was the Riverton field, where a negative yield response was observed between the 70 and 140 lb-N acre^{-1} rates, but the NDVI value obtained from the GreenSeeker showed a slight increase. Overall, the GreenSeeker accurately predicted that the all the fields needed N and that the Rexburg field needed a relatively higher rate of N. It also accurately predicted that the Aberdeen field would not show an economical response to added N above the second highest rate.

SUMMARY

These results show that the optically sensed NDVI readings for both malt barley and potato effectively delineate "greenness" attributed to N rate. These results shown that the tissue reflectance of the light used in the NDVI calculation is highly correlated to N rate early in the season, mostly before visible symptoms occur. This suggests that the NDVI can be used to variably apply N to malt barley at the Feekes 6 growth stage. Similarly, the NDVI can be used to variably apply N to potatoes prior to row closure. Additional work is needed to finish developing the algorithms necessary for use with a GreenSeeker equipped sprayer and to examine the effectiveness of this technology in a whole field circumstance.

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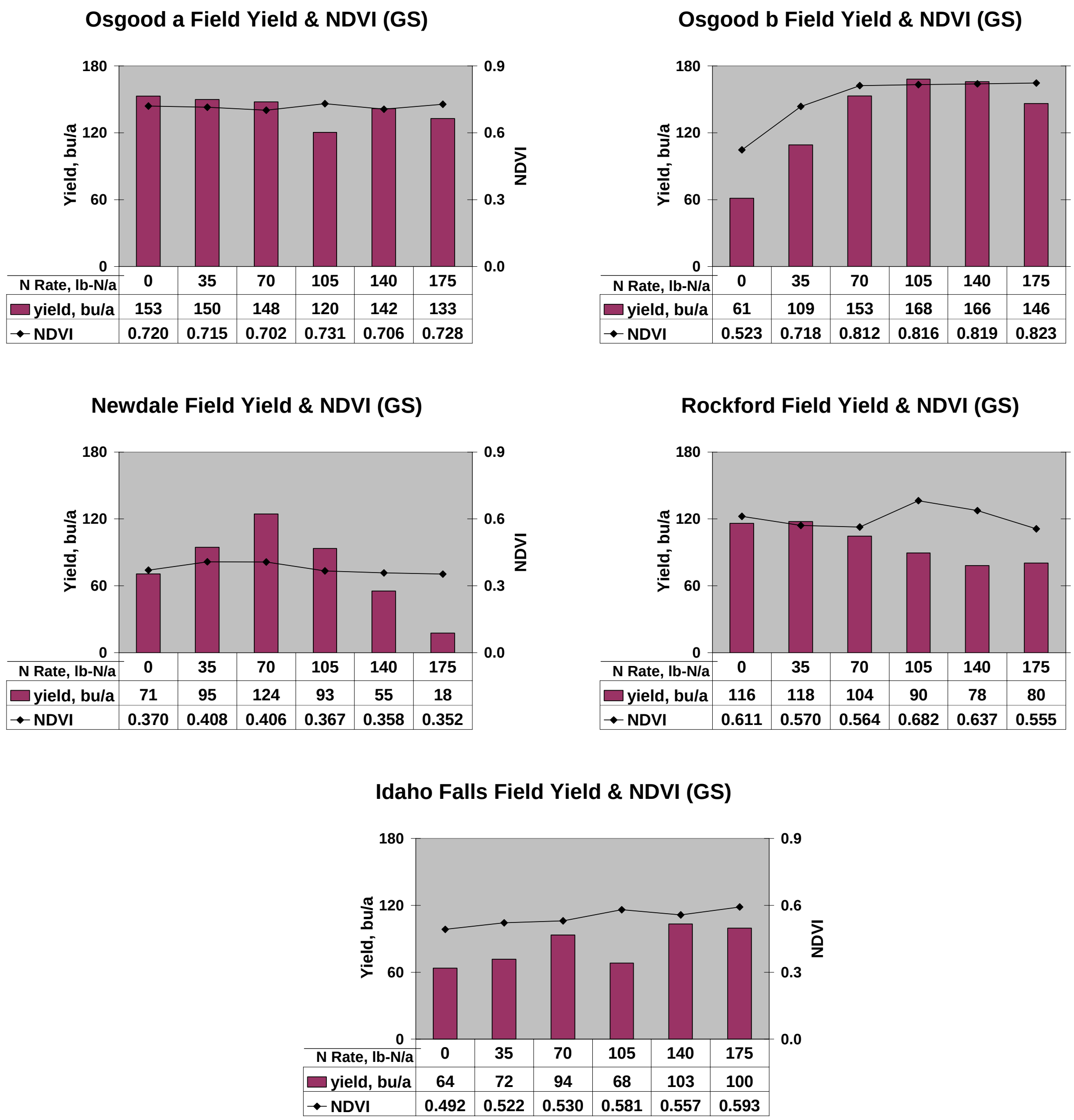

Osgood a Field Yield & NDVI (GS)

N Rate, lb-N/a	0	35	70	105	140	175
yield, bu/a	153	150	148	120	142	133
NDVI	0.720	0.715	0.702	0.731	0.706	0.728

Osgood b Field Yield & NDVI (GS)

N Rate, lb-N/a	0	35	70	105	140	175
yield, bu/a	61	109	153	168	166	146
NDVI	0.523	0.718	0.812	0.816	0.819	0.823

Newdale Field Yield & NDVI (GS)

N Rate, lb-N/a	0	35	70	105	140	175
yield, bu/a	71	95	124	93	55	18
NDVI	0.370	0.408	0.406	0.367	0.358	0.352

Rockford Field Yield & NDVI (GS)

N Rate, lb-N/a	0	35	70	105	140	175
yield, bu/a	116	118	104	90	78	80
NDVI	0.611	0.570	0.564	0.682	0.637	0.555

Idaho Falls Field Yield & NDVI (GS)

N Rate, lb-N/a	0	35	70	105	140	175
yield, bu/a	64	72	94	68	103	100
NDVI	0.492	0.522	0.530	0.581	0.557	0.593

Figure 1. Barley grain yield at harvest and Normalized Difference Vegetation Index (NDVI) at Feekes 6 growth stage for malt barley grown at five eastern Idaho locations with six N rates in 2004. The NDVI was obtained with the GreenSeeker (GS) optical sensing device held three feet above the canopy and calculated as (NIR – R/ NIR + R) where NIR is the measured reflectance in the Near Infrared spectrum and R is the measurement in the Red spectrum. In general, the NDVI value increased as yield increased.

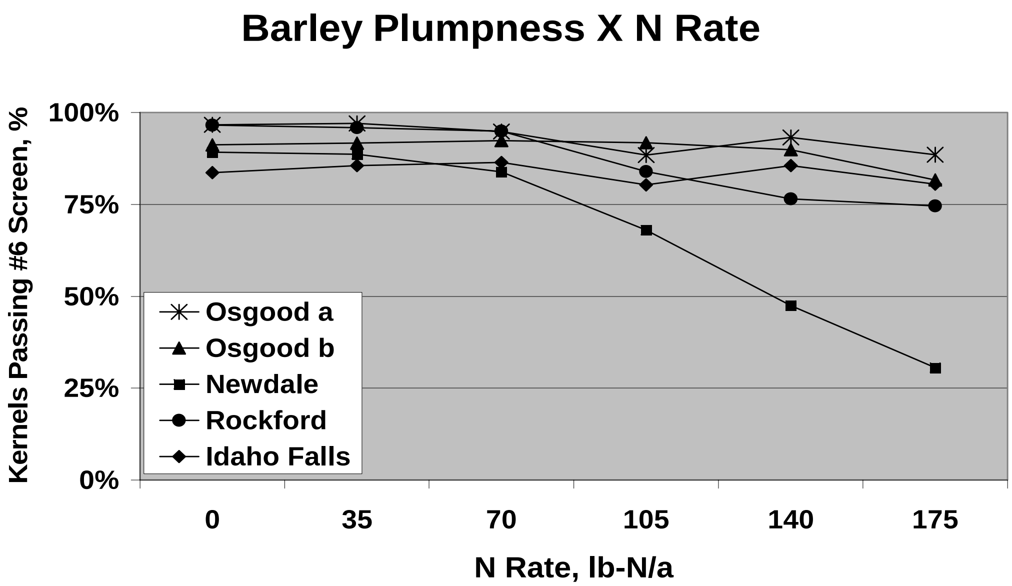

Figure 2. Percent plumps at maturity as a function of N rate for malt barley grown at five eastern Idaho locations with six N rates in 2004.

Figure 3. NDVI Aerial image taken at Feekes 6 (Zadoks 31) showing the six N rates (lb-N acre^{-1}) at the Osgood b location using a black and white color ramp with black being the lowest NDVI value and white the highest.

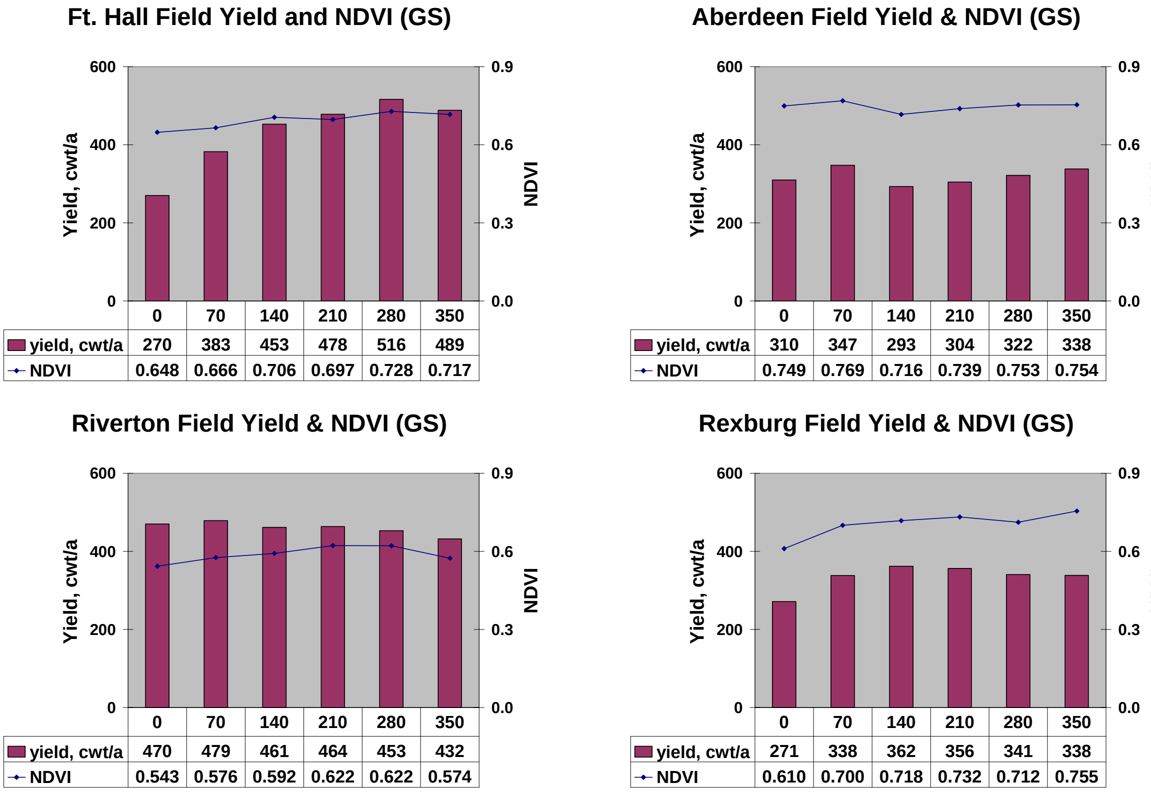

Figure 4. Yield at harvest and Normalized Difference Vegetation Index (NDVI) at two weeks prior to row closure for *Russet Burbank* potato grown at four Eastern Idaho locations with six N rates in 2004. The NDVI was obtained with the GreenSeeker (GS) optical sensing device held three feet above the canopy and calculated as (NIR – R/ NIR + R) where NIR is the measured reflectance in the Near Infrared spectrum and R is the measurement in the Red spectrum. In general, the NDVI value increased as yield increased.

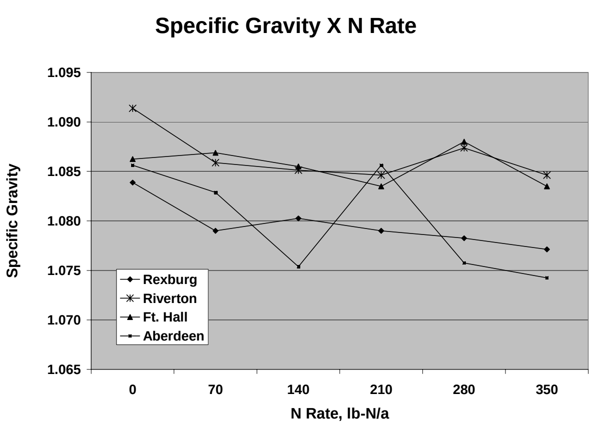

Figure 5. Tuber specific gravity as a function of N rate for potatoes grown at five eastern Idaho locations with six N rates in 2004.