PRE-SEASON VARIABLE RATE NITROGEN IN POTATOES

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ABSTRACT

Potatoes (*Solanum tuberosum*) are particularly sensitive to nitrogen (N) nutrition. Fertilizer N needed is related to both residual soil N and yield potential and, as such, is hypothesized to be spatially variable. Three methods of variable-rate N fertilization using geospatial technologies were compared to the traditional method of uniform application. Comparisons were made across five potato fields in eastern Idaho during each year of the two-year study. Each field was divided into zones based on expected productivity and other physical/chemical parameters. The methods used to divide the fields into management zones included: 1) grid mapping, 2) bare soil imagery with intensive soil sampling, and 3) apparent soil electrical conductivity (EC_a) mapping with bare soil imagery and intensive soil sampling. On average, the variable rate N techniques resulted in increased total (17 cwt acre^{-1}) and U.S. No. 1 (24 cwt acre^{-1}) yield in 2003 compared to the traditional method. In 2004, a non-significant increase of total (20 cwt acre^{-1}) and U.S. No. 1 (11 cwt acre^{-1}) yield were observed when variable rate N was compared to the traditional method. All three methods in 2003 increased net return relative to the traditional scenario with Grid at \$40 acre^{-1}, Imagery at \$267 acre^{-1}, and Imagery + EC_a at \$203 acre^{-1}; although only the latter two were statistically significant. Incidence of hollow heart was reduced with variable rate N application in the first year. In 2004 all three methods again increased yield and quality, but only the Imagery method showed an economic return at \$138 acre^{-1}. Combining the conductivity technology with bare soil imagery did not further improve yield and grade in either year. Although further work is needed, it appears that using geospatial technologies for variable rate N management in potatoes is economically viable, especially when using aerial imagery for zone delineation.

INTRODUCTION

Nutrition is crucial in determining potato yield and quality. It not only provides essential building blocks for plant growth, but also influences the plant's ability to withstand environmental pressures due to pests, water, temperature, and other stresses. Nitrogen (deficiency or excess) has more impact on yield, grade, and net return than all of the other nutrients. Economically, N is the most important nutrient in potato production systems (Stark and Westermann, 2003).

More N is needed in areas of the field with the best soil, water, microclimate, and topography. These "good" areas of a field usually produce higher yielding and better quality potatoes, and require more N as yield potential increases (Stark and Westermann, 2003). Conversely, less N is needed in areas with low yield potential. Residual soil nitrate also creates variability and may be higher in areas of low productivity and lower in higher yielding areas

(Kitchen et al., 1994). Spatial differences in residual nitrate may also be caused by differences in topography, drainage, soil texture, organic matter, and previous crop residues.

It is common to have significant spatial variability for a crop's nutritional needs. Most of the variable rate fertilization work in Idaho has been done with nutrients other than N, despite the fact that N is the mineral nutrient of greatest impact. Recent research in other areas of the U.S., mostly in crops other than potatoes, has begun to show benefits to variable rate N fertilization using geospatial technologies (Raun et al., 2002). Recent innovations allow for fertilizer to be applied precisely where it is needed using global positioning systems (GPS) and variable rate fertilizer controllers (Plant et al., 2001). Using this technology to improve N use efficiency may increase potato yield and quality while reducing risk of nitrate groundwater contamination.

Nitrogen fertilizer recommendations are traditionally made by applying a yield goal and a soil test nitrate-nitrogen (NO_3^--N) value to a research-derived table or equation (Stark and Westermann, 2003). The N rate is increased to account for immobilization when carbon-rich materials, such as grain straw, are present. Conversely, the N rate is reduced if manure or other N-rich biosolids have been applied within 1 to 2 years. Further reductions are made for N contained in irrigation water. Finally, N rate is adjusted downward if the previous crop was a legume, such as alfalfa or beans. Spatial rate adjustments for soil variability can be made as any of these parameters change across a field.

Grid soil sampling is a common method employed with variable rate fertilization. This method has been found to improve yield and fertilizer use efficiency in many circumstances. The accuracy of a grid map is directly related to the grid size. Grids larger than 1 to 2 acres have generally been shown to be insufficient to accurately capture spatial variability of soil test values. A potentially major flaw of the grid mapping philosophy is that adjustments for differing yield goals are rarely made for individual zones. However, it is reasonable to think that making a yield goal adjustment in the rates from zone to zone would enhance grid mapping results.

Another commonly employed method for determining spatially different fertilizer rates is based upon aerial imagery. Research has shown that differences in soil properties often exhibit themselves as differences in soil color (Fleming et al., 2004). These differences in soil properties can influence both yield potential and soil test values, thus, inferences about potential productivity can theoretically be made with some confidence based on soil color. This method is enhanced by ground truthing or, in other words, site assessment of each zone to confirm differences in soil color. The soil in each zone is sampled and analyzed separately. The N fertilizer rate for each zone is then determined based on both soil test and yield goal, with yield goal adjustments based on expected productivity. Yield goal adjustments are made by factoring in yield history, slope, aspect, and various chemical and physical attributes of the soil.

Steep slopes often result in lower yields and the direction of the slope (aspect) can impact yield as well. North-facing slopes can yield more in hot climates with heat-sensitive crops or where water is limiting. South-facing slopes often yield more when heat units are a limiting factor. Shallow or compacted soil is also known to result in lower yields due to insufficient root exploration or poor drainage. Soils with low organic matter also tend to produce lower yields due to slower warming in the spring, low nutrient supply and holding capacity, low water holding capacity, and low concentration of humic substances. Acid or alkaline pH can also result in yield loss, but this parameter is crop specific and is further dependent on the extent of pH stratification by depth and the presence of pH buffering minerals in the soil and irrigation water. Fertilization practices can also exacerbate or ameliorate pH effects. Alkaline soils often have additional yield limiting conditions including salts, sodium, and lime content. Finally, known presence of various soil-borne pests, such as nematodes, wireworms, and fungal diseases, may reduce expected yield.

Another layer of information that may be helpful in making fertilizer rate adjustments is apparent soil electrical conductivity (EC_a). Research in other regions has begun to show potential benefits of using soil EC_a as a means of delineating soil zones (Koch et al., 2004; Johnson et al., 2003). Soil EC_a depends on soil physical properties including, but not limited to, soil texture, carbonates, salinity, soil depth, and moisture (Corwin and Lesch, 2003; Kitchen et al.., 2003). Because of this, EC_a data is somewhat convoluted due to the fact that several factors impact a single conductivity reading. Also, because EC_a is an indirect assessment of several properties, the values can only be used to delineate zones. However, an EC_a map of a field can represent a valuable layer of data because it reflects underlying characteristics of a soil which are not otherwise apparent (especially that which can not be seen in an aerial image). An EC_a map in conjunction with bare soil imagery has been shown to be effective in some regions based on differences not visible with imagery alone (Kitchen et al., 2004; Koch et al., 2004).

Variable rate N application methods have also shown an environmental benefit by reducing over application of N fertilizer in areas where it is not needed by the crop. This equates to less residual N in the soil, thus, potentially reducing NO_3-N runoff to surface waters and leaching into shallow water tables (Halvorson et al., 2001).

MATERIAL AND METHODS

During 2003 and 2004, five eastern Idaho fields irrigated by center pivot systems and planted to Russet Burbank potatoes, were selected as study sites each year. Soil texture in these fields ranged from Mathon sandy loam to Bannock loam (Table 1). Bare soil images, apparent soil electrical conductivity (EC_a) and ground truthing were used to determine the areas of interest in each of the ten fields. After the areas of interest were identified, four adjacent 70 ft wide strips were created the length of each field. Three zones for intensive sampling and observation, perpendicularly aligned across the four strips, were identified (Figure 1), and soil samples were taken to 4 ft in 1 ft increments in these zones to test for profile NO_3^-N at the beginning and end of the season.

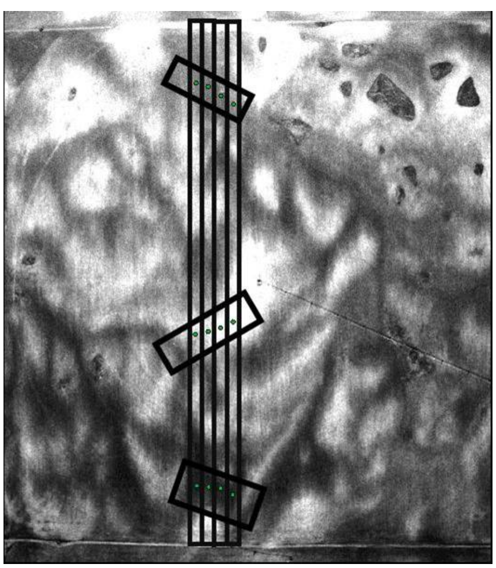

Figure 1. Bare soil image showing adjacent treatment locations and zones of sampling.

A method to determine N application rate or rates was employed for each strip based on the four techniques evaluated. These methods consisted of Traditional (TRAD) or uniform application, Grid Mapping (GRID), Bare Soil Imagery (IMAGE), and Bare Soil Imagery + EC_a (EC). Employing these various approaches, unique fertilizer N spread maps were created for each strip. Each individual zone (perpendicularly aligned sampling areas across strips) represented an observation within each strip, with each of five fields serving as blocked replicates.

The TRAD N fertilizer application rate was derived by using a single yield goal and a single composite soil sample analyzed for NO_3^-N. University of Idaho N recommendations for potatoes and historic yield goals for the area were used to determine the appropriate N application rate (Stark and Westermann, 2003). Each field had a small grain as its previous crop with similar residue amounts and none had manure history in the previous year, as such, similar N credits were given to all. The remaining three treatments reflected spatially unique N application rates.

The N fertilizer application rate for the GRID method was derived from 1.25 acre grid soil samples analyzed for NO_3^-N. Results were interpolated using ArcGIS (ESRI, Redlands, CA) software and the resulting spatial variability in residual NO_3^-N was used to divide the strip into zones (if sufficient spatial variability existed). Nitrogen application rates were based on the field average yield goal and interpolated NO_3^-N values for each zone. Nitrogen rate adjustments for differing yield goals was not made across grid zones because this technique is not practiced commonly. The N spread map generated from grid sampling was therefore used in deference to any obvious changes in soil properties, which may impact yield and nutrient availability.

Nitrogen rates for the IMAGE method were developed based primarily on bare soil aerial imagery. In the spring after tillage operations were completed, but prior to planting, a bare soil aerial image of each field was obtained using high resolution film from an airplane platform at sufficient altitude to capture the entire field within the image. These true color images had spatial resolutions of 3 ft and were geo-referenced using GPS coordinates from several targets within each field. Coordinates were obtained using a WAAS-enabled Trimble AG132 GPS receiver (Trimble, Sunnyvale, CA) which was accurate to approximately 1 to 2 ft. Strips were divided into 3 to 5 management zones based upon soil color and ground truthing to account for the expected spatial variability in crop productivity and soil test values. Residual NO_3^-N concentration for each zone was determined by taking a composite soil sample within each zone derived by appropriately combining samples from the previously described grid soil sampling. Nitrogen recommendations for each zone were based on soil type, depth, organic matter, pH, NO_3^-N concentration, lime concentration, salt concentration, elevation, slope, and aspect. Unique N fertilizer recommendations were made for each zone within the IMAGE strips based on these parameters and a variable rate N spread map was generated accordingly.

Unique zones were identified for the EC method based on a combination of the imagery technique previously discussed and EC_a, which was collected by pulling a Veris 3100 (Veris Incorporated, Salina, KS) electrical conductivity instrument across the field in parallel swaths with 70 ft intervals using a GPS lightbar. Fields were analyzed at depths of approximately 0 to 1 ft ($EC_{shallow}$) and 0 to 3 ft (EC_{deep}) for the EC_a determination. The EC_a data was then interpolated using twelve points nearest neighbor ordinary kriging techniques with ArcGIS software to generate an EC_a map for the strip locations. Zones developed through the bare soil imagery technique were then modified based on information from the EC_a map. Only data from the EC_{deep} maps were used to formulate zones due to fluctuations related more strongly to current condition soil moisture and tillage effects with the $EC_{shallow}$ maps. Similar to the IMAGE method, both residual NO_3^-N concentration and a unique yield goal were determined for each zone and used to develop the variable rate N fertilizer spread map.

Fertilizer N spread maps, which were generated using ArcGIS software, were imported into SGIS (Soilteq, Minnetonka, MN) software from which an actual spread map used by a variable rate fertilizer spread truck was created. Nitrogen fertilizer was spread as urea (46-0-0) with a 8104 Terra-Gator (Ag-Chem, Duluth, GA) variable fertilizer spreader truck with a Falcon II controller (Soilteq, Minnetonka, MN) either immediately prior to planting or at side-dress (within one week of emergence).

In-season visible and near infrared optical sensing measurements were taken three times during the season from both airplane and ground based sensors. Plant chlorophyll content was measured using a SPAD-502 chlorophyll meter (Konica Minolta Sensing, Inc., Osaka, Japan) and a Greenseeker (NTech Industries, Inc., Ukiah, CA) hand held unit. Petiole tissue samples were also collected and compared to readings from the previously mentioned instruments. Correlations were analyzed for significance between petiole samples, yield, and the optically sensed data (data not shown).

At harvest two adjacent rows, each 40 ft long, were mechanically harvested by means of a two row lifter and tubers subsequently gathered by hand. Tubers were weighed, graded, and assessed for internal and external defects to determine yield and net return for each treatment. Statistical analysis was performed by ANOVA, with zones serving as multiple measurements within each block (field) and means separated by LSD at the alpha=0.05 level of significance.

At harvest, soil samples were once again collected to a depth of 4 feet in 1 ft increments. Samples were analyzed for residual soil NO_3^--N throughout the profile and also for NO_3-N leaching within zones and across treatments.

RESULTS AND DISCUSSION

Both years showed increased yields for both total and U.S. No. 1 categories with respect to all three variable rate N methods. However, when treatments were examined with means separated by LSD at the alpha 0.05 level of significance the GRID treatment was not significant either year and EC was only significant in 2003 (Figures 2 and 3).

An average increase of 17 cwt acre^{-1} was measured in 2003 for the variable rate N application methods (GRID, IMAGE, and EC), as compared to the TRAD uniform application method. A 4% increase (24 cwt acre^{-1}) in U.S. No. 1's was also observed with variable rate N application. When methods are examined individually, these yield differences are not always statistically significant (Figure 2), but all three variable rate methods resulted in more total yield when compared to the TRAD method.

Similar to 2003, the combined effects of the variable rate N methods showed increases in yield in 2004. An average increase of 20 cwt acre^{-1} in total yield and 11 cwt acre^{-1} in U.S. No. 1 tubers was realized when comparing the variable rate methods to the TRAD method of N fertilizer application.

Yields in the IMAGE and EC strips in 2003 were significantly greater than the TRAD method, both having a 21 cwt acre^{-1} increase in total yield. The GRID method showed a 10 cwt acre^{-1} increase in total yield, but this was not statistically different from the TRAD method. This same trend was also observed with the variable rate methods for the U.S. No. 1 (USDA fresh market grade) potatoes (Figure 2). The IMAGE (35 cwt acre^{-1}) and the EC (28 cwt acre^{-1}) methods produced potatoes of significantly greater quality than the TRAD method. The GRID method also had more U.S. No. 1 potatoes (9 cwt acre^{-1}) than the TRAD method, but was not statistically significant.

In 2004, while all three variable N rate methods showed an increase in tuber yield and quality (Figure 3), only the IMAGE method was statistically significant, showing a total yield increase of 28 cwt acre^{-1} and 21 cwt acre^{-1} in U.S. No. 1 tubers over the TRAD method.

In general, variable rate N application resulted in an increase in brown center, but a decrease in hollow heart in 2003 (Figure 4). Brown center is the initial stage of hollow heart, which suggests that improved N nutrition slowed the progression of deformity. No differences were observed for brown center and hollow heart in 2004, but very little of this disorder was observed in this year.

Each of the variable rate application treatments resulted in increased production costs for the producer, ranging from \$6 to \$22 acre^{-1}. However, the net returns figured using five year average grower contracts showed an increase in net return during 2003 for all three variable rate methods (Figure 5). The IMAGE (\$267 acre^{-1}) and the EC (\$203 acre^{-1}) methods both showed significant increases in net return when using these geospatial technologies to apply N variably. In contrast, only the IMAGE method showed an increase in net return in 2004 (\$138 acre^{-1}) when compared to the TRAD method. GRID showed a net loss of (\$9 acre^{-1}) as did the EC method (\$30 acre^{-1}) when compared to the TRAD method in 2004 (Figure 6).

CONCLUSION

Results from the first two years of this study support the concept of variable rate N application in potato production, especially when based on Imagery zonal management. This method showed significant increases in total yield, as well as U.S. No. 1 tubers. The recognized increase in yield and quality more than compensated for the increased cost of this method of variable rate N fertilization. Using EC_a as an added layer of information did not further improve yield and net returns, but more research regarding interpretation of this data in Idaho soils is needed before conclusions are drawn. Grid sampling alone does not seem to be an effective method for variable rate N fertilizer application, most likely due to the fact that spatial differences in yield potential are not being considered with this method. It is reasonable to assume that the results for the grid method would improve if a variable yield goal and/or added layers of information (such as imagery) were added. The cost of making yield goal adjustments is minimal and, as such, is a recommended addition for this method. This was not included in this trial because an evaluation of grid mapping as it is currently practiced in industry was desired for comparison with the other methods. Adding imagery to the already high cost of grid sampling may be cost prohibitive, but the added layer of information would be expected to improve the results. These combinations were not evaluated in this study and, therefore, are only surmised. Further evaluation of these methods for variable rate N application is planned.

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Table 1. NRCS Soil Survey Classifications for field locations for the variable rate N fertilization trial on potatoes in eastern Idaho.

Location	Year	Texture Classification
Newdale		Mathon sandy loam 0-6 % slopes
	2003	
Menan		Ririe silt loam 4-8 % slopes
	2003	
Rexburg		Panmod silt loam 4-12 % slopes
	2003	Rexburg silt loam 2-4 % slopes
Shelley		Bannock loam 0-2 % slopes
	2003	Bock loam 0-2 % slopes
St. Anthony		Rexburg silt loam 1-12 % slopes
	2003	Rexburg hardpan substratum
Newdale		Ririe silt loam 4-12 % slopes
	2004	
Menan		Mathon sandy loam 0-6 % slopes
	2004	
Rexburg		Rexburg silt loam 4-8 % slopes
	2004	
Shelley		Bannock loam 0-2 % slopes
	2004	
St. Anthony		Rexburg silt loam 1-12 % slopes
	2004	Rexburg silt loam, bedrock substratums 1-4 % slopes

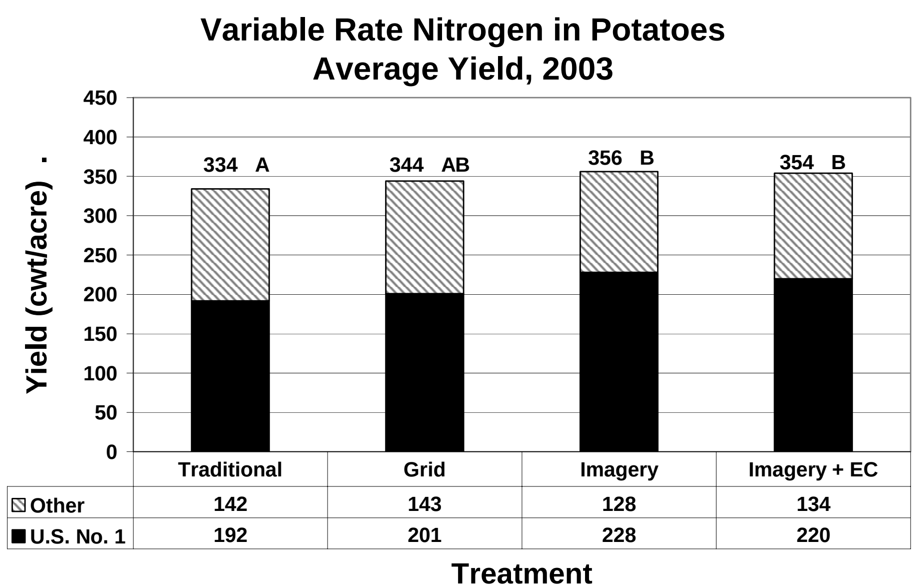
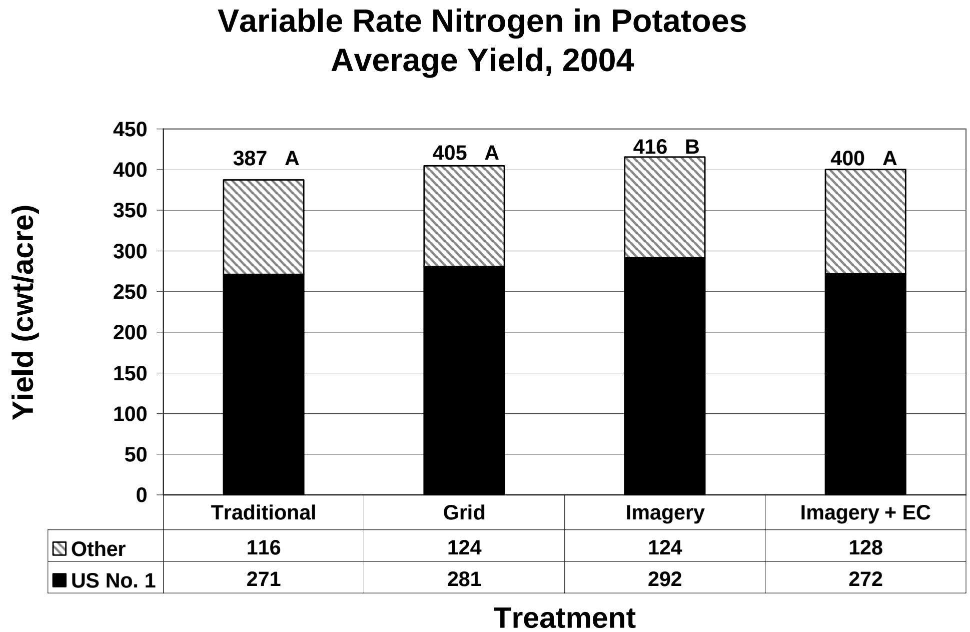


Figure 2. Average crop yield for 2003 variable rate N potato trial in eastern Idaho. Total yield is reflected at the top of each column for individual treatments. Other refers to tubers which are malformed, U.S. No. 2, and less than 4 oz. Values followed by the same letter not significantly different (0.05).



	Traditional	Grid	Imagery	Imagery + EC
Other	116	124	124	128
US No. 1	271	281	292	272

Figure 3. Average crop yield for 2004 variable rate N potato trial in eastern Idaho. Total yield is reflected at the top of each column for individual treatments. Other refers to tubers which are malformed, U.S. No. 2, and less than 4 oz. Values followed by the same letter are not significantly different (0.05).

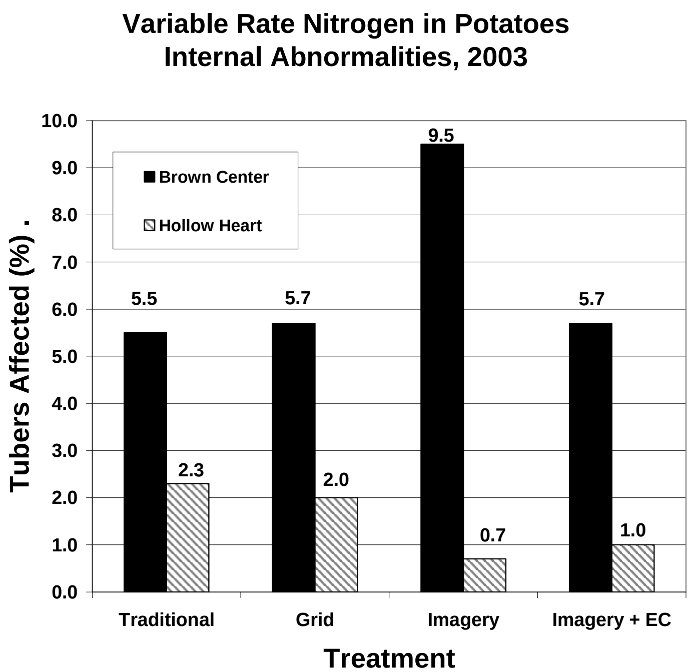


Figure 4. Percentage of tubers from each treatment in 2003 affected with Brown Center and Hollow Heart in the variable rate N potato trial in eastern Idaho. Net return is considered gross crop value less the cost of the variable rate technology.

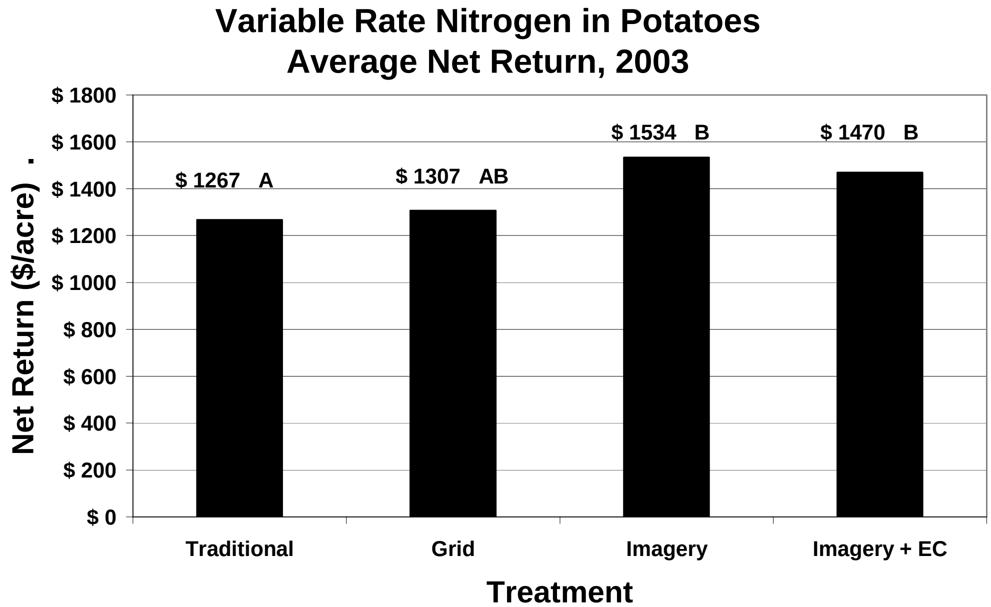


Figure 5. Average net return for 2003 variable rate N potato trial in eastern Idaho. Net return is considered gross crop value less the cost of the variable rate technology. Values followed by the same letter are not significantly different (0.05).

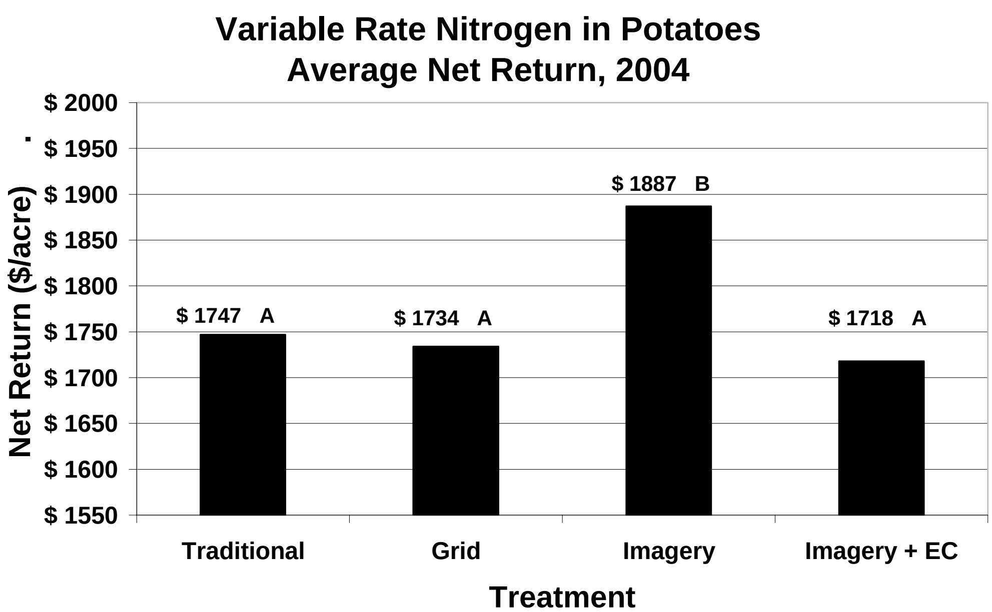


Figure 6. Average net return for 2004 variable rate N potato trial in eastern Idaho. Net return is considered gross crop value less the cost of the variable rate technology. Values followed by the same letter are not significantly different (0.05).