IMPACT OF VARIABLE-RATE NITROGEN ON POTATO YIELD, NITROGEN USE EFFICIENCY, AND PROFIT

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ABSTRACT

Applying variable N within a field could improve yields, nitrogen use efficiency (NUE), and economics. The object of this study was to evaluate impacts of high and low rate zones within a variable rate pre- and in-season N (VRPIN) system compared to traditional N management used by the grower in a potato-wheat-wheat cropping system. Nitrogen zones were created within five potato fields in 2021 and 2022 near Grace, Idaho, USA. Nitrogen rates for each zone were determined based upon yield goal levels and other variables. Uniform strips were placed through all zones as a positive control based on N management used by the grower. All N for the growing season was applied shortly after planting with a polymer coated urea (PCU). Yield samples were collected at 4-6 locations within each zone and the uniform strips to assess tuber grade, size, external and internal defects, and specific gravity. Variable rate N significantly improved total, marketable and U.S. No. 1 yield in high-yield potential zones compared to their respective control strips across all fields combined. Although yields increased, NUE decreased with increased VRN rates and increased with decreased VRN rates. The grower increased profits by an average of \$364 ac^{-1} with VRN across all potato fields.

INTRODUCTION

Nitrogen application is a vital step in crop production and continues to be an environmental concern due to its high volatilization and solubility properties (Hopkins et al., 2020). As yields can vary extensively throughout a single field, improving N management has the potential to not only improve yields and crop quality, but also improve input costs, and decrease environmental concerns (Hopkins et al., 2020). Variable rate nitrogen (VRN) is a process that could achieve these goals within agriculture. Utilizing grower field knowledge, historical yield, and other field data can determine yield potential zones for variable rate pre- and in-season N (VRPIN). Studies have used crop sensing, modeling, historical yield maps, topography and soil properties to create management zones, some collectively and some individually (Bourdin et al. 2017; Pedersen et al. 2021; Schwalbert et al. 2019). While some studies have shown success in VRN zones, others have not (Long et al. 2015; Schwalbert et al. 2019).

Utilizing VRN within potato has the potential to improve production, tuber size specific gravity and other quality components in the respective crop (Hopkins et al., 2020). While studies have been performed to test the effectiveness of in-season VRN (Bohman et al., 2019; Bohman et al., 2020), more field-scale studies are required to address the pre-emergence VRN portion of VRPIN within potato. This study was developed to create and test simple and feasible VRPIN zones that growers can utilize to optimize N management and improve nitrogen use efficiency (NUE) and economics.

A simple approach to variable-rate nitrogen management that utilizes field history and grower knowledge is needed to advance precision nitrogen management. Practicing such simple variable rate pre- and in-season N (VRPIN) approaches have the potential to reduce fertilizer needs, save money, reduce environmental impacts, and increase production. Precision nitrogen management has been studied extensively in other regions of the country, but few replicated field-level trials exist in Idaho or Utah. Local studies are needed to validate whether a simple VRPIN approach is feasible and economical for potato producers in this region.

METHODS

In 2021 and 2022, ten potato fields ranging in size of 124, 87, 45, 87, 57, 62, 22, 99, 121 and 64 ac for fields 1-10, respectively, with wheat-wheat-potato rotations, located near Grace, Idaho, USA (elevation 5535 ft above sea level) were established as field sites. This area has a semi-arid climate typified by relatively hot days and cool nights during the growing season. The average annual precipitation is 15 in with the majority occurring during winter as snow.

Two to four zones were visually identified within each field (Fig. 1) based on utilizing layers of information, including: grower field knowledge, topography, bare soil imagery, yield map histories of potato and rotational crops, historical in-season visible and normalized difference vegetation indices (NDVI) imagery. These layers were used to find overlapping patterns of zones that could represent average, high, or low yields with or without limitations that are or are not possible to correct.

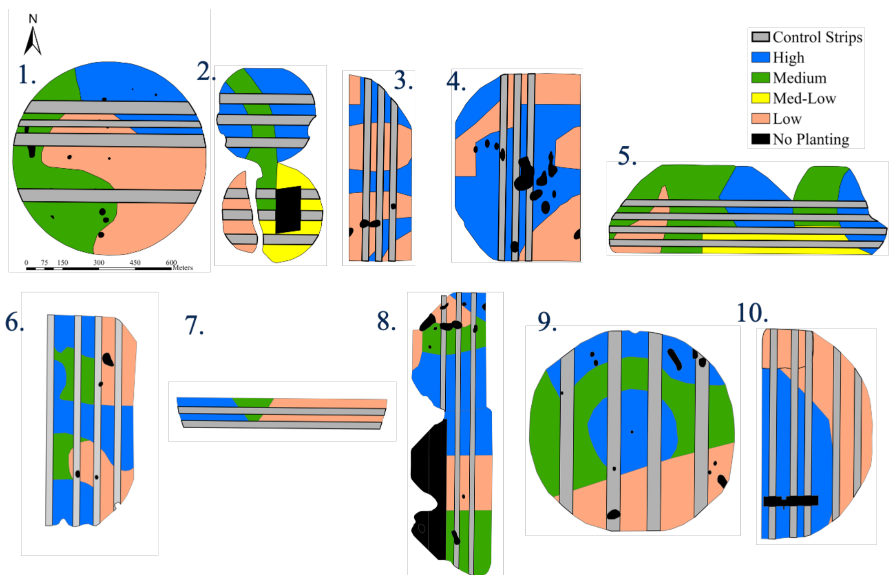

Figure 1. Nitrogen zones for ten potato fields (1-10) with 2021 experiments in fields 1-5 and 2022 experiments in fields 6-10.

Banded fertilizer was applied at 7.2 lbs N ac^{-1} uniformly to all fields prior to planting. Potatoes were planted between 11 and 15 May, 2021 and 13 and 20 May, 2022 in 2.8 ft wide rows with varieties including: Russet Burbank (fields 1, 6, 8 and 10), Frito Lay 2137 (fields 2, 4 and 9), Actrice (fields 3 and 7) and Waneta (field 5), (Fig. 1). Soil samples (12-15 cores per sample) were collected randomly throughout each zone to 1 ft deep between 18-19 May, 2021 and 6 & 8 April, 2022. These samples were air dried, ground (< 0.08 in) and analyzed for NO_3-N. The base N rates for each zone were determined as a function of variety and yield goal, with reductions for residual topsoil N, crop residue, irrigation water NO_3-N concentration, and legume and/or manure credits (if any) (Hopkins et al., 2020). The N predicted to be needed for the season was applied via broadcast with a Miller Condor fertilizer spreader (St. Nazianz, Wisconsin, USA) shortly after planting between 27 May and 03 June, 2021, and 02 June and 09

June, 2022 using a polymer coated urea (PCU; Nutrien, Saskatoon, Canada) (Table 1). Control N strips were placed through all zones as a positive control based on N management used by the grower. The N was incorporated into the soil during hilling, which occurred shortly after fertilization.

Table 1. Pre-emergence nitrogen (N) rates for each zone in ten potato fields. Zones were based on yield potential, with some fields not having all zones (not applicable = N/A).

Zone	Field									
	A	B	C	D	E	F	G	H	I	J
	- - - - - - - - - - - - - - - - - - -				lbs N ac^{-1}	- - - - - - - - - - - - - - - - - - -				
Control	160	120	130	130	140	160	130	160	130	170
High	190	150	160	160	170	190	160	190	160	200
Medium	160	120	N/A	N/A	140	160	130	160	130	N/A
Med-Low	N/A	105	N/A	N/A	120	N/A	N/A	N/A	N/A	N/A
Low	130	90	100	100	110	130	100	130	100	140

The crop canopies were monitored in-season at least twice weekly for visible and NDVI pattern changes, especially row closure differences utilizing Sentinel 2 and Landsat 8 satellite imagery (FarmShots, Durham, North Carolina, USA). Composite petiole samples (Hopkins et al., 2020) were taken in the control N strips three times within each season to evaluate overall nutrition and NO_3-N trends and then, based on the control petiole NO_3-N concentration and canopy imagery, composite petiole samples were taken in every zone and analyzed for NO_3-N by the ServiTech, Inc. laboratory (Dodge City, Kansas, USA). If NO_3-N levels were low based on Hopkins et al. (2020), additional fertilization plots were created within the applicable zone to apply VRN to small portions of each zone.

Tuber samples were collected at harvest (17-27 Sep, 2021 and 19-29 Sep, 2022), approximately 21 d after vines were chopped and then sprayed with sulfuric acid, to determine yield and quality at 4-6 locations within each zone in a paired sampling structure. Each pair consisted of a sampling from the control strip and the VRN zone. Samples were hand collected using a four-row windrower (crossover) (1 ft by 33 ft^2) in 2021 and a combination of a four-row and 6-row windrower (crossover) (1 ft by 43 ft^2) in 2022. Tubers were separated by grade (U.S. No. 1, U.S. No. 2 and malformed; USDA, 2011) and then counted and weighed for each grade. Average tuber size was calculated by dividing the weight of all tubers within a specified grade by the respective count.

All replicated data were analyzed by ANOVA (SAS Studio 3.8, SAS, Cary, North Carolina, USA) with mean separation performed by Least Significant Difference (LSD).

RESULTS AND DISCUSSION

The amount of N applied within the VRN zones were compared to the amount of N that would have been used with the control rate across the entirety of each field. The average difference in VRN rates compared to control rates resulted in an increase of 0.1 lbs N ac^{-1} with a range of -9 – 8 lbs N ac^{-1} across all fields (Fig. 2). The VRN treatments had very minor impacts on total N rates applied, as N was reappropriated from low to high productivity areas. This process resulted in the same N cost for both approaches.

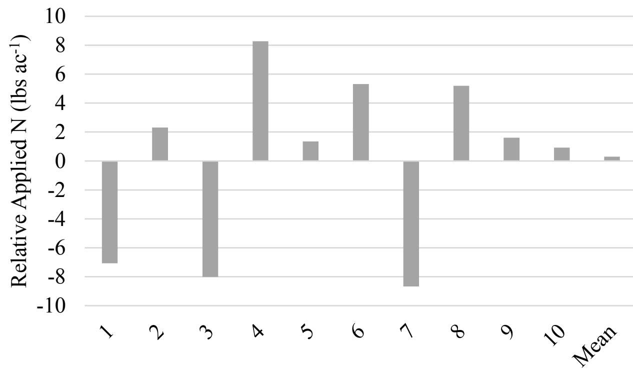

Figure 2. Difference in total amount N applied (lbs ac^{-1}) if using VRN method compared to positive control rate (grower standard practice rate) throughout entirety of fields; with data shown as VRN minus control.

In-season assessment of N status via visible scouting, NDVI imagery, and petiole tissue sampling revealed optimal N values throughout the growing season. While the option to variably apply N in-season was available, it was decided to not do so for any of the fields based on the lack of variability across zones in 2021 (all zones were classified as low; Hopkins et al., 2020). The rates applied at the pre-emergence for this study could have been high enough across all zones to negate the need for in-season VRN.

Yields measured and averaged by the potato harvester's yield monitor were 339, 393, 384, 232, 330, 312, 437, 272, 303, and 401 cwt ac^{-1} for fields 1-10, respectively and were considered good for the high elevation and seed potato region. Yield, quality, and internal measurements were collected in small plots within each VRN zone and control strip within each field. Although data on tuber size, specific gravity and internal measurements were collected and significant differences were observed, these results will not be discussed within this paper. The small plot measurements showed significant Treatment × Zone interactions for total, marketable and U.S. No. 1 yields (Table 2). Significant differences were observed between high and low VRN zones and their respective control strips in combined fields for total, marketable and U.S. No. 1 yield (Fig. 3).

Table 2. *P* values from ANOVA with statistically significant values shown in bold-face type ($P = 0.05$)

Response	Treatment	Zone	Field x Trt.	Trt. x Zone	Field x Trt. x Zone
Total Yield	**<0.0001**	**0.0022**	**0.0034**	**0.016**	0.5862
Marketable Yield	**<0.0001**	**0.0006**	**0.0009**	**0.0249**	0.5463
U.S. No. 1 Yield	**<0.0001**	**0.0002**	**0.0001**	**0.0307**	0.5849
NUE	**<0.0001**	**<0.0001**	0.089	**<0.0001**	**0.0061**

The VRN treatment yielded significantly higher than control strips in high zones across total, marketable and U.S. No. 1 yields, and although not significant, showed to yield numerically higher in low zones compared to their respective control strips (Fig. 3). This shows that the high yield potential zones did increase yields with increased rates of N, and the low yield potential zones did not result in a negative yield response with lower rates of N. A study with similar N rates showed similar results in that it did not result in significant differences in tuber yields between VRN and uniform rates when VRN rates were lower than the uniform rates (Bohman et al., 2019). Another study also found no significant differences in tuber yields between VRN and uniform rates, but the zones were not set up by the same design and was not a full-field trial (Morier et al., 2015). Bowen et al. (2022) did find positive responses in yields with the VRN rates, and also did not find any significant negative yield impacts from lowered VRN rates.

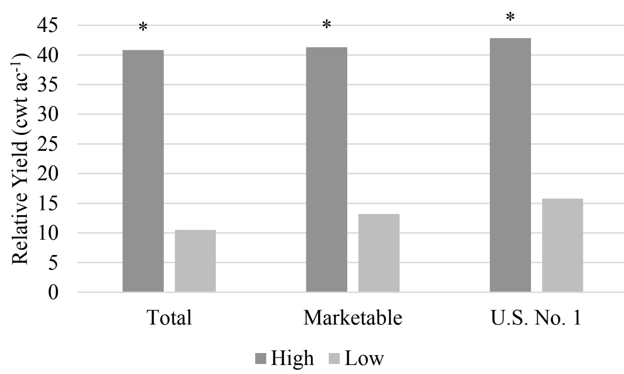

Figure 3. Relative yield (VRN – Control) by zone for total, marketable and U.S. No. 1 yields, with significant differences shown with an * ($P < 0.05$).

Relative NUE (VRN – Control) was observed based on yield (cwt ac^{-1}) ÷ N rate (lbs ac^{-1}) from small plot measurements in each field (Fig. 4). Where N rates were increased in the high zones, NUE decreased, and where N rates were lowered in the low zones, NUE increased. Overall, the differences in NUE between VRN treatments and Control strips were significant for both high and low zones with all fields combined. By observing these values, it could be determined that too much N was applied in all fields within the high zones and rates could be decreased to improve NUE. Fields 4 and 7 did not result in significant NUE differences within the low zones like the other fields did. For field 7, this could be because the variety 'Actrice' requires a lower optimal rate of N, but a higher rate of N was applied across the field for all zones, thus potentially creating a buffer effect on the NUE ratio. Field 4 yielded lower overall, and seemed to have some unknown, underlying conditions within the low zones that could be negatively impacting yields and thus lowering the relative NUE. Although NUE could have been improved, the grower increased profits by an average of \$364 ac^{-1} with VRN across fields 6-10 in 2022 alone (Ryan Christensen, personal communication). These profit gains validate the simple steps within this study.

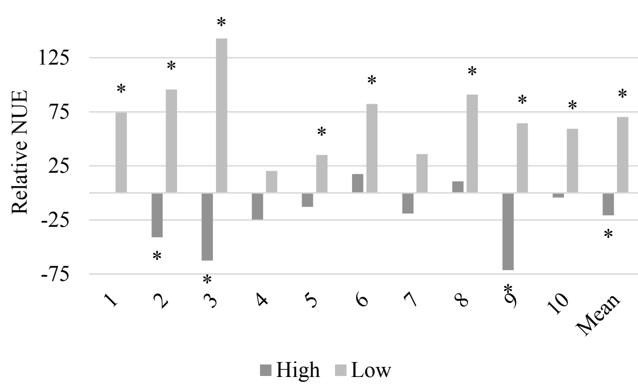

Figure 4. Relative nitrogen-use efficiency (NUE) (VRN – Control) within individual fields and zones. Significant differences shown with an * ($P < 0.05$).

CONCLUSION

In general, utilizing the VRN procedure used in this potato study benefited total, marketable and U.S. No. 1 yields significantly within the high yield potential zones, and did not negatively impact yields within the low yield potential zones. Overall, the increase in yield, crop quality and profit is possible with careful reallocation of N throughout fields, although rates could be decreased to improve NUE. These results represent ten site years of data, five from 2021 and five from 2022.

REFERENCES

Bohman, B. J., Rosen, C. J., & Mulla, D. J. (2019). Evaluation of Variable Rate Nitrogen and Reduced Irrigation Management for Potato Production. *Agronomy Journal,* 111(4), 2005-2017. https://doi:10.2134/agronj2018.09.0566

Bohman, B. J., Rosen, C. J., & Mulla, D. J. (2020). Impact of variable rate nitrogen and reduced irrigation management on nitrate leaching for potato. *Journal of Environmental Quailty*, 49, 281-291. https://doi.org/10.1002/jeq2.20028

Bourdin, F., Morell, F. J., Combemale, D., Clastre, P., Guerif, M., Chanzy, A. (2017). A toll based on remotely sensed LAI, yield maps and a crop model to recommend variable rate nitrogen fertilizer for wheat. *Advances in Animal Biosciences: Precision Agriculture (ECPA),* 8(2), 672-677. https://doi.org/10.1017/S2040470017000887

Bowen, T. R., J. W. Ellsworth, A. G. Cook, S. C. Stephens, A. K. Shiffler, & B. G. Hopkins. (2022). Variable rate nitrogen in potato. *Journal of Plant Nutrition* (In Press).

Hopkins B. G., Stark J. C., & Kelling K. A. (2020). Nutrient Management. *In* Stark J., Thornton M., Nolte P. *(ed) Potato Production Systems*. Ch. 8:155-202. New York, New York: Springer, Cham. DOI: https://doi.org/10.1007/978-3-030-39157-7_8 (ISBN978-3-030-39157-7)

Long, D. S., Whitmus, J. D., Engel, W. R. E., & Brester, G. W. (2015). Net returns from terrain-based variable-rate nitrogen management on dryland spring wheat in northern Montana. *Agronomy Journal*, 107(3), 1055-1067. https://doi.org/10.2134/agronj14.0331

Morier, T., Cambouris, A. N., & Chokmani, K. (2015). In-season nitrogen status assessment and yield estimation using hyperspectral vegetation indices in a potato crop. *Agronomy Journal*, 107, 1296-1310. https://doi.org/10.2134/agronj14.0402

Pedersen, M. F., Gyldengren, J. G., Pedersen, S. M., Diamantopoulos, E., Gislum, R., & Styczen, M. E. (2021). A simulation of variable rate nitrogen application in winter wheat with soil and sensor information – An economic feasibility study. *Agricultural Systems*, 192,103-147. https://doi.org/10.1016/j.agsy.2021.103147

Schwalbert, R. A., Amado, T. J. C., Reimche, G. B., & Gebert, F. (2019). Fine-tuning of wheat (*Triticum aestivum,* L.) variable nitrogen rate by combining crop sensing and management zones approaches in southern Brazil. *Precision Agriculture* 20, 56-77. https://doi.org/10.1007/s11119-018-9581-6