# VARIABLE RATE FERTILIZATION: SOIL MOISTURE IMPACTS

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## ABSTRACT

Variable Rate Fertilization (VRF) fertilization is a means of potentially applying nutrients more efficiently. Variable Rate Irrigation (VRI) is increasingly evaluated. However, these are generally studied in isolation, which seems contrary to the principles on which each are founded. Potential benefits of VRF, especially for N, are often confounded or repressed as a result of soil moisture variability due to runoff losses/accumulation and/or total water applied. Similarly, VRI results are impacted with interactions with biophysical chemistry when nutrients are applied uniformly to inherently variable field sites. Whole-farm Variable Rate Nitrogen (VRN) cropping systems were evaluated, including: 1) silage corn-alfalfa in Utah during 2010-2017, 2) lettuce-sweet corn-bean-onion-sweet corn-pea in Washington during 2015-2020, 3) potato-sugarbeet-wheat in Idaho during 2004-2020 and 4) potato-wheat-wheat in Idaho during 2003-2019. Each field included at least two N rate zones with optimum vs. deficit and/or excess soil moisture zones. Replication was variable with 3-5 management zones at each site. Yields increased an average of 8% when additional N was applied to zones with high yield potential when soil moisture was optimal. Yields were not negatively impacted in the optimal soil moisture zones with low yield potential when less N was applied. The effect of VRN was negated if soil moisture was excessively wet or dry, with significantly decreased yields in both. Overall, the effect was generally similar across crops. However, an orthogonal comparison of the high-yield potential zones showed the greatest response for non-legumes with minimal residual N for zones with optimal soil moisture. In-season N deficiencies were prevalent in excess soil moisture zones with reductions in Normalized Difference Vegetative Index and tissue N. Post season residual nitrate ($NO_3$-N) was significantly higher in most fields in deficit soil moisture zones (20 lbs. N/acre increase). These results show that the potential benefits of VRN can be completely overshadowed by variable soil moisture and that zonal management adjustments and/or VRI should be considered to maximize efficiency.

## INTRODUCTION

Providing the food, fuel, and fiber for the eight billion people on the planet is a critical need Hopkins, 2020). Doing so requires that nutrients and water be managed carefully for maximum economic yield (Hopkins, 2020; Hopkins et al., 2020). However, water and the geological deposits of nutrient minerals and fossil fuels required to manufacture and transport fertilizers are resources that need conservation. Additionally, the misuse of these resources results in environmental problems related to air, water, and soil quality, as well as water quantity. Applying the correct rate and managing these appropriately is essential.

Variable Rate Fertilization (VRF) is a means of more efficiently applying nutrients, especially for nitrogen (N) as Variable Rate Nitrogen (VRN) fertilization. A minimum of two basic approaches should be used when employing VRF. First, residual nutrient availability can inform varying fertilizer needs. This is particularly important for nutrients, such as phosphorus (P) and potassium (K), which tend to be stored effectively in the soil and which have a reasonably high correlation of soil test concentrations to yield response. Second, yield potential can impact the rate of nutrient need, which is particularly important for N. The N can and should be analyzed in soil, but the soil test is relatively less reliable as it is easily transformed and lost to the environment. This nutrient is the most important fertilizer that is applied to non-legume crops, making up approximately half of the fertilizer used globally due to N making up the greatest concentration of mineral nutrients in most crop canopies (~3-5%). Our research shows that yield potential is an effective approach to fertilization but, admittedly, this is disputed by some.

Variable Rate Irrigation (VRI) is relatively rare, but ours and others' work shows great potential to improve the amount of crop produced per drop of water applied (Smith et al., 2021; Svedin et al., 2021; Woolley et al., 2021). The use of VRI requires an understanding of both crop needs and the soil's ability to store and supply water.

However, VRI and VRN are generally managed and studied in isolation, which seems contrary to the principles on which each are founded. Potential benefits of VRF, especially for VRN, are often confounded or repressed as a result of soil moisture variability due to runoff losses/accumulation and/or total water applied. Similarly, VRI results are impacted with interactions with biophysical chemistry when nutrients are applied uniformly to inherently variable field sites. The objectives of this research were to evaluate VRN studies at four multi-year, multi-crop sites by parsing the data into areas of deficit, optimal, and excessive soil moisture.

## METHODS

Whole-farm VRN cropping systems were evaluated near: 1) Provo, UT with silage corn (2010, 2017) and alfalfa (2011-2016); 2) Pasco, WA with lettuce (2015), sweet corn (2016, 2019), navy bean (2017), onion (2018), and pea (2020); 3) Blackfoot, ID with potato (2004, 2007, 2010, 2013, 2016, 2019), sugarbeet (2005, 2008, 2011, 2014, 2017, 2020), and wheat (2006, 2009, 2012, 2015, 2018); and 4) Idaho Falls, ID with potato (2003, 2006, 2009, 2012, 2015, 2018) and wheat (2004-5, 2007-8, 2010-11, 2013-14, 2016-17, 2019-20). Replication was variable with three to five management zones at each location.

Fields were initially divided into management zones based on: previous crop yield history, bare soil imagery, in-season visual and Normalized Difference Vegetative Index (NDVI) imagery, topography, and grower knowledge. For purposes of the analysis, these zones were merged into two to three zones of average and below or above-average yield potential. Field edges and areas with significant problems not directly related to water or N nutrition were discarded from the analysis.

Each zone in each field had a customized N rate unique for each crop in the rotation, with 2 to 3 N rates per field. Nitrogen rates were determined based on yield potential, residual inorganic soil N, crop residue, previous crop, and irrigation water nitrate-N concentration. In general, the N rates followed typical fertilizer recommendations customized for the crop and the region. The average yield potential zones received 250 lbs. N/acre on average with a range of 180-330 lbs. N/acre for most crops, excepting legumes and crops grown after other crops with shallow and/or inefficient root systems (potato, lettuce, and onion) which received 50 lbs. N/acre. The N applied to legumes was fertigated during the middle to the later part of the season and crops following shallow crops received a concentrated band. In all cases, the low and high-yield potential zones received 50 lbs. N/acre less or more, respectively.

Each field was further evaluated during or after the season for areas with at least 0.5 acres of deficit or excess soil moisture as compared to areas with optimum soil moisture. Only sub-zones that clearly had deficit, optimal, and excess soil moisture were included in the analysis (marginal areas were excluded). The cause of deficit or excess soil moisture sub-zones was caused by problems with irrigation equipment (eg. incorrect sprinkler packages, malfunctioning regulators, leaks, etc.) and/or natural variations in field properties (slope, aspect, soil depth, soil texture, etc.). Each N zone was parsed into these soil moisture zones as determined with in-season aerial imagery, previous field history, in-field site assessment, and, in some instances global positioning system (GPS) tracking of in-season field equipment with the operating notating areas that were clearly moisture stressed or with excessive soil moisture.

For statistical analysis purposes, all combinations of three N rates and three soil moisture concentrations were analyzed by normalizing the yields against the optimal soil moisture with average yield potential and, thus N rate. As the number of zones were not balanced evenly, a General Linear Model (GLM) analysis was performed with mean separation using a Tukey-Kramer test.

## RESULTS AND DISCUSSION

Yields increased significantly (8%) when 50 lbs. N/acre was applied to zones with high yield potential having near-optimal soil moisture (Fig. 1). Yields did not decrease significantly with 50 lbs. N/acre less applied to zones with low yield potential with optimal soil moisture. This resulted in increased N use efficiency (NUE), as a similar yield was produced with less N.

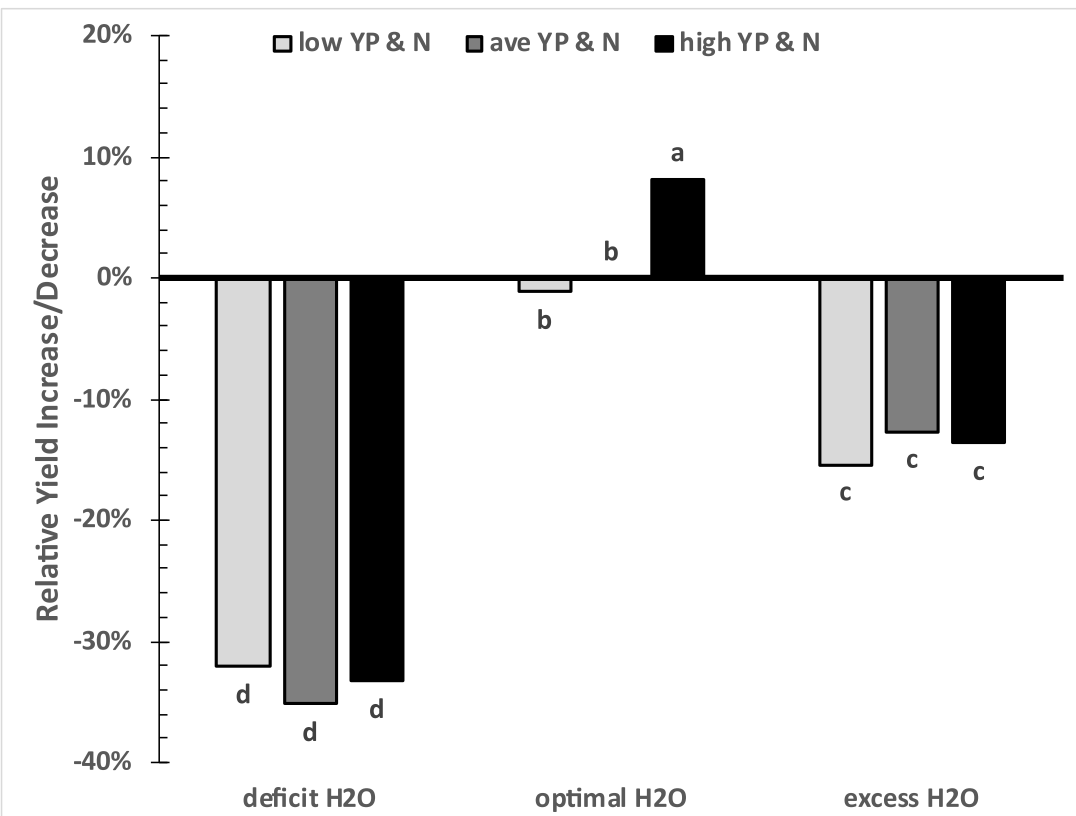


**Fig. 1. Relative yield averaged across years and crops for a variable rate nitrogen (N) study. The N varied based on yield potential (YP), with yields evaluated across soil moisture levels [deficit, optimal, or excess water (H2O)]. Averages sharing the same letter are not statistically different than one another. *P* = 0.05**

However, the positive benefits of VRN in zones with soil moisture deficits or excesses were overshadowed by the impact on soil moisture. Yields significantly decreased in deficit or excess subzones compared to optimal soil moisture, regardless of yield potential driven N rate (Fig. 1). In subzones with deficit soil moisture, the lower yields would have resulted in lower N demand. This was also likely at least part of the cause of yield reductions with excess moisture but, additionally, leaching and denitrification likely resulted in less N availability in all zones.

Overall, the effect was generally similar across crops. However, an orthogonal comparison of just the high yield potential/N rate compared to the average yield potential/N rate with optimal soil moisture showed a differential response across crops (Fig. 2). Not surprisingly, the legumes (navy bean, alfalfa, and pea) were relatively less responsive to additional N.

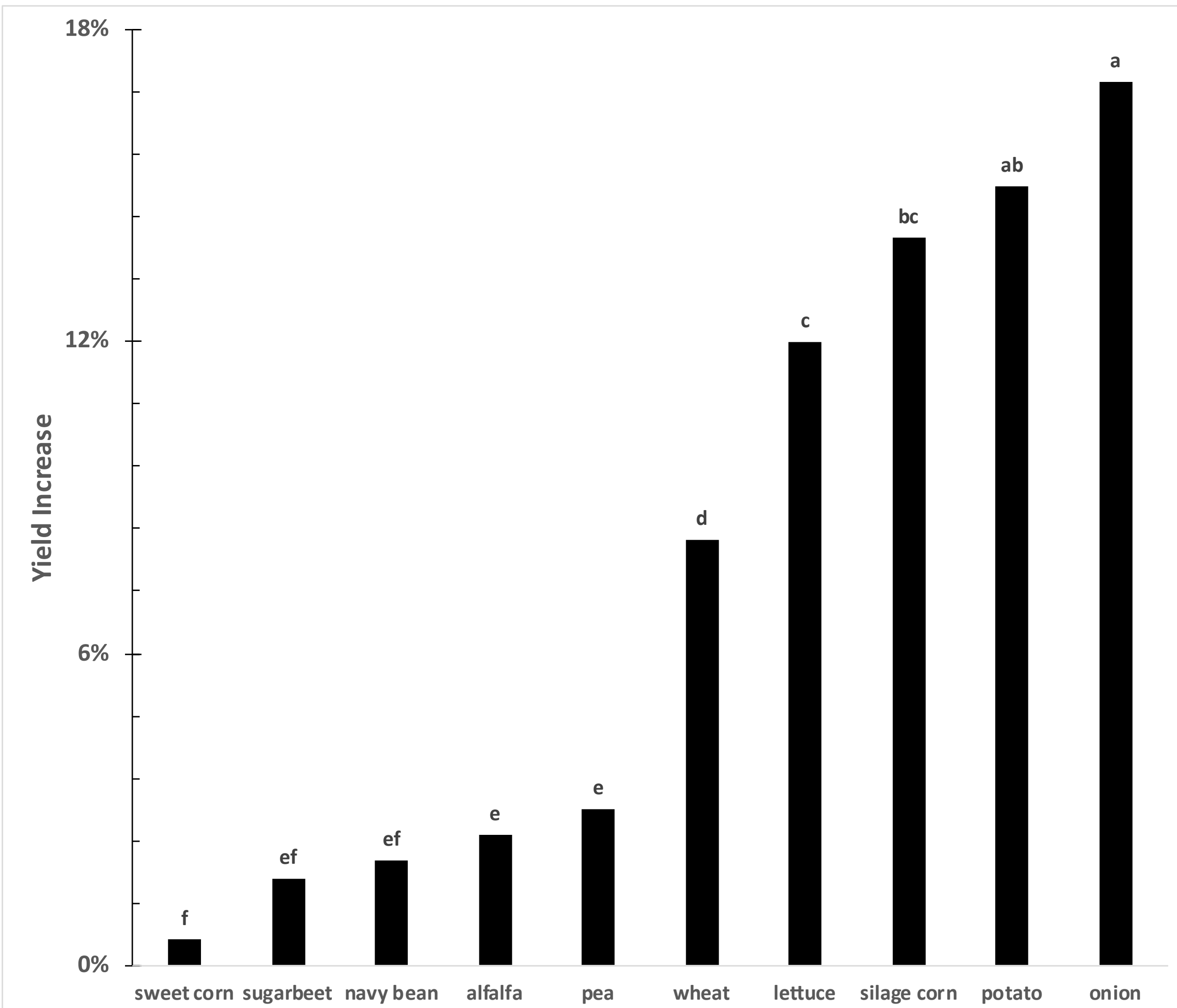


**Fig. 2. Yield increase with an additional 50 lbs. N/acre in high yield potential zones compared to average yield potential zones when both have optimal soil moisture. Averages sharing the same letter are not statistically different than one another. *P* = 0.05**

Additionally, deep-rooted species (wheat, sweet corn, and sugarbeet) tended to not respond to N fertilizer (Fig. 2) when these were grown in the year another crop that has inefficient/shallow rooting (potato, lettuce, and onion). Although the average increase for wheat was significant (Fig. 2), six of the 17 sites were following potato with a 0% average yield increase in these instances (comparing high yield potential/N rate zones to the average in the optimal soil moisture zones). However, in areas of excess moisture, the additional N did positively impact yield in these instances (Fig. 3).

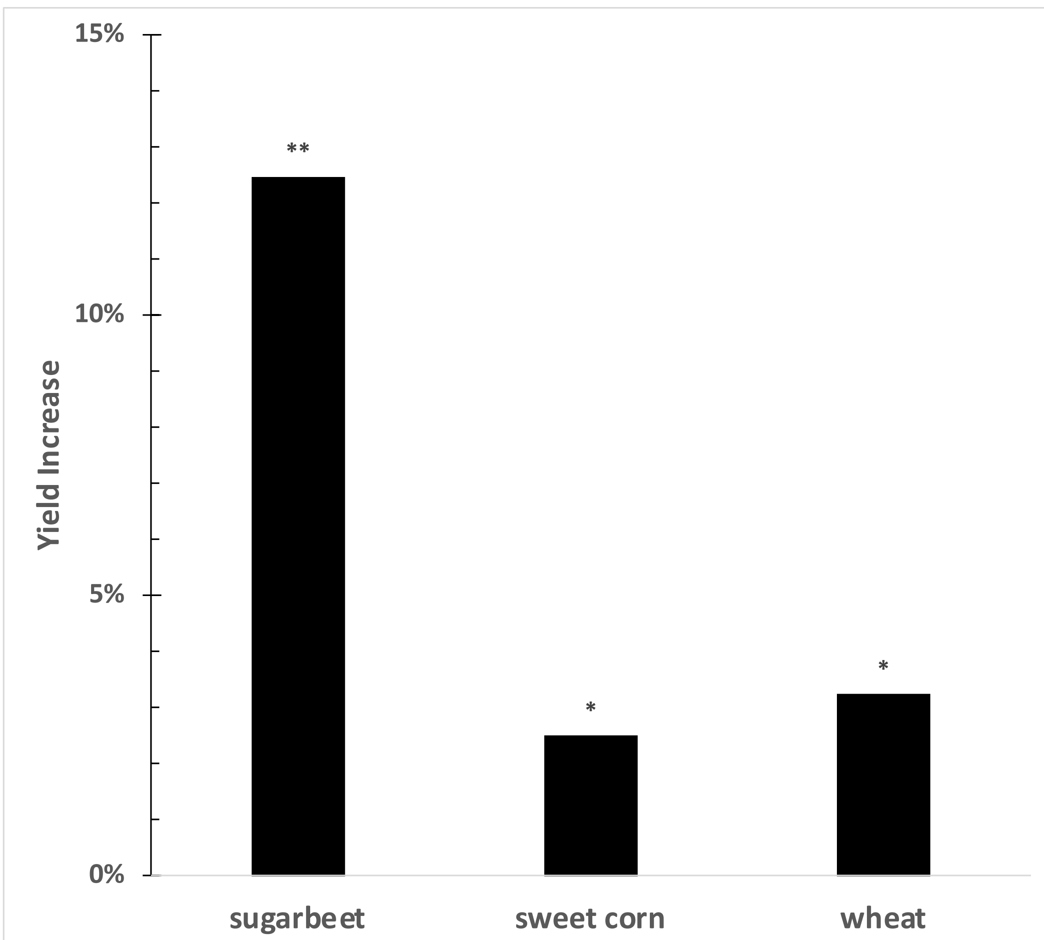


**Fig. 3. Yield increase with an additional 50 lbs. N/acre when grown in soils with excessive moisture for deep-rooted crops grown after crops with shallow and/or inefficient rooting systems (sugarbeet grown after potato, sweet corn after lettuce or onion, and wheat grown after potato).**

Not surprisingly, in-season N deficiencies were prevalent in excess soil moisture zones as identified through significant differences in Normalized Difference Vegetative Index (NDVI; 0.11 average decrease) and tissue analysis (0.35% average decrease). Post-season residual nitrate ($NO_3$-N) was significantly higher in most fields in deficit soil moisture zones (5 ppm increase =

~20 lbs. N/acre in the top 2 feet of soil). Furthermore, field areas where alfalfa was repeatedly and severely moisture stressed had 74% stand/yield reductions with the net effect of an estimated 105 lbs./acre reduced N credit to the subsequent corn crop (data not shown).

Finally, consistently lower yields generally resulted in increased residual soil test phosphorus (4 ppm bicarbonate extractable P) and, in some instances, potassium (15 ppm bicarbonate extractable K). These results suggest a further interaction requiring adjustment to other nutrients in addition to N. No other nutrients seemed to be consistently impacted, although there was a confirmed sulfur deficiency in potato in zones in a field with grossly excessive water accumulation.

These results show that the potential benefits of VRN can be completely overshadowed by variable soil moisture and that zonal management adjustments and/or VRI should be considered to maximize efficiency. The technology is readily available, relatively easy to access and use, and generally affordable, especially for VRF and increasingly with VRI. It is a best management practice to variably manage water and nutrients in harmony with each other.

With the increasing negative impacts of a mega drought plaguing the Western USA, it is critical that growers individually, and society generally, strive for increased water use efficiency. We need to not decrease agricultural production to support the earth's population into the future, but rather we do need to increase the amount of "crop per drop" (personal communication, Neil C. Hansen; Brigham Young University).

One aspect of this is an effort to increase soil moisture uniformity across fields. Often, this can be done through proper irrigation system design and maintenance. This was observed in a majority of the fields studied herein. In some instances, steep slopes resulted in water runoff to lower elevations, which can be at least partially corrected with practices such as increased surface residues, reservoir tillage, and application of water penetrants that break the surface tension and increase water infiltration. In some cases, such as our WA location, soils with vastly different water holding capacity (eg. sands vs. loams) in the same field may need adjustments in fertilizer and other inputs due to low yield potentials with minimal opportunity for improvement. If water parity is achievable, VRF should be considered in an effort to maximize efficiency and reduce waste and environmental contamination.

## REFERENCES


Hopkins, B.G. 2020. Developments in the use of fertilizers. *In* Rengel, Z. *(ed.) Achieving Sustainable Crop Nutrition.* Ch. 19: 555-588. Cambridge, UK: Burleigh Dodds Science Publishing. *(ISBN: 978 1 78676 312 9; www.bdspublishing.com)*

Hopkins B.G., Stark J.C., and 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)

Smith, R., L. Oyler, C. Campbell, E.A. Woolley, B.G. Hopkins, R. Kerry, and N.C. Hansen. 2021. A new approach for estimating and delineating within-field crop water stress zones with satellite imagery. *International Journal of Remote Sensing.* 42(16): 6005-024. https://doi:10.1080/01431161.2021.1931536.

Svedin, J.D., R. Kerry, N.C. Hansen, and B.G. Hopkins. 2021. Identifying within-field spatial and temporal crop water stress to conserve irrigation resources with variable-rate irrigation. *Agronomy* 11(7): 1377. https://doi.org/10.3390/agronomy11071377

Woolley, E.A., R. Kerry, N.C. Hansen, and B.G. Hopkins. 2021. Variable rate irrigation: Investigating within zone variability. *Precision Agriculture '21 (*presented at the *13th European Conference on Precision Agriculture*; 19-22. July 2021; Budapest, Hungary.)