New satellite-based sampling protocols for grapevine nutrient monitoring

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Abstract:

Context and purpose of the study

Extension specialists often recommend nutrient monitoring through leaf blade or petiole sampling twice a season for each vineyard block. However, due to the time and labor required to collect a large, random sample, many growers complete the task infrequently or incorrectly. Readily available remote sensing images capture the vineyard variability at both spatial and temporal scales, which can capture canopy and soil variability and be used to guide growers to representative sampling locations.

Material and methods

Mean composites of Sentinel-1 Synthetic Aperture Radar (SAR) images as a proxy of soil characteristics and Sentinel-2 Normalized Difference Vegetation Index (NDVI) as a proxy of canopy characteristics were clustered into three clusters (low-medium-high variability zones) using the Kmeans++ algorithm. Two spatial sampling protocols: (i) Grower Path (GP) (ii) NDVI+SAR3 and one standard Random20 (R20) protocol, were tested against the full block nutrient concentration (control of the study). R20 was a computer-generated random sample of 20 locations in each vineyard block. GP consisted of three sampling locations which were the centroid of the low-medium-high variability zones. NDVI+SAR3 was one location sampling grid (30mx30m) calculated using the mean absolute distance between each pixel and its cluster centroid. Field-specific sampling trials were conducted at bloom and veraison in the vineyards of Western New York and the Finger Lakes region in 2021 and 2022. Both macro (N, P, K, Ca, Mg) and micro-nutrients (Al, B, Cu, S, Fe, Mn, Na, Zn) were analyzed. All pixels were sampled for two blocks of cultivars - Riesling and Concord. The mean absolute percentage error (MAPE) was calculated for each block, comparing GP, NDVI+SAR3, and R20 with overall nutrient concentration.

Results

R20 explained overall nutrient variation with approximately <1% MAPE for macro and micronutrients at bloom and veraison in both years. In comparison, GP had higher error rates for macro (3.6%) and micro-nutrients (8.9%) at bloom and similar with 3.8% and 9.4% error at veraison. At bloom, GP captured variability of important macronutrients like N, P, and K with 4.2%, 6.9% and 1.0% error rates. Micro-nutrients like Cu and B had higher errors of 9.2% and 6.8%, respectively. At veraison, these error rates were approximately the same for macronutrients but much larger for micro-nutrients. NDVI+SAR3 exhibited lower errors compared to GP and slightly higher errors compared to R20. The MAPE for N, P, K and Mg for macronutrients was between 1-3% at bloom and veraison. For micronutrients, like Cu and B, the MAPE was 2%-3% at bloom, almost doubling at veraison (6%). The errors were marginally higher at veraison than bloom across all sampling protocols, with a difference of <0.5% for macro-nutrients and <2% for micro-nutrients using R20 and NDVI+SAR3. Further exploration should exploit narrow-band remote sensing images for the block's different size, climate, soil and topography. Future work should use R20 nutrient concentrations to compare with spatial sampling protocols as it captures the vineyard variability adequately.

Keywords: Viticulture, nutrient sampling, remote sensing, Sentinel, spatial sampling.

1. Introduction

Nutrient management in the vineyard affects vine growth, wine composition, and environmental sustainability. As an example, lower Nitrogen (N) concentration in grapevines causes lower yeast assimilable nitrogen (YAN) in the must, making the fermentation process longer or sluggish, whereas excessive nitrogen concentration may cause eutrophication (Schreiner et al. 2018). Nutrient concentrations of vines are heavily impacted by nutrient availability which is partially determined by soil moisture (Schreiner et al. 2006). The traditional method of tissue testing in grapes is based on sampling petioles or leaf blades once or twice a season for each block. The extension specialist recommends sampling randomly across the block to capture unknown variability. However, due to the time and effort required the task either remains incomplete or incorporates bias.
Thus, this study aims to develop a new spatial sampling protocol for grapevine nutrients by capturing the soil and canopy variability using readily available remote sensing images. The total number of sampling locations is aimed to the number of sample locations without compromising the accuracy, which may reduce the time and cost required for nutrient sampling significantly compared to a random sampling method.

2. Material and methods

Nutrient sampling protocols

Nutrient protocols – Mean composites of Sentinel-1 Synthetic Aperture Radar (SAR) as a proxy of soil moisture and Sentinel-2 Normalized Difference Vegetation Index (NDVI) as a proxy of the canopy were used in 2021 and 2022. These 10x10m images were clustered into three zones which proximate low – medium – high nutrient variability zones using the Kmeans++ algorithm. Two new sampling protocols, grower path (GP) and NDVI+SAR3, as well as R20, were tested against overall block nutrient concentrations. Eight vines nearby every pixel centroid were sampled for each block to quantify overall nutrient concentration. R20 was 20 computer-selected locations for each block to represent a random sample, and one vine per location was sampled. GP consisted of three sampling locations which were the cluster centroid of each low-medium-high variability zones; six vines per location were sampled. NDVI+SAR3 was one location sampling grid (30x30m) having minimum cumulative mean absolute distance between each pixel and its cluster centroid. For NDVI+SAR3, 14 vines per location or grid of 9 pixels were sampled. The number of leaf blade samples collected for each of the three methods were same, which is total of 40-42 leaves. Two blocks were sampled twice a season at bloom and veraison across Western New York and the Finger Lakes region blocks in 2021 and 2022. Only leaf blades were collected as it exhibits lower variability in nutrient concentrations compared to the petiole (Karl et al. 2023).

Statistical analysis – The percentage error (PE) was calculated between nutrient concentrations measured using R20 vs. GP and R20 vs. NDVI+SAR3 using the equation:

$$PE = \frac{Observed\ nutrient\ concentration - Expected\ nutrient\ concentration}{Expected\ nutrient\ concentration}\ x\ 100.$$

Here, the measured full block concentrations were set as expected and R20, GP or NDVI+SAR3 were set as observed. The mean absolute percentage error (MAPE) was calculated across nutrients, sampling protocols, or a phenological stage for easy comparison.

3. Results and discussion

3.1. *Comparison of sampling protocols for macronutrients*

Overall, R20 explained the lowest MAPE for each macronutrient compared to GP and NDVI+SAR3. The averaged MAPE across nutrients was highest for GP (3.7%), whereas R20 (1.4%) and NDVI+SAR3 (2.4%) had approximately similar error rates. MAPE across two blocks for R20 were generally <1% for N, K and Ca at both bloom and veraison (Figure 1a and 1b). P and Mg (at veraison) had slightly higher errors (2-2.1%). Comparing GP to R20, all macronutrients had significantly higher error rates, especially for N and P with (N - 4.2%, 2.5%) and (P - 6.9%, 4.9%) MAPE at bloom and veraison, respectively. A relatively lower rate for K was observed for GP

at bloom (1%) but not at veraison (3.3%). NDVI+SAR3, on the other hand, explained extremely lower errors compared to GP and slightly higher errors compared to R20. The difference between MAPE of R20 and NDVI+SAR3 was marginal (<1.5%) for nutrients like N, P, K (at veraison only) and Mg, exhibiting that NDVI+SAR3 captures accurate variability of nutrient concentration across vineyards. NDVI+SAR3 reduced a total of 1% error compared to GP for N and K (at veraison) and 4% for P (at bloom).

3.2. Comparison of sampling protocols for micronutrients

The error rates were generally higher for micronutrients than macro-nutrients for each sampling protocol,. The average MAPE across micronutrients for R20 (2.1%) was the lowest, followed by NDVI+SAR3 (5.4%) and GP (8.9%) at both bloom and veraison (Figure 2). R20 had the highest error for Al at bloom and Cu at veraison; the rest of the nutrients had error rates of 1% to 3%. However, in comparison, all the nutrients had significantly greater errors using GP, especially for Cu (9.2%) and for B (6.8%-7%) at both bloom and veraison. NDVI+SAR3 had a similar error rate of 6% for these nutrients at veraison, but it was almost reduced by half at bloom (2.6% for B; 3.1% for Cu).

3.3. Comparison of sampling protocols at bloom and veraison

The marginal difference was observed between the averaged MAPE of bloom and veraison for macro and micronutrients sampled using R20. The average MAPE of R20 for macronutrients was 1.5% and 1.7%, and for micronutrients was 2.2% and 2.1% at bloom and veraison, respectively. However, the error rates were relatively higher in veraison than bloom in samples collected using GP and NDVI+SAR3. The average MAPE across macronutrients in veraison was only increased by 0.2% and 0.5% for GP and NDVI+SAR3, respectively. Compared to this, micro-nutrients had slightly higher errors at veraison, that was, 8.3% (at bloom) and 9.4% (at veraison) for GP and 4.7% (at bloom) and 6.1% (at veraison).

4. Conclusions

The study focuses on developing new satellite image-based sampling protocols for grapevine nutrients. Multi-sensor Sentienel-1 SAR and Sentinel-2 NDVI images were used to develop two spatial sampling protocols: grower path and NDVI+SAR3. These spatial sampling protocols and standard R20 were tested against overall block nutrient concentrations. The R20 explained lower percentage errors for macro (N, P, K, Ca, Mg) and micro-nutrients (Al, B, Cu, S, Fe, Mn, Na, Zn) at both bloom and veraison. NDVI+SAR3 exhibits a lower error for macronutrients but slightly higher errors for micro-nutrients at both bloom and veraison. The difference between macro and micro-nutrient error rates was much higher than bloom vs. veraison, especially for GP. Various vineyard blocks incorporating different soil, cultivars and climates need to be sampled for future work.

5. Acknowledgments

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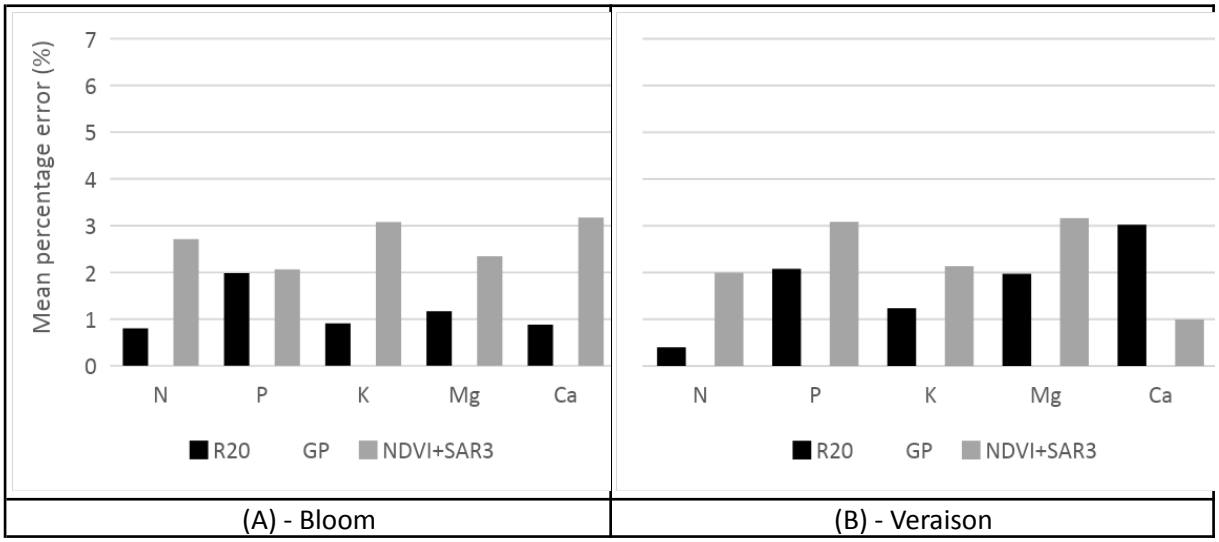

Figure 1:(A) Mean absolute percentage error for macronutrients at bloom for R20, GP, NDVI+SAR3, **(B)** Mean absolute percentage error for macronutrients at veraison for R20, GP, NDVI+SAR3. The mean absolute percentage errors are the average of nutrient-specific absolute percentage errors across both blocks.

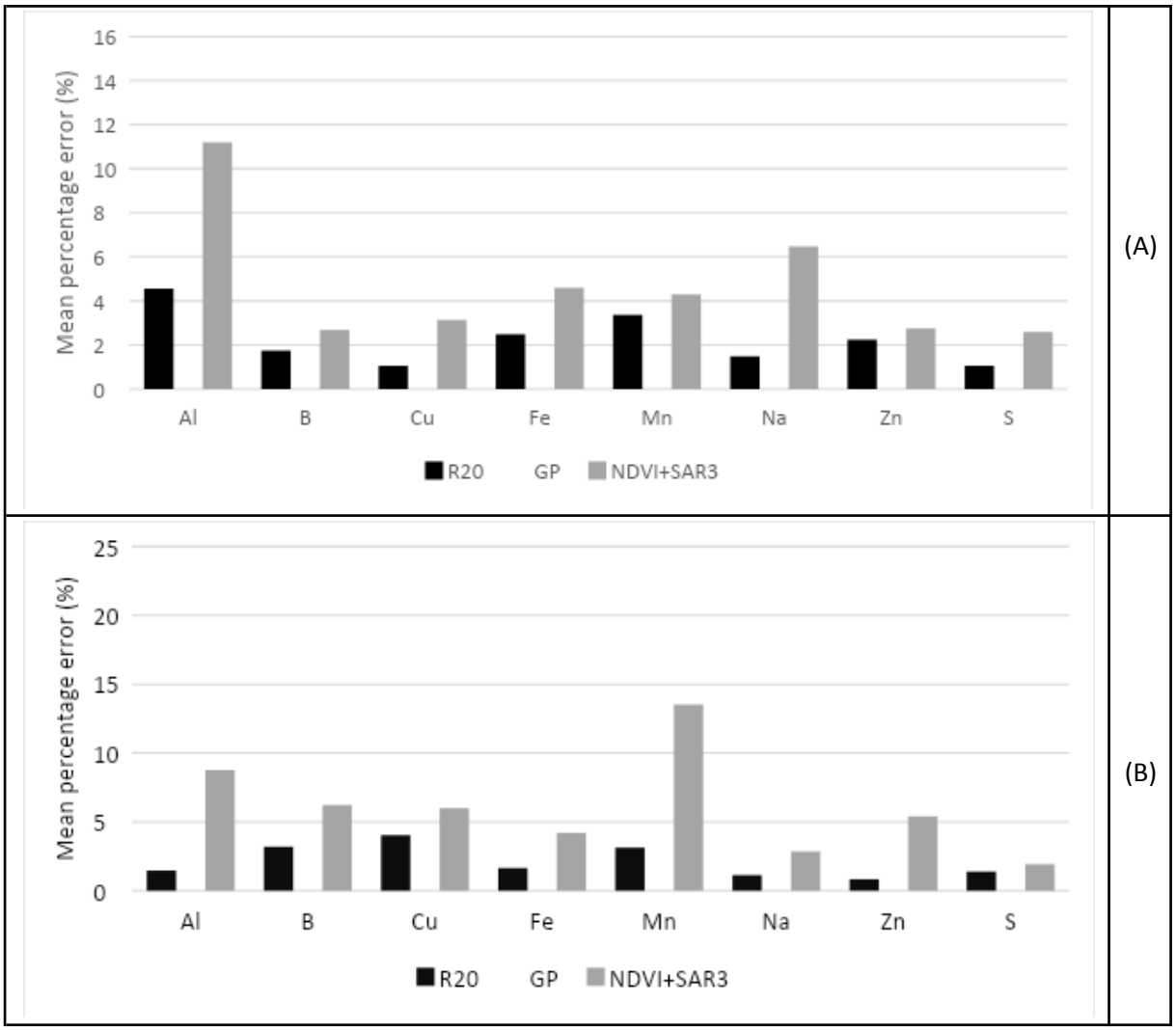

Figure 2:(A) Mean absolute percentage error for micro-nutrients at bloom for R20, GP, NDVI+SAR3, **(B)** Mean absolute percentage error for micro-nutrients at veraison for R20, GP, NDVI+SAR3. The mean absolute percentage errors are the average of nutrient-specific absolute percentage errors across both blocks.