Final Report For: Michigan Wheat Checkoff Program
Title: Understanding and Managing Factors Affecting Wheat Yields in Michigan: A Modeling Framework to Help Farmers Make Better Decisions in the contest of Climate-Smart Commodities. (Second year continuation)
MWP Tracking Number: 21-08-01-BS
MSU Number (Optional): RC114635
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Objectives

The overall goal of this project was to quantify the yield gap in Michigan's wheat crop and gain understanding of the factors that limit farmers' yields to guide farmers in making more informed decisions regarding inputs, leading to increased profitability and sustainability.

Specific Objectives:

- Continue to apply the SALUS crop model simulation results with the YEN farms observed data
- Continue to develop high resolution maps of wheat potential and actual yield across the MI wheat growing areas
- Continue to calculate yield gaps and map the impact of the contributing factors to the yield gaps
- Evaluate the risk associated with the management decision to implement in relation to climate and soil variability by using results from over a long-time period of climate data and historical satellite images
- Introduce the concept of climate-smart commodities with farmers that have opportunity to adopt regenerative agriculture practices or digital agriculture

Methodology

Collaboration with the Yield Enhanced Network (YEN) Program provided critical insights on management practices for 140 field-years (Table 1). The YEN field sites were mostly located in Michigan and Ontario, Canada, with additional sites in Ohio, New York, Wisconsin, and Kentucky (Figure 1). The YEN dataset provided many measured data, including soil sample results, field-specific management, crop phenology, and harvested yields, for 2021 and 2022.

We were able to create yield stability maps using satellite NDVI imagery from Planet Labs for each field in the YEN dataset. The satellite images from June to September for 2016-2022 were downloaded and processed to create stability maps for each field (Figure 2). The stability maps delineated areas that consistently produce high, medium, and low yields, called High & Stable, Medium & Stable, or Low & Stable. There are also unpredictable areas in the field, where yield levels fluctuate depending on the growing season, which we characterize by topographic features, labeled Unstable Depression, Unstable Slope and Unstable Hilltop.

For the SALUS simulations, input data of weather and soil is required. We used NASA Power climate dataset which provides daily weather at a global spatial extent. The YEN dataset provided measured soil sample results. The measured soil organic matter (SOM), pH, sand, silt, and clay content were used to represent the field. Bulk density was estimated from the measured

SOM values. Because the provided soil sample results are only for the top 8 inches of the soil, we downloaded SSURGO for the U.S. sites and Soil Landscapes of Canada (SLC) for the Ontario sites to fill in the deeper layers of the soil profile.

The provided field-specific management of planting date, seeding rate, row width, N fertilizer applied, number of N fertilizer applications, manure (yes/no), cultivation strategy, and harvest date were used to customize the simulations for each field (Figure 3). The measured aboveground biomass, yield, and phenological timings for emergence, stem extension, flowering, and hard dough were used to calibrate the wheat cultivar for the simulations to accurately represent the current cultivar genetics.

The SALUS simulations were performed for each stability zone within the field, using soil heuristics to represent the different zones. We used 4 simulated scenarios to investigate the causes of yield gaps: 1) Real-World, 2) Irrigated, 3) Unlimited N, 4) Potential. The Real-World scenario has both water and N stress to represent reality, and the Potential scenario is without stress to represent the crop potential. The intermediate scenarios Irrigated (unlimited water + N stress) and Unlimited N (unlimited N + water stress) investigate the causes of the gap between Real-World and Potential yields.

Results

In 2021, the High & Stable zones yielded the highest, followed by Medium & Stable zones, and the Low & Stable zones were the lowest yielding in both the Real-World and Unlimited N scenarios (Figure 4). However, the Low & Stable zones are very similar to High and Medium Stable zones in the Irrigated scenario. This change in behavior in the Low & Stable zones indicates in 2021 the Low & Stable zones were impacted significantly by the amount of water available.

In both 2021 and 2022, the Potential yields are much higher than the Real-World yields. In 2021, there is not a clear stress factor causing the yields to fall below potential; both water and N stress reduce the yields. The effect of the water and N stressors may vary for each field. In 2022, the yields in the Unlimited N scenario almost reached the Potential yields, especially in the High & Stable zones. The yields in the Irrigated scenario are very similar to the yields in the Real-World scenario. The patterns indicate that in 2022, water stress did not play a major role in causing a yield gap, instead a lack of N has caused yields to fall below their potential.

The simulated yield for the unstable zones in 2021-2022 highlights the dependency on weather in these areas within the fields (Figure 5). In 2021, the Unstable Depression zones performed the best, because water pools in the low-lying depressions in the field, providing the highest amount of water to the crop in these areas. The Unstable Slope and Unstable Hilltop zones are locations where the soil cannot hold as much water and the rainfall cannot pool, and therefore have significantly lower yields in 2021 in the Real-World and Unlimited N scenarios. However, in 2022 the Unstable Slope and Unstable Hilltop zones perform much better, due to adequate rainfall in the Real-World scenario.

A further investigation into the stress factors shows that in 2021, both water and N stresses are present in the Real-World scenario (Figure 6). The Low & Stable, Unstable Slope, and Unstable

Hilltop zones consistently have higher water stress than the other stability zones. Conversely, these zones also have lower N stress than the other zones. The lower N stress is most likely due to these zones producing smaller plants, and correspondingly smaller yields, which do not require as much N as larger, higher yielding plants. Compared to 2021, there is much lower water stress and higher N stress in 2022. In 2022, water stress only played a small role and mostly in the Low & Stable, Unstable Slope, and Unstable Hilltop zones. In 2022, N stress was the significant factor in the reduction of yields in the Real-World scenario.

The results by stability zone allow us to visual the spatial patterns for each field under each stress scenario (Figure 7). The Irrigated and Potential scenarios create uniform yields within the field. The Real-World and Unlimited N scenarios show differing yields by stability zone.

Conclusions

While the weather will always continue to have the largest effect on crop yields, in years with adequate rainfall, like 2022, N fertilizer is the limiting factor, causing a gap between reality and potential yields. In these years, we can increase the N fertilizer amounts to reduce the yield gap. In years without adequate rainfall, like in 2021, we can predict within-field yield responses using stability zones. Applying less N fertilizer to the Low & Stable, Unstable Slope, and Unstable Hilltop zones in these years can increase farmer profitability. The simulations have helped us gain understanding about the causes of the yield gaps we see in farmers' fields. We can use this research to customize N applications to reduce the yield gap and to increase profitability when the potential yields cannot be achieved due to the weather.

References

NASA Power: The Prediction Of Worldwide Energy Resources (POWER) project

Soil Survey Staff. Gridded Soil Survey Geographic (gSSURGO) Database for the Conterminous United States. United States Department of Agriculture, Natural Resources Conservation Service. Available online at https://gdg.sc.egov.usda.gov/. January 2, 2020 (FY2020 official release).

Soil Landscapes of Canada Working Group, 2011. Soil Landscapes of Canada version 3.2. Agriculture and Agri-Food Canada.

Tables and Figures

Table 1. Number of fields in the YEN dataset for 2021 and 2022.

Location	2021	2022
Kentucky	0	4
Michigan	18	22
New York	0	3
Ohio	2	18
Ontario, Canada	23	49
Wisconsin	0	1
Total	**43**	**97**

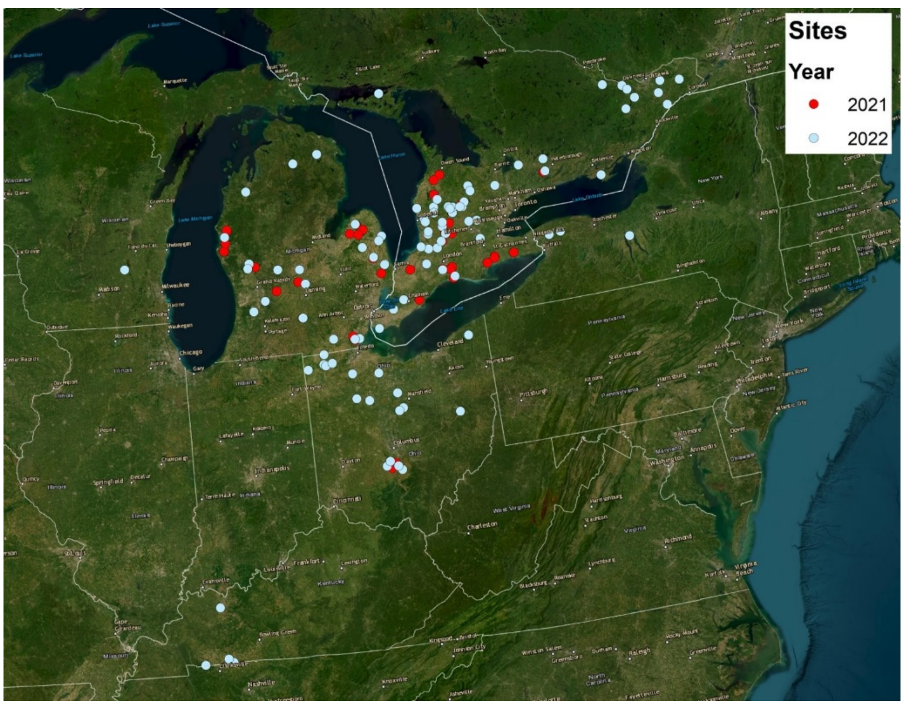

Figure 1. YEN field locations for 2021 and 2022.

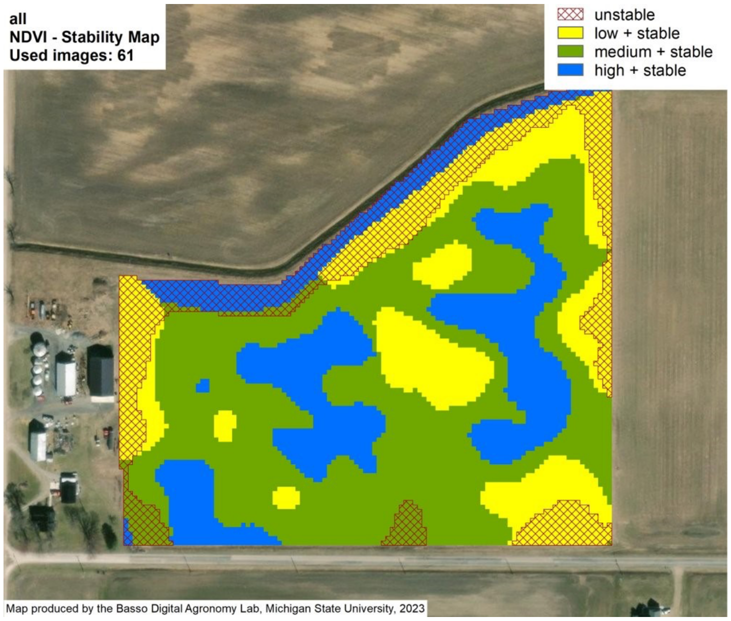

Figure 2. Yield stability map created from NDVI images.

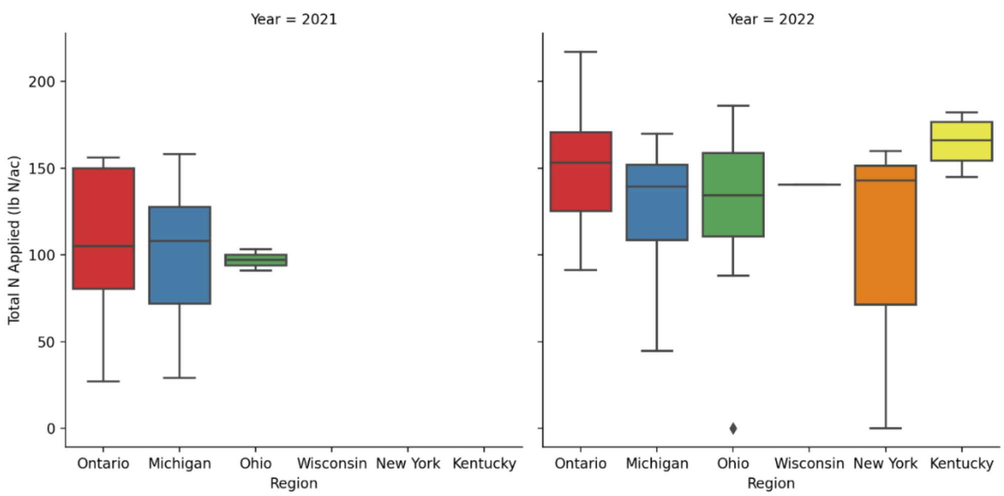

Figure 3. Reported total N applied (lb N/ac) for 2021 and 2021. These values do not include manure applications.

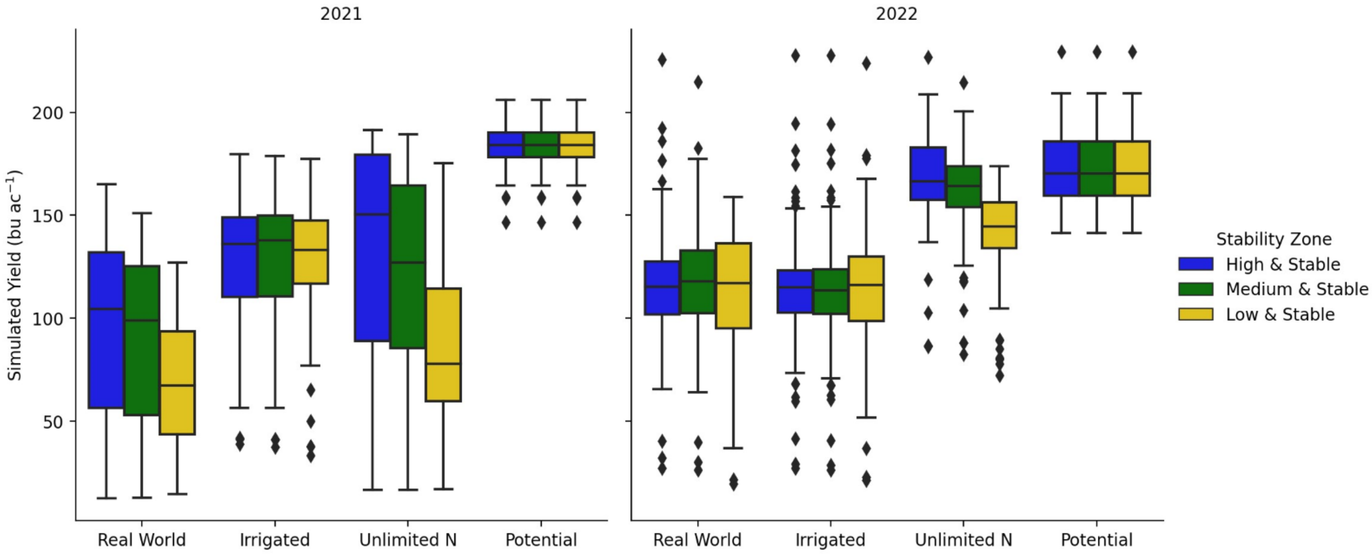

Figure 4. Yield response to stress in stable zones in 2021 and 2022.

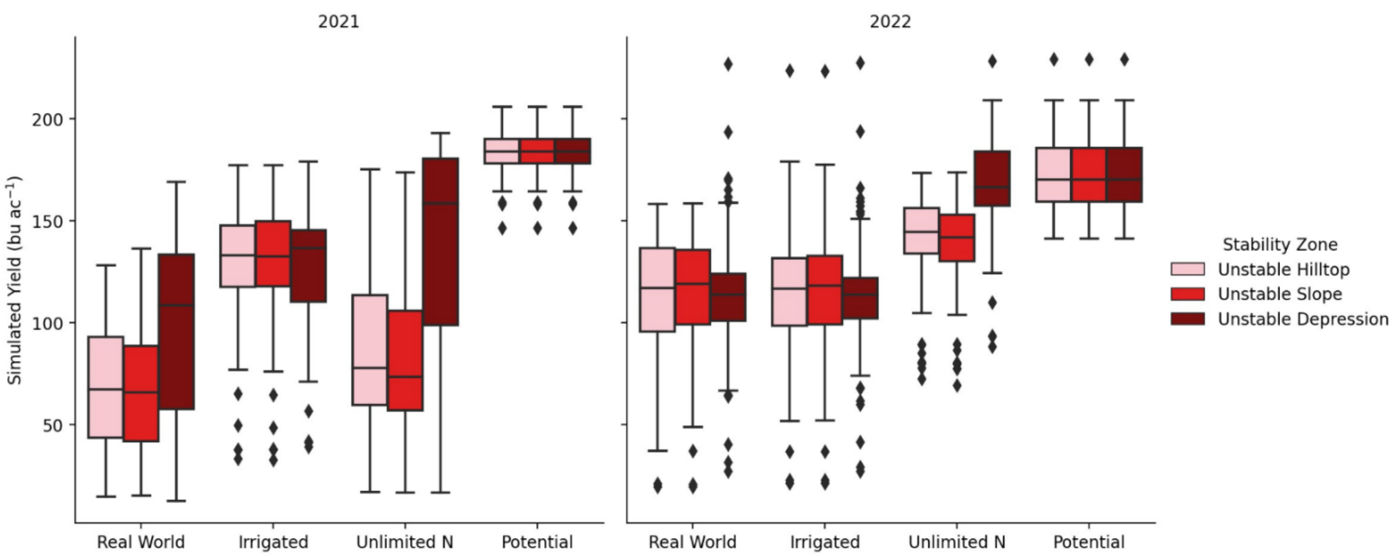

Figure 5. Yield response to stress in unstable zones in 2021 and 2022.

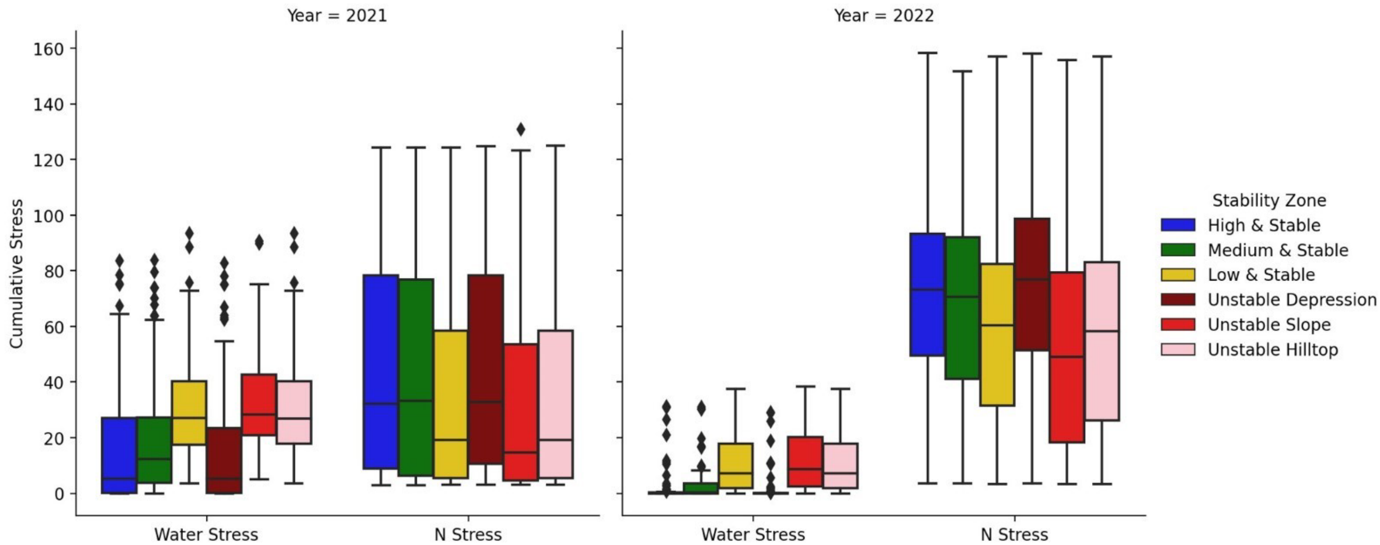

Figure 6. Cumulative stress in the reality scenario for 2021 and 2022 for each stability zone. A higher value indicates higher stress.

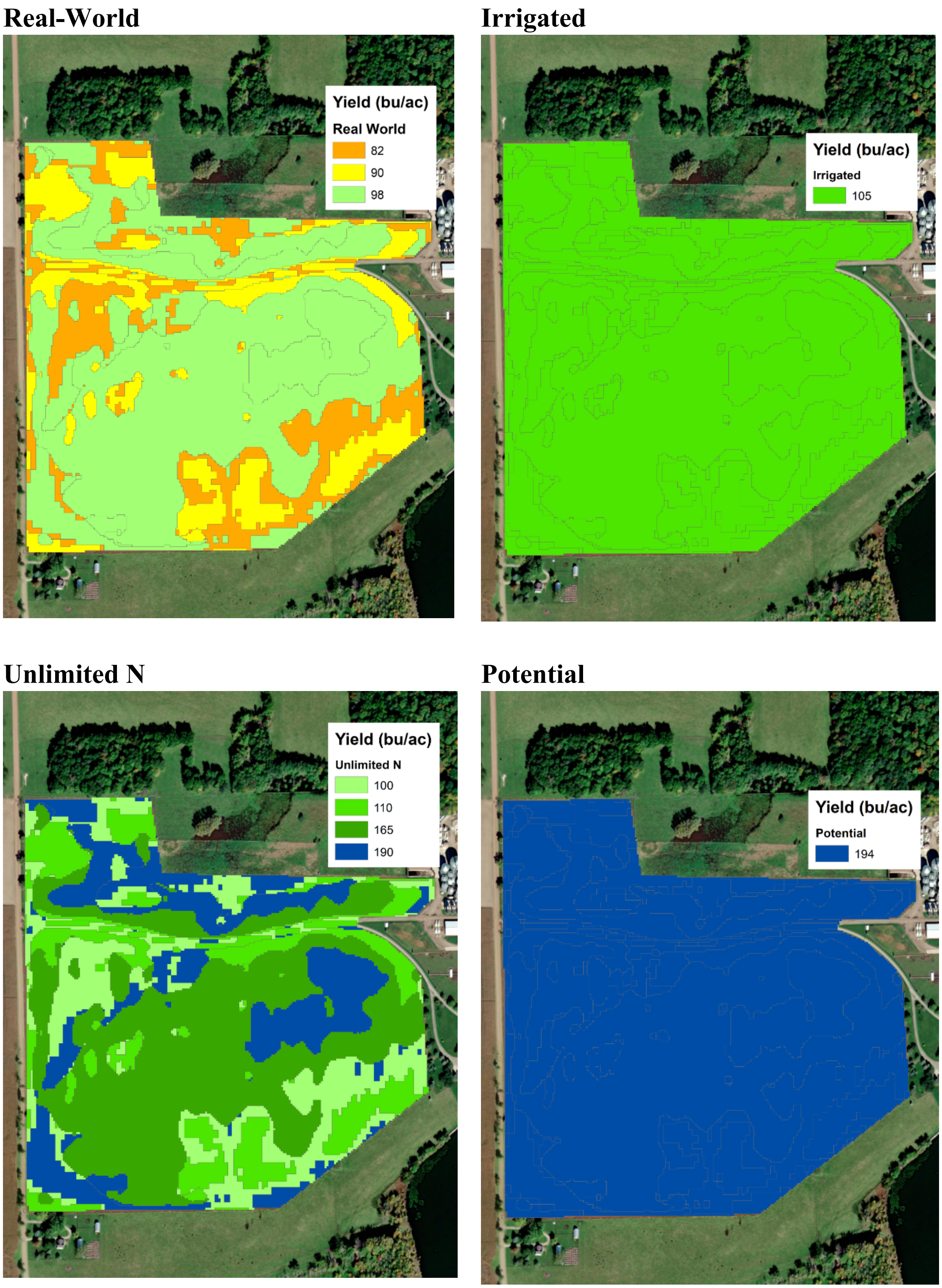

Figure 7. Within-field maps of simulated yields under Real-World, Irrigated, Unlimited N, and Potential scenarios.