Optimizing Crop Yield with Spatially Varied Fertilizer Application

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Introduction

Optimization helps farmers produce more of their crops more efficiently while also minimizing negative impacts on the environment. Not all cropland is equal; some parts of a field can be better at growing a crop than others. Precision agriculture seeks to place the best plan to place nutrients (fertilizer) across a farm field. In approaching this, researchers need to create an algorithm to compute the best possible solution to the question of where and how much fertilizer needs to be placed in a specific area of the field. One such algorithm was created in this study. The approach used was to employ past yield maps to inform the development of best plan (an optimization) for future fertilizer placement. The combination of crop yield mapping and optimization is important because farmers could produce more crops and receive more profit if past yield performance is used to inform future decisions.

The computer programming language, Python, was used to create a code that will demonstrate an example of precision agriculture**.** Variable-rate application (VRA) is the action of a prescribed rate of material, for example fertilizer, being applied to each location within a field based on past crop yield, soil test results (Alabama Cooperative Extension System 2009), or other information. Variable-rate technology (VRT) combines a control system with application equipment to apply inputs at a precise time and/or location to achieve site-specific application rates of inputs (Alabama Cooperative Extension System 2009). The joining of Python programming, variable rate application and variable rate technology to adjust the fertilizer rate in a field ensures that the crop will grow in greater quantity and quality. The purpose of optimization is to improve production efficiency and profit from the production of crop yield, while minimizing negative impacts on the environment.

Method

A Python code was written to read from an Excel file that contained spatially varied, observed yield values. The rows and columns in the Excel correspond to the locations in the crop yield. A pixel (pixel 1), a small piece of land, is randomly chosen and its historical observed yield is retrieved. A line is drawn from the fictitious point, (-1, 1) through the observed yield to develop a unique, idealized yield rate curve for each pixel in the farm field. This concept uses the slope-intercept formula, y=mx+b, as y is the yield and x is the amount of fertilizer applied. This process is repeated for a second location, pixel 2.

Figure 1

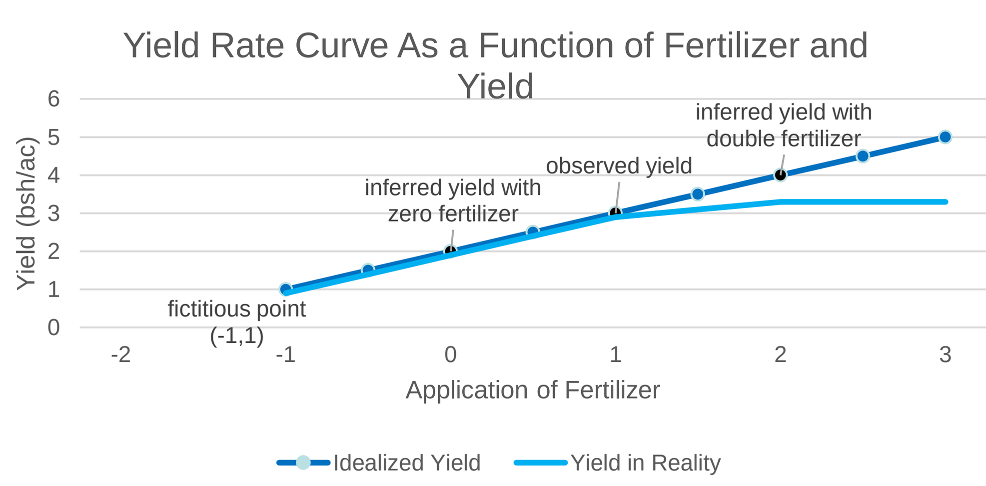

Figure 1 shows how yield varies with fertilizer application both as idealized here (dark blue line) and in reality (light blue line). In our idealized model yield increases linearly with application of more fertilizer. In reality, the total amount of yield eventually “saturates” at the point that the crop growth derives all the nutrients possible from the fertilizer and is limited by other factors. After the historical yield values of the two pixels have been found, a possible trade is examined by exploring the crop productivity if zero fertilizer is applied at pixel 1 and double fertilizer is applied at pixel 2. If the sum of the productivity between the two pixels after the trade is bigger than the sum of the observed yields at these two pixels. The trade is accepted, otherwise it is rejected. If a trade is accepted, the pixels involved in the trade are recorded so they will not be used again in a subsequent trade and the yield and fertilizer applied at the locations are updated. Trading continues for other randomly chosen pairs of pixels. At the completion of all trades, an excel file is written by the Python program, recording the revised yields at all field locations on one sheet and the revised fertilizer rates at all field locations on another sheet.

Findings

Three experiments were conducted: Variation Among Realizations, Annual Spatial Patterns, and Sensitivity Analysis.

The first experiment used a python program to examine the variation of total optimized yield between 100 realizations. Figure 2 is a histogram with the bars representing how many of the 100 realizations fell into the objective function bins based on the optimized yield.

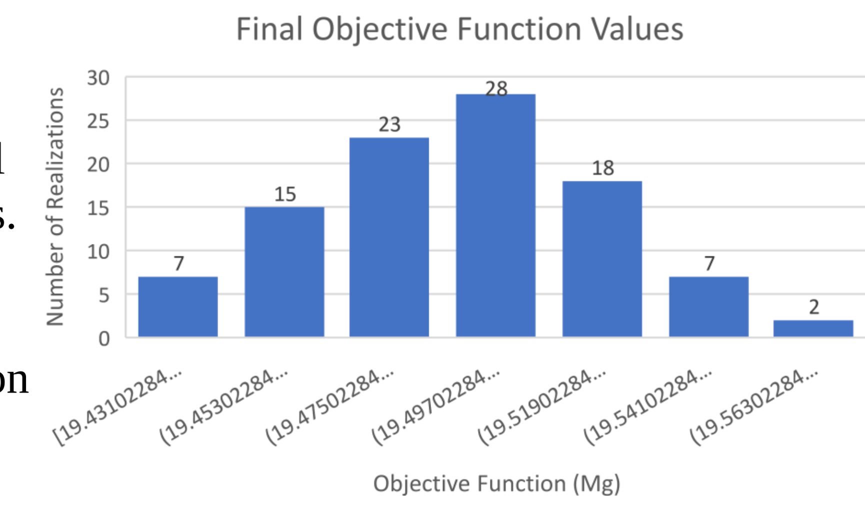

Figure 2: Final objective functions values using the fictitious point (-1,1).

The second experiment used Geographic Information System (GIS) software to spatially compare the yields from APU-7 field for years 2016 and 2017. Figures 3 and 4 show the optimized fertilizer ratio that maximizes yield in this field in those years. Note that, although not identical, the spatial patterns for these two years are very similar.

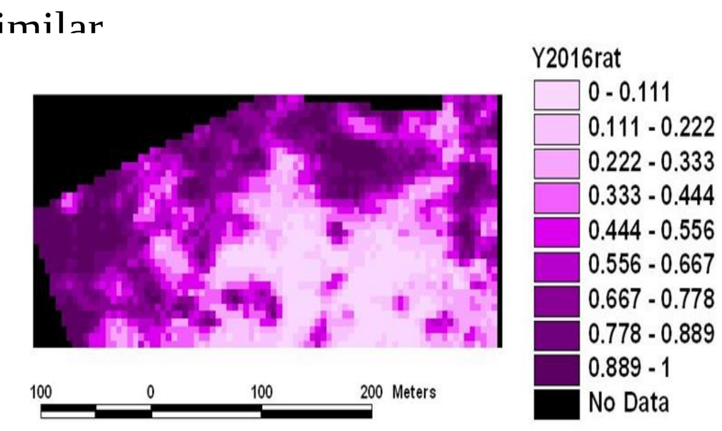

Figure 3: Optimized fertilizer ratio for the APU-7 field in 2016.

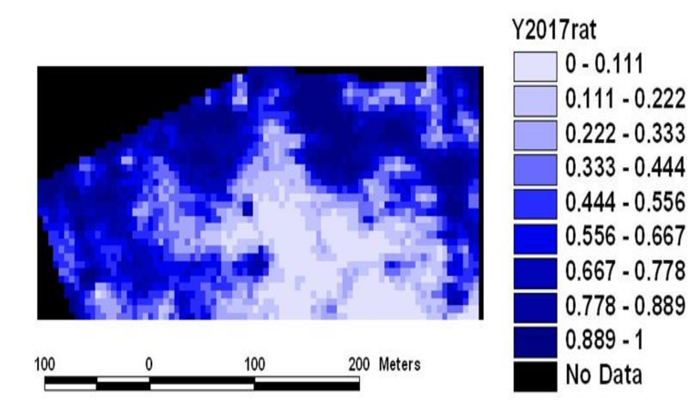

Figure 4: Optimized fertilizer ratio for the APU-7 field in 2017.

The third experiment also used the python program, examining different yield rate curves to discover how the change will influence the optimized yield total. Figure 5 is an example of how the fictitious points Used sensitivity to determine their yield curves. Figure 6 shows the variation in optimized yield across 100 realizations for each of four different assumed yield rate curves.

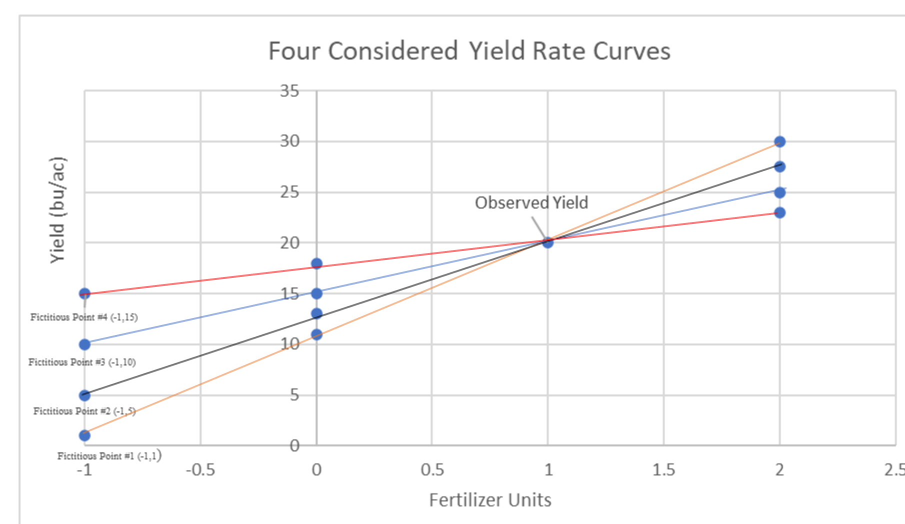

Figure 5 (above): The four considered yield rate curves used to test the sensitivity of optimized yield to the yield rate function.

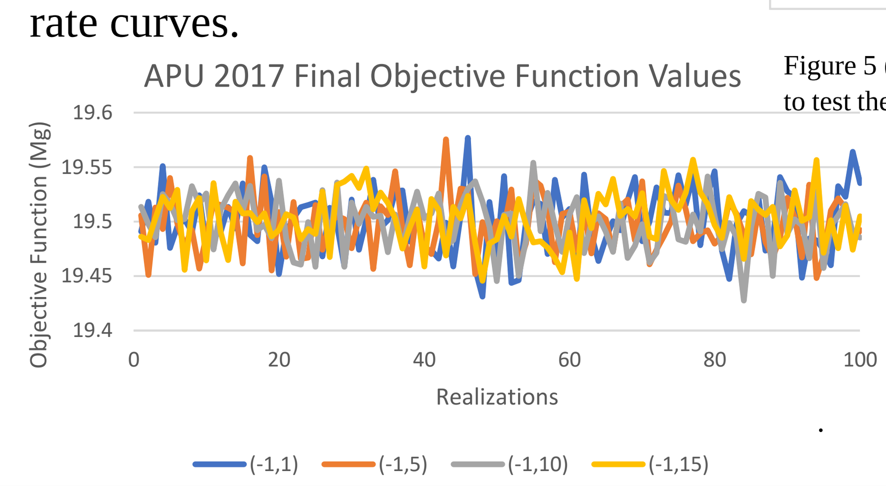

Figure 6 (left): Optimized yield determined for the four different yield rate curves across 100 realizations

Conclusion

The value of optimization is to identify the most efficient solution to a problem subject to a set of constraints. In this case, optimization was applied to crop yield subject to a limited amount of fertilizer and the growing conditions presented by a specific agricultural field located at the Beltsville Agricultural Research Center in Beltsville, MD. The efficient use of fertilizer is important, not only to maximize crop growth, but also to minimize the negative effects on the surrounding habitats and environment. Three specific experiments were performed. Experiment 1, “Variation Among Realizations”, investigated the variation between optimized yield from 100 random realizations. Experiment 2, “Annual Spatial Patterns”, investigated the observed yield, optimized yield, and optimized fertilizer application patterns for the APU-7 2016 and APU-7 2017 soybean field. Experiment 3, “Sensitivity Analysis”, investigated the effects of assumptions about the shape of the yield rate curve on the optimized yield totals.

In short, it can be concluded that: 1) there is small variation in results when the optimization model is applied on the same initial observed yield data, 2) the spatial behavior of the optimized crop yield from one season can be predicted based on the previous season. Both seasons will demonstrate similar spatial patterns, and 3) adjusting the assumed shape of the yield rate curve does not significantly change the results of the optimized yield.

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References

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