Ceres Trust Graduate Student Grant – Final Report

Project Title: Collecting on-farm environmental data: towards resilient organic vegetable varieties

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Introduction

This project, "Collecting on-farm environmental data: towards resilient organic vegetable varieties," was an effort to pilot the collection of weather and soil data in conjunction with an existing organic vegetable variety trial project. The investigators work on the Northern Organic Vegetable Improvement Collaborative (NOVIC), a variety trialing network in the northern tier of the U.S., which tests commercial varieties and breeding lines for adaptability to organic systems in Washington, Oregon, Wisconsin, and New York. This grant enabled us to collect weather and soil data on the farm and research station sites where we conducted the variety trial, with the long-term aim of integrating environmental data to understand varietal stability in variable weather conditions. The main short-term **objective** of this project was to pilot the use of on-farm weather stations at the Wisconsin trialing sites and identify challenges and opportunities for wider use of weather stations in future projects.

Methods

2015 Data Collection

In May 2015, we purchased seven weather stations from Spectrum Technologies, Inc. In June, we installed the weather stations on six farms in south central Wisconsin and at our research plots at the West Madison Agricultural Research Station (WMARS). The weather stations remained in the field until November 2015.

The weather stations included sensors to detect air and soil temperature, humidity, rainfall, and PAR light. The weather stations recorded data with each of these sensors every fifteen minutes over the course of the season. In addition to weather data collection, we also collected soil samples from each participating farm in September. These samples were analyzed for pH, organic matter content, and P, K, B, Mn, Zn, and S content.

Finally, we conducted vegetable variety trials on each farm and at WMARS. The trials included varieties of cabbage, kale, pepper, squash, and tomato, with all crops growth at WMARS and a subset of crops grown at each farm. *Table 1* shows the crops grown at each participating farm. Data at WMARS was collected by researchers in the Silva lab, and on-farm data was collected by the participating farmers. *Table 2* indicates the data that was collected on each farm for each crop.

Table 1: Crops grown at participating farms.

Farm ID	Cabbage	Kale	Pepper	Squash	Tomato
Farm 1	x	x			
Farm 2			x		x
Farm 3		x		x	
Farm 4		x	x	x	x
Farm 5				x	
Farm 6			x		

Table 2: On-farm data collected for each crop.

Crop	Measure	Units
Cabbage	Head Size	1 to 5 scale
	Taste	1 to 5 scale
	Overall Marketability	1 to 5 scale
Kale	Yield Potential	Rank
	Taste	Rank
	Disease Resistance	Rank
	Pest Resistance	Rank
	Frost Tolerance	Rank
	Overall	Rank
	What do you like?	Comment
	What do you dislike?	Comment
	Would you grow this variety again?	Comment
Pepper	Yield	Rank
	Taste	Rank
	Overall	Rank
Squash	Powdery Mildew	1 to 9 scale
	Striped Cucumber Beetle Damage	1 to 9 scale
	Yield	Rank
	Taste	Rank
Tomato	Yield Potential	1 to 5 scale
	Overall	1 to 5 scale
	Overall	Rank
	Disease/Pest Pressure	0 to 3 scale
	What is good about the variety?	Comment
	What is bad about the variety?	Comment
	Would you growth the variety again?	Comment

2016 Data Collection

Due to some data collection challenges described in the *Results* section below, we conducted a second season of weather and variety data collection in 2016. We installed weather stations on three farms and at WMARS and collected the same weather data as in the previous season (air and soil temperature, humidity, rainfall, and PAR light). In addition to using farmer-collected data, researchers collected data on disease ratings for tomatoes from three replications at WMARS and all three farms at three time points throughout the season. Specifically, we collected data on percentage of leaf area covered by disease symptoms (including Septoria and Early Blight) on individual plants in their lower, middle, and upper canopies.

Data Analysis

In 2015, due to the variable quality of the farmer-collected data, we did not conduct AA analysis on the variety trial data. However, in 2016 we were able to conduct AA analysis on the data. The AA method requires the following data analysis steps, derived from Hildebrand and Russell (1996):

1. Calculate the environmental index (EI)
    - EI is typically calculated as the mean of the yields for all varieties grown at a particular farm site.
    - In our analysis, we calculate EI for each research site at each of the three data collection dates, based on the mean disease rating across a given plot.
2. Relate treatment response to environment
    - In our analysis, we constructed a plot for each variety tested, which included the EI for each research site at each of the three data collection dates, plotted against the mean disease rating for that variety at that site-date.

The next steps of AA involve:

- Estimation of variety response to EI
- Estimation of variety by EI interaction
- Estimation of correlation between EI and weather parameters

However, in order to find statistically valid estimates of these relationships, we need 15-20 environments (Hildebrand and Russell 1996). In this pilot experiment, we had only four total environments, which are insufficient to draw statistically sound conclusions. Therefore, we could not take the AA any further than the graphical representations of EI vs. variety ratings produced in *Step 2*.

The weather stations at each research site produced a data point every fifteen minutes throughout the growing season. To analyze the weather data produced at each research site, we produced graphs of the parameters over the course of the season and calculated daily and seasonal averages, totals, maximums, and minimums as appropriate for each weather parameter.

Results

2015 Results

As described above, in 2015 we primarily collected qualitative and descriptive data on-farm. As these data were not used in the AA, we will not include the full results here. We provide an example of the types information we collected in *Table 3* below, which contains a summary of the 2015 kale trial results.

Table 3: 2015 Kale Variety Trial, On-Farm Results

Rank	Variety	Production	Pests/Diseases	Flavor
1	Old Growth Palm	Tall, large leaves; productivity varied	Black rot on one farm, but planted near outbreak	"a bit tough but sweet"
2	Nash's Red	Very tall and productive; one farm had poor late-season production	Early flea beetle damage on one farm; others saw high pest/disease resistance	"buttery, sweet" "leaves got tough"
3	Nash's Green	Very tall and productive; one farm had poor late-season production	Early flea beetle damage on one farm; others saw high pest/disease resistance	"mildly sweet" "leaves got tough"
4	Toscano	Leaves small and narrow	No pest/disease issues	"good flavor"
5	Hudson Valley Dino	Large leaves, tall plants; productivity varied	No pest/disease issues	"bad aftertaste" "above average flavor"
6	Starbor	Short growth habit; productivity varied	No pest/disease issues	Poor, bland flavor
7	Black Tuscan	Tall plants, wide leaves	No pest/disease issues	"creamy texture but bland" "good flavor"
8	Black Magic	Low yields	No disease; one farm saw good recovery from woodchuck damage	Tender but bland
9	Wild Garden Lacinato	Low yields	No pest/disease issues	"full kale flavor" "average flavor"
10	Sutherland	Productivity varied	Flea beetles destroyed on one farm; crop failure due to black rot on another farm	Good flavor, poor texture

Again, we did not use weather data in AA for either year due to the number of field sites, but it is useful to see examples of the types of data we collected and the variation among field sites. For example, in *Figures 1* and *2*, we see the air temperature and soil temperature in the two farm sites furthest from each other. Despite their geographical distance, we see largely similar temperature patterns over time. However, *Figures 3* and *4* show the precipitation patterns on the same two farms, and this appears to vary more dramatically between the two locations.

Figure 1: 2015 Air and Soil Temperature for Luna Circle. Air temperature is displayed in blue and soil temperature is displayed in tan.

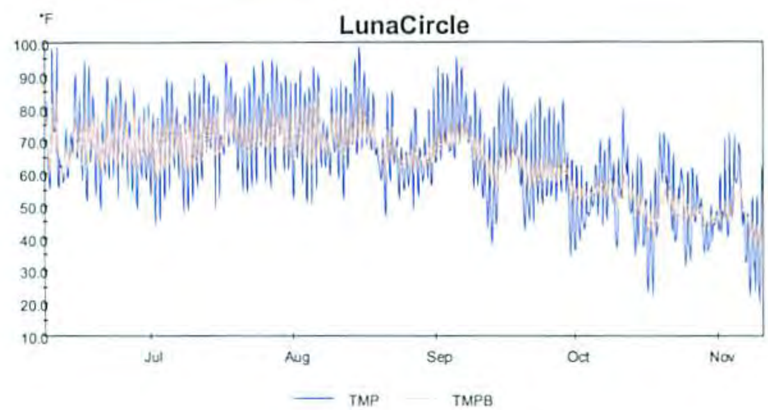


Figure 2: 2015 Air and Soil Temperature for Tipi Produce. Air temperature is displayed in blue and soil temperature is displayed in tan.

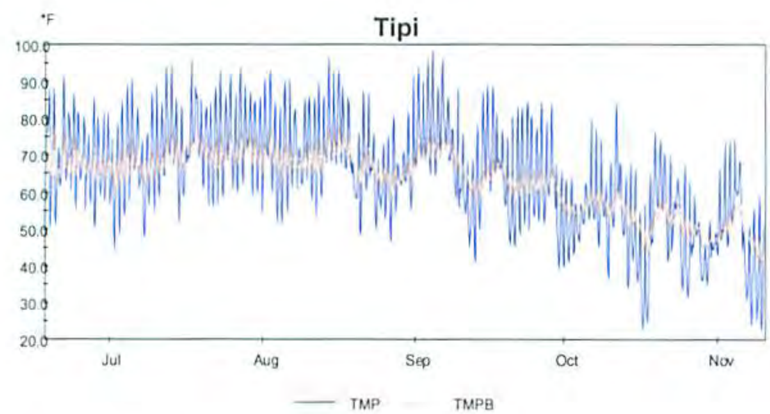


Figure 3: 2015 Precipitation for Luna Circle.

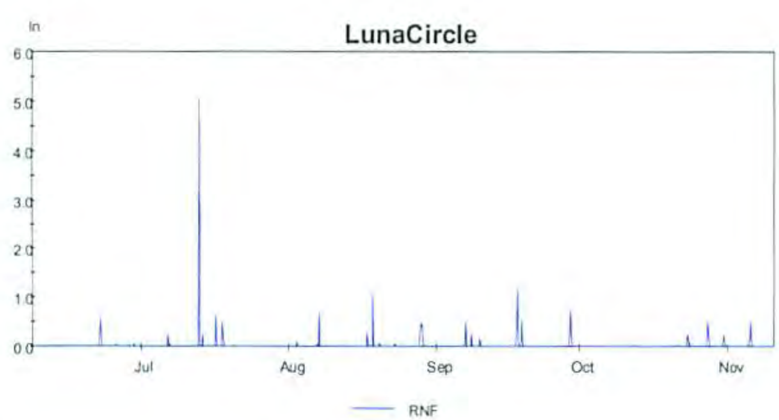
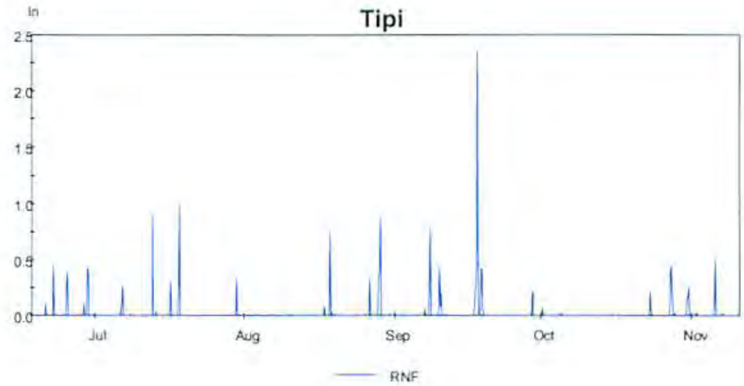


Figure 4: 2015 Precipitation for Tipi Produce.



2016 Results

Over the course of 2016, we saw significant variation in disease incidence across farm sites. All sites except LotFotL farm had Septoria pressure, and Scotch Hill farm also had Early Blight. Luna Circle and Scotch Hill Farms saw especially bad disease pressure at the second time point (8/25), but had seen significant tissue regrowth and some plant recovery by the third time point (9/17). *Table 4* shows the disease ratings at each of the three time points.

Table 4: Environmental indices (EI) expressed as disease ratings at WMARS and three farm sites in 2016. EI are calculated as an average percentage of leaf area affected by disease across entire plots.

Location	EI on 8/5/16	EI on 8/25/16	EI on 9/17/16
WMARS	3.5	61.6	83
LotFotL Farm	0.8	1.4	20.8
Luna Circle Farm	23.2	91.9	69.6
Scotch Hill Farm	55.4	87.5	53.6

We can see examples of the relationship between EI and specific variety performance in *Figures 1* and *2*. For all figures, EI is plotted along the horizontal axis and the variety disease rating is plotted along the vertical axis, with higher values corresponding to more disease. The solid diagonal line in each figure corresponds to y = x, such that if a point is above the line, the variety had more disease symptoms than average in that environment, and if a point is below the line, the variety had less disease symptoms than average. The dotted line is a best fit line of the EI vs. variety data. We plotted each of the three time points with different symbols to visualize whether relationships between environment, variety, and disease change over time. Again, we do not have enough separate environments to perform statistically valid tests, and a visual assessment does not in general show strong trends between varieties and environments – some varieties (e.g. Stellar in *Figure 1*) show mostly better than average performance across environments and time points, but most others (e.g. Mountain Merit in *Figure 2*) show variety values that line up closely with EI.

Figure 1: Stellar EI vs. variety plot

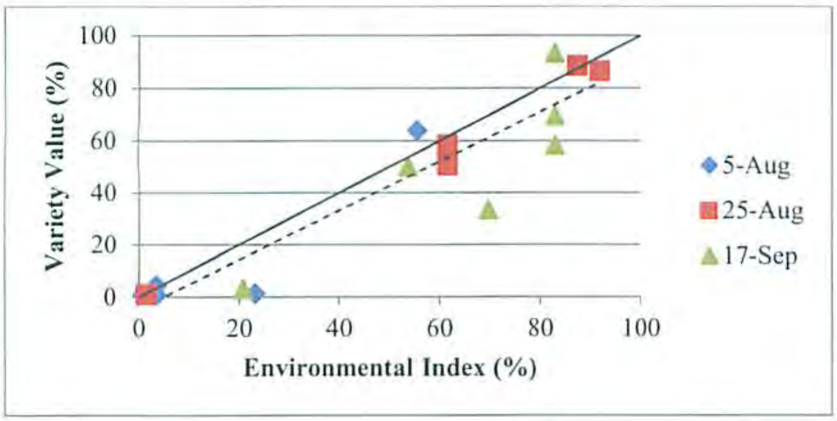
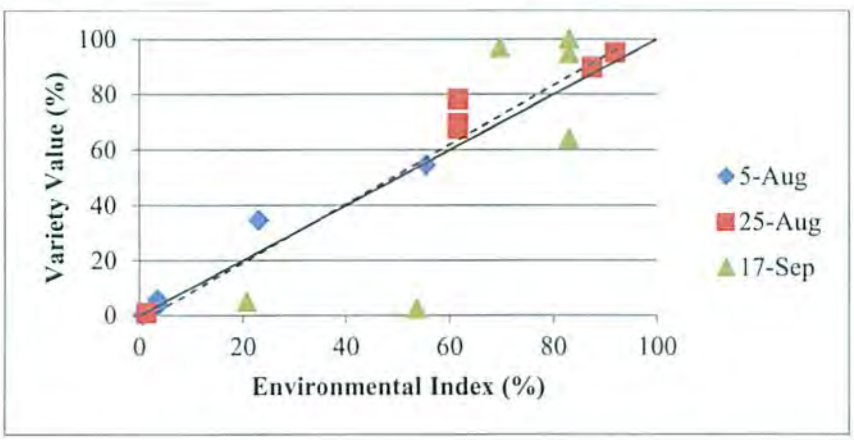


Figure 2: Mountain Merit EI vs. variety plot



Given the biology of the two most prevalent diseases present in 2016, Septoria and Early Blight, we predicted that the environmental parameters most likely to influence variety performance were air temperature and precipitation. We do not see wide variation in the mean temperatures at the four sites, but there is much larger variation in total precipitation. *Table 5* shows mean temperature and total precipitation data for WMARS and the three farm sites.

Table 5: Temperature and Precipitation Data, 6/16/16-9/17/16

Site	Mean Temperature (F)	Total Precipitation (inches)
WMARS*	71.3	19.6
LotFotL Farm*	71.3	12.3
Luna Circle Farm	73.5	14.9
Scotch Hill Farm	75.3	8.7

*Incomplete data set from on-farm weather stations required use of NOAA weather data.

Discussion

The primary purpose of this project was to assess the value and feasibility of integrating weather data into an existing vegetable variety trial, with the potential of expanding the weather station component from Wisconsin sites to the other trial locations in Washington, Oregon, and New York. We found logistical and technical challenges in implementing the project, and have developed a series of recommendations for potential future use of weather stations in the variety trialing network. These challenges and recommendations fall into the following broad categories:

1. Variety data collection
2. Weather station monitoring
3. Site variability

Variety Data Collection

One primary challenges of the variety trialing project in general has been developing appropriate protocols for on-farm trials. Over the course of the project, we have in general moved from having researchers collect on-farm data to asking farmers collect this data. There are costs and benefits to each approach – with the number of farm sites in each state, the distance separating each of these sites, and the fact that data collection typically needed to happen at all sites simultaneously, it became logistically impractical for researchers to collect the on-farm data. However, in many cases, farmers do not have the capacity to collect a large amount of quantitative data for the trial. We found it was most feasible for farmers to conduct qualitative rankings on a few traits and record general impressions for each variety. This data also tends to be more useful for other farmers considering adopting a particular variety. While this solution is workable for most aspects of the project, conducting AA requires quantitative variety data that can be used to make inferences about variety performance along environmental gradients. So, after following the qualitative farmer data collection protocol in 2015, we transitioned in 2016 to researcher-collected data at a subset of farm sites.

Using researcher-collected data was relatively feasible for three farm sites, but may not be feasible for a larger number of sites (e.g. the 15-20 sites required to conduct AA). In the future, when constructing the EI gradient, it would be preferable to select a trait that can be measured at a single time point during the season to minimize the requirement for farm visits. Traditionally, EI is calculated using crop yield, which is more feasible for grain crops that are harvested a single time at the end of the season, but many vegetable crops (e.g. tomatoes) are harvested more or less continuously, which does not lend itself to on-farm data collection.

Weather Station Monitoring

Another significant challenge during both growing seasons involved the logistics of monitoring the weather stations. In 2015, one of the sensors at a farm site was unplugged for a period of time during the growing season, and at another farm site, the weather station storage space filled before the data was downloaded. In both cases, this led to missing data for part of the growing season. In 2016, one of weather stations produced an error message every time we attempted to download the data; we replaced the station with a functioning one, but as a consequence we have missing data for part of the growing season at this farm site. These technical glitches could have been avoided with higher-quality equipment, or may have been caught earlier with more regular researcher visits to download data, but perhaps the best solution to these problems would be using weather stations with remote data monitoring capabilities. The weather stations we used required the researchers to physically visit the site to download the data onto a console. If we could download data remotely, we would be able to monitor whether the station was functioning properly in real time. An alternative would be to purchase extra consoles and software for each participating farmer, so that the farmers themselves could download the data more regularly. In either case, the project would have more utility for farmers; currently, weather data is not available to farmers until after the growing season, whereas remote monitoring or farmer data management would allow farmers to use the data to make decisions during the growing season.

Site Variability

Because we do not have enough different environments in the study to conduct a full AA, we cannot make any assertions about correlation between the EI and specific environmental variables. However, it is important to note that, for logistical reasons, the research stations and farm sites were all located within two hours of each other in south central Wisconsin. While there was certainly day-to-day variation between these sites, they lacked wide variation in mean weather patterns over the course of the growing season. Therefore, it seems unlikely that we would have found any significant patterns in the relationship between EI and weather data even if we had included more environments. This leads us to posit that inclusion of weather data only useful over larger geographic ranges with greater climatic variability. If, for example, we expanded use of weather data to the other trial locations in Washington, Oregon, and New York, we may have seen more interesting patterns in the data.

Costs

It is critical to consider the value of expanding this pilot to other sites given the costs of installing and monitoring weather stations. Each station we installed had a cost of over $900 including sensors and software, and in order to implement some recommendations (e.g.

increasing the number of stations and/or download consoles, using weather stations with remote monitoring capabilities), there will be significant additional infrastructure costs. Depending on how data is collected, there is also a significant labor burden for multiple site visits from researchers, or potentially additional stipends for farmers. Given these costs, it is critical to assess whether on-farm weather varies significantly from publicly available weather data collected regionally – microclimates may pose a barrier to using regional weather data, but using regional data would lower project infrastructure and labor costs substantially.

Recommendations

1. In future projects, select a crop and trait for AA that can be measured on a single date to minimize data collection burden.
2. Assess the financial and logistical feasibility of collecting weather and variety data on the 15-20 sites required for AA.
3. Use a weather station that allows for remote data monitoring and/or arrange for farmers to download the weather data both for improved monitoring of weather station function and for improved utility of data for farmers.
4. Select sites with wide climatic variability to provide strong enough seasonal differences to be detected by AA.
5. Assess the reliability of using publicly available weather data in lieu of on-farm weather stations for use in AA.

Outreach

We have presented two posters from the results of this project. Virginia Moore, the graduate student investigator, presented a poster at the 2016 Midwest Organic and Sustainable Education Service (MOSES) conference, entitled "Vegetable Variety Trials for Organic Systems." This poster focused on the variety trial results from the 2015 season and described the weather station component of the project as well. Indigo Leslie, an undergraduate student investigator assisting with the project, presented a poster at the 2017 MOSES conference, entitled "Evaluation of disease resistance in the Northern Organic Vegetable Improvement Collaborative tomato variety trial." This poster focused on the tomato disease results from the 2016 season.

References

Hildebrand, P.E. and J.T. Russell. 1996. *Adaptability Analysis: A Method for the Design, Analysis and Interpretation of On-Farm Research-Extension*. Iowa State University Press: Ames, IA.