Increasing the Competitiveness of Manitoba's Potato Industry

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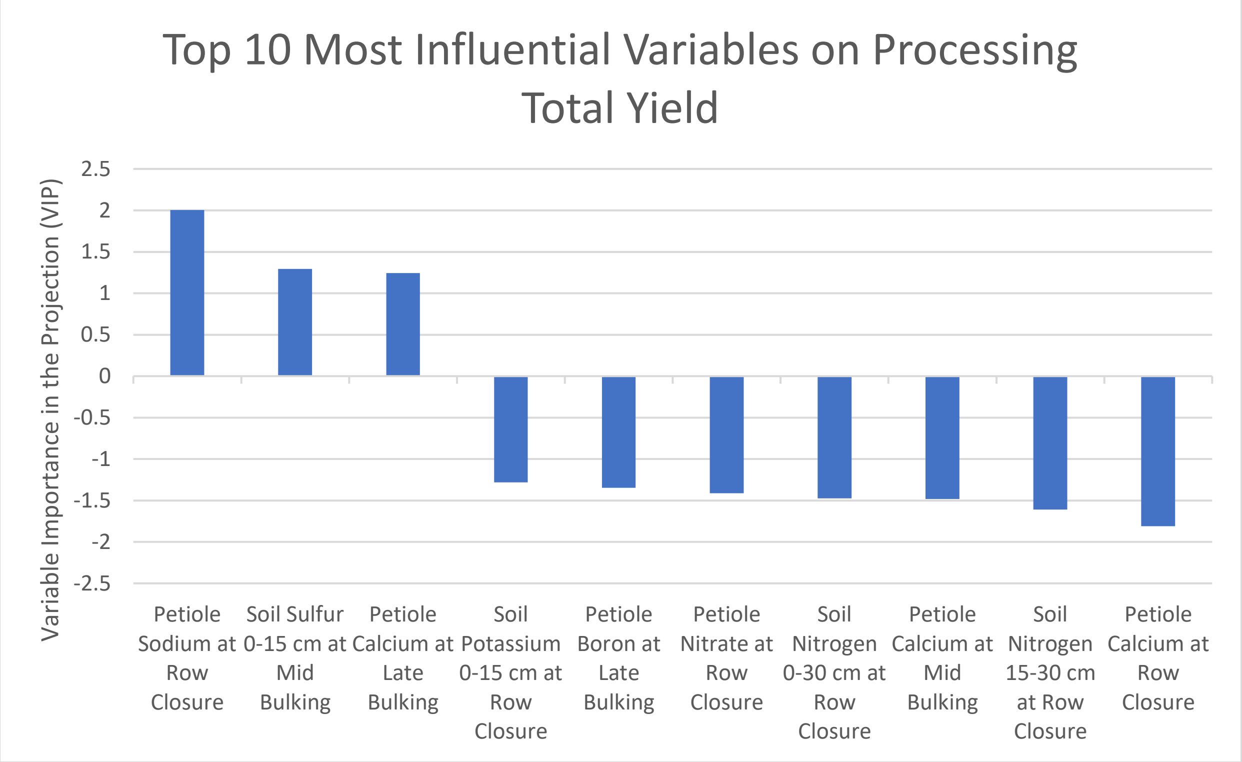
The following report would not be possible without the contributions of the above individuals

Executive Summary
Increasing the Competitiveness of Manitoba's Potato Industry

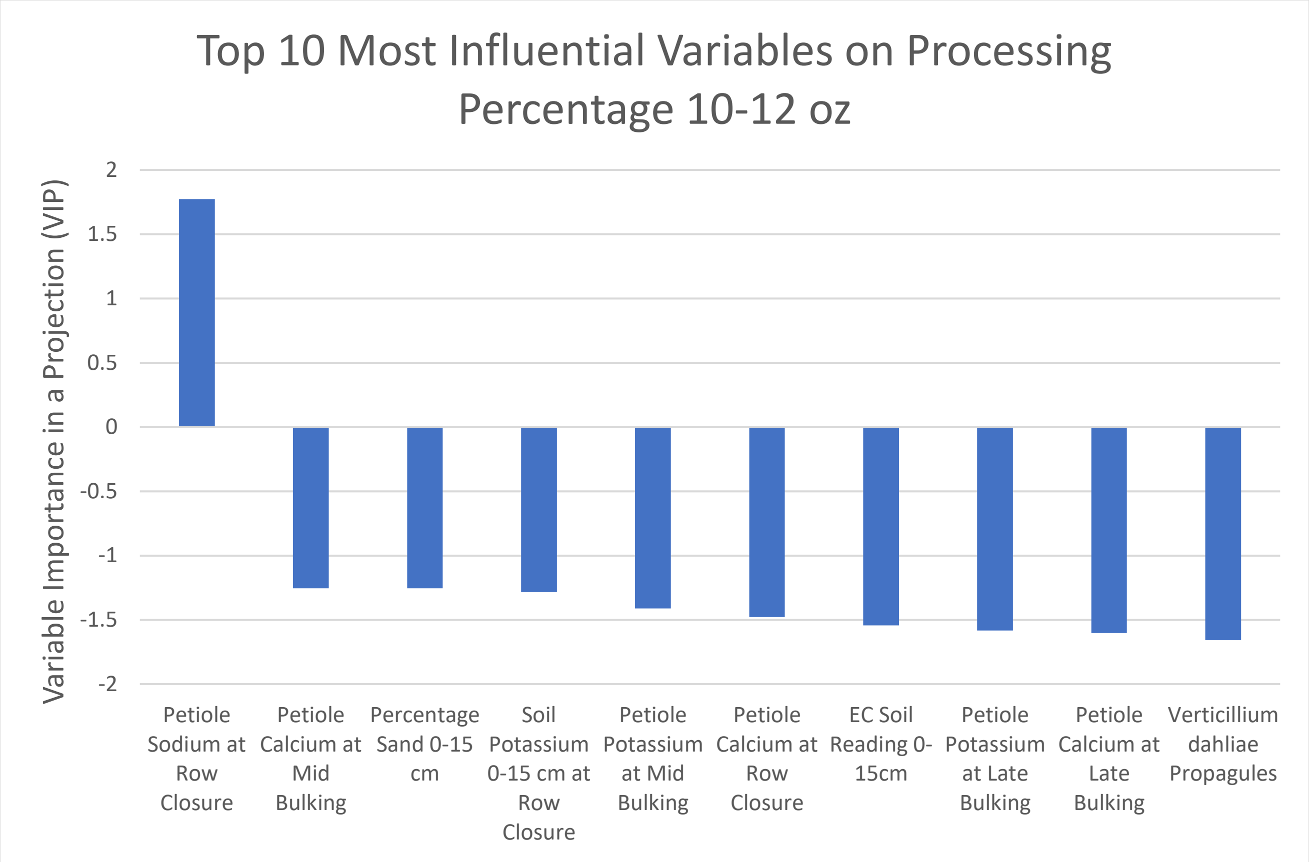
Manitoba potato growers must generate an increased yield of a high-quality crop grown in a sustainable, cost effective manner to improve market competitiveness because of an upcoming expansion in processing potential within Manitoba. Competitive factors outside our influence include Manitoba's distance to markets, global supply and demand of processed potato products, and volatility in the exchange rate between Canada and the United States. Yield increases must be achieved through regional research, development, and evaluation of crop management strategies because the long-distance importation of research results from other areas risks overlooking regionally significant yield-limiting factors. The overall goal of the research program "Increasing the Competitiveness of Manitoba's Potato Industry" is to foster sustainable, competitive growth of the Manitoba potato industry through a research program within Manitoba. The current objective of this research program was to identify areas of variable potato yield and to characterize the variables responsible for variable yield. The future objective is to compile the most important variables responsible for variable yield and evaluate strategies to remediate each factor in-field.

The variables associated with variability in the value (in dollars), specific gravity, and tuber size profiles of <3 oz, 3-6 oz, 6-10 oz, 10-12 oz, and > 12 oz of processing tubers are covered in detail in the full report. In the case of each dependant variables, such as total yield, a model was created which listed the major contributing variables and denotes if the association was positive or negative. In this summary, the results for total yield are included:



Listed above are the top ten most influential positive and negative variables on total yield of processing fields evaluated 2015-2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil and PPM in petioles, as determined by Agvise testing. The Y axis identifies the Variable of Importance in Projection (VIP) in the creation of the model predicting total yield. Greater positive VIP (above zero) indicates that variable has a bigger, positive association with yield. In other words, a bigger VIP indicates that greater total yield from sampling points was associated with the increasing amount of this nutrient in the soil or petiole. Lower, negative VIPs (below zero) indicates that variable has a bigger negative association with yield. As the VIP drops, the increasing amount of that nutrient is associated with the lowest yielding sampling points. The exact relationship between a negative VIP and too much or too little of nutrient must be determined by a resource such as Agvise recommendations or the Manitoba Soil Fertility guide (https://www.gov.mb.ca/agriculture/crops/soil-fertility/soil-fertility-guide/). It is important to note that 45-55 variables were associated with yield for all tuber size categories and total yield, but only the top ten were reported here for simplicity.

The same type of models were created for each of the tuber size categories as total yield. It is important to note that not all variables are consistent across total yield and each size category, meaning that some variables are important for specific size categories. These variables can be the target of remediation efforts if interest lies in improving the yield of that specific size category. Variables that show up across some or all size categories are consistently associated with greater or lesser potato yield, and the consistency is an important observation for remediation efforts to improve yield regardless of size category. The figure below lists the top ten most influential variables on 10-12 oz tubers to compare and contrast with total yield.



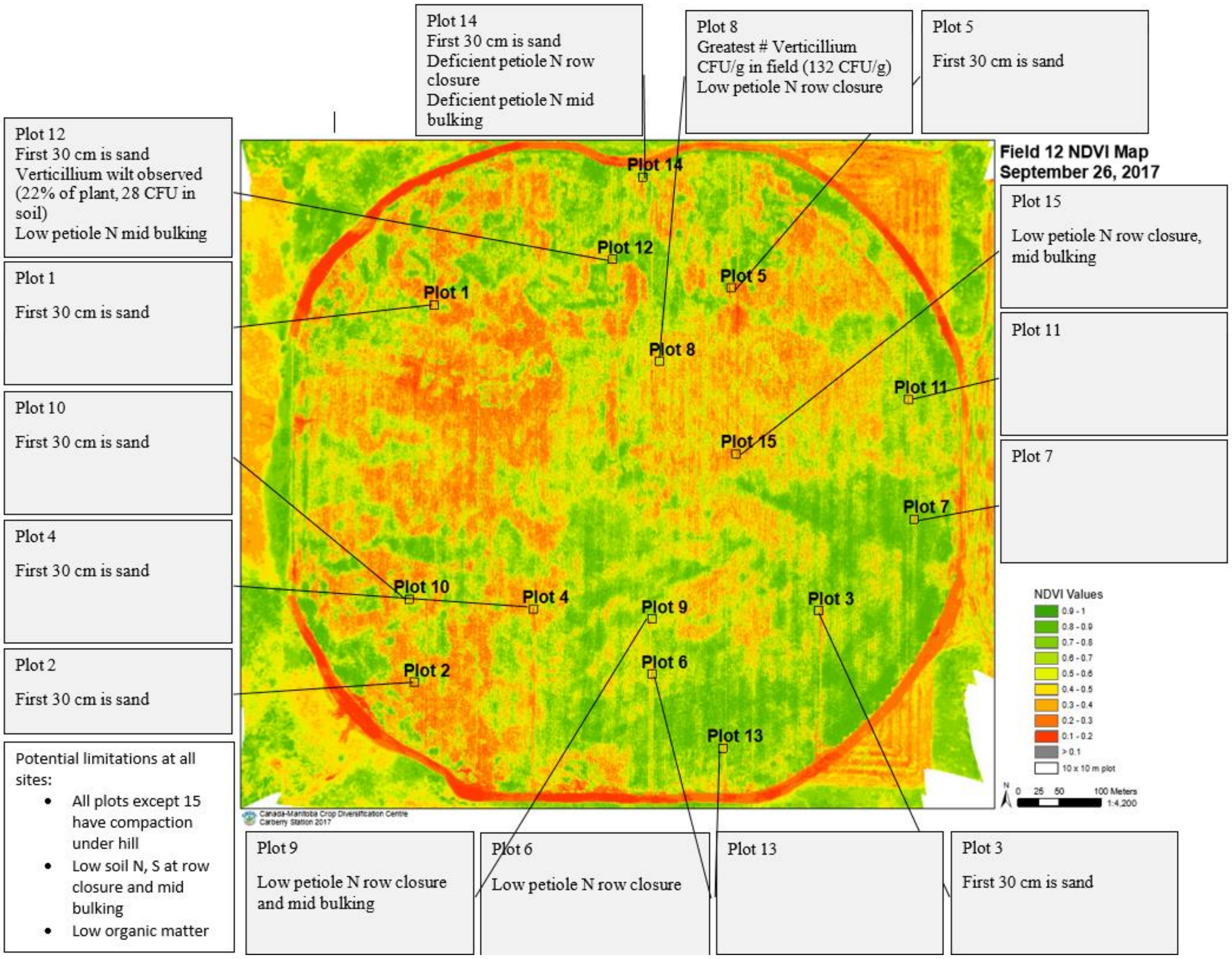
The most important variables contributing positively to both 10-12 oz tubers and total yield was petiole sodium at row closure. Over the course of the experiment, the percentage sodium recorded in the petiole by Agvise varied from 0.01% to 0.07%, indicating the percentage range of positive benefit was small. However, the analysis indicated that the higher percentages were associated with higher yielding sampling points. It is also important to note that the petiole sodium content became a negative yield association from mid bulking and late bulking, albeit not one of the top ten.

There were also two variables that were negatively associated with yield for both total yield and 10-12 oz yield. In these cases, too much or too little of either nutrient was associated with lower yielding sampling points. A soil test and reference are necessary to determine whether it was too much or too little – the model will not inform this result. Soil potassium at row closure from 0-15 cm was one such example, and 91 to 1150 PPM recorded as lowest to very high. The other consistent variables were petiole calcium at row closure and mid bulking. The percentage of petiole calcium at row closure ranged from 0.87-2.48%, which appeared to range from high to very high. It is possible that excessive calcium was part of the negative yield association. Field experimentation to address the relationship between calcium or potassium on negative yield associations is absolutely necessary to verify this claim, especially before major management decisions are implemented.

There are also many variables that appear on the top ten for total yield, but not 10-12 oz yield. For example, sampling points with greater petiole nitrate at row closure are associated with total yield negatively (i.e. greater petiole nitrate at row closure is associated with the lowest yielding sampling points). The PPM of nitrate in the petiole ranged from 3,892 to 24,852. Ten of the sixty sampling points were deficient at this time, and fifteen of the sixty were low. No sampling point had high petiole nitrate at this time. It is likely that the negative yield association for total yield was observed with low to deficient petiole nitrate sampling points. As with soil potassium and petiole calcium, field experimentation is necessary to demonstrate this relationship and evaluate remediation approaches.

Increasing numbers of *Verticillium* propagules were the largest negative contribution to 10-12 oz yield. *Verticillium* infection is likely preventing the tubers from sizing in the 10-12 oz category more so than the smaller categories. The fact that these variables appear in only one tuber size category is an important consideration for specific remediation strategies aimed at improving yield to just this size of tuber.

In addition to evaluating the impact of variables on yield of all the processing fields combined, individual fields from 2017 were rated for nutrient, soil, disease, and plant health status. Drone imagery was used in conjunction with scouting, nutrient status as determined by Agvise recommendations, and yield to visualize variability at each sampling point and what trends were apparent in the overall yield. The point of this individual analysis is to demonstrate the usefulness of the PLS analysis from all processing fields in identifying one or a few major yield-limiting factors from a larger list of potential problems listed for a specific site. This information begins the conversation with a local consultant and grower about priorities in remediating yield variability, and ultimately ideal practices to remediate the situation. The results are covered in detail in the following report. In summary, the results for one 2017 processing field are included:



Plot 14
First 30 cm is sand
Deficient petiole N row closure
Deficient petiole N mid bulking

Plot 8
Greatest # Verticillium CFU/g in field (132 CFU/g)
Low petiole N row closure

Plot 5
First 30 cm is sand

Plot 12
First 30 cm is sand
Verticillium wilt observed (22% of plant, 28 CFU in soil)
Low petiole N mid bulking

Plot 15
Low petiole N row closure, mid bulking

Plot 1
First 30 cm is sand

Plot 11

Plot 10
First 30 cm is sand

Plot 7

Plot 4
First 30 cm is sand

Plot 2
First 30 cm is sand

Potential limitations at all sites:
- All plots except 15 have compaction under hill
- Low soil N, S at row closure and mid bulking
- Low organic matter

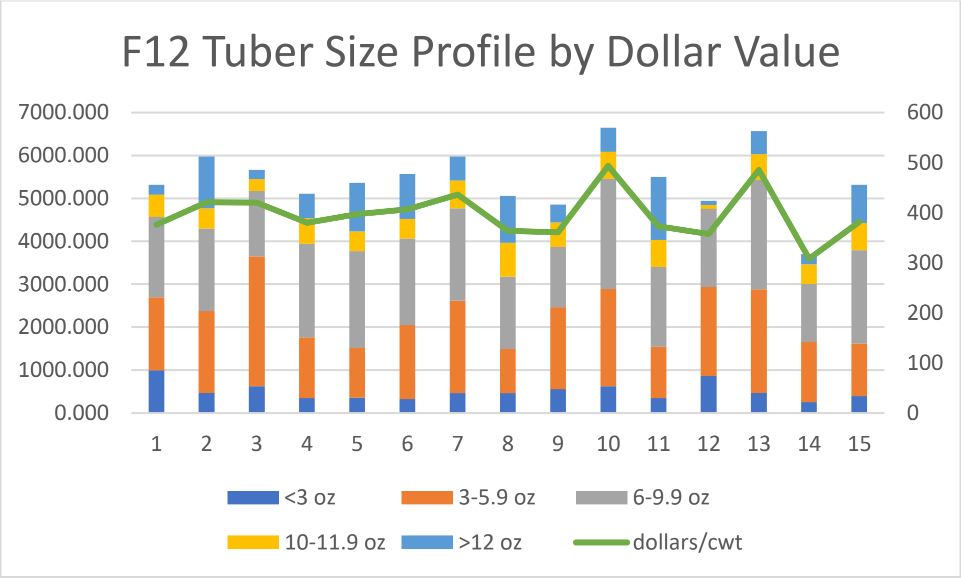
Plot 9
Low petiole N row closure and mid bulking

Plot 6
Low petiole N row closure

Plot 13

Plot 3
First 30 cm is sand

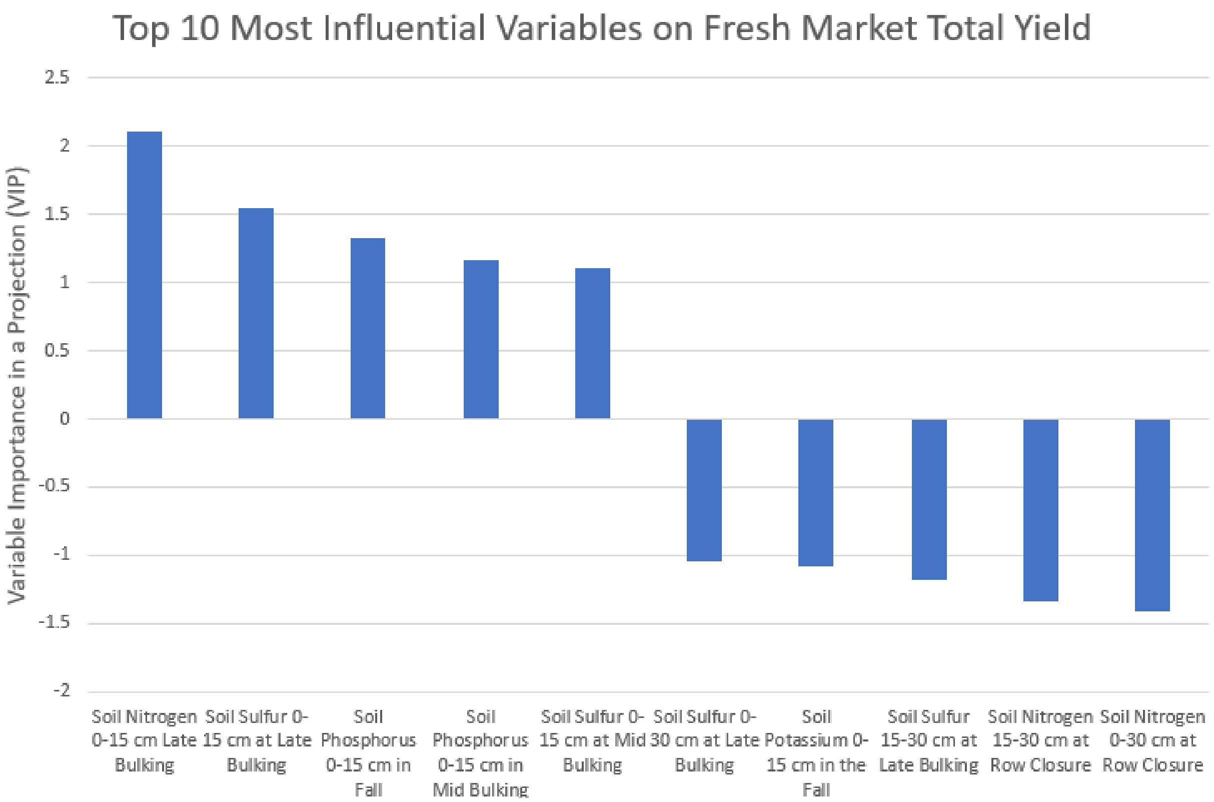
Green on above drone image indicates the living potato plants from a drone flight on September 25th, while varying degrees of yellow indicate areas of plant die-down. Red indicates bare earth. Each of the 15 sampling points is geo-referenced and were selected to represent the full variation in soil nutrient content, organic matter, texture, and topography. Possible factors for yield variability, as indicated by the Manitoba Soil Fertility guide, are highlighted for each point and on a field-wide basis.



The yield of the same field (#12), split by tuber size profile, is listed about by each sampling point. Each point (1-15) on the above image corresponds to the plot numbers in the previous image. Each color represents a specific tuber size profile. For example, yellow bars near the top indicate the 10-11.9 oz tuber size. The yield is measured in hundredweight per acre (Cwt/A) on the right side, and the harvest date was the first week in September. The green line connecting the bars is the estimated dollar value of the sampling point. The scale for the dollar value is on the left side.

In comparing the drone image of field 12 to the tuber size profile, some trends become apparent. The lowest yielding sampling point number 14 was observed to have compaction under 30 cm, low soil nitrogen and sulfur at row closure and mid bulking, low organic matter, high sand composition, and deficient petiole nitrogen at row closure and mid bulking. It is possible that the combination of some or all of these factors contributed to the yield limitation. This situation is where the partial least squares regression (PLS) analysis from earlier can provide some clarity. The sulfur concentration in the soil at mid bulking was an important, positive yield association for total yield. The low soil sulfur at mid bulking could possibly be a large contributor to this yield reduction. In addition, the noted low soil nitrogen availability is also an important variable identified in the PLS regression analysis for all processing fields. Further trends are apparent as the potential problems of an individual sampling point are cross-referenced with the PLS regression analysis for each tuber size profile further into this report. The full set of conclusions complete objective of this research program was to identify areas of variable potato yield and to characterize the factors responsible for variable yield. These conclusions are expected to influence the choices in meaningful yield variability remediation strategies and products are evaluated moving forward in the future of this project.

Fields destined for processing were not the only market consideration throughout the course of this project. Two fresh market fields were analyzed separately from processing fields in 2017. The variables associated with variability in the misshapen tubers, knobs, growth cracks, enlarged lenticels, russeting, and tuber size profiles of <2 in, 2-2.25 in, 2.25-3 in, 3-3.5 in, and > 3.5 in of fresh market tubers is also covered in detail in the full report. In summary, only the results for total yield are included:



Listed above are the top ten most influential positive and negative variables on total yield of fresh market fields evaluated in 2017. As before, a bigger VIP indicates that greater total yield from sampling points was associated with the increasing amount of this nutrient in the soil or petiole. As the VIP drops, the increasing or decreasing amount of that nutrient is associated with the lowest yielding sampling points.

Sampling points with greater soil nitrogen concentration at late bulking are associated with total yield positively (i.e. greater soil nitrogen at late bulking is associated with the highest yielding sampling points). Conversely, greater soil nitrogen concentration (0-30 cm) at row closure was negative associated with yield – more soil nitrogen at row closure was associated with lower yielding points. Greater soil sulfur in the upper (0-15 cm) soil layer were associated with the highest yielding sampling points at mid and late bulking. The most pronounced benefit of soil sulfur was more strongly associated with late bulking than mid bulking. In contradiction, soil sulfur from the deeper (15-30 cm) soil layer was negatively associated with fresh market yield at late bulking.

The objective of this research program was to identify areas of variable potato yield and to characterize the factors responsible for variable yield. Lists of the top ten most important variables associated with variable yield for fresh market and processing tubers sizes have been established. Moving forward, the objective will be to revisit fields coming back into the potato rotation at the beginning of the study to observe if these same yield-limiting variables can be observed repeatedly. In addition, yield-limiting variables identified and mapped in the first objective will be used to develop and evaluate remediation strategies in-field. Improving yield of desirable tuber sizes in less-than-ideal patches of fields in the project will add to the value of the crop, thereby improving the competitiveness of the Manitoba potato farmer in the market. This is important as processing expansions in Manitoba come into effect in the near future. Once cooperators are satisfied by remediation strategies to variable yield, other Manitoba growers can judge the fit of the practice to their operation. Remediation strategies that are adopted on a larger scale provincially will amplify the desired goal to reach and improve the competitiveness of all Manitoba potato growers.

Most studies examining one of the factors in the experiment, such as a nutrient, analyze said factor in isolation as part of integrity the scientific method. While this regimented, narrowed focus is imperative for results of ideal scientific integrity, the possibility exists that several factors are inter-related. Strategies with the intent to mitigate one factor may require additional adjustment to other areas to achieve the desired association observed in the results of this document. Experience has taught the author that understand the complete range of interactions of these 97 variables is very difficult for a singular individual entity to keep in mind, yet these interactions remain important. The route to limiting this problem is the combined, group efforts of the research committee, as well as growers and consultants. Only in working together can the true objective of increasing the competitiveness of Manitoba’s potato industry be realized.

Introduction

Manitoba potato production has averaged 20.5 million hundredweight (cwt) annually from 2000 to 2013, landing the province with the #2 rank in Canadian potato production. Manitoba produces 20% of all the potatoes grown in Canada as of 2014 (Informa Economics, 2014). Manitoba has a long history of growing potatoes, which is demonstrated in part by Fig. 1.

Fig 1. Potato harvest in Carberry, Manitoba in the mid-1960s. Several items are particularly interesting about this photograph. For example, the axel on the tractor with the digger (right) has been extended to allow placement of a one-row digger. The operator of the digger was the first person on the line to sort material out of the harvested potatoes. The preparation of the field for harvest is also interesting in that the majority of plant matter was shredded and removed prior to harvest, which could have potential implications on setting skins for harvest and removal of infected plant matter before propagules of organisms like *Colletotrichum coccodes* and *Verticillium dahliae* return to the soil. Photo credit: Earl Baron.

Potato yield in Manitoba has varied between approximately 16 and 25 million cwt from 2005 to 2013 (Fig. 2), with more recent advances being attributed to the implementation of sustainable best management practices (Informa Economics, 2014). These recent improvements identify that there is opportunity for continued improvement through the collaboration of research and the potato community to define and improve these best management practices.

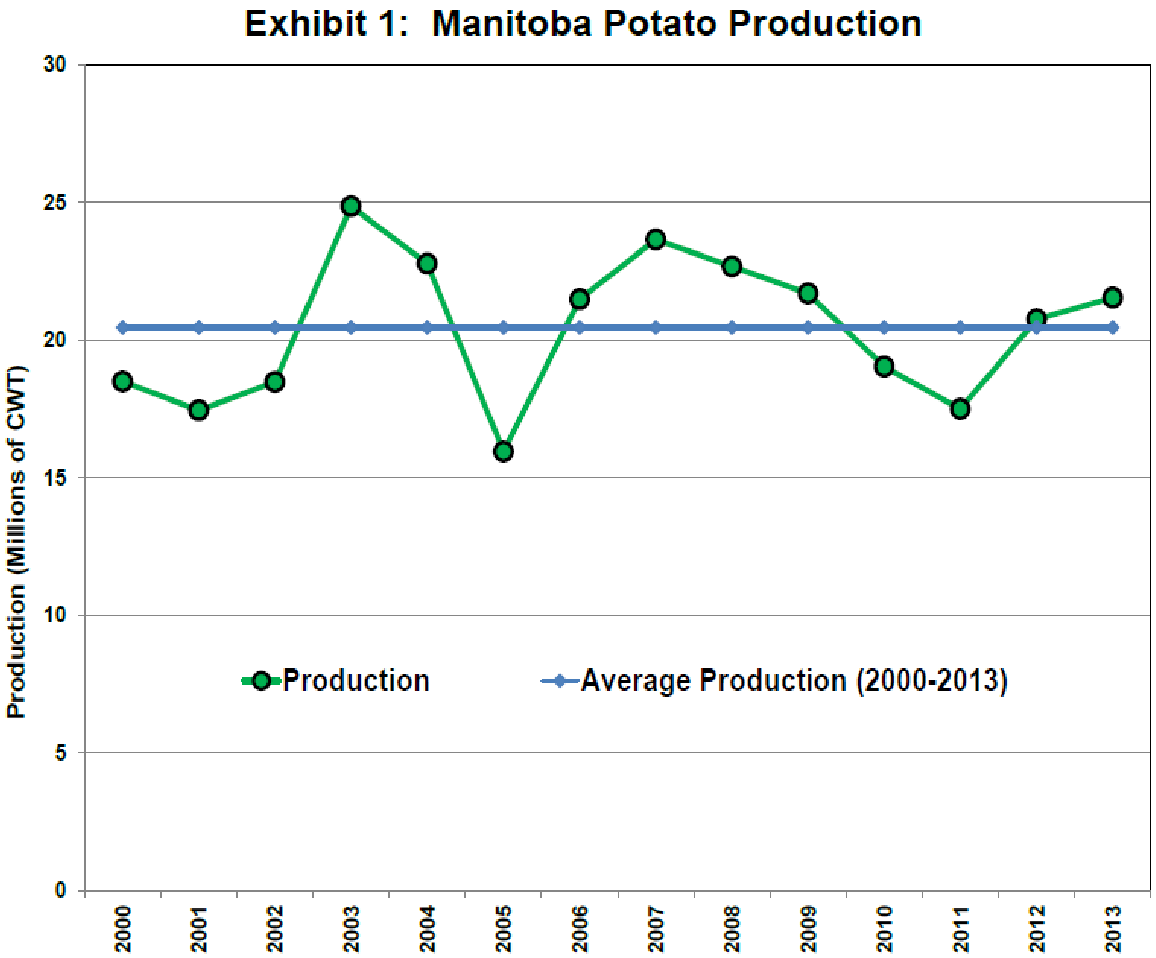


Exhibit 1: Manitoba Potato Production

Source: Statistics Canada

Fig 2. Line graphical display of Manitoba potato production yield by each year from 2005 to 2013. The green line links annual production (in millions cwt) by year, whereas the blue line represents the average across all year. Sourced and created by Informa Economics (2014) from Statistics Canada.

The direct application of research to engage communities to promote growers and their commodities is the hallmark of cooperative extension (CED-81-119), which will be referred to as extension from here onward. The key to extension is the exchange of information between people with different perspectives and experience is necessary in order to overcome a problem together. This exchange educates both parties to make informed choices, which in this case improves the crop and encourages other members of the community to seek what was done differently in order to achieve the same result for themselves. This report is one such attempt to supply research results that can integrate into the conversation about improving the yield and quality of potatoes grown in Manitoba. This report is only meaningful if you, the reader, provide feedback on what interests you, why, and how you think we can overcome yield limitations together.

The concept of cooperative extension is not new to North America– agricultural clubs and societies of the early 19th century encouraged farmers to report their achievements on yield and problem-solving. This practice of coming together to share knowledge to boost crop yield and quality eventually led to events sponsored by local governments and universities the United States, which eventually precipitated the formation of the land-grant college system in 1862 (CED-81-119). Attempts to overcome the current limitations of an agricultural system, potatoes in this case, are inextricably intertwined with research and communal education efforts.

The Manitoba Crop Diversification Centre (MCDC) was established in 1993 with a ten-year agreement amongst a community consisting of the Government of Canada, the Government of Manitoba, and Manitoba Horticulture Productivity Enhancement Centre Inc. (MHPEC). Applied research continues to this day under the name of the Canada-Manitoba Crop Diversification Centre (CMCDC) on a five-year (2013-2018) agreement (Anonymous, 2017). Part of the necessary information exchange for extension occurs at CMCDC through research in the areas of crop diversification, intensive crop production technology practices, such as irrigation, and facilitating development of value added processing of Manitoba-grown crops (Anonymous, 2016). Research reporting days, space for meetings for growers and industry, and individual consultation with research agronomists means CMCDC is an integral part of the conversation to exchange information to complete the purpose of extension for the Manitoba potato community. The conversation to enhance Manitoba potato growers, as well as those involved in potato processing and marketing, brings new challenges and opportunities for further research and extension going into the future.

Manitoba potato growers must generate an increased yield of a high-quality crop grown in a sustainable, cost effective manner to improve market competitiveness because of an upcoming expansion in processing potential within Manitoba. Competitive factors outside our influence include Manitoba's distance to markets, global supply and demand of processed potato products, and volatility in the exchange rate between Canada and the United States. Yield increases must be achieved through regional research, development, and evaluation of crop management strategies because the long-distance importation of research results from other areas risks overlooking regionally significant yield-limiting factors. The overall goal of the research program "Increasing the Competitiveness of Manitoba's Potato Industry" is to foster sustainable, competitive growth of the Manitoba potato industry through a research program within Manitoba. This research program is conducted within grower fields, but is housed at CMCDC and aligns with the centre's objective of research into intensive crop production technology practices.

The research program consisted of two objectives, and the first objective was to identify areas of variable potato yield in specific fields and to characterize the factors responsible for variable yield. A second objective uses yield-limiting factors identified in the previous objective to select and evaluate strategies aimed at mitigating or compensating for these factors in field settings specific to Manitoba.

This research program is designed to supply information on the remediation of yield limiting factors for specific fields in Manitoba, which are generally representative of commercial processing potato acres in Manitoba. The broader impact of this research is that remediation strategies can be employed elsewhere in Manitoba to improve the yield or cost-effectiveness of the potato crop. For example, the opposite of practices that are identified as selecting for larger processing tubers could be considered by a seed grower for smaller seed potatoes. This goal can only be achieved through the combined experience and research capacity of the Manitoba potato growers, Manitoba Agriculture, Agriculture and Agri-Food Canada, the University of Manitoba, the Keystone Potato Producers Association (KPPA), McCain Foods (Canada), Simplot Canada II, the Chipping Potato Grower Association of Manitoba (CPGAM), and the Seed Potato Growers Association of Manitoba (SPGAM).

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Results and Brief Discussion

Partial Least Squares regression analysis of all processing fields 2015-2017 (pooled data set)

Total Yield

Partial least squares analysis showed that 56% of the variability in all response variables taken together was explained by a model containing 46 of the 97 independent variables tested (Table 1). The seven most influential variables with negative contributions to the model, greatest to least influential, were petiole calcium concentration at row closure, soil nitrogen concentration at row closure from depths of 15-30 cm, petiole concentration of calcium at mid bulking, soil nitrogen 0-30 cm at row closure, nitrate concentration in the petiole at row closure, boron concentration in the petiole at late bulking, and soil potassium availability in the soil at row closure from depths 0-15 cm (Fig. 3).

Among the top ten most important explanatory variables was the available sodium in petioles at row closure, which was positively associated with yield. The two other positive yield associations were soil sulfur at mid bulking (from depths of 0-15 cm) and soil phosphorus at late bulking (from depths of 0-15 cm, Fig. 3).

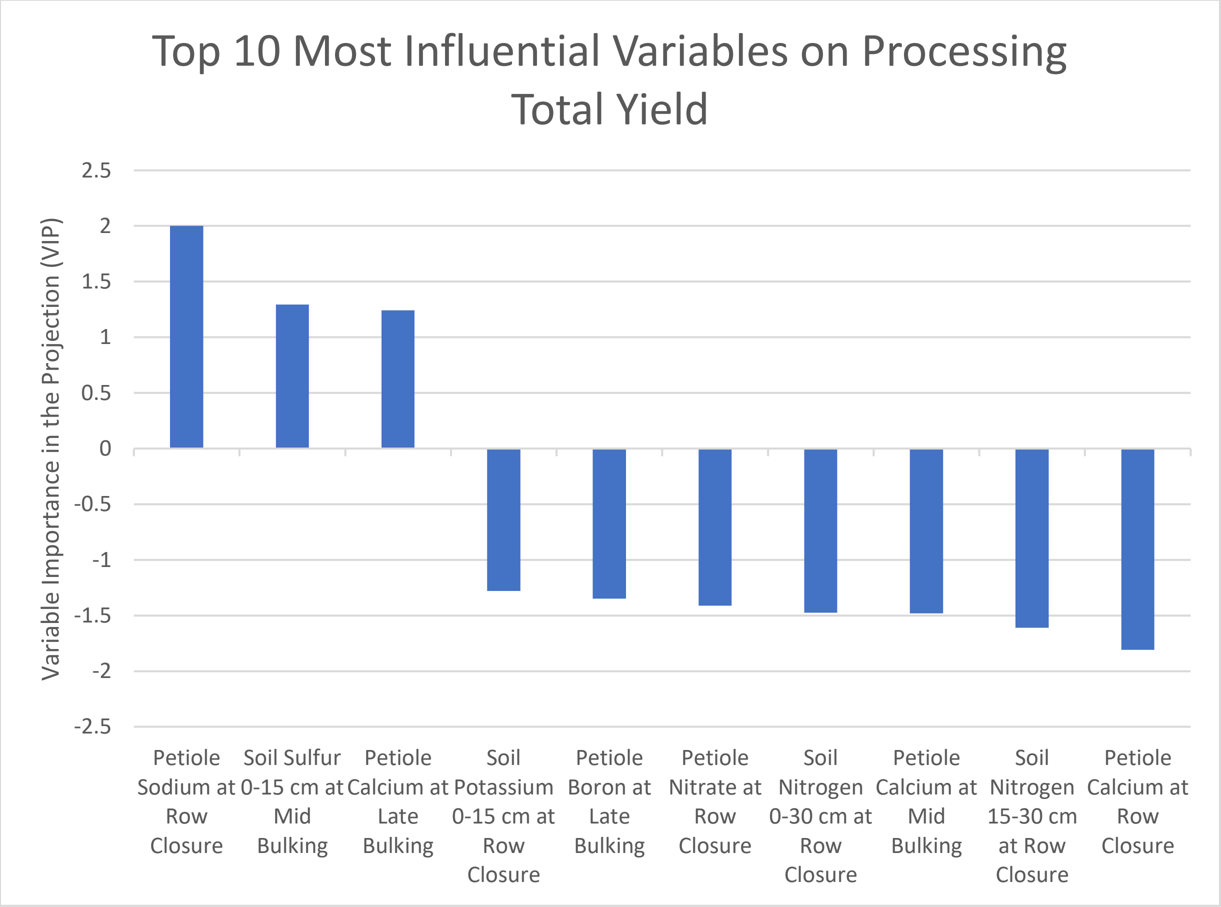


Fig. 3. Listed above are the top ten most influential positive and negative variables on total yield of processing fields evaluated 2015-2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil and PPM in petioles, as determined by Agvise testing. The Y axis identifies the Variable of Importance in Projection (VIP) in the creation of the model predicting total yield. Greater positive VIP (above zero) indicates that variable has a bigger, positive association with yield. In other words, a bigger VIP indicates that greater total yield from sampling points was associated with the increasing amount of this nutrient in the soil or petiole. Lower, negative VIPs (below zero) indicates that variable has a bigger negative association with yield. As the VIP drops, the increasing or decreasing amount of that nutrient is associated with the lowest yielding sampling points. The exact relationship between a negative VIP and too much or too little of nutrient must be determined by a resource such as Agvise recommendations or the Manitoba Soil Fertility guide (https://www.gov.mb.ca/agriculture/crops/soil-fertility/soil-fertility-guide/). It is important to note that 45-55 variables were associated with yield for all tuber size categories and total yield, but only the top ten were reported here for simplicity.

The interpretation of these results is that variables with greater VIPs have greater significance to the model (Table 1), and therefore have greater variance between the sampling points with greater and lesser total yield. For example, sampling points with greater petiole nitrogen at row closure are associated with total yield negatively and could be translated as less petiole nitrate at row closure is associated with our lowest yielding sampling points. Over the course of the experiment, petiole nitrate results varied from 3892 to 32668. The association with decreasing total yield would focus on the upper range of 32668, but the exact cut off of when the benefit of available nitrogen turns to detriment cannot be determined by this form of analysis. Recommendations from Agvise suggest that the cut off is around 25000, but experimental validation with a remediation strategy (objective 2) aimed at identifying nitrogen practices prior to row closure and their effect on the ideal petiole range are needed before experimentally-validated recommendations can be issued.

Variables such as available sodium in the petiole are positively associated with total yield, indicating the best-yielding sampling points were associated with more petiole sodium than the lower yielding points. Over the course of the experiment, the percentage sodium recorded in the petiole by Agvise varied from 0.01% to 0.07%, indicating the percentage range of positive benefit was small. However, the analysis indicated that the higher percentages were associated with higher yielding sampling points. It is also important to note that the petiole sodium content became a negative yield association from mid bulking and late bulking, albeit not one of the top ten.

Similarly, increased sulfur concentration in the upper (0-15 cm) horizon of the soil at mid bulking was associated with our highest yielding sampling points. However, the benefit to total yield associated with greater petiole sodium is larger than the benefit from increased soil sulfur, as indicated by an increased VIP in the model (i.e. the higher the bar is on the positive side, the greater the benefit, and the lower the bar on the negative side indicates incrementally larger negative effect).

The results on petiole calcium are also interesting in that sampling points with greater petiole calcium had lower total yield. In this case, too much or too little of calcium was associated with lower yielding sampling points. A soil test and reference are necessary to determine whether it was too much or too little – the model will not inform this result. The percentage of petiole calcium at row closure ranged from 0.87-2.48%, which appeared to range from high to very high. It is possible that excessive calcium was part of the negative yield association. Field experimentation to address the relationship with calcium on negative yield associations is absolutely necessary to verify this claim, especially before major management decisions are implemented.

It is very to get lost in the morass of results and interpretation of the following results for each size category. Repetition is key to the integrity of any result from any scientific study. The conclusions section will list the consistent results across all size categories and total yield for the processing and fresh sections of this report.

Value of the crop in dollars

When the total dollar value of the crop was tested individually, a two-component model containing 46 variables explained 58% of the variability was generated with strong predictive power (Table 2). The seven most influential variables with negative contributions to the model, greatest to least influential, were calcium concentration in the petiole at row closure, nitrogen concentration in the 15-30 cm soil layer at row closure, soil nitrogen concentration from 0-30 cm at row closure, calcium concentration in the petiole at mid bulking, sulfur concentration in the 15-30 cm soil layer at row closure, calcium concentration in the petiole at late bulking, and sodium concentration in the petiole at late bulking (Fig. 4).

The three most influential variables with a significant, positive contributions to the model, greatest to least influential, were the sodium concentration in the petiole at row closure, soil nitrogen 0-15 cm at row closure, and soil potassium 0-15 cm at row closure (Fig. 4).

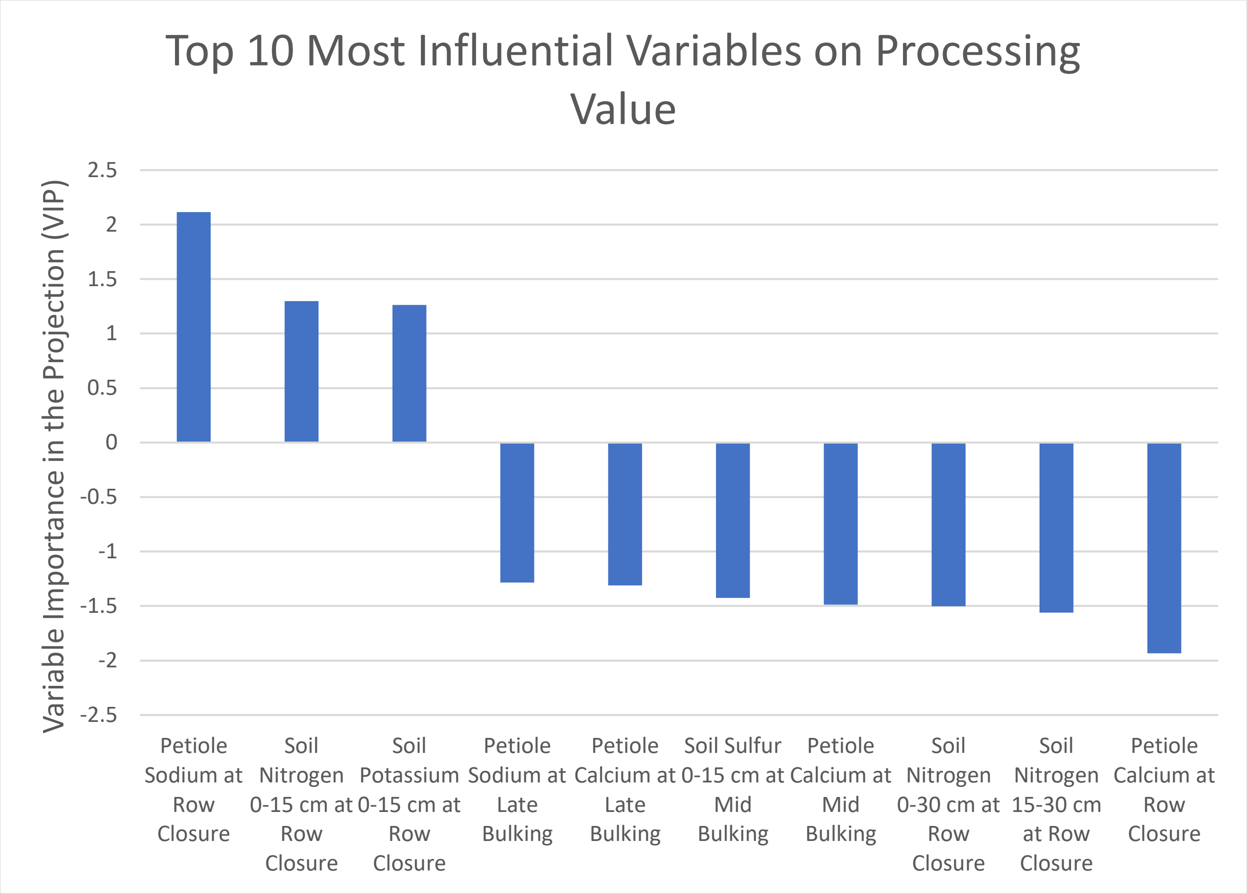


Fig. 4. The top 10 most influential positive and negative variables on the value of processing fields evaluated 2015-2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil as determined by Agvise testing and nutrient recommendations. The Y axis identifies the Variable of Importance in Projection (VIP) in the creation of the model for this yield category. Greater positive VIP (above zero) indicates that variable has a bigger positive association with yield. Lesser negative VIP (below zero) indicates that variable has a bigger negative association with yield.

The interpretation of these results is that variables with greater VIPs have greater significance to the model (Table 2), and therefore have greater variance between the sampling points with greater and lesser value in dollars. More valuable sampling points were associated with higher petiole sodium at row closure than less valuable sampling points. More valuable sampling points were associated with lower calcium concentrations in the petiole at row closure or lower nitrogen concentration in the 0-15 cm soil layer at row closure than less valuable sampling points, for example. The negative association with petiole calcium at row closure was greater than soil nitrogen at row closure (VIP greater for petiole calcium).

The pounds of nitrogen available in the soil varied at row closure from 5 to 160 lbs, which can explain the anomalous result that increasing soil nitrogen can be a positive value association, but too much or too little is a negative value association. Five pounds of available soil nitrogen is too little by row closure – limiting growth and eventual bulking, and ultimately reducing value. The consultants that took part in the 2017 year of the project seem to aim for 130-180 lbs of nitrogen in the soil by row closure, which includes the upper range of 160 lbs nitrogen in the soil observed in the experiment. This could explain the result where increasing soil nitrogen (up to the 160 lbs max observed) at the 0-15 cm is a positive yield association. However, too much or too little decrease value. Field experimentation is necessary to place the association in the context of an actual on-farm practice.

Yield: percentage of the undersized (< 3 oz) tubers

A two-component model containing 42 variables explained 53% of the variability was generated with strong predictive power for variables associated with the yield of undersize tubers (Table 3). The eight most influential variables with negative contributions to the model, greatest to least influential, were the sodium concentration in the petiole at row closure, sulfur concentration in the 0-15 cm soil layer at mid bulking, petiole sulfur concentration at mid bulking, petiole magnesium concentration at mid bulking, soil sulfur concentrations from 0-30 cm (especially the 15-30 cm layer) at late bulking, petiole concentration of sulfur at row closure, and soil concentration of sulfur at 15-30 cm at mid bulking (Fig. 5).

The two most influential variables with a significant, positive contributions to the model, greatest to least influential, were the potassium concentration in the petioles at late bulking and calcium concentration in the petiole at row closure (Fig. 5).

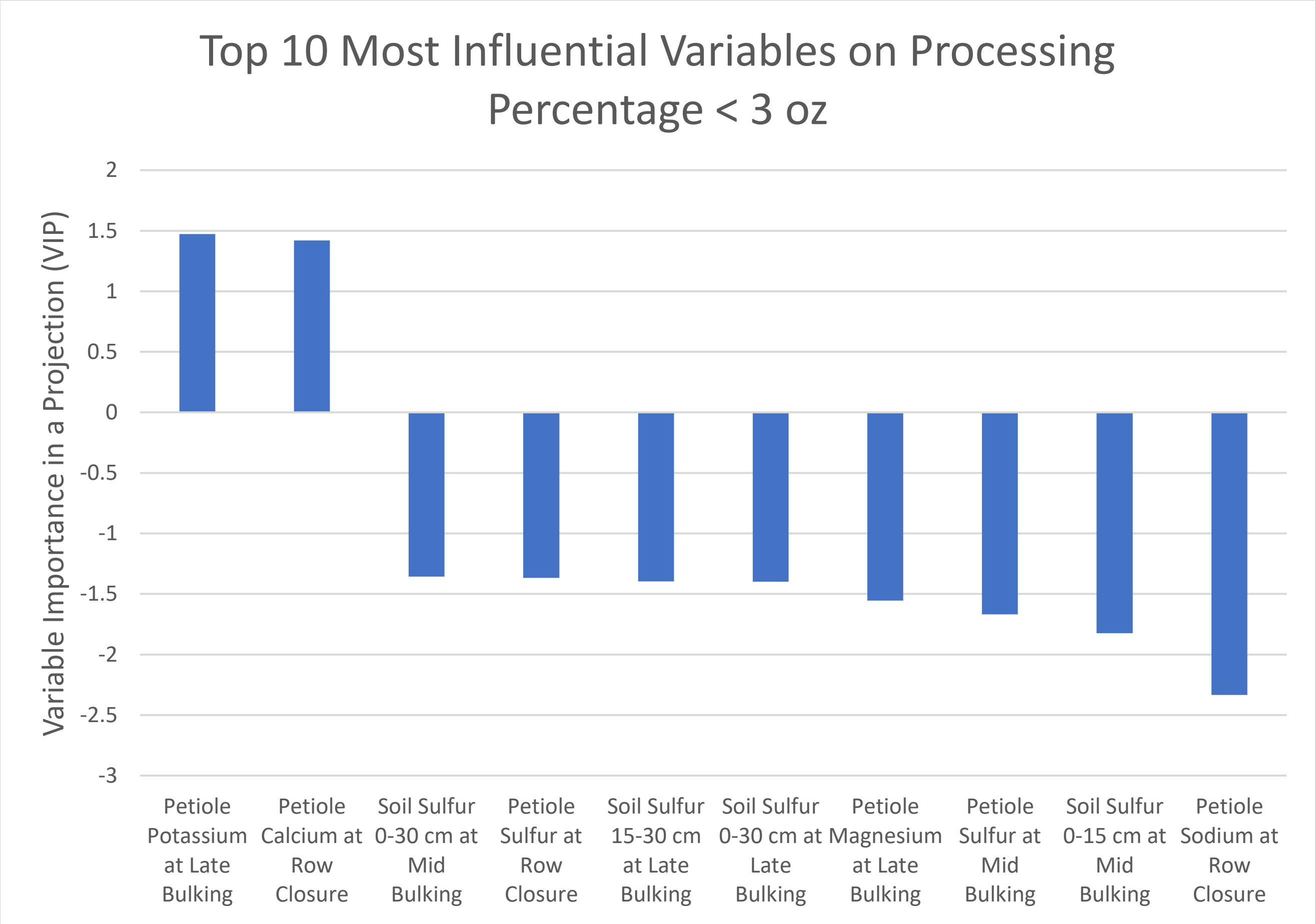


Fig. 5. The top 10 most influential positive and negative variables on the yield <3 oz tubers for processing fields evaluated 2015-2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil as determined by Agvise testing and nutrient recommendations. The Y axis identifies the Variable of Importance in Projection (VIP) in the creation of the model for this yield category. Greater positive VIP (above zero) indicates that variable has a bigger positive association with yield. Lesser negative VIP (below zero) indicates that variable has a bigger negative association with yield.

The interpretation of these results is that variables with greater VIPs have greater significance to the model (Table 3), and therefore have greater variance between the sampling points with greater and lesser yield of undersize tubers. For example, sampling points with more calcium and potassium in the petioles at row closure had more undersize tubers than sampling points with less of either nutrient. Sulfur was consistently negatively associated with undersize tubers and therefore the sampling points with more available sulfur in the soil and petioles at mid and late bulking were associated with fewer undersize tubers. The association between more sulfur in petiole and soil and fewer undersize tubers is more pronounced at mid bulking than at row closure.

Yield: percentage of the small tubers (3-6 oz)

A two-component model containing 46 variables explained 46% of the variability was generated with strong predictive power for variables associated with the yield of undersize tubers (Table 4). The eight most influential variables with negative contributions to the model, greatest to least influential, were the soil sulfur concentration from 0-15 cm at mid bulking and petiole sodium concentration at row closure (Fig. 6).

The two most influential variables with a significant, positive contributions to the model, greatest to least influential, were the petiole calcium concentration at row closure, soil nitrogen concentration at 0-30 cm at row closure, soil nitrogen concentration at 15-30 cm at row closure, soil nitrogen concentration at 0-15 cm at row closure, petiole concentration of calcium at late bulking, soil potassium concentration at 0-15 cm at row closure, EC soil reading from 0-15 cm, and soil sulfur concentration at 0-15 cm at row closure (Fig. 6).

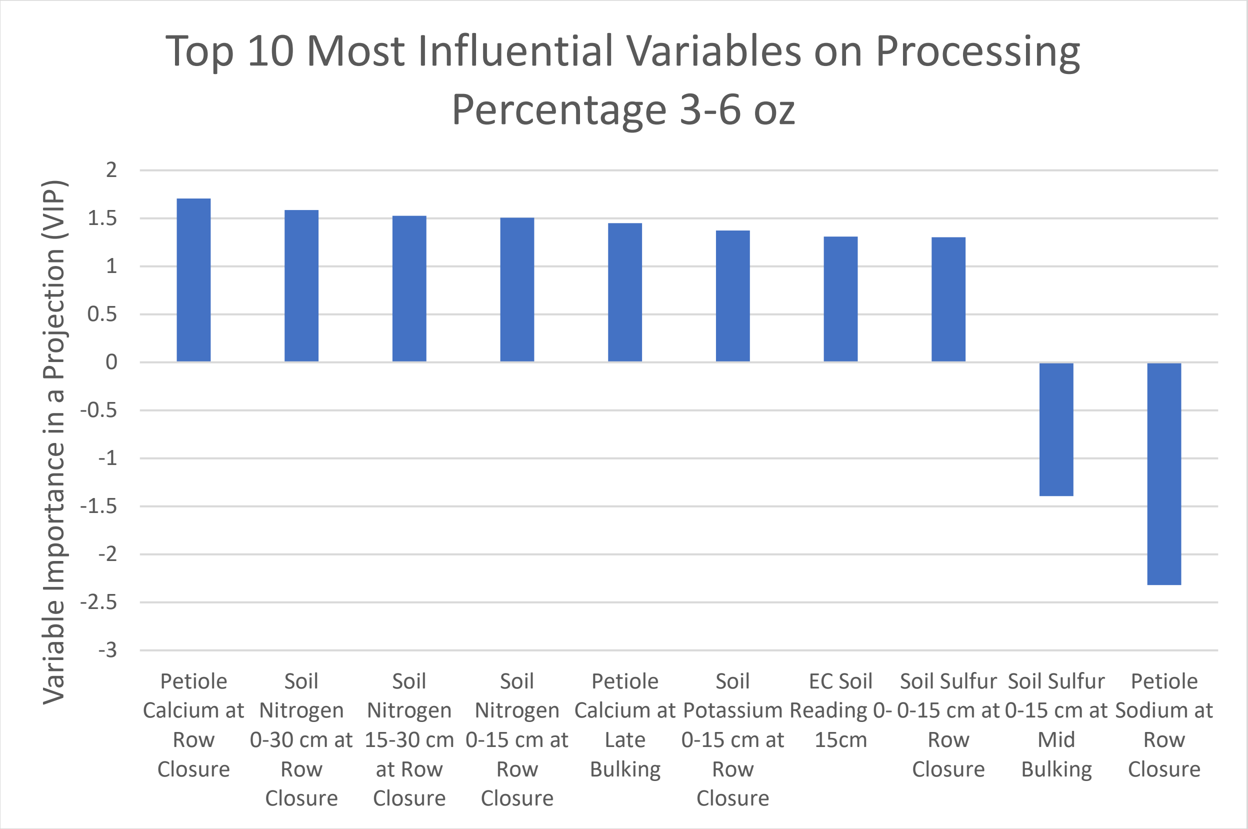


Fig. 6. The top 10 most influential positive and negative variables on the yield 3-6 oz tubers for processing fields evaluated 2015-2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil as determined by Agvise testing and nutrient recommendations. The Y axis identifies the Variable of Importance in Projection (VIP) in the creation of the model for this yield category. Greater positive VIP (above zero) indicates that variable has a bigger positive association with yield. Lesser negative VIP (below zero) indicates that variable has a bigger negative association with yield.

The interpretation of these results is that variables with greater VIPs have greater significance to the model (Table 4), and therefore have greater variance between the sampling points with greater and lesser yield of 3-6 oz tubers. For example, sampling points with fewer 3-6 oz tubers were associated with less petiole sodium at row closure and less soil sulfur at mid bulking. The effect of petiole sodium concentration was greater than soil sulfur at mid bulking in terms of association of fewer 3-6 oz tubers. Sampling points with greater 3-6 oz yield were associated with increased petiole calcium concentration at row closure and soil nitrogen concentration at row closure. The effect of increased petiole concentration of calcium on increased 3-6 oz yield was greater than the effect of soil nitrogen.

Yield: percentage of the 6-10 oz tubers

A two-component model containing 46 variables explained 46% of the variability was generated with strong predictive power for variables associated with the yield of 6-10 oz tubers (Table 5). The five most influential variables with negative contributions to the model, greatest to least influential, were nitrogen concentration in the soil at both depths of 0-15 and 0-30 cm at late bulking, the boron concentration in the petiole at late bulking, calcium concentration in the petiole at row closure, soil sulfur concentration in the soil from 0-15cm at mid bulking.

The five most influential variables with a significant, positive contributions to the model, greatest to least influential, were the sodium concentration in the petiole at row closure, nitrate concentration in the petioles at late bulking, sulfur concentration in the petiole at row closure, soil nitrogen concentration in the soil from 0-15 cm at mid bulking, and sulfur concentration in the petiole at mid bulking (Fig. 7).

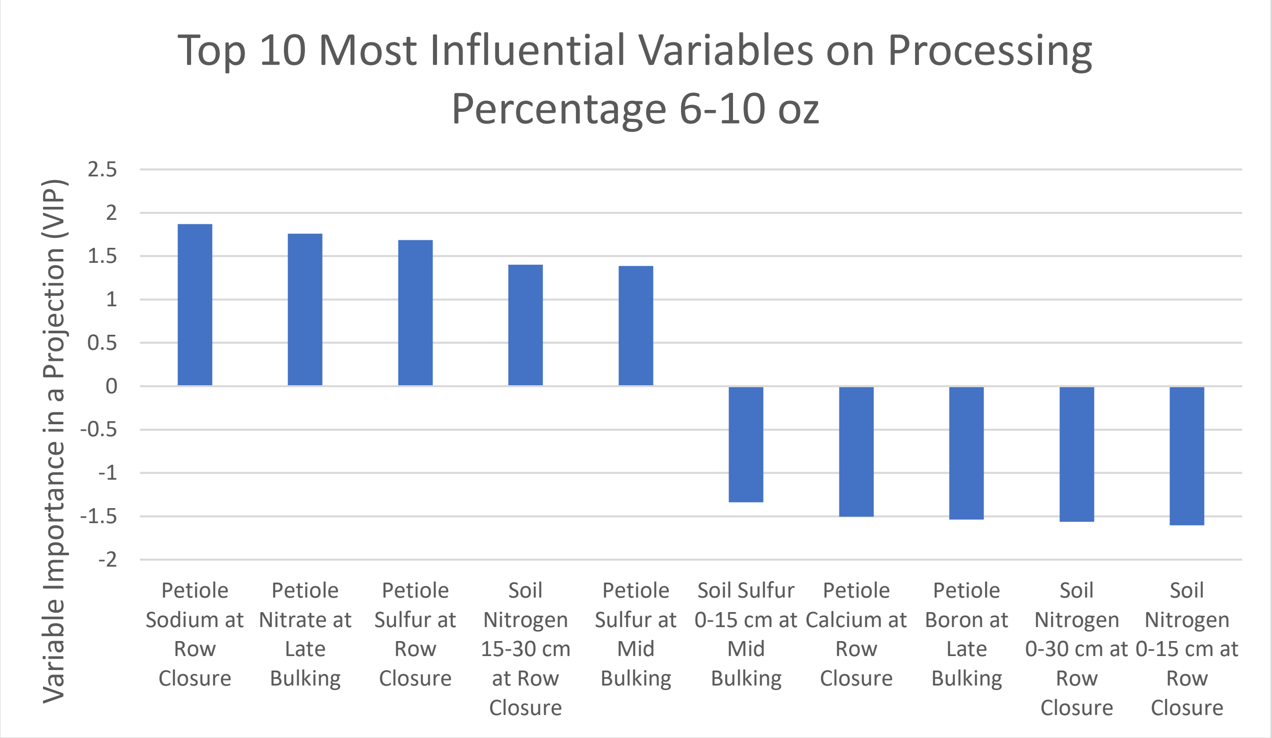


Fig. 7. The top 10 most influential positive and negative variables on the yield 6-10 oz tubers for processing fields evaluated 2015-2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil as determined by Agvise testing and nutrient recommendations. The Y axis identifies the Variable of Importance in Projection (VIP) in the creation of the model for this yield category. Greater positive VIP (above zero) indicates that variable has a bigger positive association with yield. Lesser negative VIP (below zero) indicates that variable has a bigger negative association with yield.

The interpretation of these results is that variables with greater VIPs have greater significance to the model (Table 5), and therefore have greater variance between the sampling points with greater and lesser yield of 6-10 oz tubers. For example, sampling points with more sodium and nitrate in the petioles at row closure had more 6-10 oz tubers than sampling points with less of either nutrient. Sulfur was also positively associated with 6-10 oz tubers and therefore the sampling points with more available sulfur in the petioles at mid and late bulking were associated with more of this desirable tuber range. The association between more sulfur in petiole and more 6-10 oz tubers is more pronounced at row closure than mid bulking. However, sampling points with more petiole boron and soil nitrogen at late bulking were associated with fewer 6-10 oz tubers.

Yield: percentage of the 10-12 oz tubers

A two-component model containing 50 variables explained 52% of the variability was generated with strong predictive power for variables associated with the yield of 10-12 oz tubers (Table 6). The nine most influential variables with negative contributions to the model, greatest to least influential, were the number of *Verticillium dahliae* propagules (as evaluated by the PCR test), calcium concentration in the petioles at late bulking, potassium concentration in the petiole at late bulking, EC soil reading from 0-15cm, calcium concentration in the petiole at row closure, petiole potassium concentration at row closure, soil potassium concentration from 0-15 cm at row closure, percentage sand 0-15 cm, and the calcium concentration in the petiole at mid bulking (Fig. 8).

The only influential variable (of the top 10 total) with a significant, positive contribution to the model was the petiole sodium concentration by row closure (Fig. 8).

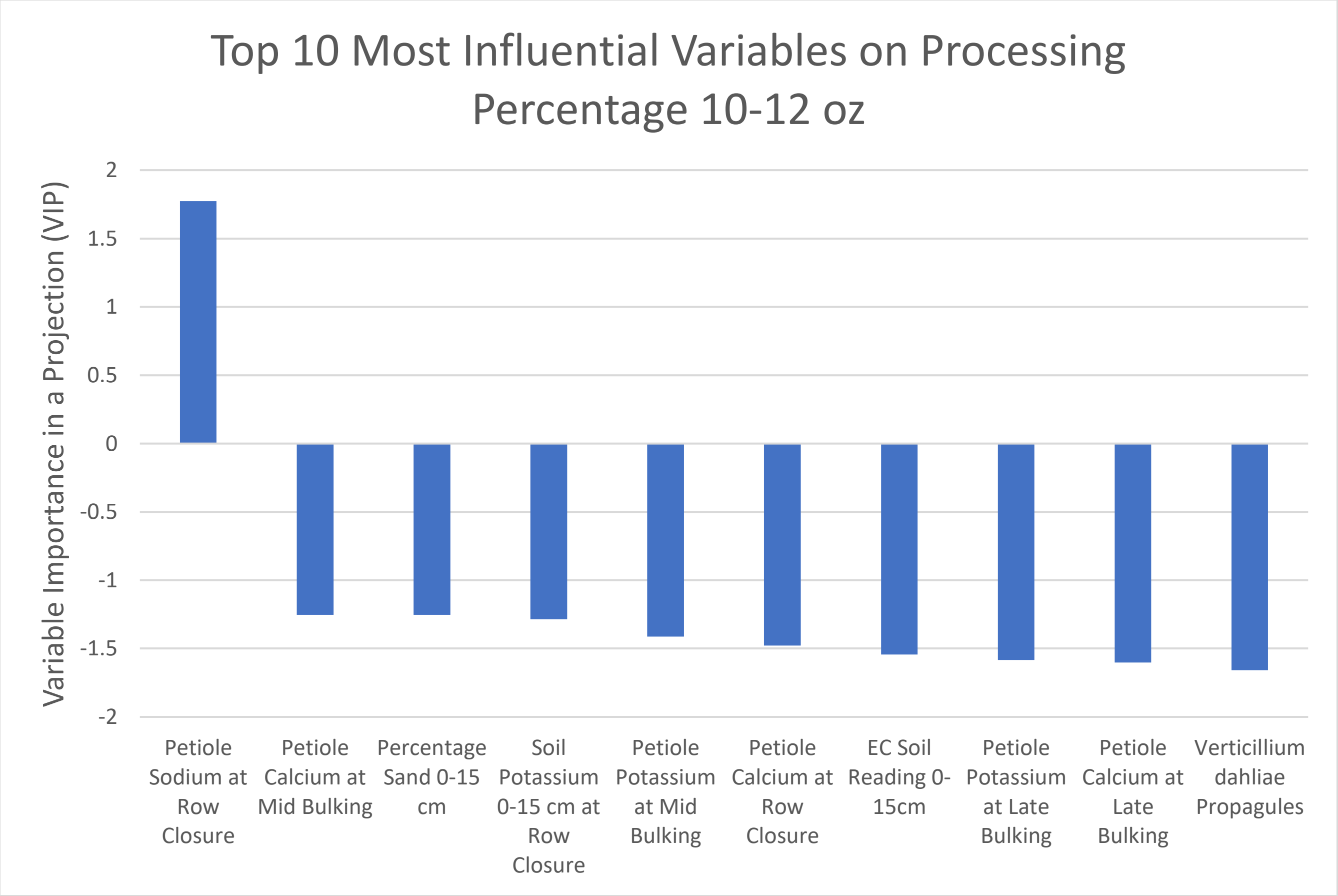


Fig. 8. The top 10 most influential positive and negative variables on the yield 10-12 oz tubers for processing fields evaluated 2015-2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil as determined by Agvise testing and nutrient recommendations. The Y axis identifies the Variable of Importance in Projection (VIP)

in the creation of the model for this yield category. Greater positive VIP (above zero) indicates that variable has a bigger positive association with yield. Lesser negative VIP (below zero) indicates that variable has a bigger negative association with yield.

The interpretation of these results is that variables with greater VIPs have greater significance to the model (Table 6), and therefore have greater variance between the sampling points with greater and lesser yield of 10-12 oz tubers. There was only one variable observed, sodium concentration in the petiole at row closure, where sampling points with more 10-12 oz tubers had more sodium than sampling points with lower 10-12 oz yield. Over the course of the experiment, the percentage sodium recorded in the petiole by Agvise varied from 0.01% to 0.07%, indicating the percentage range of positive benefit was small. However, the analysis indicated that the higher percentages were associated with higher yielding sampling points. It is also important to note that the petiole sodium content became a negative yield association from mid bulking and late bulking, albeit not one of the top ten.

Interestingly, sampling points with more *Verticillium* propagules had fewer 10-12 oz tubers. This is the only observation in the whole experiment where *Verticillium* was a variable of greater significance than most of the nutrients tested on impacting the yield of a specific tuber size profile. In the case of Verticillium, greater numbers of propagules per gram of soil were associated with the sampling points with the lowest percentages of 10-12 oz tubers. It is generally accepted that 5 to 30 CFUs per gram of soil are necessary to infect a potato plant (Colony Forming Units – a form of propagule observed under a microscope while growing on a petri plate). In the case of the experiment, CFU counts in excess of 100 in sampling points is where 10-12 oz yield begins to drop. More discussion on Verticillium counts in specific fields can be found in the “2017 Processing Field Individual Analysis” section.

The results on petiole calcium are also interesting in that sampling points with greater petiole calcium had fewer 10-12 oz tubers at any of the sampling dates, but our earliest sampling at row closure had the most pronounced effect of the three sampling dates. The final result to note is that more available sulfur in the petioles and soil at mid and late bulking improved 6-10 oz yield, but more soil sulfur at mid bulking decreased 10-12 oz yield. In these cases, too much or too little of either nutrient was associated with lower yielding sampling points. A soil test and reference are necessary to determine whether it was too much or too little – the model will not inform this result. Soil potassium at row closure from 0-15 cm was one such example, and 91 to 1150 PPM recorded as lowest to very high. The other consistent variables were petiole calcium at row closure and mid bulking. The percentage of petiole calcium at row closure ranged from 0.87-2.48%, which appeared to range from high to very high. It is possible that excessive calcium was part of the negative yield association. Field experimentation to address the relationship between calcium or potassium on negative yield associations is absolutely necessary to verify this claim, especially before major management decisions are implemented.

Yield: percentage of the 6-12 oz combined tuber size categories

A two-component model containing 44 variables explained 57% of the variability was generated with strong predictive power for variables associated with the yield of 6-12 oz tubers (Table 7). The seven most influential variables with negative contributions to the model, greatest to least influential, were the calcium concentration in the petiole at row closure, nitrogen concentration in the soil at both depths of 0-15 and 0-30 cm, boron concentration in the petiole at late bulking, EC reading for 0-15 cm, soil nitrogen from depths of 15-30 cm, and calcium concentration in the petiole at late bulking (Fig. 9)

The three most influential variables with a significant, positive contributions to the model, greatest to least influential, were the sodium concentration in the petiole at row closure, sulfur concentration in the petiole at row closure and mid bulking (Fig. 9).

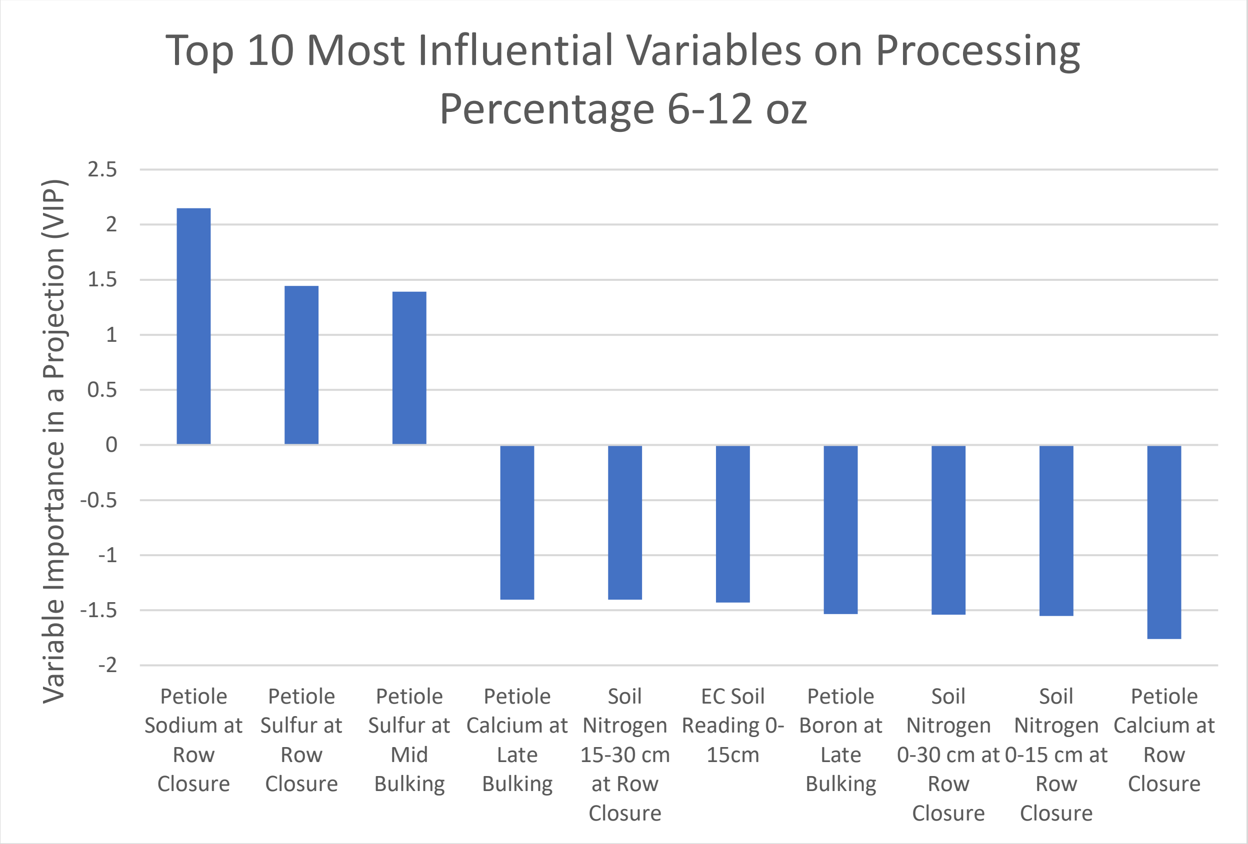


Fig. 9. The top 10 most influential positive and negative variables on the yield 6-12 oz tubers for processing fields evaluated 2015-2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil as determined by Agvise testing and nutrient recommendations. The Y axis identifies the Variable of Importance in Projection (VIP) in the creation of the model for this yield category. Greater positive VIP (above zero) indicates that variable has a bigger positive association with yield. Lesser negative VIP (below zero) indicates that variable has a bigger negative association with yield.

The interpretation of these results is that variables with greater VIPs have greater significance to the model (Table 7), and therefore have greater variance between the sampling points with greater and lesser yield of 6-12 oz tubers. When the 6-10 and 10-12 oz data sets are combined, the positive associations of sulfur in the petioles on 6-12 oz tubers outweighs the drawback of sulfur in the soil at mid bulking on 10-12 oz tubers. Calcium concentration in the petioles at row closure and late bulking remains negatively associated with 6-12 oz yield, and more so at row closure than at late bulking. Nitrogen in the soil remains negatively associated with 6-12 oz yield, but less so than the other nutrients previously listed. The *Verticillium* propagules are notably absent from the top 10 list of negative associations of 6-12 oz tubers, meaning *Verticillium* still negatively impacts yield, but the nutrients listed previously are more deleterious to yield than *Verticillium* in the fields we have sampled at this time. It is important to note that, as a biological system, areas where *Verticillium dahliae* infections become a prominent potato problem tend to grow in size and increase in severity with time, necessitating long-term management strategies even if it currently isn't the most important yield limiting factor.

Yield: percentage of the > 12 oz tubers

A two-component model containing 43 variables explained 48% of the variability was generated with strong predictive power for variables associated with the yield of >12 oz tubers (Table 8). The seven most influential variables with negative contributions to the model, greatest to least influential, were the soil nitrogen availability at row closure for both depths of 0-15 and 15-30 cm, organic matter at depths of 0-15 cm, percentage of soil silt 0-15 cm, soil sulfur concentration at mid bulking, and gravimetric water content 0-12 cm (Fig. 10).

The three most influential variables with a significant, positive contributions to the model, greatest to least influential, were the sodium concentration in the petiole at row closure, sulfur concentration in the soil from depths of 0-15 and 0-30 cm at row closure (Fig. 10).

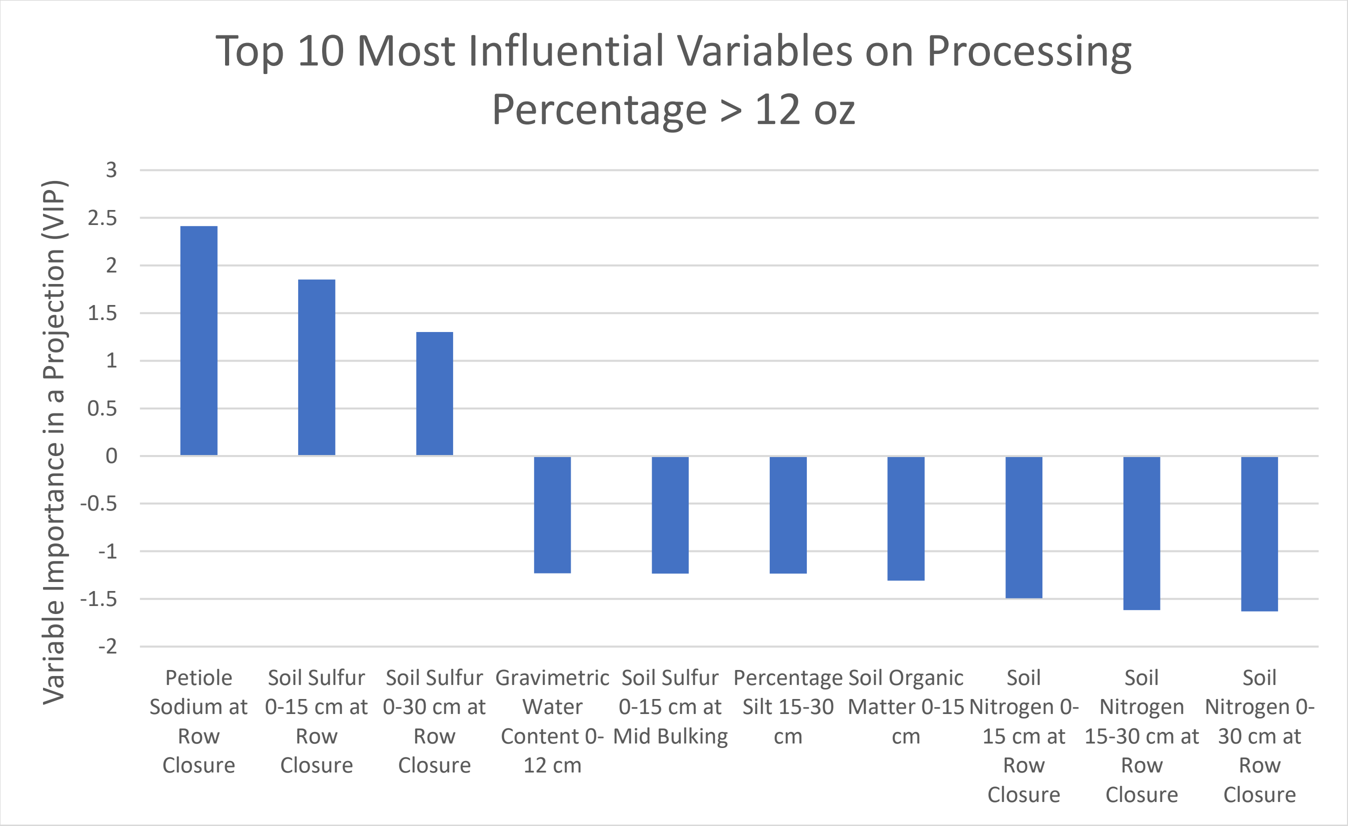


Fig. 10. The top 10 most influential positive and negative variables on the yield > 12 oz tubers for processing fields evaluated 2015-2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil as determined by Agvise testing and nutrient recommendations. The Y axis identifies the Variable of Importance in Projection (VIP)

in the creation of the model for this yield category. Greater positive VIP (above zero) indicates that variable has a bigger positive association with yield. Lesser negative VIP (below zero) indicates that variable has a bigger negative association with yield.

The interpretation of these results is that variables with greater VIPs have greater significance to the model (Table 9), and therefore have greater variance between the sampling points with greater and lesser yield of > 12 oz tubers. Increased soil nitrogen at row closure, regardless of depth, is associated with decreased yield of tubers > 12 oz and 6-10 oz. This stands in contrast to increased soil nitrogen at row closure associating with more >3 oz tubers. The > 12 oz size category is unique in that organic matter, silt percentage, and moisture content are in the top ten most influential variables that are negatively associated with yield. The positive association of soil sulfur at row closure with >12 oz yield aligns with the general positive yield associations with sulfur on 6-10 oz and 6-12 oz tubers.

Tuber specific gravity

A two-component model containing 48 variables explained 60% of the variability was generated with strong predictive power for variables associated with tuber specific gravity (Table 9). The seven most influential variables with negative contributions to the model, greatest to least influential, were the potassium concentration from petioles at late bulking, sodium concentration from petioles at mid bulking, potassium concentration at row closure from soils at depths of 0-15 cm, soil nitrogen concentration at row closure from depths of 15-30cm, soil nitrogen concentration at late bulking from depths 0-30 cm, soil potassium concentrations at late bulking from depths of 0-15cm, and soil potassium concentration at row closure from depths of 15-30cm (Fig. 11).

The three most influential variables with a significant, positive contributions to the model, greatest to least influential, were the pH of soil from the depth of 15-30 cm, boron concentration in the petiole at late bulking, and soil compaction from the depth of 15-30 cm (Fig. 11).

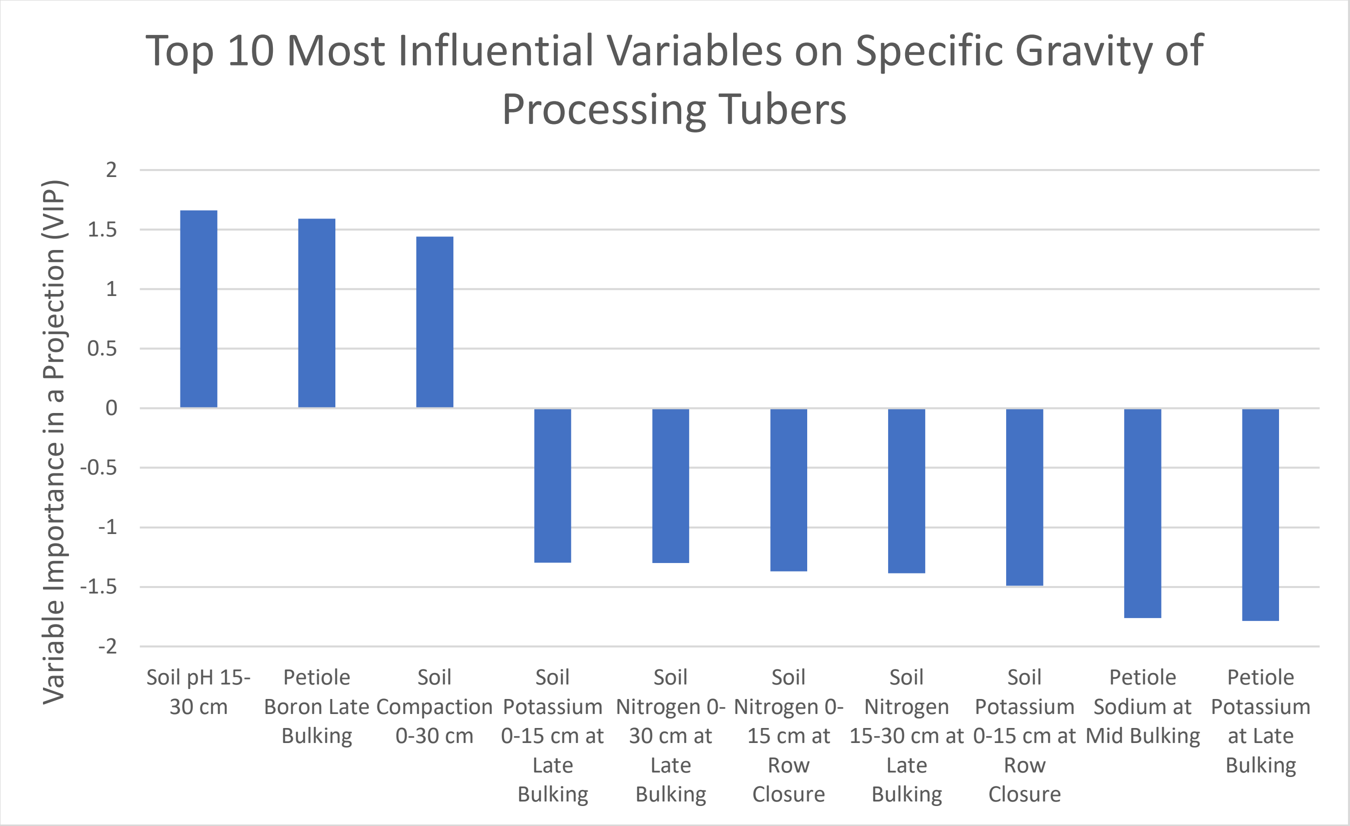


Fig. 11. The top 10 most influential positive and negative variables on specific gravity of processing tubers evaluated 2015-2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil as determined by Agvise testing and nutrient recommendations. The Y axis identifies the Variable of Importance in Projection (VIP) in the creation of the model for this yield category. Greater positive VIP (above zero) indicates that variable has a bigger positive association with yield. Lesser negative VIP (below zero) indicates that variable has a bigger negative association with yield.

The interpretation of these results is that variables with greater VIPs have greater significance to the model (Table 10), and therefore have greater variance between the sampling points with greater and lesser specific gravity of tubers. Boron concentration of the petiole was higher in sampling points with higher specific gravity at late bulking. Petiole boron varied from 22 to 39 PPM over the course of the experiment, although this analysis doesn’t exactly identify the relationship at which too much petiole boron pushes for too high of a specific gravity.

Tuber specific gravity was otherwise observed as increasing as soil compaction and pH increased at depths of 15-30 cm.

Too much or too little soil potassium and nitrogen was associated with decreased specific gravity. The soil nitrogen values have been identified previously, but the late bulking soil potassium values varied from 87 to 1032 lbs. It is possible that both too much and too little soil potassium could present problems, but further field experimentation is necessary to link exact soil potassium values with specific gravity variability.

Drone Image Analysis

Drone images from 2017 processing fields had the NDVI values (scale 0-1 vegetative index) were extracted and pooled for all processing fields for regression analysis independent of the partial least squares regression discussed previously. This data was analyzed separately because there was only data for only one year, which doesn't represent the entire project. The limitation of this analysis is that factors outside of those listed could influence the result, but could not be part of the analysis. More years of data are necessary to solidify the following results, and results that interest the committee merit the creation of their own, independent experiment to fully validate results before recommendations can be issued.

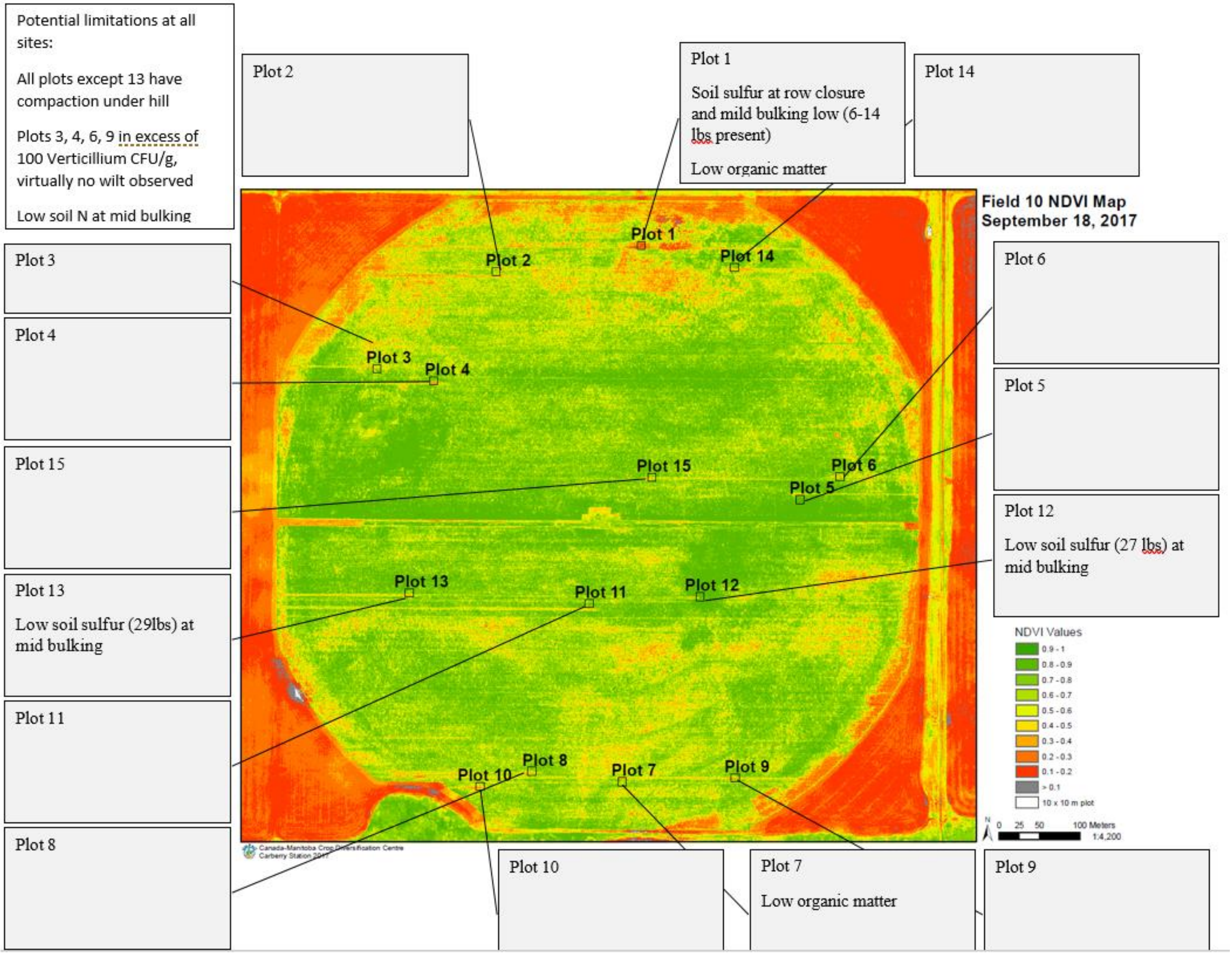
In summary, only significant results will be presented.

- Drone flights taken in June were positively associated with total yield (i.e. the greener spots identified by the drone correlated well with the highest yielding points (P = 0.0031).
- Drone flights taken in June (P = 0.0051) and August 18-21 (P = 0.0265) were negatively associated with 3-6 oz yield. Drone images at these dates could become part of a predictive tool using the drone to associate certain parts of the field with less 3-6 oz tubers.
- Drone flights taken in June were positively associated with 6-12 oz yield (i.e. the greener spots identified by the drone correlated well with the highest yielding points (P = 0.0467).

The June flight results are interesting when combined with individual field analysis drone images to follow in that there is a possibility of using the June flight as a predictive tool for problem places in certain fields.

2017 Processing Field Individual Analysis

Field 10: Pictured below (Fig. 12) is a drone image identifying potential limiting factors to the whole field or specific points



Field 10 NDVI Map
September 18, 2017

Potential limitations at all sites:

All plots except 13 have compaction under hill

Plots 3, 4, 6, 9 in excess of 100 Verticillium CFU/g, virtually no wilt observed

Low soil N at mid bulking

Plot 2

Plot 1

Soil sulfur at row closure and mild bulking low (6-14 lbs present)

Low organic matter

Plot 14

Plot 3

Plot 4

Plot 15

Plot 13

Low soil sulfur (29lbs) at mid bulking

Plot 11

Plot 8

Plot 6

Plot 5

Plot 12

Low soil sulfur (27 lbs) at mid bulking

Plot 10

Plot 7

Low organic matter

Plot 9

In addition to evaluating the impact of variables on yield of fresh and processing fields together, individual fields from 2017 were rated for nutrient, soil, disease, and plant health status. Drone imagery was used in conjunction with scouting, nutrient status as determined by Agvise recommendations, and yield to visualize variability at each sampling point and what trends were apparent in the overall yield. The point of this individual analysis is to demonstrate the usefulness of the Partial Least Square (PLS) analysis from all processing fields in identifying one or a few major yield-limiting factors from a larger list of potential problems listed for a specific site. This information begins the conversation with a local consultant and grower about priorities in remediating yield variability, and ultimately develop practices to remediate the situation.

Plot numbers in the drone images refer to the 15 sampling points in each field. The top of each image is north in each field, and the color scale refers to the NDVI values recorded by the drone. NDVI was recorded on a scale of 0-1, zero being red and refers to bare earth, 1 refers to green tissue, and varying shades of green to yellow indicate senescencing plant matter. It is important to note that weed canopy color will be recorded as well as potato, although no significant weed pressure was recorded in the sampling points in field 10.

For each individual field, certain variables were identified as potential problems for the whole field or individual collection points that could contribute to variable yield. Field 10 was observed to have compaction under the hill (beneath 30 cm/11.8 in from top of hill) with an excess of 300 PSI. The only sampling point that was not compacted at this layer was plot 13, on the southwestern side of the field. Compaction was not among the top ten most influential variables listed in the complete processing analysis, indicating that it could be a problem on an individual field basis, but not among the worse problems across all processing fields.

Very little Verticillium wilt was recorded in the field, but *Verticillium* species counts exceeded 100 CFU /g in plots 3, 4, 6, and 9. It is generally accepted that 5-30 CFU/g of *V. dahliae* are necessary for infection. This plate count will encompass all Verticillium species, which doesn't accurately rely the number of *V. dahliae* CFU. Verticillium will likely need to be monitored in the field, but the disease is unlikely to be the cause of variable yield observed this year. The combined processing analysis indicated that the 10-12oz yield category is the size range most negatively impacted by high *Vertcillium* counts, as severely infected plants are killed or debilitated during late bulking when tubers are sizing in this range. Concern about any drops in 10-12 oz yield should consider the *Verticillium* counts in future years based on this information.

The main indicators of variable yield, among the variables recorded for the study, in this field are low soil nitrogen and sulfur at mid bulking. Low soil nitrogen was recorded across all collection points at mid bulking, whereas low soil sulfur was a more sporadic problem with no obvious trend. Both sulfur and nitrogen were important nutrients involved in variable yield across all processing fields, with low soil sulfur at mid bulking and soil nitrogen at row closure being associated with lower yielding sampling points.

Throughout the study, the lowest yielding points often had multiple potential limiting factors listed in the drone image like Fig. 12. Some of these limiting factors are inter-related, such as sand texture and nitrogen leaching. In the case of field 10, only point one had four potential factors. It is extremely likely that the combined effects of multiple problems contribute to yield limitation greater when combined than each factor individually.

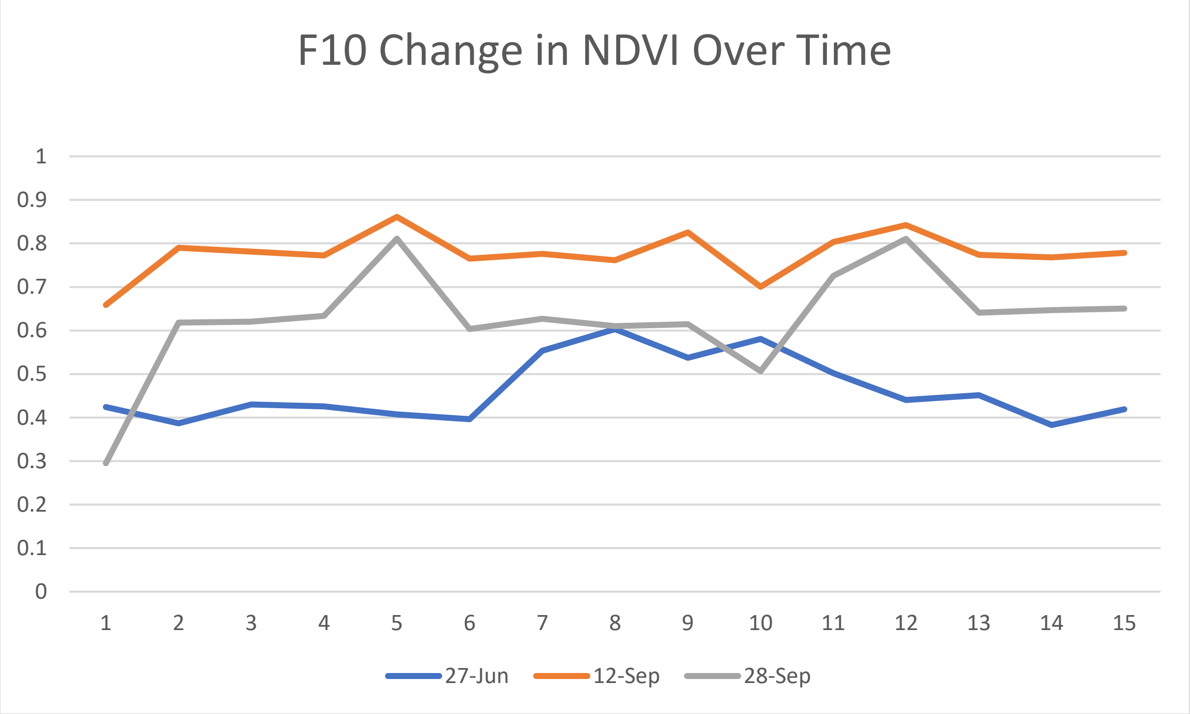


Fig 13. (Above) is another method of viewing the drone image from three drone flights at once. Each line represents an individual flight, and each flight date is on the bottom. The 1-15 on the bottom (X-axis) refers to each of the 15 sampling points. The scale on the Y-axis on the left refers to the same 0-1 NDVI scale as in Fig. 13 where zero is a dead plant and one is a perfectly green plant. The flights selected only show the beginning and end of the season. The scale is lower in June as some places have yet to close, and by July (not shown) the scale is at one across all points. As the line moves across the collection points, some trends in the greener (higher NDVI) points are apparent as opposed to the browner (lower NDVI) points. In June (blue line), the lowest points are 2, 6, and 14. Points 8 and 10 were noticeably greener than most other points as of June. By September points 1 and 10 are becoming browner, while points 5 and 12 are the greenest. Point 1 where there were five potential yield limiting factors, which was the greatest number of

potential problems recorded in the field. Point 1 is also the numerically greatest decrease in the NVDI value (greenness) between the start and end of September. It is possible that drone images can identify problem areas after the season is over if viewed in the manner. This ability is only of limited use to a grower or consultant who wants to identify a problem while corrective action can still be taken. In the case of this field, no clear trend was apparent in June or July to identify which point would see the greatest decrease in NDVI as September progressed. This wasn't the case for other fields in the study, where collection points with many factors associated with yield limitations were present and the point had noticeably lower NDVI as of June. In these fields, the NDVI recovered to 1 as of July, but the same pattern of decreased NDVI returned in August and became more pronounced throughout September. In these cases, a drone flight in June may identify areas where the canopy will die prematurely in August with a NDVI value that is already low in June, but the level of greenness is not discernable to the human eye on the ground. The fact that this June prescription would not have been accurate with field 10 indicates that this advice must be taken on an individual field basis based on the understanding the grower and consultant have of the situation. This interesting observation will absolutely be the subject of more study in the variability project.

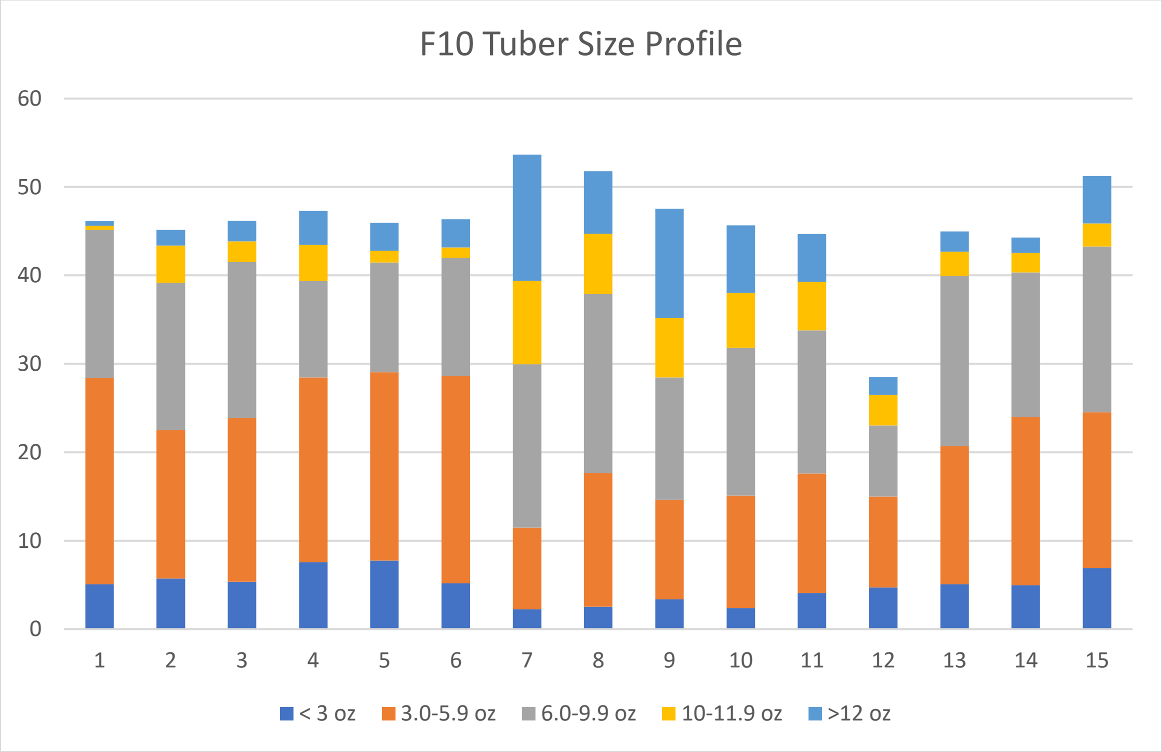
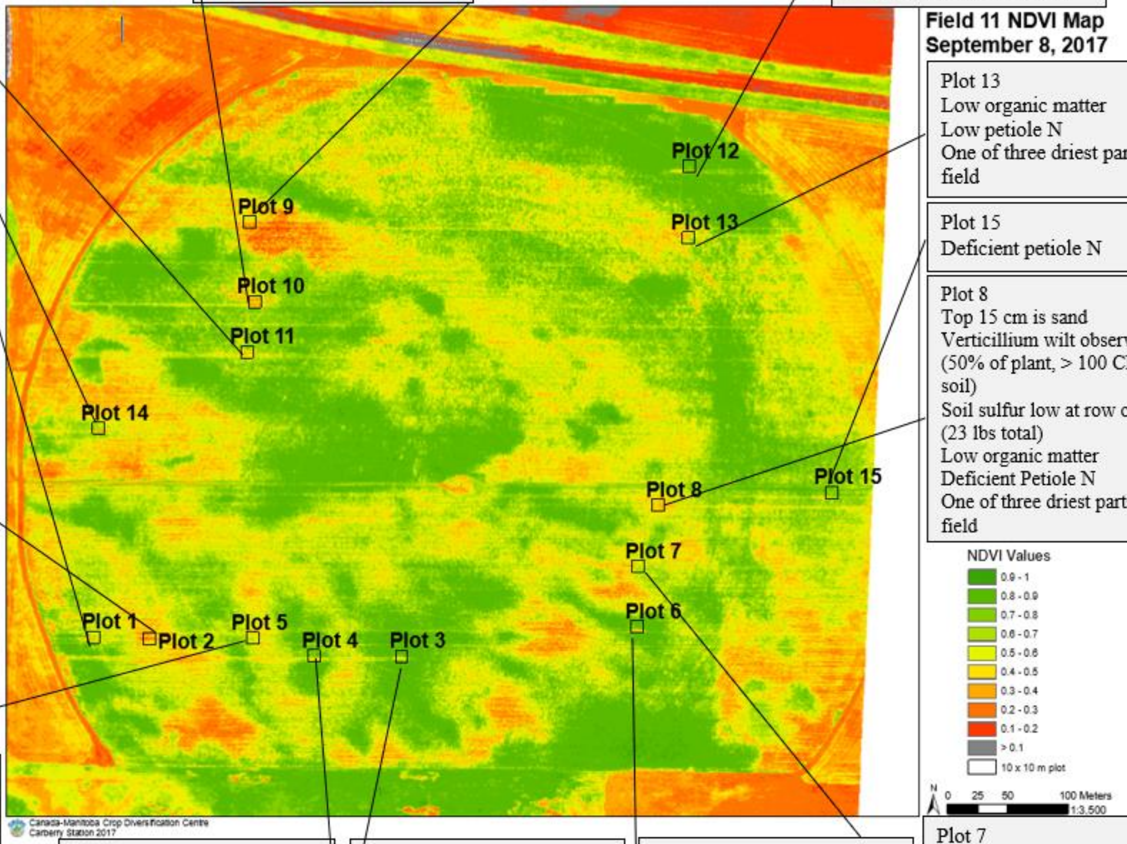


Fig. 14 (above) shows the total yield (after rot and green tubers removed) by size category. Each color represents a specific tuber size profile. For example, yellow bars near the top indicate the 10-11.9 oz tuber size. The yield is measured in hundredweight per acre (Cwt/A) on the right side, and the harvest date was the first week in September.

The lowest yielding sampling point numerically was point 12. In Fig. 12, this place in the field was noted as having compaction, low soil sulfur and nitrogen at mid bulking. In Fig. 13, this point didn't have much of a numerical drop in NDVI value throughout September. It is possible that the underlying causes of this low yield didn't kill the plant or enhance early die based on the drone results. In examining figure 14, it appears that the 3-6 oz and 6-10 oz are notably less than most other collection points. In the combined analysis for all processing fields, high soil sulfur at mid bulking was associated with yield limitation for 3-6 oz and 6-10 oz. It is quite possible that low soil sulfur also has a pronounced effect on these size categories based on observations from this field, although not tested by the analysis. Soil nitrogen was also important negative yield impact in the 6-10 oz size category, although it was excess soil nitrogen at row closure associated with less 6-10 oz tubers. In this field, it appears that less soil nitrogen at bulking also contributed to lower yield. The exact effects of sulfur and nitrogen individually on yield are not able to be separated based on observation or association with the partial least squares regression employed for all processing fields.

A final observation of note in field 10 is the high yielding sampling point was number seven, which was located in the south-central part of the field. This collection point had one of the largest yields with numerically greater 10-12 oz tubers and >12 oz tubers. What is notable aside from yield is that this point was not the greenest point in the drone flights and was limited by soil nitrogen at mid bulking, compaction, and low organic matter. This point was not limited by sulfur. It is possible that a factor outside of the study was part of the final yield, but the combination of nutrient limitations is interesting in terms of studying the effect of sulfur availability on yield remediation as a practice that can be altered by grower practice to increase 10-12 oz yield.

Field 11: Pictured below (Fig. 15) is a drone image identifying potential limiting factors to the whole field or specific points



Plot 10

High Verticillium CFU (>300), few wilted plants

Plot 9

Low organic matter

One of three driest parts of field

Plot 12
Only loam soil texture in field
Soil sulfur low at row closure (23 lbs total)
Low petiole N row closure

Plot 11

Low petiole N row closure

Plot 14
Top 15 cm is sand
Deficient petiole N

Plot 1

High Verticillium CFU (>300), few wilted plants

Plot 2
Top 30 cm is sand
Verticillium wilt observed (22% of plant, > 100 CFU in soil)
Soil sulfur low at row closure (22 lbs total) and mid bulking (18 lbs total)
Low organic matter
Deficient petiole N

Plot 5
Top 30 cm is sand
Low organic matter
Deficient petiole N

Potential limitations at all sites:

- All plots except 11, 12, 15 have compaction under hill
- Soil N low at row closure and mid bulking
- Petiole N low to deficient most sampling dates

Plot 4

Plot 3

Plot 6

Plot 13
Low organic matter
Low petiole N
One of three driest parts of field

Plot 15
Deficient petiole N

Plot 8
Top 15 cm is sand
Verticillium wilt observed (50% of plant, > 100 CFU in soil)
Soil sulfur low at row closure (23 lbs total)
Low organic matter
Deficient Petiole N
One of three driest parts of field

Plot 7
0-15 cm sandy loam, 15-30 cm is sand
High Verticillium CFU (>300), few wilted plants
Low organic matter
Deficient Petiole N

In addition to evaluating the impact of variables on yield of fresh and processing fields together, individual fields from 2017 were rated for nutrient, soil, disease, and plant health status. Drone imagery was used in conjunction with scouting, nutrient status as determined by Agvise recommendations, and yield to visualize variability at each sampling point and what trends were apparent in the overall yield. The point of this individual analysis is to demonstrate the usefulness of the Partial Least Square (PLS) analysis from all processing fields in identifying one or a few major yield-limiting factors from a larger list of potential problems listed for a specific site. This information begins the conversation with a local consultant and grower about priorities in remediating yield variability, and ultimately develop practices to remediate the situation.

Plot numbers in the drone images refer to the 15 sampling points in each field. The top of each image is north in each field, and the color scale refers to the NDVI values recorded by the drone. NDVI was recorded on a scale of 0-1, zero being red and refers to bare earth, 1 refers to green tissue, and varying shades of green to yellow indicate senescencing plant matter. It is important to note that weed canopy color will be recorded as well as potato, although no significant weed pressure was recorded in the sampling points in field 11.

For each individual field, certain variables were identified as potential problems for the whole field or individual collection points that could contribute to variable yield. Field 11 was observed to have compaction under the hill (beneath 30 cm/11.8 in from top of hill) with an excess of 300 PSI. Compaction was not among the top ten most influential variables listed in the complete processing analysis, indicating that it could be a problem on an individual field basis, but not among the worse problems across all processing fields.

Very little Verticillium wilt was recorded in the field, with the most disease observed on the south side of the field in points 1, 2, 7, and 8. *Verticillium* species counts exceeded 100 CFU /g in most points and >300 in points 1, 2, 7, and 10. It is generally accepted that 5-30 CFU/g of *V. dahliae* are necessary for infection. This plate count will encompass all Verticillium species, which doesn’t accurately rely the number of *V. dahliae* CFU. Verticillium wilt will need to be monitored in the field and it could be a factor in variable yield. The combined processing analysis indicated that the 10-12oz yield category is the size range most negatively impacted by high *Vertcillium* counts, as severely infected plants are killed or debilitated during late bulking when tubers are sizing in this range. Concern about any drops in 10-12 oz yield should consider the *Verticillium* counts in future years based on this information.

The main indicators of variable yield, among the variables recorded for the study, in this field are low soil nitrogen and sulfur in petioles and soil throughout the production season. Low soil nitrogen was recorded across all collection points at row closure and mid bulking, whereas low soil sulfur was a more sporadic problem with no obvious trend. Both sulfur and nitrogen were important nutrients involved in variable yield across all processing fields, and lower yield was associated with lower nitrogen or sulfur. In this case, the deficiency of petiole nitrate stands out as one of the largest issues. Petiole nitrate was low at row closure, while soil nitrogen was depleted. Petiole nitrate moved into deficiency at mid bulking.

Throughout the study, the lowest yielding points often had multiple potential limiting factors listed in the drone image like Fig. 12. Some of these limiting factors are inter-related, such as sand texture and nitrogen leaching. In the case of field 11, some sampling points like plot 15 had ten potential yield-limiting factors. <u>It is extremely likely that the combined effects of multiple problems contribute to yield limitation greater when combined than each factor individually</u>.

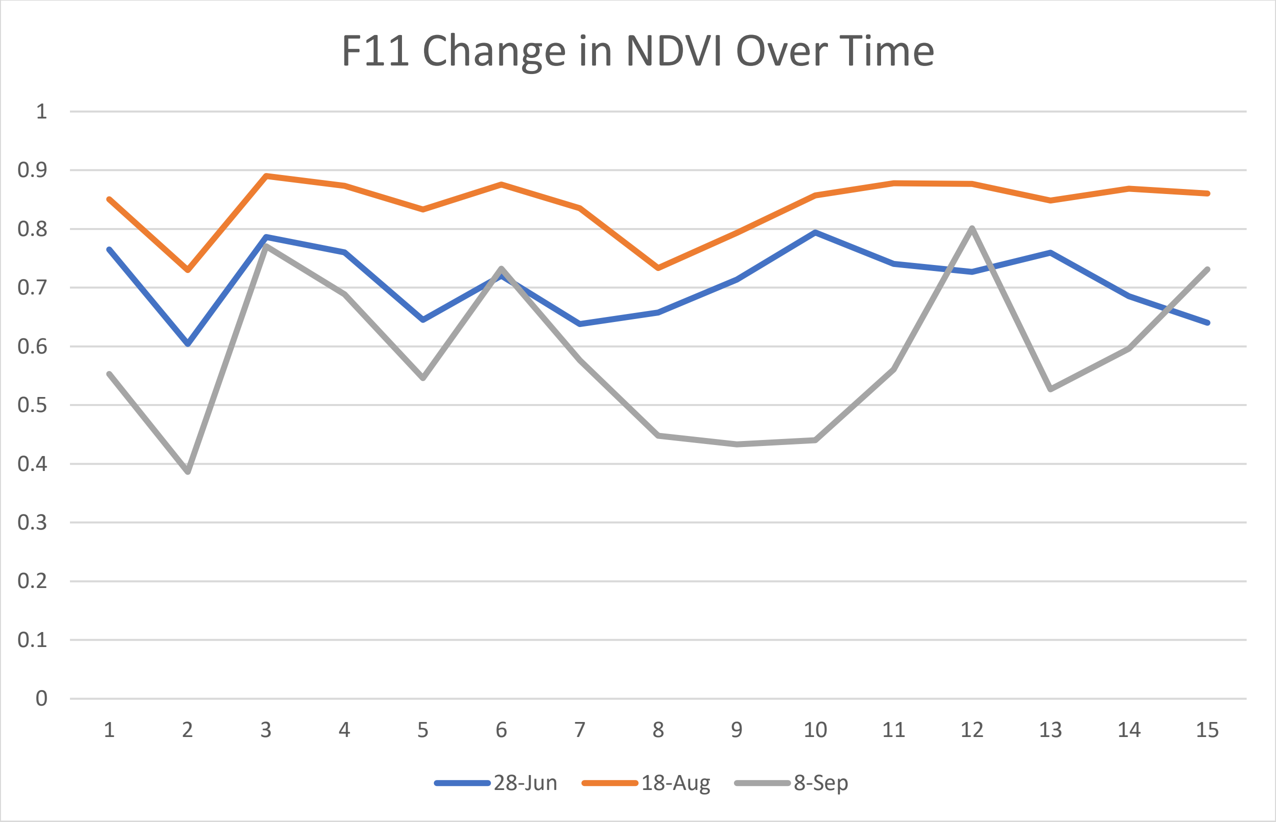


Fig 16. (Above) is another method of viewing the drone image from three drone flights at once. Each line represents an individual flight, and each flight date is on the bottom. The 1-15 on the bottom (X-axis) refers to each of the 15 sampling points. The scale on the Y-axis on the left refers to the same 0-1 NDVI scale as in Fig. 15 where zero is a dead plant and one is a perfectly green plant. The flights selected only show the beginning and end of the season. The scale is lower in June as some places have yet to close, and by July (not shown) the scale is at one across all points. As the line moves across the collection points, some trends in the greener (higher NDVI) points are apparent as opposed to the browner (lower NDVI) points. In June (blue line), the lowest points are 2, 5, 7, and 15. Points 3 and 10 were noticeably greener than most other points as of June. By September points 2, 8-10, and 13 are becoming browner, while points 3, 6, and 12 are the greenest. In the case of this field, no clear trend was apparent in June or July to identify which point would see the greatest decrease in NDVI as September progressed. Sampling points 2, 5, 7, 8, 12, and 13 had multiple yield-limiting factors observed throughout the production season in Fig. 15. These sampling points with many factors associated with yield limitations were present and the point had noticeably lower NDVI as of June. In these fields, the NDVI recovered to 1 as of July, but the same pattern of decreased NDVI returned in August and became more pronounced into September. In these cases, a drone flight in June may identify areas where the canopy will die prematurely in August with a NDVI value that is already low in June, but the level of greenness is not necessarily discernable to the human eye on the ground. This interesting observation will absolutely be the subject of more study in the variability project.

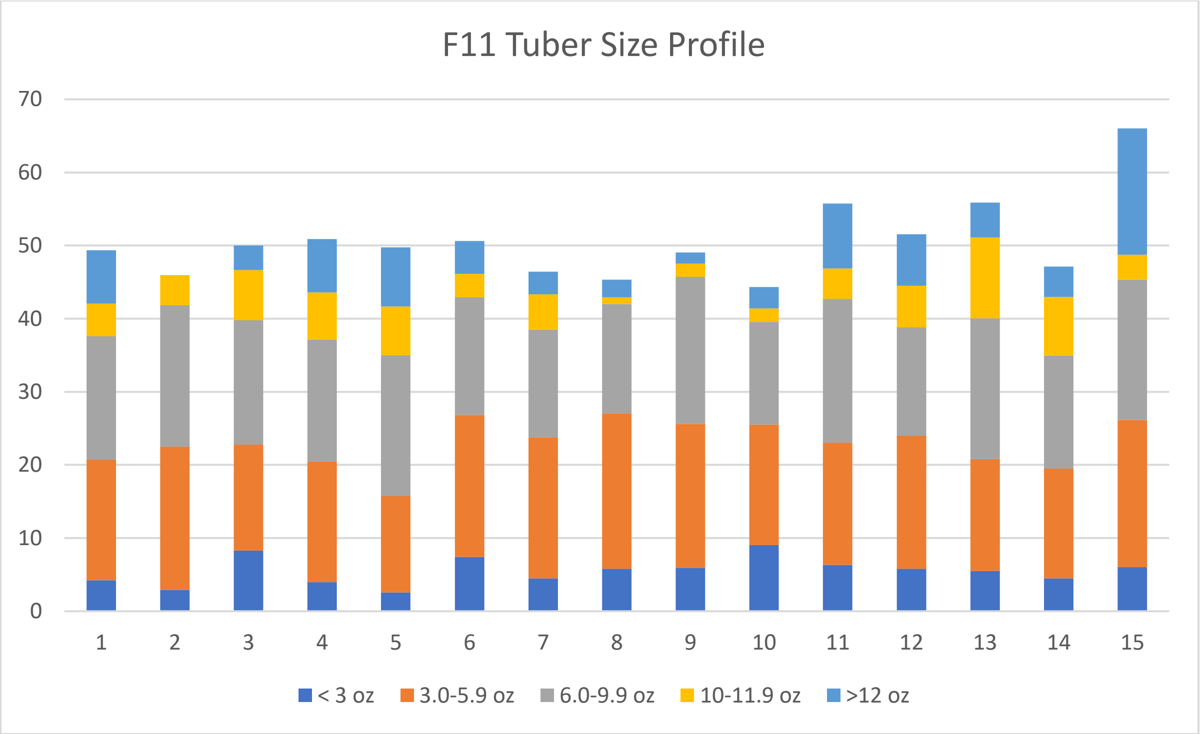
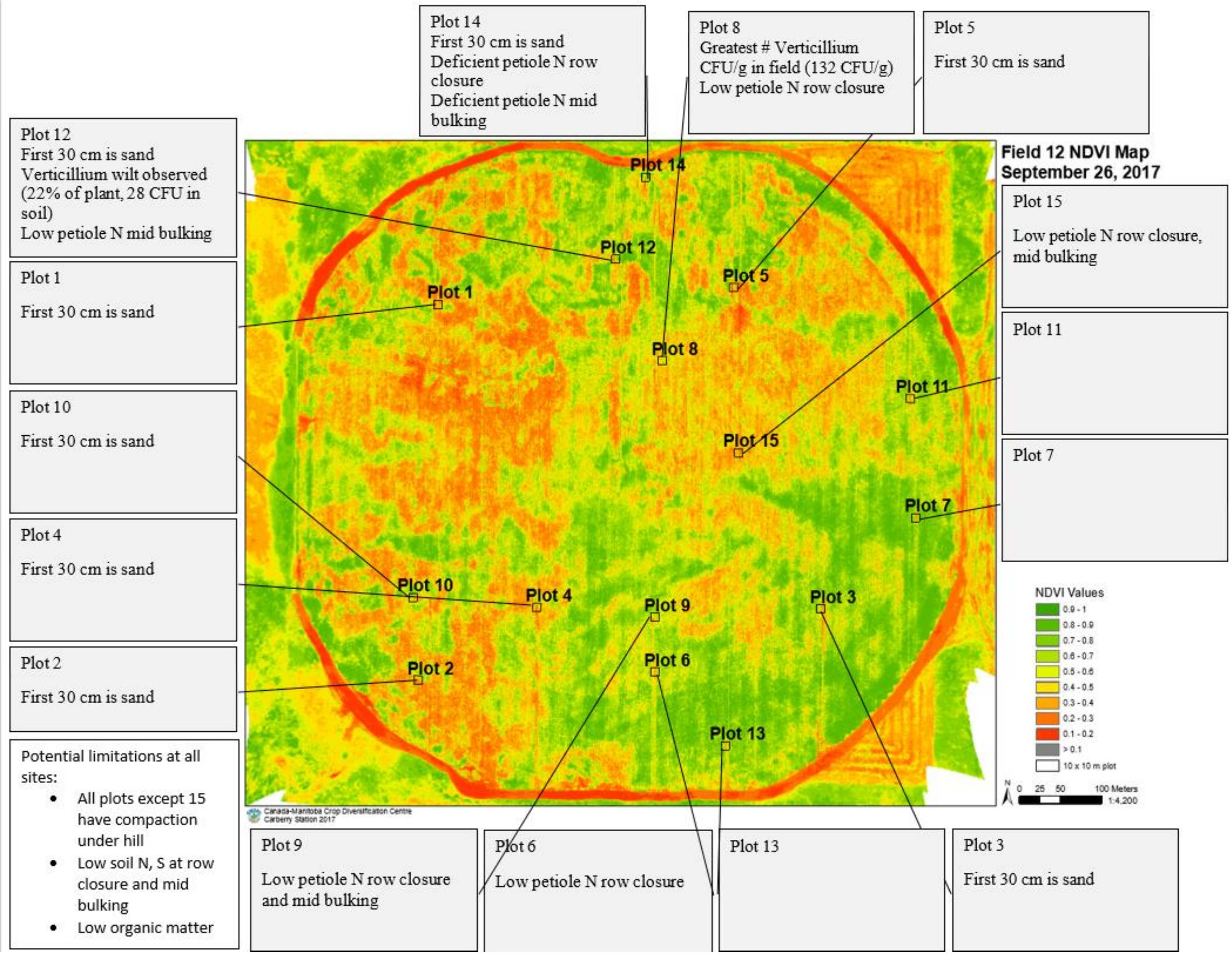


Fig. 17 (above) shows the total yield (after rot and green tubers removed) by size category. Each color represents a specific tuber size profile. For example, yellow bars near the top indicate the 10-11.9 oz tuber size. The yield is measured in hundredweight per acre (Cwt/A) on the right side, and the harvest date was the first week in September.

Despite the number of yield-limiting problems identified in previous sections, as well as the die down on drone images, it is not easy to numerically identify the lowest yielding sampling points in the field. The composition of 10-12 oz and >12 oz fluctuates point to point. The combined analysis of all processing fields identified *Verticillium* as the number one negative yield association for 10-12 oz tubers. More plainly, as soil *Verticillium* counts rise, the number of 10-12 oz tubers generally decreases. Points 1, 2, 7, and 10 had the greatest *Verticillium* counts, and fewer 10-12 and > 12 oz tubers. Points 8 and 9 also had fewer 10-12 and > 12 oz tubers, indicating more than *Verticillium* needs to be considered. Points 8 and 9 also had low organic matter and soil moisture throughout the season, in addition to the nitrogen problems outlined earlier. These factors could contribute to the fewer 10-12 and > 12 oz tubers.

It is relatively easier to look at Fig. 14 and identify point 15 as the numerically greatest yield. It appears that there were many > 12 oz tubers in this point in the far east of the field. The list of potential problems is also shorter at point 15, and only includes the nitrogen problems previously mentioned. The combined analysis of all processing fields associates more >12 oz yield with less soil nitrogen at row closure and more soil sulfur at row closure. The nitrogen problems at this point could have been of benefit in not providing excess nitrogen, and the availability of sulfur could have improved the >12 oz yield in this point. However, field notes indicate the entire field was recently extended eastward. This sampling point is likely to have a different cropping history than the remainder of the field that was not included in this study that could contribute to the >12 oz yield.

Field 12 Pictured below (Fig. 18) is a drone image identifying potential limiting factors to the whole field or specific points



Plot 14
First 30 cm is sand
Deficient petiole N row closure
Deficient petiole N mid bulking

Plot 8
Greatest # Verticillium CFU/g in field (132 CFU/g)
Low petiole N row closure

Plot 5

First 30 cm is sand

Plot 12
First 30 cm is sand
Verticillium wilt observed (22% of plant, 28 CFU in soil)
Low petiole N mid bulking

Plot 1

First 30 cm is sand

Plot 10

First 30 cm is sand

Plot 4

First 30 cm is sand

Plot 2

First 30 cm is sand

Plot 15

Low petiole N row closure, mid bulking

Plot 11

Plot 7

Plot 9

Low petiole N row closure and mid bulking

Plot 6

Low petiole N row closure

Plot 13

Plot 3

First 30 cm is sand

Potential limitations at all sites:

- All plots except 15 have compaction under hill
- Low soil N, S at row closure and mid bulking
- Low organic matter

In addition to evaluating the impact of variables on yield of fresh and processing fields together, individual fields from 2017 were rated for nutrient, soil, disease, and plant health status. Drone imagery was used in conjunction with scouting, nutrient status as determined by Agvise recommendations, and yield to visualize variability at each sampling point and what trends were apparent in the overall yield. The point of this individual analysis is to demonstrate the usefulness of the Partial Least Square (PLS) analysis from all processing fields in identifying one or a few major yield-limiting factors from a larger list of potential problems listed for a specific site. This information begins the conversation with a local consultant and grower about priorities in remediating yield variability, and ultimately develop practices to remediate the situation.

Plot numbers in the drone images refer to the 15 sampling points in each field. The top of each image is north in each field, and the color scale refers to the NDVI values recorded by the drone. NDVI was recorded on a scale of 0-1, zero being red and refers to bare earth, 1 refers to green tissue, and varying shades of green to yellow indicate senescencing plant matter. It is important to note that weed canopy color will be recorded as well as potato, and all points in the northern half of the field were noted to have eastern black nightshade.

For each individual field, certain variables were identified as potential problems for the whole field or individual collection points that could contribute to variable yield. Field 12 was observed to have compaction under the hill (beneath 30 cm/11.8 in from top of hill) with an excess of 300 PSI. Compaction was not among the top ten most influential variables listed in the complete processing analysis, indicating that it could be a problem on an individual field basis, but not among the worse problems across all processing fields.

Very little Verticillium wilt was recorded in the field, with the most disease observed on the south side of the field in point 8. *Verticillium* species counts exceeded 100 CFU /g in plot 8. Wilt was only observed in plot 12, which had a low (28 CFU) count. It is generally accepted that 5-30 CFU/g of *V. dahliae* are necessary for infection. This plate count will encompass all Verticillium species, which doesn't accurately rely the number of *V. dahliae* CFU. Verticillium wilt will need to be monitored in the field and it could be a factor in variable yield. The combined processing analysis indicated that the 10-12 oz yield category is the size range most negatively impacted by high *Verticillium* counts, as severely infected plants are killed or debilitated during late bulking when tubers are sizing in this range. Concern about any drops in 10-12 oz yield should consider the *Verticillium* counts in future years based on this information. Eastern black nightshade was noted as a problem in most collection points on the north side of the field. There is a known interaction with *Verticillium* and nightshade where nightshade is not only a host, but also trains the *Verticillium* to be aggressive on potato. As the *Verticillium* becomes aggressive to potato, lower counts are necessary to induce higher levels of disease. Nightshade control then becomes another factor to keep in mind for this specific field but will be overlooked by the total analysis of combined processing fields because nightshade wasn't present in all fields.

The main indicators of variable yield, among the variables recorded for the study, in this field are low soil nitrogen and sulfur in petioles and soil at row closure and mid bulking. Both sulfur and nitrogen were important nutrients involved in variable yield across all processing fields, and lower yield was associated with lower nitrogen or sulfur.

Throughout the study, the lowest yielding points often had multiple potential limiting factors listed in the drone image. Some of these limiting factors are inter-related, such as sand texture and nitrogen leaching. In the case of field 12, some sampling points like plot 14 had ten potential yield-limiting factors. <u>It is extremely likely that the combined effects of multiple problems contribute to yield limitation greater when combined than each factor individually</u>.

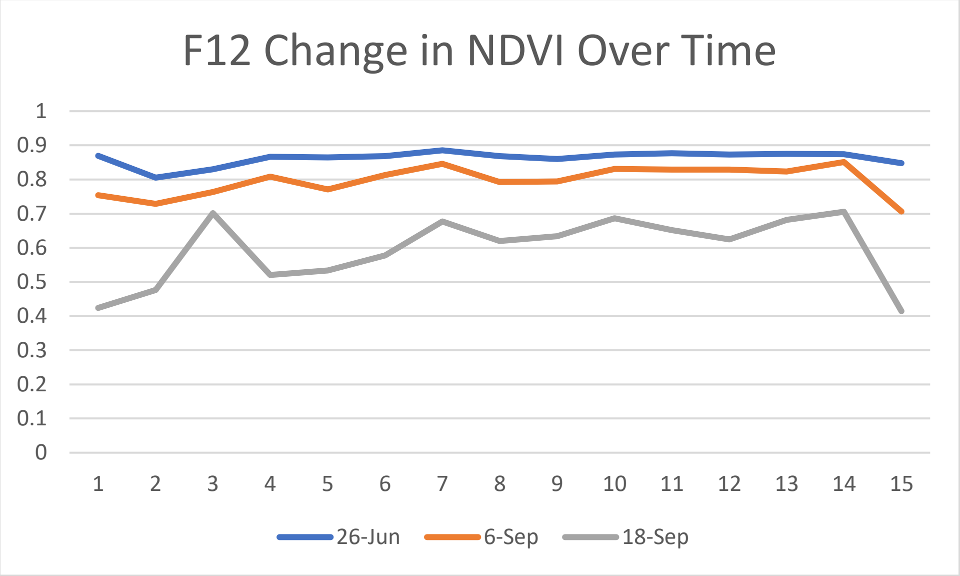


Fig 19. (Above) is another method of viewing the drone image from three drone flights at once. Each line represents an individual flight, and each flight date is on the bottom. The 1-15 on the bottom (X-axis) refers to each of the 15 sampling points. The scale on the Y-axis on the left refers to the same 0-1 NDVI scale as in Fig. 15 where zero is a dead plant and one is a perfectly green plant. The flights selected only show the beginning and end of the season. As the line moves across the collection points, some trends in the greener (higher NDVI) points are apparent as opposed to the browner (lower NDVI) points. In some fields in 2017, the line between collection

points was similar in June as it was in September, indicating we can see the weaker sampling points via drone flight months before early die sets in. Your field is a counter example where the lowest (less green) sampling point in June (plot 2) was not the lowest point in September. Additionally, plot 14 had numerous yield-limiting factors associated with it and yet was one of the greenest points. More research would be necessary to develop the June drone image as a predictive tool for early die.

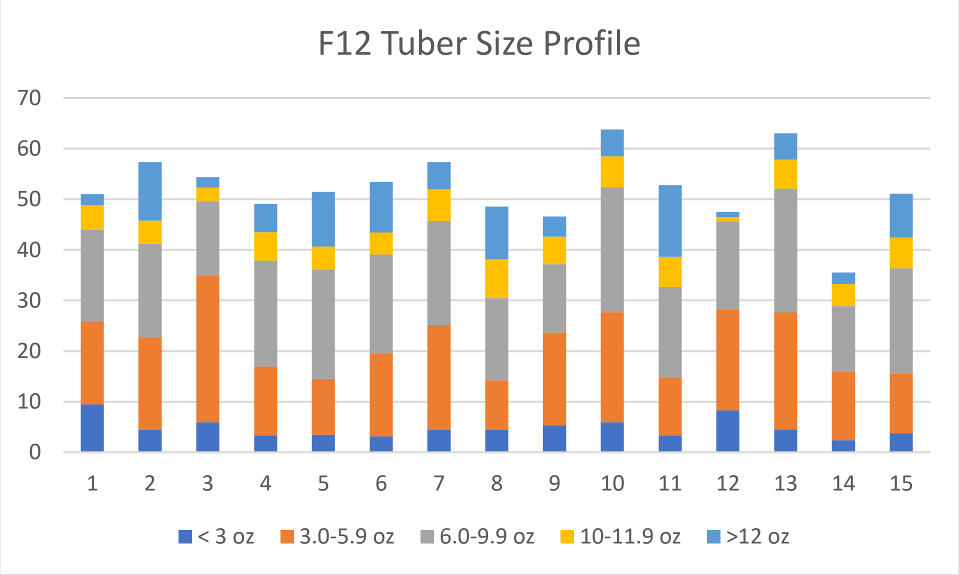
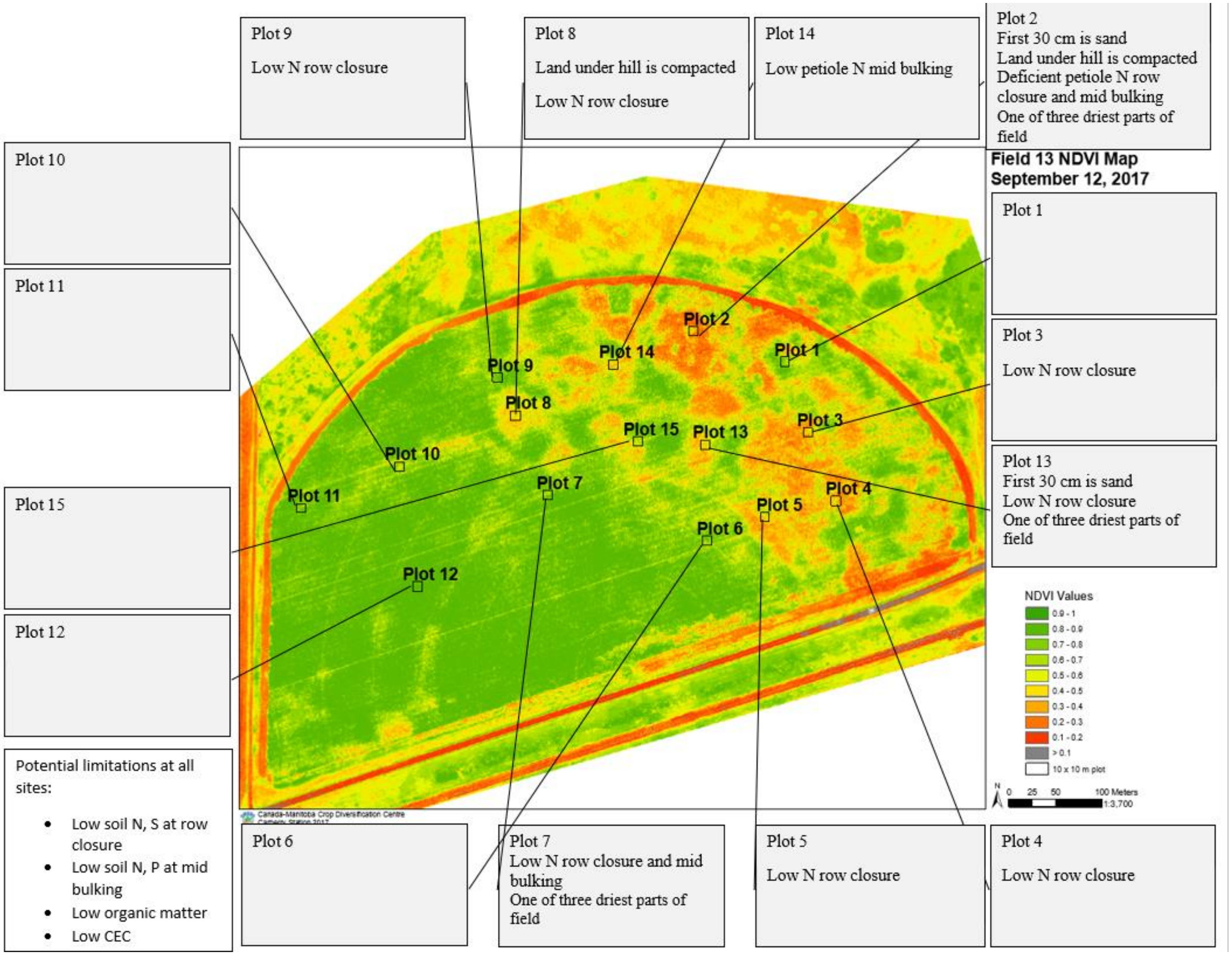


Fig. 20 (above) shows the total yield (after rot and green tubers removed) by size category. Each color represents a specific tuber size profile. For example, yellow bars near the top indicate the 10-11.9 oz tuber size. The yield is measured in hundredweight per acre (Cwt/A) on the right side, and the harvest date was the first week in September.

Despite the number of yield-limiting problems identified in previous sections, as well as the die down on drone images, it is not easy to numerically identify the lowest yielding sampling points in the field. Without statistics, it appears that point 14 is has the lowest total yield and all size categories are less than the remaining points. Plot 14 had six possible yield-limiting factors identified though soil and petiole samples for the project. Plot 14 also had many Eastern Black Nightshade plants that could reduce yield. The highest yielding points (numerically) were sites 10 and 13, which had few to no potential yield-limiting factors identified.

Field 13 Pictured below (Fig. 21) is a drone image identifying potential limiting factors to the whole field or specific points



Plot 9

Low N row closure

Plot 8

Land under hill is compacted

Low N row closure

Plot 14

Low petiole N mid bulking

Plot 2
First 30 cm is sand
Land under hill is compacted
Deficient petiole N row closure and mid bulking
One of three driest parts of field

Plot 10

Plot 11

Plot 1

Plot 3

Low N row closure

Plot 13
First 30 cm is sand
Low N row closure
One of three driest parts of field

Plot 15

Plot 12

Potential limitations at all sites:

- Low soil N, S at row closure
- Low soil N, P at mid bulking
- Low organic matter
- Low CEC

Plot 6

Plot 7
Low N row closure and mid bulking
One of three driest parts of field

Plot 5

Low N row closure

Plot 4

Low N row closure

In addition to evaluating the impact of variables on yield of fresh and processing fields together, individual fields from 2017 were rated for nutrient, soil, disease, and plant health status. Drone imagery was used in conjunction with scouting, nutrient status as determined by Agvise recommendations, and yield to visualize variability at each sampling point and what trends were apparent in the overall yield. The point of this individual analysis is to demonstrate the usefulness of the Partial Least Square (PLS) analysis from all processing fields in identifying one or a few major yield-limiting factors from a larger list of potential problems listed for a specific site. This information begins the conversation with a local consultant and grower about priorities in remediating yield variability, and ultimately develop practices to remediate the situation.

Plot numbers in the drone images refer to the 15 sampling points in each field. The top of each image is north in each field, and the color scale refers to the NDVI values recorded by the drone. NDVI was recorded on a scale of 0-1, zero being red and refers to bare earth, 1 refers to green tissue, and varying shades of green to yellow indicate senescencing plant matter. It is important to note that weed canopy color will be recorded as well as potato, and all points in the northern half of the field were noted to have eastern black nightshade.

For each individual field, certain variables were identified as potential problems for the whole field or individual collection points that could contribute to variable yield. Field 13 was generally sandy loam, but only two points of 2 and 13 had sand texture. Sand points were generally the driest points in the field. Little *Verticillium* and few points of compaction were observed, which is unusual for this experiment. Chlorosis unlikely to be Verticillium wilt as most points were under 30 CFU/g, which is theoretically capable of causing disease but not often observed in the field.

The main indicators of variable yield, among the variables recorded for the study, in this field are low soil nitrogen and sulfur in petioles and soil at row closure and mid bulking. Both sulfur and nitrogen were important nutrients involved in variable yield across all processing fields, and lower yield was associated with lower nitrogen or sulfur.

Throughout the study, the lowest yielding points often had multiple potential limiting factors listed in the drone image. Some of these limiting factors are inter-related, such as sand texture and nitrogen leaching. In the case of field 13, some sampling points like plot 2 had six potential yield-limiting factors. It is extremely likely that the combined effects of multiple problems contribute to yield limitation greater when combined than each factor individually.

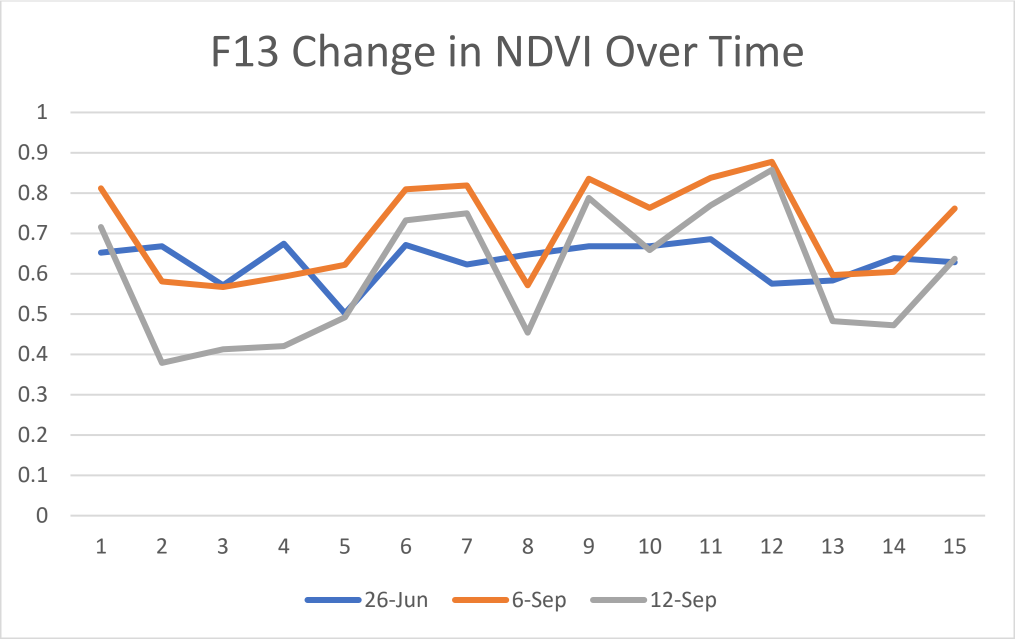


Fig 22. (Above) is another method of viewing the drone image from three drone flights at once. Each line represents an individual flight, and each flight date is on the bottom. The 1-15 on the bottom (X-axis) refers to each of the 15 sampling points. The scale on the Y-axis on the left refers to the same 0-1 NDVI scale as in Fig. 15 where zero is a dead plant and one is a perfectly green plant. The flights selected only show the beginning and end of the season. The scale is lower in June as some places have yet to close, and by July (not shown) the scale is at one across all points. As the line moves across the collection points, some trends in the greener (higher NDVI) points are apparent as opposed to the browner (lower NDVI) points. In some fields in the experiment, the line and trends are similar between June (blue) and September (orange and grey).

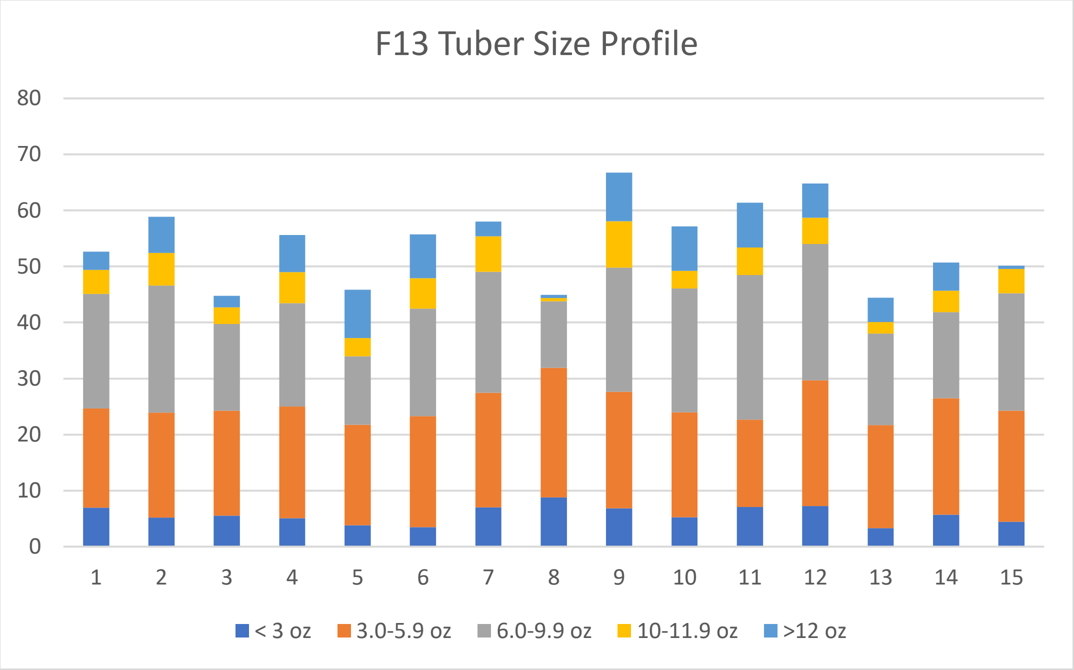


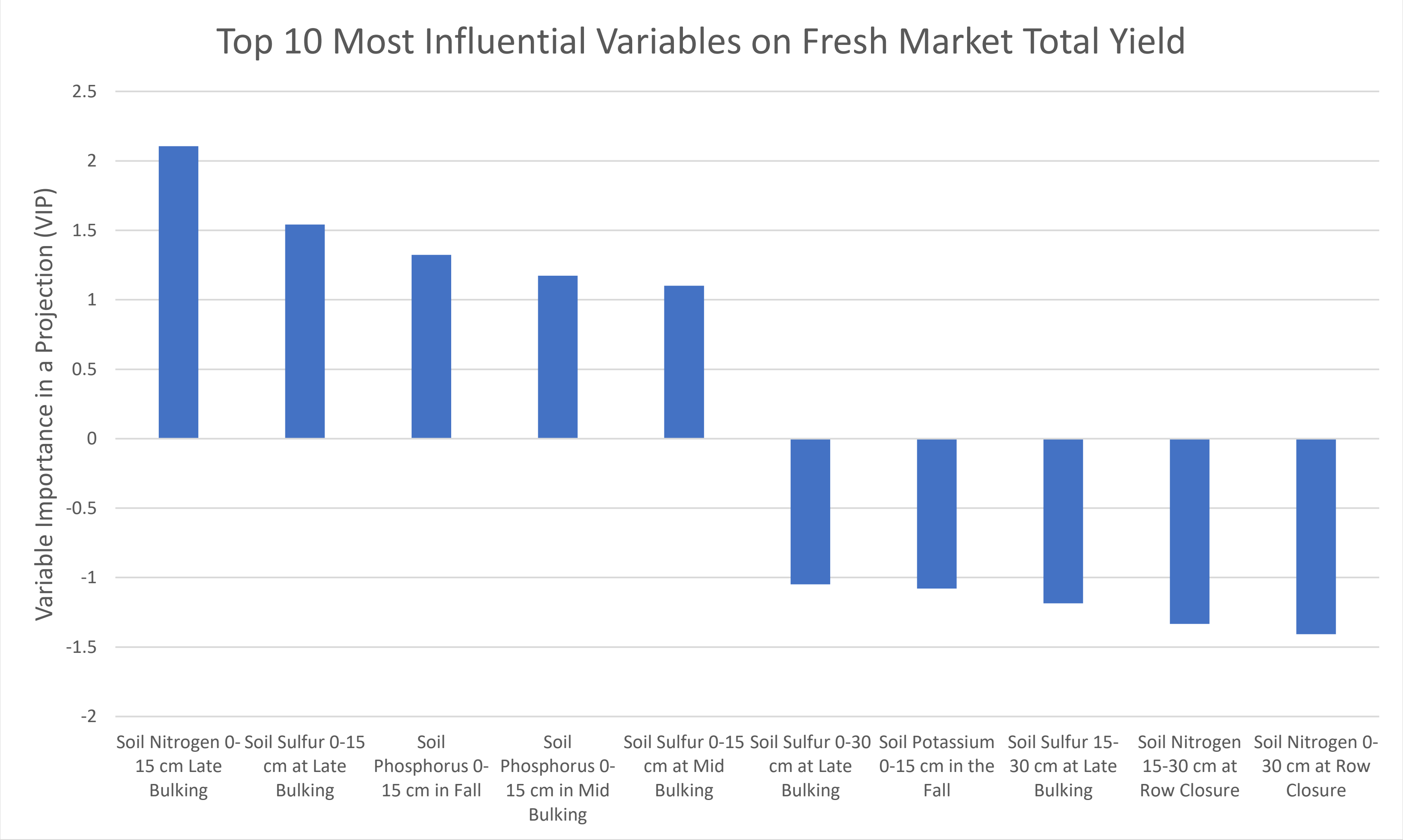
Fig. 22 (above) shows the total yield (after rot and green tubers removed) by size category. Each color represents a specific tuber size profile. For example, yellow bars near the top indicate the 10-11.9 oz tuber size. The yield is measured in hundredweight per acre (Cwt/A) on the right side, and the harvest date was the first week in September.

Despite the number of yield-limiting problems identified in previous sections, as well as the die down on drone images, it is not easy to statistically identify the lowest yielding sampling points in the field. Without statistics, it appears that point 13 is the lowest total yield and all size categories are less than the remaining points. Plot 13 had seven possible yield-limiting factors identified though soil and petiole samples for the project. The highest yielding points (numerically) were sites 9 and 12, which had few to no potential yield-limiting factors identified.

Fresh Market Fields

Total Yield Using one model for all response variables

A 4-component model containing 21 variables explained 96% of the variability in fresh market total yield (Table 10).



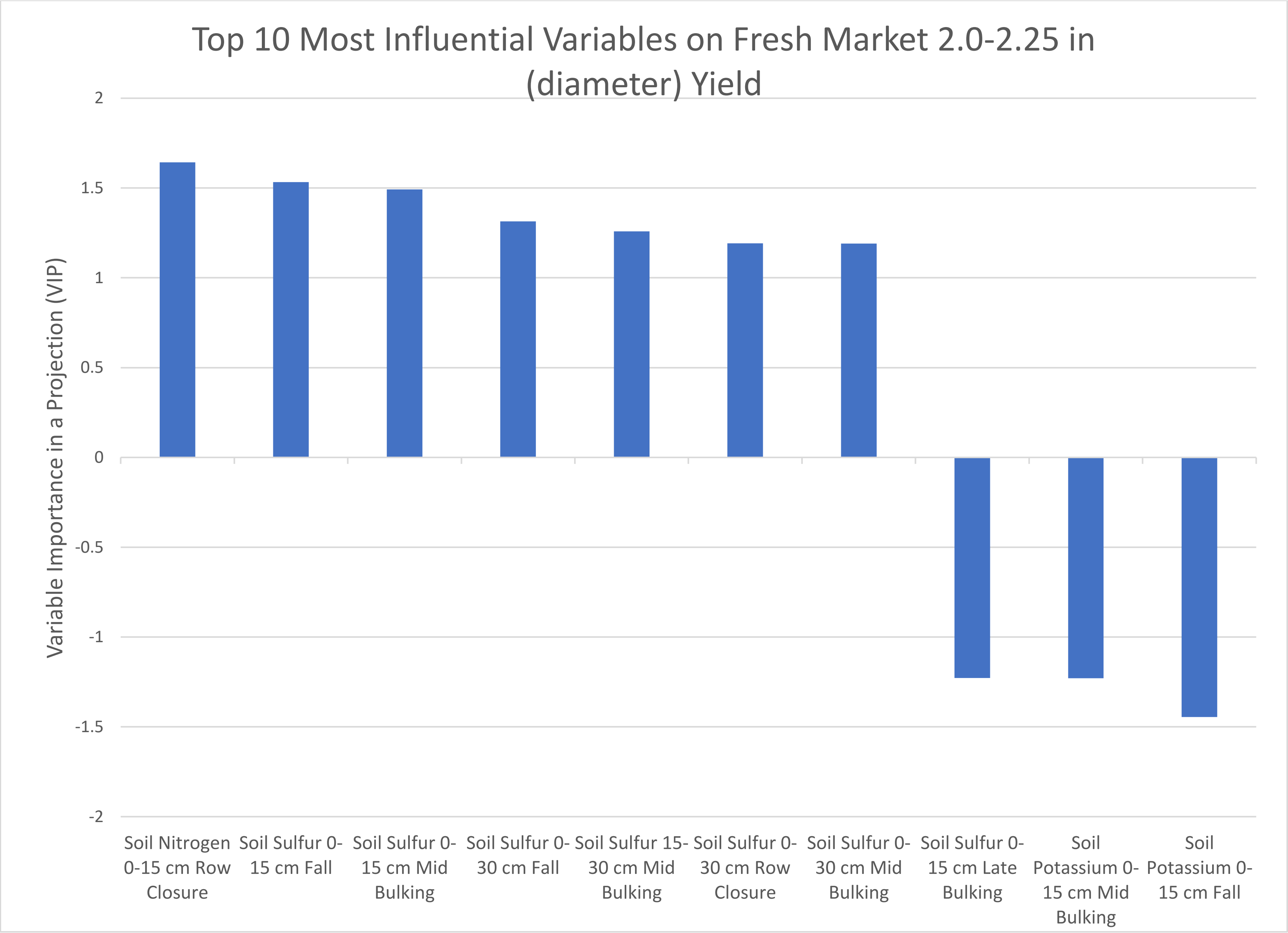
Listed above (Fig. 23) are the top ten most influential positive and negative variables on total yield of two 'Red Norland' fresh market fields evaluated in 2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil and PPM in petioles, as determined by Agvise testing. The Y axis identifies the Variable of Importance in Projection (VIP) in the creation of the model predicting total yield. Greater positive VIP (above zero) indicates that variable has a bigger, positive association with yield. In other words, a bigger VIP indicates that greater total yield from sampling points was associated with the increasing amount of this nutrient in the soil or petiole. Lower, negative VIPs (below zero) indicates that variable has a bigger negative association with yield. As the VIP drops, the increasing or decreasing amount of that nutrient is associated with the lowest yielding sampling points. The exact relationship between a negative VIP and too much or too little of nutrient must be determined by a resource such as Agvise recommendations or the Manitoba Soil Fertility guide (https://www.gov.mb.ca/agriculture/crops/soil-fertility/soil-fertility-guide/), which is designed for 'Russet Burbank'. It is important to note that 15-25 variables were associated with yield for all tuber size categories and total yield, but only the top ten were reported here for simplicity.

Soil nitrogen, sulfur, and phosphorus at several growth stages are associated positively with total yield. Translated plainly, the higher ranges of those three nutrients were associated with our highest-yielding points. Soil nitrogen at late bulking varied from 3.5 – 25.0 lbs available at late bulking. Soil sulfur at late bulking ranged from 0-88 lbs. Soil phosphorus varied in the fall from 12-46 PPM and 10-49 PPM at mid bulking. As the VIP increases, the positive effect on yield also increases. For example, the positive effect of more soil nitrogen at late bulking is greater than soil sulfur at late bulking. Each of these results is an association based on field conditions, which is worthy of note, but requires field validation before experimentally-validated recommendations to remediate nutrient deficiencies can be reliably issued.

On the negative side of the equation, soil nitrogen at row closure was a negative yield association. Soil nitrogen at row closure ranged from 10.5 to 117.5 lbs N available, with more sampling points being low-to-deficient rather than in excess of the needed nitrogen. It is possible that too little nitrogen at row closure is what is responsible for the negative yield association. The same situation is observed with soil potassium and sulfur negative yield associations – too little of that nutrient is likely the root cause of the negative yield association.

2 to 2.25-inch diameter category

The 2-component model containing 19 variables explained 41% of the variability in the percentage of yield in the fresh market 2-2.25-inch diameter category (Table 11).

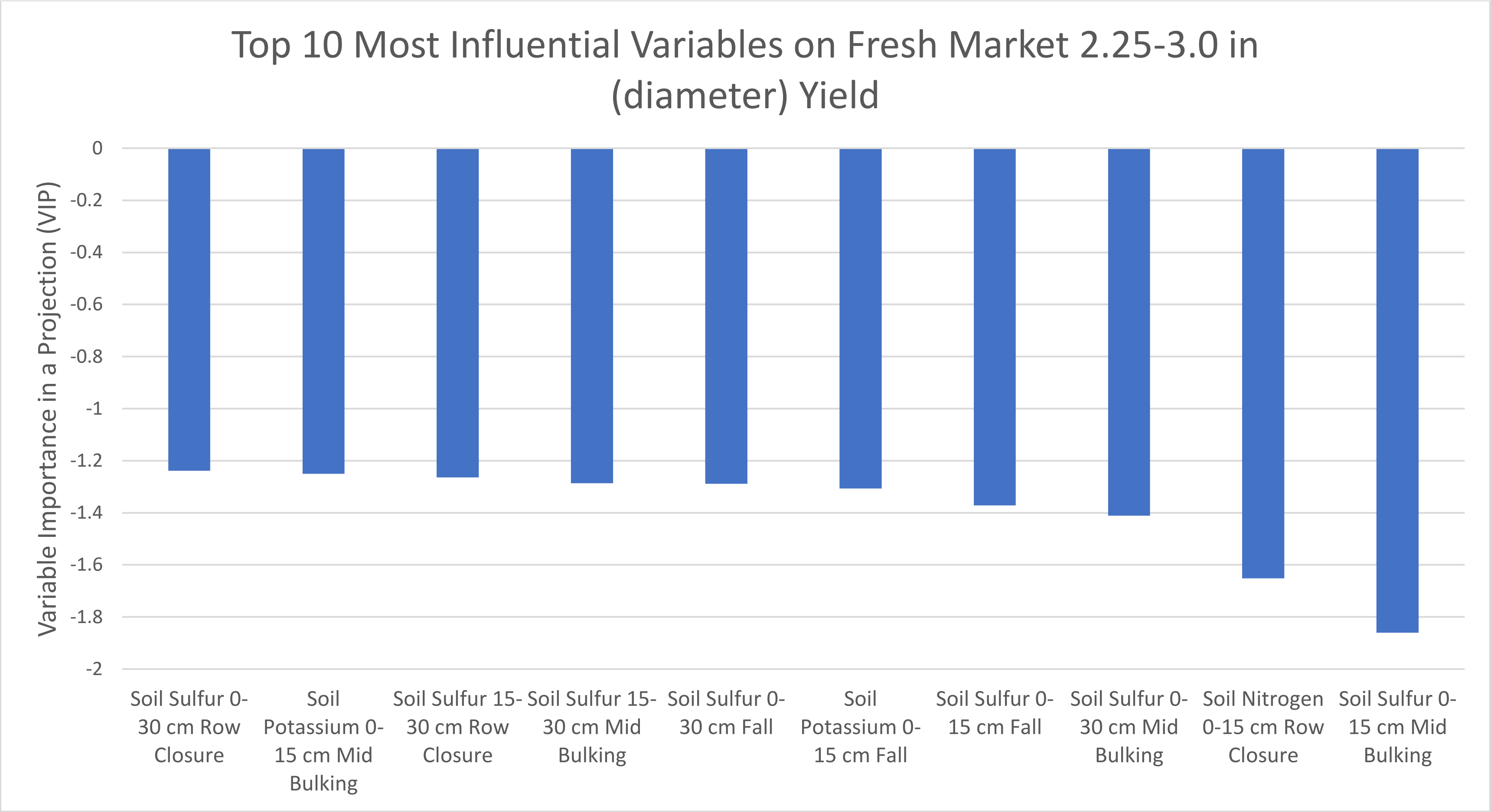

Top 10 Most Influential Variables on Fresh Market 2.0-2.25 in (diameter) Yield
Variable Importance in a Projection (VIP)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Soil Nitrogen 0-15 cm Row Closure
Soil Sulfur 0-15 cm Fall
Soil Sulfur 0-15 cm Mid Bulking
Soil Sulfur 0-30 cm Fall
Soil Sulfur 15-30 cm Mid Bulking
Soil Sulfur 0-30 cm Row Closure
Soil Sulfur 0-30 cm Mid Bulking
Soil Sulfur 0-15 cm Late Bulking
Soil Potassium 0-15 cm Mid Bulking
Soil Potassium 0-15 cm Fall

Listed above (Fig. 24) are the top ten most influential positive and negative variables on total yield of two ‘Red Norland’ fresh market fields evaluated in 2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil and PPM in petioles, as determined by Agvise testing. The Y axis identifies the Variable of Importance in Projection (VIP) in the creation of the model predicting total yield. Greater positive VIP (above zero) indicates that variable has a bigger, positive association with yield. In other words, a bigger VIP indicates that greater total yield from sampling points was associated with the increasing amount of this nutrient in the soil or petiole. Lower, negative VIPs (below zero) indicates that variable has a bigger negative association with yield.

Soil nitrogen and sulfur at several growth stages are associated positively with total yield. Translated plainly, the higher ranges of those nutrients were associated with our highest-yielding points. Soil nitrogen at row closure ranged from 10.5 to 117.5 lbs N available, with more sampling points being low-to-deficient rather than in excess of the needed nitrogen. Soil sulfur varied from 0-120 lbs available in the soil throughout the sampling date from row closure to fall soil sampling (postharvest), which would range from deficient to very high for ‘Russet Burbanks’. The positive yield association points to the higher ranges (40-60 lbs were common high observations in the experiment) as the likely yield-benefitting range, but field experimentation is needed to identify this exact range and the best practices to get there. This is especially important given our range of quality was determined for another cultivar other than ‘Red Norland’. The negative yield associations for sulfur and potassium likely originate from soil samples deficient in these nutrients.

2.25 to 3.0-inch diameter category

The 2-component model containing 17 variables explained 52% of the variability in the percentage of yield in the fresh market 2.25 to 3.0-inch diameter category (Table 12).

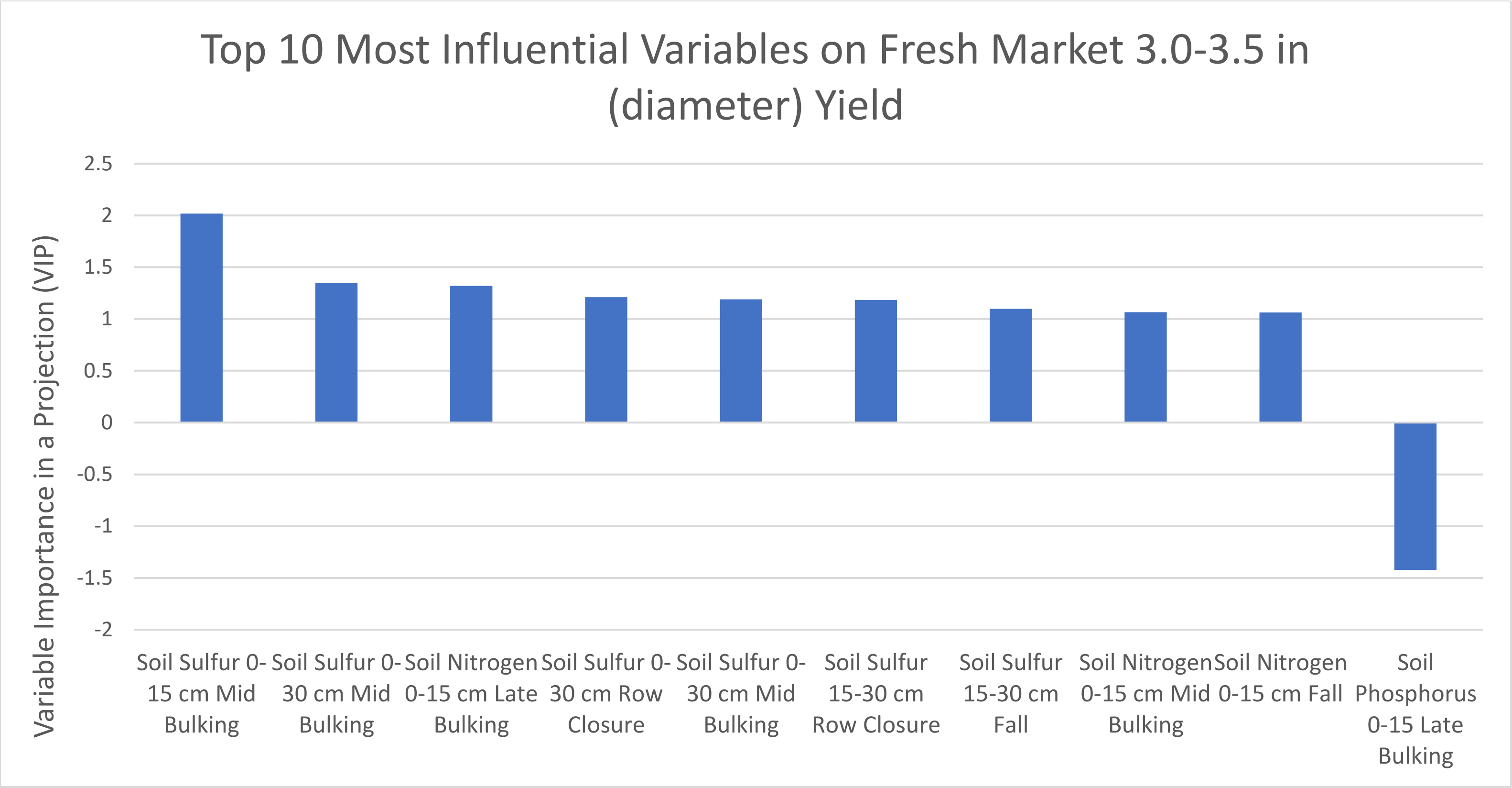


Listed above (Fig. 25) are the top ten most influential positive and negative variables on total yield of two ‘Red Norland’ fresh market fields evaluated in 2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil and PPM in petioles, as determined by Agvise testing. The Y axis identifies the Variable of Importance in Projection (VIP) in the creation of the model predicting total yield. Greater positive VIP (above zero) indicates that variable has a bigger, positive association with yield. In other words, a bigger VIP indicates that greater total yield from sampling points was associated with the increasing amount of this nutrient in the soil or petiole. Lower, negative VIPs (below zero) indicates that variable has a bigger negative association with yield.

These results are unusual in that this is the only size category in the whole experiment, fresh market or processing, where the top 10 most influential variables were all negative. Based on previous results with nitrogen, potassium, and sulfur in the soil, low to deficient soil status is a likely culprit for the negative yield association.

3.0 to 3.5-inch diameter category

The 2-component model containing 22 variables explained 78% of the variability in the percentage of yield in the fresh market 3.0 to 3.5-inch diameter category.



Listed above (Fig. 26) are the top ten most influential positive and negative variables on total yield of two ‘Red Norland’ fresh market fields evaluated in 2017. The X axis (bottom) identifies the variable recorded, whether it was from the soil or petioles, and the time of year it was collected. Nutrients were generally recorded as lbs available to the plant in soil and PPM in petioles, as determined by Agvise testing. The Y axis identifies the Variable of Importance in Projection (VIP) in the creation of the model predicting total yield. Greater positive VIP (above zero) indicates that variable has a bigger, positive association with yield. In other words, a bigger VIP indicates that greater total yield from sampling points was associated with the increasing amount of this nutrient in the soil or petiole. Lower, negative VIPs (below zero) indicates that variable has a bigger negative association with yield.

The interpretation of these results is that higher ranges of soil sulfur and nitrogen at several growth stages have positive yield associations with these larger tubers. Interestingly, the soil sulfur at mid bulking has the strongest, positive yield association of all the growth stages. This is very consistent with previous results for smaller diameter tubers and even total yield. Consistency is important in evaluating the quality of the results of any study, this one included. Based on previous results with potassium in the soil, low to deficient soil status is a likely culprit for the negative yield association.

2017 Fresh Market Field Individual Analysis

Field 14

The total yield for field 14 (Fig. 27, below) is shown. Offhand, there appears to be more variability in total yield for these fresh market fields planted to ‘Red Norland’, but less variability within the tuber size profiles on the lower end (2.25 inches and under). However, this comparison is not one that can be subject to statistics due to differences in market class, location, and cultivar differences between the fresh market and processing fields included in the experiment. It is important to note that sampling points 2, 6, and 10 had numerically higher numbers of misshapen tubers than the other points (all over 1 lb of the harvested potatoes). Sampling points 9, 12 and 15 had the only russeting recorded in the experiment with 0.3, 1.78, and 0.64 lbs, respectively. Most of the yield variability came from 2.25-3.0 in. diameter tubers and 3.0-3.5 in tubers. No tubers were harvested that were in excess of 3.5 inches.

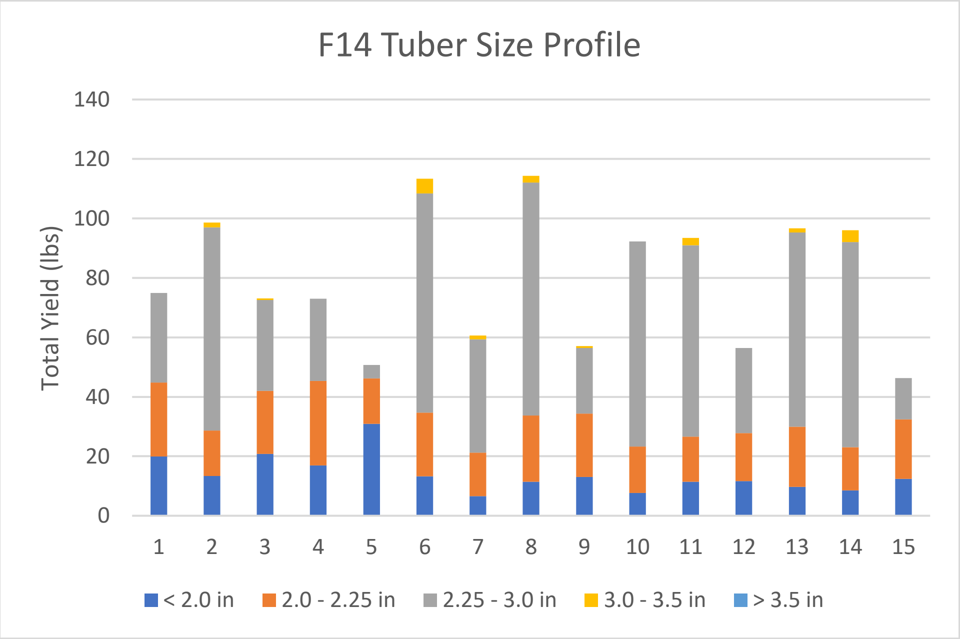


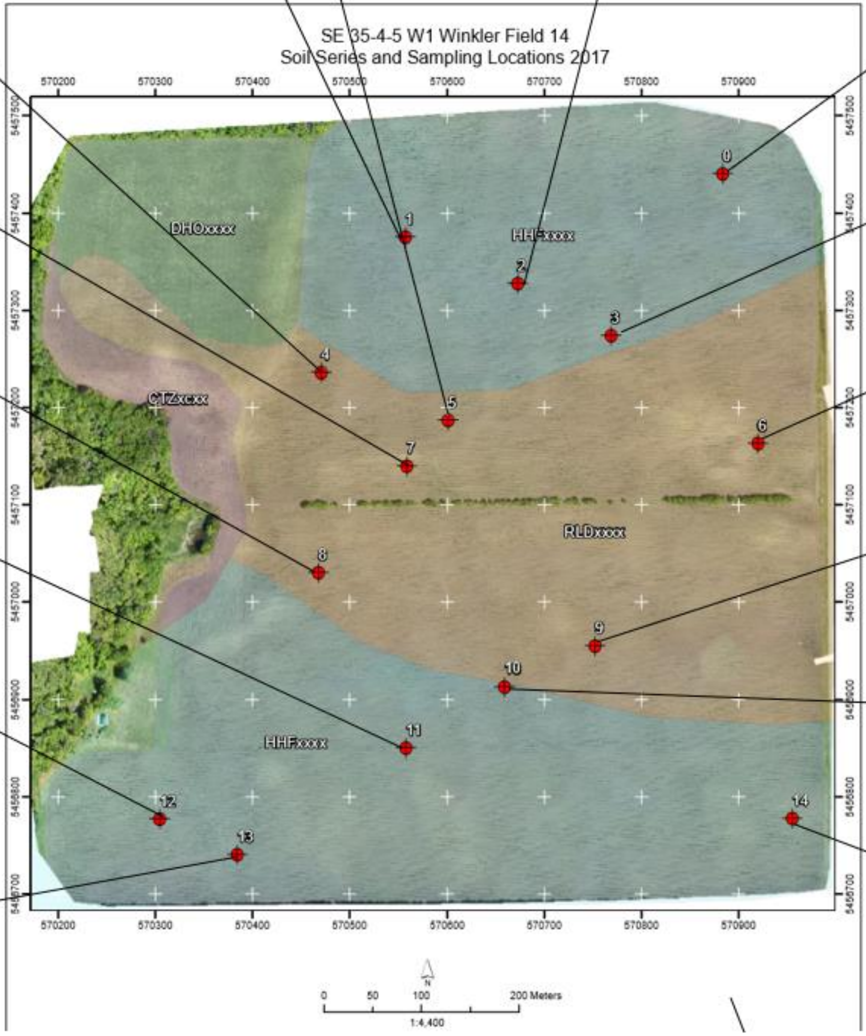
Fig. 27 Total yield of field 14 (‘Red Norland’) in lbs for each of the 15 sampling points. The colors denote the lbs of each size category recorded in the one 10-meter harvest row of each sampling point.

The following page will have a bare earth drone image from the start of the season of field 14 (Fig. 28). The image identifies where the 15 sampling points were placed in the field and list potential yield-limiting variables. It is important to note that the recommendations were for ‘Russet Burbank’, and differences will exist between the needs of different cultivars destined for different market classes.

The Verticillium counts are particularly noteworthy for this field in that points 8, 10, 11, and 13 had counts in excess of 100 CFU/g soil (CFU colony forming units – a measure determined by growth on a petri plate. This is important because dead or growth-inhibited colony forming units are of no threat). This result is peculiar in that these sampling points because they were also some of the highest yielding (Fig. 27). Verticillium wilt generally reduced the larger (10-12 oz) tubers from ‘Russet Burbank’, thereby reducing the total yield and value of a sampling point. There is no obvious answer why that did not happen here. It is generally accepted that 5-30 CFU of *Verticillium dahliae* are necessary to infect most Verticillium wilt-susceptible russet varieties. The counts provided on this analysis do not reliably differentiate between Verticillium species, implying that high counts are likely a mixture of species. However, the probability of exceeding the 5-30 CFU of *V. dahliae* is greater when the total Verticillium species count is in excess of 100 or 200. While the effect of Verticillium wilt may not be discernable for subsequent potato rotations, these areas of the field with high counts risk Verticillium wilt-related economic loss in the long term if no form of management is ever enacted. Verticillium is the kind of problem that builds with time, especially on the scale of decades. As the problem can take a long time to build, it may be possible to enact small management changes that also work over the long scale at which Verticillium is operating on.

The lowest yielding sampling points in this field, such as points 5, 7, 9, 12, and 15, were recorded as low to deficient petiole N at mid bulking. Granted, the scale of low to deficient was set for ‘Russet Burbank’, not ‘Red Norland’. However, Burbank yield of larger (10-12 oz tubers) and total yield decreased when nitrogen deficiencies were noted in the petiole or soil. It is possible that the shortage of N contributed to the lack of yield. It is also not impossible that another factor outside of the variables recorded in the experiment also contributed to the lack of yield at these sampling points. This information would have to be combined with the grower and consultants experience with this specific field in order to clarify if other explanations could exist for this specific field, but not both fresh market fields included in this experiment.

Fig. 24



Plot 1

Plot 5

Low petiole N mid bulking

Plot 2

Deficient petiole N mid bulking

Plot 4

Plot 7

Low petiole N mid bulking

Plot 8
High Verticillium CFU/g
(>100 CFU)
Deficient petiole N mid bulking

Plot 11

High Verticillium CFU/g
(>100 CFU)

Plot 12

Low petiole N mid bulking

Plot 13

High Verticillium CFU/g
(>200 CFU)

Low N, P mid bulking
(Russet Burbank standards)

Low petiole N mid bulking

Plot 15

Low petiole N mid bulking

Plot 3

Low petiole N mid bulking

Plot 6

Plot 9

Plot 10

High Verticillium CFU/g
(>100 CFU)

Low petiole N mid bulking

Plot 14

High Verticillium CFU/g
(>200 CFU)

Field 15

The total yield for field 14 (Fig. 29, below) is shown. Offhand, there appears to be more variability in total yield for these fresh market fields planted to 'Red Norland', but less variability within the tuber size profiles on the lower end (2.25 inches and under). Most of the yield variability came from the 2.25-3.0 in size category. However, this comparison is not one that can be subject to statistics due to differences in market class, location, and cultivar differences between the fresh market and processing fields included in the experiment. It is important to note that every sampling point had between 1-3 lbs of misshapen tubers and 12-33 lbs of tubers with enlarged lenticels. Only sampling point 2 had >1 lb of tubers with cracks.

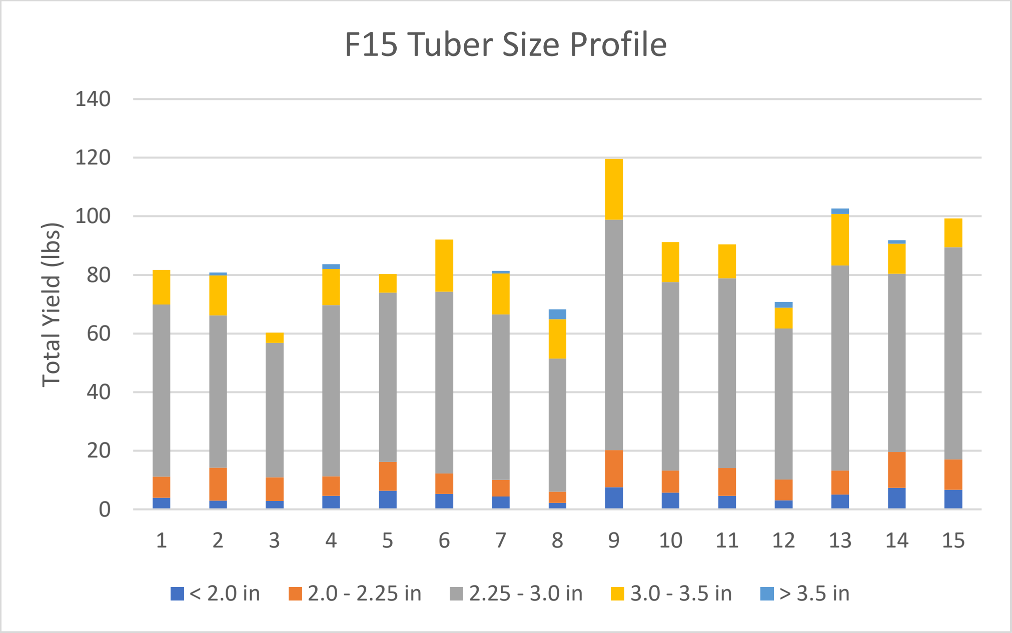


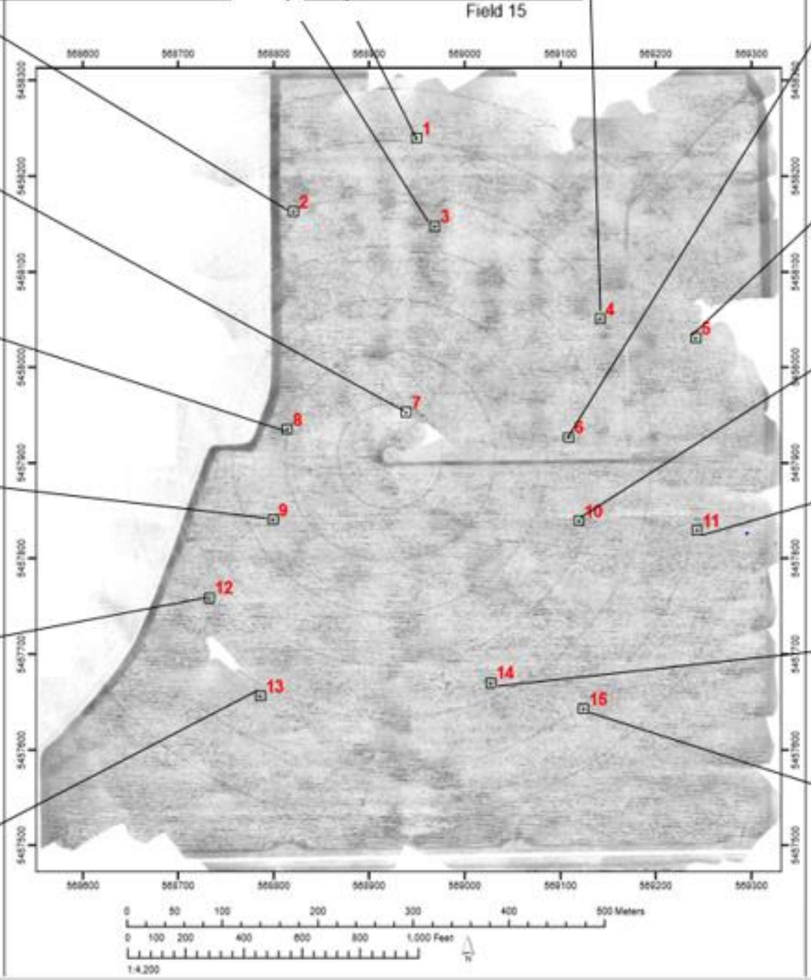
Fig. 29 Total yield of field 14 ('Red Norland') in lbs for each of the 15 sampling points. The colors denote the lbs of each size category recorded in the one 10-meter harvest row of each sampling point.

The following page will have a drone image from the start of the season of field 15 (Fig. 30). This image shows the location of the 15 sampling points used in the experiment. The box leading to each sampling point shows the potential yield-limiting variables at each site.

The Verticillium counts are particularly noteworthy for this field in that most sampling points had counts in excess of 100 CFU/g soil (CFU colony forming units – a measure determined by growth on a petri plate. This is important because dead or growth-inhibited colony forming units are of no threat). Verticillium wilt generally reduced the larger (10-12 oz) tubers from ‘Russet Burbank’, thereby reducing the total yield and value of a sampling point. It is possible that one explanation for the lack of 3.0 in or greater diameter tubers is the prevalence of *Verticllium* in the field. It is generally accepted that 5-30 CFU of *Verticillium dahliae* are necessary to infect most Verticillium wilt-susceptible russet varieties. The counts provided on this analysis do not reliably differentiate between Verticillium species, implying that high counts are likely a mixture of species. However, the probability of exceeding the 5-30 CFU of *V. dahliae* is greater when the total Verticillium species count is in excess of 100 or 200. A second piece of information that is critical in identifying the areas at risk for Verticillium wilt are when the soil counts are high and disease is observed, like in sampling point 2. In the case of point 2, it is likely that *Verticillium* count of > 200 CFU/g soil exceeds the threshold of *V. dahliae* in the soil necessary to cause disease. While the effect of Verticillium wilt may not be discernable for subsequent potato rotations, these areas of the field with high counts risk Verticillium wilt-related economic loss in the long term if no form of management is ever enacted. Verticillium is the kind of problem that builds with time, especially on the scale of decades. As the problem can take a long time to build, it may be possible to enact small management changes that also work over the long scale at which Verticillium is operating on.

The lowest yielding sampling points in this field, such as points 3,8 and 12, were also noted to have low soil sulfur. Granted, the scale of low to deficient was set for ‘Russet Burbank’, not ‘Red Norland’. However, a lack of soil sulfur was negative yield association for ‘Russet Burbank’. It is possible that the shortage of sulfur contributed to the lack of yield. It is also not impossible that another factor outside of the variables recorded in the experiment also contributed to the lack of yield at these sampling points. This information would have to be combined with the grower and consultants experience with this specific field in order to clarify if other explanations could exist for this specific field, but not both fresh market fields included in this experiment.

Fig. 26



Plot 3
High Verticillium CFU/g (>200 CFU), some wilt observed (20% of infected plants).
Low soil sulfur at row closure and mid bulking

Plot 1
Compaction under 30 cm
High Verticillium CFU/g (>100 CFU), little wilt observed
Low soil sulfur at row closure and mid bulking

Plot 4
High Verticillium CFU/g (>200 CFU), little wilt observed
Low soil sulfur at row closure and mid bulking

Plot 6

High Verticillium CFU/g (>100 CFU)

Low soil sulfur at row closure and mid bulking

Plot 2
High Verticillium CFU/g (>200 CFU), little wilt observed
Low soil sulfur at row closure and mid bulking

Plot 7

Low soil sulfur at row closure and mid bulking
Low soil N at mid bulking

Plot 8

Low soil sulfur at row closure and mid bulking

Plot 9

Compaction under 30 cm

Low soil sulfur at row closure

Plot 12
High Verticillium CFU/g (>200 CFU), little wilt observed
Low soil sulfur at row closure and mid bulking

Plot 13

Compaction under 30 cm

High Verticillium CFU/g (>100 CFU), little wilt observed

Low soil N at mid bulking

Plot 5

Compaction under 30 cm

Plot 10
Compaction under 30 cm
High Verticillium CFU/g (>300 CFU), little wilt observed
Low soil N at mid bulking

Plot 11

High Verticillium CFU/g (>100 CFU), little wilt observed

Plot 14

Low soil N at mid bulking
Low petiole N mid bulking

Plot 15

Compaction under 30 cm

Low soil N at mid bulking

Conclusions

This analysis shows that key soil and plant parameters measured at different potato growth stages can adequately explain the variability in potato yield categories and tuber specific gravity when implemented via PLS regression. The predictive power of the model improved as more years and fields are incorporated into the study, but only the top ten most influential variables encompass many of the main, repeatedly observed variables that are important to many size categories.

There are also many variables that appear on the top ten for processing total yield, but not in certain size categories. For example, sampling points with lower petiole nitrate at row closure are associated with total yield negatively (i.e. lower petiole nitrate at row closure is associated with the lowest yielding sampling points). The PPM of nitrate in the petiole ranged from 3,892 to 24,852. Ten of the sixty sampling points were deficient at this time, and fifteen of the sixty were low. No sampling point had high petiole nitrate at this time. It is likely that the negative yield association for total yield was observed with low to deficient petiole nitrate sampling points. As with soil potassium and petiole calcium, field experimentation is necessary to demonstrate this relationship and evaluate remediation approaches.

Verticillium wilt, while an important disease to potato production, was only on the top ten list of important variables for only one size category – 10 to 12 oz. Increasing numbers of *Verticillium* propagules were the largest negative contribution to 10-12 oz yield. *Verticillium* infection is likely preventing the tubers from sizing in the 10-12 oz category more so than the smaller categories. The fact that these variables appear in only one tuber size category is an important consideration for specific remediation strategies aimed at improving yield to just this size of tuber.

Several key results were repeated across the processing total yield and one or more of the size categories. One example involves the availability of nitrogen in the soil. The pounds of nitrogen available in the soil varied at row closure from 5 to 160 lbs, which can explain the anomalous result that increasing soil nitrogen can be a positive value association, but too much or too little is a negative value association. Five pounds of available soil nitrogen is too little by row closure – limiting growth and eventual bulking, and ultimately reducing value. The consultants that took part in the 2017 year of the project seem to aim for 130-180 lbs of nitrogen in the soil by row closure, which includes the upper range of 160 lbs nitrogen in the soil observed in the experiment. This could explain the result where increasing soil nitrogen (up to the 160 lbs max observed) at the 0-15 cm is a positive yield association.

Sampling points with greater petiole nitrogen at row closure are associated with the processing total yield negatively and could be translated as greater petiole nitrate at row closure is associated with our lowest yielding sampling points. Over the course of the experiment, petiole nitrate results varied from 3892 to 32668. The association with decreasing total yield would focus on the upper range of 32668, but the exact cut off of when the benefit of available nitrogen turns to detriment cannot be determined by this form of analysis. Recommendations from Agvise suggest that the cut off is around 25000, but experimental validation with a remediation strategy (objective 2) aimed at identifying nitrogen practices prior to row closure and their effect on the ideal petiole range are needed before experimentally-validated recommendations can be issued.

Variables such as available sodium in the petiole are positively associated with the processing total yield, indicating the best-yielding sampling points were associated with more petiole sodium than the lower yielding points. The most unusual part of this observation was that petiole sodium was often the greatest positive effect on yield or certain size categories. Over the course of the experiment, the percentage sodium recorded in the petiole by Agvise varied from 0.01% to 0.07%, indicating the percentage range of positive benefit was small. However, the analysis indicated that the higher percentages were associated with higher yielding sampling points. It is also important to note that the petiole sodium content became a negative yield association from mid bulking and late bulking, albeit not one of the top ten.

The results on petiole calcium are also interesting in that sampling points with greater petiole calcium had lower total yield. In this case, too much or too little of calcium was associated with lower yielding sampling points. A soil test and reference are necessary to determine whether it was too much or too little – the model will not inform this result. The percentage of petiole calcium at row closure ranged from 0.87-2.48%, which appeared to range from high to very high. It is possible that excessive calcium was part of the negative yield association. As with the nitrogen result, field experimentation is necessary to move this result from association to concrete result that can influence recommendations.

In addition to evaluating the impact of variables on yield of all the processing fields combined, individual fields from 2017 were rated for nutrient, soil, disease, and plant health status. Drone imagery was used in conjunction with scouting, nutrient status as determined by Agvise recommendations, and yield to visualize variability at each sampling point and what trends were apparent in the overall yield. The point of this individual analysis is to demonstrate the usefulness of the PLS analysis from all processing fields in identifying one or a few major yield-limiting factors from a larger list of potential problems listed for a specific site. This information begins the conversation with a local consultant and grower about priorities in remediating yield variability, and ultimately ideal practices to remediate the situation.

Individual field analysis also highlights an interesting interaction between the June drone flight and points of premature die down of the potato canopy. There is a possibility of using the June flight as a predictive tool for problem places in certain fields because some spots of unhealthy canopy already manifest by June.

On the fresh market fields, soil nitrogen and sulfur at several growth stages are associated positively with total yield and virtually all of the size categories. Translated plainly, the higher ranges of those nutrients were associated with our highest-yielding points. Soil nitrogen at row closure ranged from 10.5 to 117.5 lbs N available, with more sampling points being low-to-deficient rather than in excess of the needed nitrogen. Soil sulfur varied from 0-120 lbs available in the soil throughout the sampling date from row closure to fall soil sampling (postharvest), which would range from deficient to very high for ‘Russet Burbanks’. The positive yield association points to the higher ranges (40-60 lbs were common high observations in the experiment) as the likely yield-benefitting range, but field experimentation is needed to identify this exact range and the best practices to get there. This is especially important given our range of quality was determined for another cultivar other than ‘Red Norland’. The negative yield associations for sulfur and potassium likely originate from soil samples deficient in these nutrients.

There are several major limitations to these results that are necessary to keep in mind when reading this report. Curious, interesting, or unexpected results are not necessarily biased, wrong, or statistically inflated. These associations are based on observations across the fields included in the experiment, and associations need a field study to further characterize the link. It is after that characterization that scientists and consultants can try to influence that variable to full benefit on yield. <u>Field experimentation is especially important to address the relationship between calcium or potassium on negative yield associations, especially before major management decisions are implemented.</u> Field experimentation for remediation strategies within in-field settings is a key part of the study moving forward in order to realize these results within a potato system in an economically feasible manner.

Most studies examining one of the factors in the experiment, such as a nutrient, analyze said factor in isolation as part of integrity the scientific method. While this regimented, narrowed focus is imperative for results of ideal scientific integrity, the possibility exists that several factors are inter-related. Strategies with the intent to mitigate one factor may require additional adjustment to other areas to achieve the desired association observed in the results of this document. Experience has taught the author that understand the complete range of interactions of these 97 variables is very difficult for a singular individual entity to keep in mind, yet these interactions remain important. The route to limiting this problem is the combined, group efforts of the research committee, as well as growers and consultants. Only in working together can the true objective of increasing the competitiveness of Manitoba's potato industry be realized.

Materials and Methods

Field Variability Study

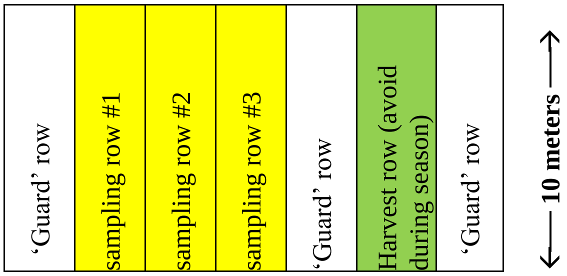
Field selection. Potato fields were deliberately chosen for exhibiting yield or quality limitations due to soil type, topography, limited water holding capacity, compaction, or for unknown reasons. Fields destined for French fry processing were planted with potato cultivar ‘Russet Burbank’, and fields destined for the fresh market (that were included for analysis) were planted to potato cultivar ‘Red Norland’. The cultivar was kept constant within the same market class to eliminate a potential variable from analysis, and the market classes were kept separate due to differences in cultivar growth and nutrient requirements, spatial distance between fields, as well as the demands of each market.

Ideal fields for selection would specifically have some or all the following features: range in variable yield and quality of previous potato crops, representative of growing conditions and soils of potatoes in Manitoba, availability of yield maps and variability information previous to project initiation, and grower cooperator, consultant, and processor approval of in-field equipment use.

Having a range of yield or quality of potatoes varies within each field is important for two reasons in order to have fields that exhibit limitations severe enough to observe repeatedly and for the producer to consider mitigation strategies to be economically feasible. It was imperative for fields to represent the range of conditions and practices found in Manitoba (soil types, management practices, and environmental conditions) because the conclusions of the study need to be applicable to the entire province, not just one growing area and crops destined for one market. In practice, fields were selected for different soil types: sandy, clay, and silt with varying types in-between, such as sandy-loam. Varying management practices were also taken in to consideration, such as crop rotations, planting date, row width, irrigation type and frequency, plant spacing, tillage practices, as well as the herbicides, fungicides, and fertilizers employed. Encompassing Manitoba growing parameters also included environmental conditions: prevailing weather onsite from wind speed/direction, hours of sunlight, temperature of air and soil, and precipitation. Information and maps on previous crops in the same fields was important for informing site selection in order to represent the maximum variability in the field. Specifically, this included yield maps from rotational crops, other variability maps, elevation maps where available (soils maps, soil EM maps), and aerial images from previous crops. Finally, the growers, along with associated consultants and agronomists, are willing to consider having treatment strips (or plots) applied in the field as well as machinery, such as quads and a tractor with 1-row digger attached for harvest.

Sampling point selection within fields. Fifteen sampling points were established in each study field by each May of the study year. Sampling points were determined in consultation with each grower and their consultants using all available information: aerial imagery, variability and yield maps, as well as producer and agronomist knowledge of the field. The sampling points will be chosen to represent the range of field conditions and capture the areas of historical potato yield and/or quality variability. The GPS coordinates of each sampling point would be captured by the mapping software that each consultant used and recorded. Sampling points were manually entered and tracked with a Garmin GPSmap 78S.

Sampling points were marked with 6-foot, fiberglass-pole flags in May to June, depending on when the grower had completed hilling and remaining tillage operations. Sampling points consisted of seven 4 x 10 meter row lengths with one guard row, followed by 3 adjacent rows flagged for destructive sampling and observations (soil sampling, petiole sampling, etc.). A fourth row will be flagged as a guard row. The fifth row will be designated as the harvest row and remain undisturbed through the season, avoiding heavy foot traffic, for final yield determination. The seventh and final row will be a guard row. Each sampling point was surrounded by the field crop, e.g. there was no unplanted space around each sampling point.



Arrangement of rows in a sampling point

Determining *Verticillium* propagule levels. Soil samples were collected in the spring at full crop emergence for each of the sampling points within the study fields. Full emergence was anticipated by late May to early June 2017. Composite soil samples (Seven cores per sampling point) were taken from 0-15 cm depths from each collection point. Approximately 200 grams of sieved soil (to remove solid mass) would be stored at 4°C until processed. Soil samples were transported on ice to the University of Manitoba to Dr. Mario Tenuta for Verticillium propagule enumeration via a plate counting method for *Verticillium* species and PCR amplification of *Verticillium dahliae*.

Determining soil penetration and soil density (bulk density). Soil bulk density was evaluated in the spring at full crop emergence at each of the sampling points within the study fields. The collection date coincided with the Verticillium soil collection dates.

Bulk density evaluation required the following materials: 30 Bulk Density rings, hammer, block of wood, ruler, trowel, and Ziploc bags for soil collection. The procedure was as follows:

1. Determine which numbered ring corresponds to which of the two depths recorded at each collection point.
2. Push or hammer ring into soil (use block of wood to protect ring) to depths of 0-12 and 12-24 cm.
3. Excavate soil around ring to expose and remove ring without disturbing soil in ring
4. Place caps on ring to contain soil and place into labeled Ziploc bag.
5. Place bulk density rings into cooler until processing.
6. Weigh each tin can and record the weight and the number on the tin under proper sampling point on the Bulk Density Weigh sheet before placing soil in tin.
7. Remove caps and scrape all soil out of ring into tin cans in the lab.
8. Weigh the soil and can together and write combined weight onto Bulk Density Weigh Sheet.

9. Place uncovered tins in oven at 106°C for three days.
10. Weigh the tins and soil combined again and then subtract the weight of the tin for final dry weight and record on sheet
11. Input data from Bulk Density Weight sheet into excel spreadsheet with following formulas:
    a) Calculate volume of ring – $V=\pi r^2 h$
    b) Bulk density (g/cm^3) = Dry soil weight (g)/soil volume (cm^3)
    c) Water content = ((wet weight – dry weight) / dry weight) * 100

Bulk density can be impacted by soil type, compaction, and tillage. Taking one bulk density reading in a season was expected to be sufficient unless any of those three factors change after we take our reading.

Subsurface soil compaction will be evaluated using the Manometer penetrometer available at CMCDC at mid-bulking, which was late July in most fields. Recommended penetrometer use is 24 hours after rain, when the soil is at field capacity. Moisture must be constant for comparisons across sites as reading can vary as soil moisture varies. A Delta-T HH2 moisture meter with WET-2 sensor was used to determine that soil penetrometer readings are within reasonable surface soil moisture content between sites and fields. The WET-2 sensor of the Detlta-T HH2 was used to collect 3 moisture readings from different locations within the sampling point from depths of 4-5 cm using the following protocol (borrowed liberally from the operating manual):

1. Press Esc to wake the Moisture Meter if it is asleep.

2. Connect the sensor. The HH2 initially will assume it is an ML2 ThetaProbe in mineral soil unless you tell it otherwise using the Options, Device menu.

3. Press Read to read and display a result.

4. Press Store to store it (or Esc to not store it).

Averaging can be done after each reading (whether or not you stored it)

5. Press the hash # key once to display the previous cumulative average. (Initially “No Average” is displayed).

6. Press # again to update the cumulative average with the current reading (or Esc to back out).

7. Write down the final cumulative average if you wish to retain it.

8. To erase the cumulative average press Esc until you return to “Delta-T Devices”.

9. Output data was manually recorded on a Penetrometer Data Sheet and then data was entered into excel sheet to calculate cone resistance with the following formula:

Cone Resistance = ((Manometer Reading)/(Base Area of Cone))/100 Mpa

Soil texture and water holding capacity. Composite soil samples (Seven cores per sampling point) were taken from 0-15 cm depths from each collection point to determine % of sand, silt and clay. In addition, a subsample will be used to determine water holding capacity. A second set of soil samples (five cores) be collected at a depth of 15-30 cm, which will also be testing for water holding capacity and soil texture. Samples will be collected early in the season along with *Verticillium* testing and Bulk Density testing (Close to full crop emergence). Soil samples were dried for three days after collection. Samples will be sent to Agvise for texture and water holding capacity determination.

Soil moisture and temperature. Decagon EC50 soil data loggers with three sets of soil moisture and temperature sensors for each logger (1 5TM 3-pronged red sensor and 2 Ec-5 2-pronged blue sensors) have been acquired for the study to be placed in each of the 15 collection points in two fields. The loggers were placed in June, which generally coincided with soil sampling and bulk density.

Cellular EM50G Decagon logger and sensor protocol

Materials:

- Sensors (3/logger)
    a) One 5TM sensor
    b) Two EC-5 sensors
- Decagon Logger
- Tall Stake
- Auger
- Ruler
- Flags
- Zip ties (2/logger)
- Batteries (5/logger)
- Desiccant Pack
- Antenna
- Computer and USB cord to connect manually to logger
- Burlap sack

Preparation:

- Go to http://www.ech2o.com/accounts/login/?next=/ and enter each unique Device ID and password that comes with each individual EM50G logger. Also add this information into DataTrac3 to get live feeds of data being collected.
- Connect every EM50G logger to Ech2o Utility or DataTrac3 program to configure EM50G logger. Set measurement interval to one hour on each logger, under Device Identity and Name, enter logger name that is on the front of the logger. Under Data Storage and Port Sensor 1, 2, 3, choose which sensors you are using. Under Device Location and Site Name, enter the point at which the logger is being installed.
- Preform communication test by connecting logger with antenna attached to Ech2o or DataTrac3 program and clicking on "Actions" pull down menu and then selecting "Communications Test," then click "Test." If the logger does not have a good connection quality, try moving to a different location or outside of the building, or change the

batteries. You can also select “List Cellular Carries” under the “Actions” pull down menu to see if the logger is picking up any signal from any cellular carrier.

- Label each sensor at the non-probe end corresponding to which port it will be inserted in to. The 5TM sensor (3-pronged red sensor) should be labelled “1” and the two EC-5 (2-pronged blue sensors) should be labelled “2” and the other “3.” If the sensor cables are of different lengths, reserve the longer one for the deeper depth. On the inside of the logger, there will be a paper slip in the sleeve called “Em50 Port Configuration.” On this sheet, indicate which depths the sensors will be installed at. “1” should be the 5TM sensor installed at depth of 6 cm, “2” is the EC-5 sensor installed at 15 cm, “3” the last EC-5 sensor installed at 30 cm.

Installation:

1. Dig a hole in the hill with the auger to desired depth (30 cm). As you dig, place the soil onto the burlap sack so that each horizon can approximately be placed back in the same order after completion of sensor installation.
2. Place the ruler on the flat edge of the hole made by the auger and make pilot holes with a pin flag at depths of 6 cm, 15 cm, and 30 cm. Then, insert the prongs of the sensors from the bottom depth up into the pilot holes with the EC-5 sensor labelled “3” at 30 cm, the EC-5 sensor labelled “2” at 15 cm, and the 5TM sensor labelled “1” at 6 cm. Make sure that the prongs have sufficient soil contact for an accurate reading, later in season, potatoes may grow and dislodge the prongs or may grow into the prongs themselves and give an inaccurate moisture reading that is too high. If this happens, re-installation of the affected sensors will be required.
3. Unravel the appropriate amount of chord needed for the sensor to reach to the logger at the top of the stake (make sure the stake is tall enough so that the antenna on the logger will be above the canopy for a good cellular signal). Group the male input ends of the cable together, so that once the hole is filled, all wires will come up out of the ground at the same site. Bundle the unneeded amount of cable back up with the twist tie and then bury the cables with soil that was laid to the side on the burlap sack. Attempt to replace the soil back at the correct horizons.
4. Attach the logger to the top of the stake with the two provided zip ties. Insert the batteries and the male input into the correct ports labelled “1,” “2,” and “3.” Attach the antenna to the top of the logger, place desiccant pack inside and close the logger.
5. Manually connect the logger to the laptop with the USB chord and open Ech2o utility. Once connected, select scan to ensure that the sensors were installed correctly and are producing moisture readings.
6. Mark the location of the wires with pin flags and ensure that the stake is marked with bright colour so that it is clearly visible to field workers.

Soil nutrient evaluation. Soil and Petiole samples were collected at row closure, mid bulking, and late bulking to determine in-season nutrient availability. Soils were collected from each of the 15 sampling points in each field, and each point had be previously marked out with flags that were not removed between sampling dates, implying that GPS confirmation of location was not necessary between collection dates. Row closure was anticipated in early July, mid bulking in late July, and late bulking in late August. Soils were sampled five times with a probe at 0-15 cm and 15-30 cm, and composite soil samples from both depths at each sampling point were tested through Agvise for NO_3, P-Olsen, K, and S. Soils were kept at 4ºC between field sampling and shipment for testing.

Soil samples will also be collected in the fall following crop harvest, which is anticipated to be complete by October. Flags denoting sampling points were removed before harvest, necessitating the following protocol for fall soil sampling:

Procedure:

1. Use GPS to re-locate points after harvest
2. Samples from two depths will be taken, 0-15 cm and 15-60 cm. Take three full length cores (0-60 cm) with the hydraulic-probe and take an additional three 0-15 cm cores with the hand-probe.
3. Twist both bags for each depth together and tie. Store for processing later
4. Lay soil out in chem shed or Bernie's shed on butcher paper, place labelled field soil collection bag underneath butcher paper with corresponding sample ontop
5. Allow soil to dry for three days
6. Sieve soil and place into labelled Agvise bags and place into Agvise box along with proper spreadsheet containing the information of each sampling point
7. Ship to Portage

Analysis by Agvise was completed for fall soil samples. Specifically, nitrogen (2 depths), phosphorus, potassium, pH, soluble salts, sulfur, zinc, calcium, magnesium, sodium, CEC, and percentage organic matter were evaluated.

Plant assessment. Plant counts will be collected on the 10-meter row lengths of the harvest row for each study point after crop emergence, but before row closure.

Counts on sampling row lengths are collected to determine the number of plants being assessed at later visits. Comparable numbers of plants between sampling points is important when comparing factors such as yield, which can be influenced by the number of plants. Plant counts therefore served as a quality control check for the initial health of the stand and crop before that collection point is used for continued experimentation.

Plant disease assessments. Field visits assessed crop growth and health following emergence at each sampling point in each field. Field visits varied in frequency from once a week to once every two weeks. The notes from these visits were to be used with data and imagery interpretation at a later date. If crop issues arise during the growing season within study fields, regular visits and notes may point to additional sampling or data collection. Field notes to be taken included: crop growth stage**, v**isual crop stress symptoms**, v**isual crop disease symptoms**,** and crop pests and weeds notes.

The only consistent disease rating across two years of study (2016-17) was aVerticillium rating, in which one of the established 10 m sampling rows was chosen to evaluate vascular discoloration in potato stems and wilt symptoms for the whole plant using published disease charts (below). These charts were provided by Dr. Vikram Bisht. In 2017, direct estimation of total plant chlorosis (0-100% instead of a sale) was conducted by Dr. Zachary Frederick in mid-August and late August, rating the same rows as were subject to rating using Dr. Bisht's scale.

Verticillium wilt rating scale:

Verticillium Wilt of potato Rating Scale

Figure 4.1 Rating scale for the Wilt severity on potato plants caused by *V. dahliae*: 0 – no Wilt symptoms;1 – interveinal chlorosis in the lower leaves; 2 – moderate necrosis and defoliation of the lower leaves; 3 – severe leaf necrosis and defoliation, stunted growth; and 4 – severe defoliation accompanied by pronounced stunting, chlorosis and necrosis of the remaining leaves.

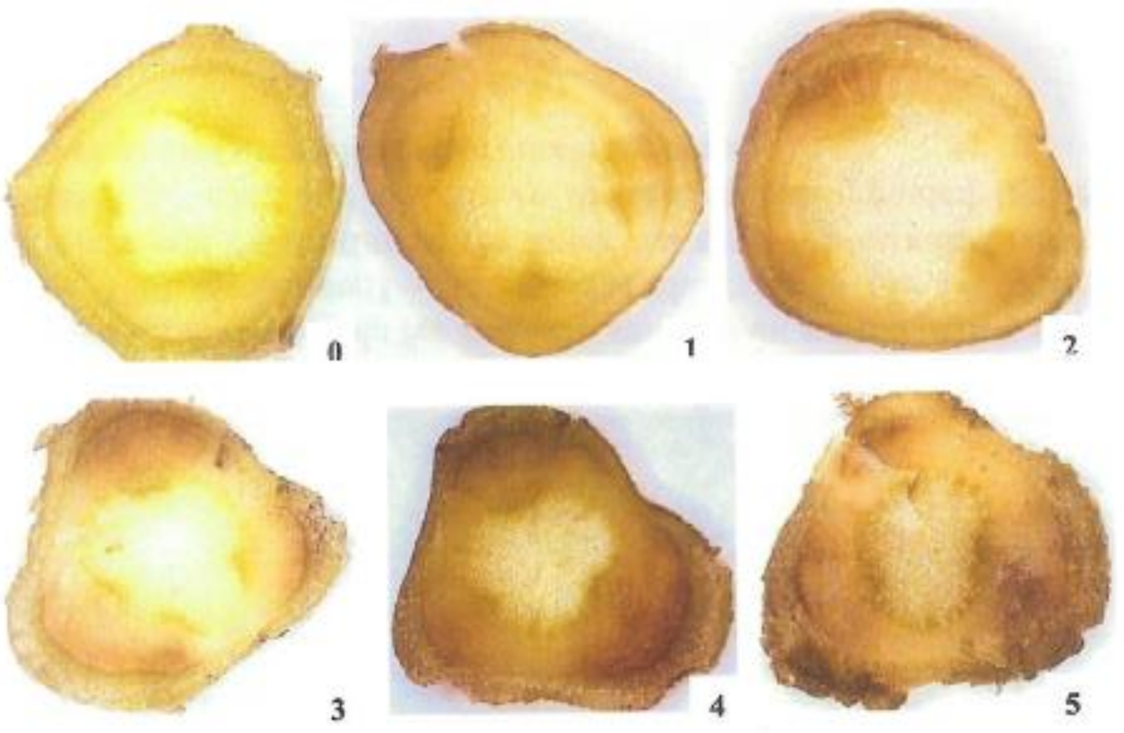


Figure 4.2 Rating scale for the severity of vascular discoloration of potato stems caused by *Verticillium dahliae*: 0 – no vascular discoloration; 1 – trace to less than 9% of the stem cross-section show vascular discoloration; 2 – 10 to less than 24 % of the stem cross-section show vascular discoloration; 3 – 25 to 49 % of the stem cross-section show vascular discoloration; 4 – 50 to less than 74 % of the stem cross-section show vascular discoloration; and 5 – 74 to 100 % of the stem cross-section show vascular discoloration.

Direct estimation of Verticillium wily severity was assessed from 0 to 100% wilt symptoms (chlorosis mainly in practice) in the plant and 0-100% vascular discoloration or necrosis as determined by field observation. Both direct estimation and charts will be used at the same time for two sampling dates to ensure quality data is recorded and analyzed.

Petiole sampling. Potato petiole samples were collected three times during the growing season during row closure, mid-bulk, and late bulk for analysis of N, P, K and S levels in plants. The data were used to assess the nutrient status of the plants at the various field sampling points through the season. Thirty petioles were collected from sampling rows 1-3 in each collection site of each field. Given the sensitivity of petiole sampling to human-inducer (user) error, training was conducted by John Lee from Agvise for correctly identifying the second, third, and fourth leaflet in Russet Burbanks in June 2017. Petiole collection was done through the following method:

Fields should not have been sprayed with pesticides or foliar nutrients for 3-5 days

- Sample from all 15 sites, use rows 1 and 2 and 3, 30 petioles per site, go in zig zag down the rows.
- Select plants without an inflorescence if possible.
- Attempt to maintain similar sizes of petiole throughout sample, attempt to maintain petiole length of a minimum of three inches after stripping leaves
- Do no include snapped, torn, crushed, or otherwise damaged petioles
- Select 4th petiole from the top of the meristem, samples should not come in contact with dirt.
- Samples must be maintained in as cool temperatures as possible and not be exposed to sunlight.
- Samples should be delivered for processing immediately.

Tuber yield and quality. The selected 10m harvest row will be harvested in Late August or September, and will be ahead of the producer's harvest but be as close as possible. Total harvest weight and quality grading will be done separately on each of the 15 samples taken from the study fields, and based on crop sector (fresh or processing). Processing yield and quality will be determined by Agworld at the McCain Foods (Canada) plant in Carberry. Fresh market field yield and quality will be determined by a consultant, Kurt Ginter, in Winkler.

Weather data. Weather information from available weather stations near to the fields were used to better understand the interactions between the factors associated to field variability and the crop performance. Mean temperature, daily minimums and maximums, relative humidity, rain events and wind will be recorded in an excel spreadsheet. One field in each year of study will also have a Hobo weather station temporarily installed onsite, with sensors for Mean temperature, daily minimums and maximums, relative humidity, rain events, solar radiation, and wind.

Drone Imagery. Drone images will be collected from the beginning of the season on bare soil to capture elevation, moisture and any other observable variability factors within the field. Drone images will also be collected three times throughout the season: At row closure, late bulking, and at senescence.

NIR and true color images will be collected at each of the three in-crop image dates. Four ground-control points be established in each 2017 processing field (4 fields total) prior to the collection of the drone imagery to assist with proper geo-referencing of the images. Ther fixed-wing drone used a parrot sequoia camera that records green, red, red edge, near IR. It has a 70 degree field of view and catches one image per second that was stitched together using ArcGIS. We get about 13 cm per pixel at 120m. The 15 collection points per field were identified in 2017 based on GPS coordinates recorded on the ground, the average Normalized Difference Vegetation Index (NDVI) value for the collection point was extracted into a table using ArcGIS and Microsoft Excel. These tables were then used for statistical analysis in SAS and graphical display in Microsoft Excel.

Statistical Analysis with the Partial Least Squares Regression method

The relationships between potato yield and quality parameters as dependent variables and 97 independent variables were explored with Partial Least Squares regression analysis with the primary goal to identify the key ten to twenty variables explaining the yield and quality variability in the response variables for potatoes destined for processing or fresh markets. The market classifications were analyzed separately for the same reasons outlined previously, but essentially summarized as the markets have different quality parameters and cultivar differences. The approach employed in the analysis involved developing a separate model for each of the response variables of interest after initially conducting an analysis of all response variables taken together.

Since many of the soil variables are inherently correlated, standard (ordinary least squares) regression approaches present challenges because they are designed for explanatory variables that are not correlated. Furthermore, the sheer size of the subject data set relative to the number of explanatory variables is not suitable for ordinary least squares regression. Therefore, a technique that works well for this type of data – Partial Least Squares regression – was employed in the analysis, using the PLS procedure of the SAS statistical package. The approach has some similarity with Principal Component Analysis, but differs in that it is also a regression technique that can be used to predict outcomes given a set of measurements of suitable independent variables.

Using this approach, all explanatory variables that contributed significantly to explaining the variability in each dependent variable (i.e., yield in the different tuber size categories, specific gravity) individually and combined were initially explored and identified based on their influence, or variable importance in the projection (VIP). Variables with VIP > 0.8 were considered significant predictors in the model. Subsequently, the effect of sequentially removing variables that appeared less influential was determined. If there was a measurable loss in the predictive power of the model or the percent of variability accounted for, the variable was retained in the model; otherwise, it was excluded so that a simpler model was developed. The best model was deemed to be the one that used a minimum of the available explanatory variables to give a reasonable prediction of the yield and tuber quality. <u>Generally speaking, PLS regression in this scenario highlights which factors vary between high and low-yielding points in all fields of a particular market class. Specifically, explanatory variables that score high VIPs are the variables that vary between high and low yielding sampling points. Factors that do not score very high VIPs do not vary between high and low yielding sampling points.</u>

The number of PLS factors (latent variables) was selected using a cross validation method in which the original data set was divided into two groups: a training or calibration set and a test or validation set. The number of extracted factors with the minimum predictive residual sum of squares (PRESS) statistic was chosen as the optimum. Using the CVTEST option of the PLS procedure, the optimum or minimizing number of factors was compared to the PRESS for fewer factors to test whether there was a significant difference. In the absence of a significant difference, the model with fewer factors was chosen.

A comparison of model predictive power was also performed to determine whether fewer predictors selected based on VIP > 1.5 could be included in the model without significantly reducing the predictive power. Response variables that were modeled better using the VIP > 0.8 criterion were yield in the size categories 6-10 oz (1-factor model) and 3-6 oz (2-factor model), and tuber specific gravity (2-factor model). By comparison, yield in the categories 10-12 oz (2-factor model), > 12 oz (1-factor model), and < 3 oz (1-factor model), and all response variables analyzed together (3-factor model) were adequately modelled using fewer factors selected using the VIP > 1.5 threshold. Additionally, attempts were made to create the same models with 97 dependent variables and 10, 20, or 30 of the most influential dependent variables. Decreasing the number of dependant variables decreased predictive power and the quality of the resulting model, therefore all 97 dependant variables were used. The top 10 dependant variables could still be reported, but it is important to consider that the model requires as many inputs from dependant variables as possible to achieve the “best” predictive model (best defined as the model greatest predictive power, least scatter).

Tables

Table 1. The 46 of the 97 independent variables that were identified through partial least squares analysis showed that 56% of the variability in all response variables taken together for the processing total yield.

Obs	Label	VIP†
1	Napetrc	2.0026
2	Capetrc	1.80988
3	Nrc624	1.61129
4	Capetmb	1.48229
5	Nrc024	1.4743
6	NO3petrc	1.41181
7	Bpetlb	1.34772
8	Smb06	1.29528
9	Krc06	1.28069
10	Capetlb	1.24301
11	pHf06	1.21799
12	Nrc06	1.18379
13	OMf624	1.17585
14	Plb06	1.16401
15	Spetrc	1.14619
16	NO3petmb	1.14344
17	Klb06	1.12154
18	Kmb06	1.12083
19	Smb624	1.11924
20	Kpetmb	1.11382
21	mc1224	1.11024
22	Napetlb	1.10085
23	OMf06	1.0864
24	sa1530	1.08607
25	si1530	1.0788
26	si015	1.07253
27	sa015	1.06566
28	vertcopies	1.06107
29	Ppetlb	1.04159
30	pHf624	1.04055
31	mc012	1.02729
32	penf030	1.0195
33	cl1530	1.00754
34	Slb06	0.9956
35	penf3060	0.98307

36	ECf06	0.98001
37	cl015	0.96815
38	penh3060	0.95447
39	Ppetrc	0.94666
40	bd012	0.94248
41	Slb024	0.90615
42	Slb624	0.87738
43	Pmb06	0.86759
44	Bpetmb	0.83645
45	Mgpetrc	0.82972
46	Mgpetlb	0.79698

† Variable importance in the projection.

Table 2. The 46 of the 97 independent variables that were identified through partial least squares analysis showed that 58% of the variability in all response variables taken together for the processing value.

Obs	Label	VIP †
1	Napetrc	2.11621
2	Capetrc	1.93348
3	Nrc624	1.55998
4	Nrc024	1.50282
5	Capetmb	1.48782
6	Smb06	1.42632
7	Capetlb	1.31038
8	Nrc06	1.29746
9	Napetlb	1.28349
10	Krc06	1.26368
11	NO3petrc	1.2524
12	Bpetlb	1.17175
13	Plb06	1.16575
14	OMf624	1.1594
15	vertcopies	1.13335
16	Kpetmb	1.13124
17	Spetrc	1.1191
18	ECf06	1.11586
19	mc1224	1.10633
20	NO3petmb	1.09028
21	si1530	1.08177
22	penf030	1.07939
23	OMf06	1.07078
24	Klb06	1.07038
25	sa1530	1.0693

26	Slb06	1.06399
27	Kmb06	1.05606
28	si015	1.05419
29	pHf06	1.05159
30	sa015	1.04887
31	Ppetlb	1.04552
32	mc012	1.04519
33	Slb024	1.01048
34	penf3060	1.00388
35	penh3060	0.97919
36	cl015	0.95998
37	cl1530	0.95994
38	Slb624	0.95615
39	bd012	0.95314
40	Counts	0.91475
41	Ppetrc	0.9024
42	Smb624	0.88195
43	Kpetlb	0.87733
44	Src024	0.86087
45	Src06	0.8361
46	Smb024	0.82821

† Variable importance in the projection.

Table 3. The 42 of the 97 independent variables that were identified through partial least squares analysis showed that 53% of the variability in all response variables taken together for the percentage of processing tubers < 3 oz.

Obs	Label	VIP †
1	Napetrc	2.33517
2	Smb06	1.82333
3	Spetmb	1.66885
4	Mgpetlb	1.55429
5	Kpetlb	1.47288
6	Capetrc	1.41899
7	Slb024	1.3979
8	Slb624	1.39502
9	Spetrc	1.36668
10	Smb024	1.3563
11	Nrc624	1.34666
12	Kpetmb	1.29612
13	Nrc024	1.26591
14	Ppetlb	1.25934
15	Src06	1.25287
16	NO3petlb	1.25262
17	sa015	1.19658
18	mc012	1.16833
19	si015	1.16397
20	OMf624	1.1621
21	ECf624	1.14585
22	si1530	1.14497
23	cl015	1.142
24	Spetlb	1.12973
25	sa1530	1.1229
26	OMf06	1.09355
27	Nrc06	1.06498
28	cl1530	1.04347
29	Mgpetmb	1.03079

30	ECf06	1.0282
31	Slb06	1.01257
32	Src024	1.01168
33	Bpetlb	0.99534
34	Ppetmb	0.96861
35	Kmb06	0.91097
36	penf3060	0.88523
37	Krc06	0.88117
38	penh3060	0.88054
39	bd012	0.87423
40	Nlb06	0.85891
41	Smb624	0.84683
42	Klb06	0.82722

† Variable importance in the projection

Table 4. The 46 of the 97 independent variables that were identified through partial least squares analysis showed that 61% of the variability in all response variables taken together for the percentage of 3-6 oz processing tubers.

Obs	Label	VIP †
1	Napetrc	2.31904
2	Capetrc	1.70787
3	Nrc024	1.58526
4	Nrc624	1.52515
5	Nrc06	1.50554
6	Capetlb	1.45137
7	Smb06	1.39233
8	Krc06	1.37347
9	ECf06	1.3095
10	Src06	1.30299
11	OMf06	1.29627
12	Bpetlb	1.2742
13	Spetrc	1.26497
14	si1530	1.20922
15	sa1530	1.19932
16	mc012	1.1989
17	Kmb06	1.19191
18	sa015	1.17462
19	Capetmb	1.16742
20	si015	1.16164
21	OMf624	1.16101
22	Spetmb	1.13846
23	Slb024	1.13097
24	Napetlb	1.12677
25	Klb06	1.11183
26	cl1530	1.11171

27	cl015	1.09116
28	penh3060	1.0892
29	Slb624	1.08403
30	penf3060	1.0834
31	NO3petmb	1.01849
32	vertcopies	1.01358
33	Slb06	1.00587
34	Src024	0.96671
35	bd012	0.96547
36	penf030	0.96373
37	Smb024	0.90537
38	Kpetlb	0.89841
39	Counts	0.84933
40	NO3petrc	0.84799
41	Nlb06	0.83971
42	Smb624	0.83455
43	Bpetrc	0.82373
44	NO3petlb	0.82027
45	Mgpetlb	0.80826
46	ECf624	0.80794

† Variable importance in the projection.

Table 5. The 46 of the 97 independent variables that were identified through partial least squares analysis showed that 46% of the variability in all response variables taken together for the percentage of 6-10 oz processing tubers.

Obs	Label	VIP †
1	Napetrc	1.87159
2	NO3petlb	1.75929
3	Spetrc	1.68456
4	Nrc06	1.60333
5	Nrc024	1.56449
6	Bpetlb	1.5389
7	Capetrc	1.50346
8	Nrc624	1.39974
9	Spetmb	1.3878
10	Smb06	1.34013
11	OMf624	1.2688
12	cl1530	1.23204
13	cl015	1.22936
14	Bpetrc	1.22593
15	sa015	1.19163
16	Kmb06	1.18195
17	Krc06	1.16299
18	Nlb024	1.15628
19	Nlb06	1.15039
20	penf030	1.11293
21	Nmb06	1.10159
22	si015	1.09521
23	mc012	1.07732
24	Slb024	1.0737
25	Nlb624	1.06405
26	Klb06	1.05889
27	Slb624	1.02609
28	Capetlb	1.02104
29	bd012	1.01594
30	Bpetmb	1.01312
31	Capetmb	1.01217
32	Ppetmb	1.00991
33	Src624	0.98694
34	Slb06	0.98418
35	sa1530	0.97911
36	si1530	0.97199

37	Spetlb	0.97011
38	Smb024	0.96723
39	OMf06	0.9412
40	penh030	0.93167
41	ECf06	0.91897
42	Napetmb	0.90827
43	Src024	0.90343
44	penh3060	0.86532
45	penf3060	0.85096
46	NO3petmb	0.81521

† Variable importance in the projection.

Table 6. The 50 of the 97 independent variables that were identified through partial least squares analysis showed that 52% of the variability in all response variables taken together for the percentage of 10-12 oz processing tubers.

Obs	Label	VIP †
1	Napetrc	1.77281
2	vertcopies	1.65872
3	Capetlb	1.60297
4	Kpetlb	1.58411
5	ECf06	1.54282
6	Capetrc	1.47907
7	Kpetmb	1.41185
8	Krc06	1.28551
9	sa015	1.25384
10	Capetmb	1.25353
11	mc012	1.24535
12	Smb624	1.23504
13	OMf06	1.23149
14	sa1530	1.22217
15	si1530	1.2195
16	cl015	1.21577
17	Bpetlb	1.21306
18	Kmb06	1.21277
19	penf3060	1.2121
20	si015	1.2098
21	cl1530	1.15886
22	OMf624	1.15386
23	NO3petmb	1.14681
24	Src06	1.13202
25	Napetlb	1.11318
26	Klb06	1.09529
27	Smb06	1.09068
28	penh3060	1.05467
29	Slb024	1.02883
30	Src024	1.02689
31	Nlb624	1.00225
32	bd012	1.00224
33	Slb624	0.9933
34	Mgpetlb	0.95901
35	pHf06	0.94037
36	Smb024	0.92422

37	penf030	0.91802
38	NO3petrc	0.9161
39	Spetrc	0.90672
40	Slb06	0.90531
41	Ppetlb	0.90027
42	Nlb024	0.86592
43	ECf624	0.86044
44	Nrc024	0.85544
45	Spetmb	0.84456
46	Nrc624	0.83334
47	Counts	0.82633
48	Mgpetmb	0.8212
49	penh030	0.81982
50	Nrc06	0.8066

† Variable importance in the projection.

Table 7. The 50 of the 97 independent variables that were identified through partial least squares analysis showed that 57% of the variability in all response variables taken together for the percentage of 6-12 oz processing tubers.

Obs	Label	VIP †
1	Napetrc	2.14939
2	Capetrc	1.76201
3	Nrc06	1.5534
4	Nrc024	1.54132
5	Bpetlb	1.53551
6	Spetrc	1.44346
7	ECf06	1.43153
8	Nrc624	1.40466
9	Capetlb	1.4041
10	Spetmb	1.39256
11	Krc06	1.34764
12	Smb06	1.32659
13	Kmb06	1.23722
14	OMf624	1.20433
15	OMf06	1.18574
16	sa015	1.16058
17	Bpetrc	1.15251
18	cl1530	1.14903
19	sa1530	1.1485
20	Capetmb	1.14679
21	mc012	1.14527
22	si1530	1.14398
23	si015	1.1334
24	penf3060	1.10311
25	Klb06	1.09879
26	cl015	1.09648

27	Slb024	1.05855
28	penf030	1.03406
29	Slb624	1.00952
30	NO3petlb	1.00514
31	NO3petmb	0.99918
32	bd012	0.99849
33	Slb06	0.99271
34	penh3060	0.98582
35	vertcopies	0.90706
36	Mgpetlb	0.90496
37	Src624	0.89824
38	Napetlb	0.88469
39	Src024	0.87833
40	Src06	0.86273
41	Smb024	0.85542
42	Smb624	0.82847
43	pHf06	0.81454
44	Kpetlb	0.81345
45	NO3petrc	0.78793
46	Kpetmb	0.77594
47	ECf624	0.76113
48	Bpetmb	0.73878
49	pHf624	0.71009
50	mc1224	0.67876

† Variable importance in the projection.

Table 8. The 43 of the 97 independent variables that were identified through partial least squares analysis showed that 48% of the variability in all response variables taken together for the percentage of > 12 oz processing tubers.

Obs	Label	VIP †
1	Napetrc	2.41186
2	Src06	1.85284
3	Nrc024	1.62971
4	Nrc624	1.61612
5	Nrc06	1.4933
6	OMf06	1.30749
7	Src024	1.30103
8	si1530	1.23523
9	Smb06	1.23233
10	mc012	1.22936
11	Capetrc	1.22625
12	sa1530	1.22174
13	sa015	1.21622
14	si015	1.20476
15	Slb024	1.18934
16	OMf624	1.18556
17	Napetlb	1.17703
18	Slb624	1.17069
19	Spetmb	1.16565
20	ECf06	1.14082
21	Krc06	1.13818
22	Kmb06	1.1265
23	cl015	1.1255
24	Klb06	1.10892
25	cl1530	1.10694
26	penf3060	1.08945
27	Nlb06	1.04871
28	Capetlb	1.04618
29	Spetrc	1.0414

30	penh3060	1.03008
31	NO3petrc	1.02217
32	bd012	1.00114
33	Smb024	0.98928
34	Bpetlb	0.98144
35	Capetmb	0.9608
36	Mgpetlb	0.95784
37	Slb06	0.94082
38	ECf624	0.92528
39	penf030	0.88401
40	NO3petlb	0.88237
41	Kpetlb	0.88011
42	Nlb024	0.8683
43	NO3petmb	0.83142

† Variable importance in the projection.

Table 9. The 48 of the 97 independent variables that were identified through partial least squares analysis showed that 60% of the variability in all response variables taken together for the specific gravity of processing tubers.

Obs	Label	VIP †
1	Kpetlb	1.78478
2	Napetmb	1.76281
3	pHf624	1.65996
4	Bpetlb	1.59166
5	Krc06	1.49081
6	penf030	1.44048
7	Nlb624	1.3842
8	Nrc06	1.36883
9	Nlb024	1.29916
10	Klb06	1.29745
11	Nrc024	1.28148
12	Kmb06	1.27232
13	Counts	1.24828
14	pHf06	1.23367
15	Nmb06	1.23282
16	NO3petlb	1.21707
17	Mgpetmb	1.19928
18	CFUgsoil	1.14798
19	Smb624	1.12092
20	Napetlb	1.12011
21	Nrc624	1.10835
22	Kpetrc	1.09921
23	ECf624	1.09301
24	Spetrc	1.09134
25	Capetmb	1.07351
26	Slb624	1.05964
27	Kpetmb	1.05153
28	NO3petmb	1.05046
29	Bpetmb	1.03406

30	Mgpetlb	1.03024
31	Slb024	1.02283
32	mc012	1.01947
33	Smb024	1.01147
34	Nlb06	1.00215
35	Capetlb	0.98487
36	Nmb024	0.96497
37	OMf624	0.95744
38	sa015	0.88815
39	ECf06	0.88487
40	cl015	0.87916
41	bd012	0.85497
42	OMf06	0.85287
43	penf3060	0.84611
44	sa1530	0.84484
45	si015	0.84053
46	cl1530	0.83498
47	NO3petrc	0.8221
48	si1530	0.81742

† Variable importance in the projection.

Table 10. A 4-component model containing 21 variables explained 96% of the variability in fresh market total yield.

Obs	Label	VIP †
1	Nlb06	2.1064
2	Slb06	1.54193
3	Nrc024	1.40725
4	Nrc624	1.33334
5	Pf06	1.32418
6	Slb624	1.18478
7	Pmb06	1.17267
8	Smb06	1.10193
9	Kf06	1.07792
10	Slb024	1.04854
11	Kmb06	0.98969
12	Src06	0.97613
13	Sf06	0.97512
14	Nrc06	0.94587
15	Krc06	0.93541
16	Src624	0.92026
17	Src024	0.90982
18	Plb06	0.88626
19	Klb06	0.88208
20	Nmb624	0.86022
21	Nmb024	0.80683
22	Nf624	0.79373
23	Prc06	0.76329
24	Smb624	0.68605
25	Smb024	0.66732
26	Nf024	0.63827
27	Nlb624	0.6154

28	Sf024	0.60916
29	Nlb024	0.57677
30	Sf624	0.48484
31	Nf06	0.4344
32	Nmb06	0.30858

† Variable importance in the projection.

Table 11. A 2-component model containing 19 variables explained 41% of the variability in the percentage of yield in the fresh market 2-2.25-inch diameter category.

Obs	Label	VIP †
1	Nrc06	1.64245
2	Sf06	1.53348
3	Smb06	1.49209
4	Kf06	1.44525
5	Sf024	1.31407
6	Smb024	1.25916
7	Kmb06	1.22948
8	Slb06	1.22776
9	Src624	1.19172
10	Smb624	1.19015
11	Src024	1.17743
12	Sf624	1.12652
13	Klb06	1.11036
14	Krc06	1.10205
15	Slb624	1.09071
16	Slb024	0.98989
17	Src06	0.98205
18	Nlb024	0.88786
19	Pf06	0.84085
20	Nlb624	0.79781
21	Nrc024	0.77767
22	Nlb06	0.72016
23	Nf06	0.66697
24	Plb06	0.59926
25	Nf024	0.5672
26	Nf624	0.48648
27	Nmb624	0.41712

28	Nmb024	0.41101
29	Nrc624	0.352
30	Prc06	0.23954
31	Nmb06	0.21868
32	Pmb06	0.20353

† Variable importance in the projection.

Table 12. A 2-component model containing 17 variables explained 52% of the variability in the percentage of yield in the fresh market 2.25 to 3.0-inch diameter category.

Obs	Label	VIP †
1	Smb06	1.86031
2	Nrc06	1.65166
3	Smb024	1.41118
4	Sf06	1.37166
5	Kf06	1.30696
6	Sf024	1.28875
7	Smb624	1.28632
8	Src624	1.26438
9	Kmb06	1.25066
10	Src024	1.23864
11	Klb06	1.19088
12	Sf624	1.19055
13	Krc06	1.11581
14	Slb624	1.10322
15	Slb024	1.04242
16	Src06	0.93008
17	Nf06	0.91616
18	Nrc024	0.77504
19	Nf024	0.74318
20	Slb06	0.737
21	Pf06	0.63511
22	Nf624	0.55272
23	Nmb024	0.52433
24	Nmb624	0.50932
25	Pmb06	0.49097
26	Prc06	0.47319
27	Nlb624	0.44465

28	Nlb024	0.41362
29	Nmb06	0.36672
30	Nrc624	0.31101
31	Plb06	0.26122
32	Nlb06	0.23745

† Variable importance in the projection.

Table 13. A 2-component model containing 22 variables explained 78% of the variability in the percentage of yield in the fresh market 3.0 to 3.5-inch diameter category.

Obs	Label	VIP †
1	Smb06	2.01853
2	Plb06	1.42494
3	Smb024	1.34518
4	Nlb06	1.31923
5	Src024	1.21066
6	Smb624	1.19106
7	Src624	1.18386
8	Sf624	1.09904
9	Nmb06	1.06481
10	Nf06	1.06142
11	Slb024	1.06086
12	Klb06	1.05775
13	Sf024	1.03577
14	Kmb06	1.01485
15	Slb624	0.98895
16	Slb06	0.97556
17	Src06	0.96702
18	Nrc06	0.95823
19	Nf024	0.92219
20	Krc06	0.91932
21	Nf624	0.85109
22	Kf06	0.80749
23	Nmb024	0.79711
24	Pmb06	0.75952
25	Nlb024	0.72393
26	Sf06	0.70738
27	Nmb624	0.66425

28	Prc06	0.60669
29	Nrc024	0.3561
30	Nlb624	0.33077
31	Pf06	0.28076
32	Nrc624	0.16717

† Variable importance in the projection