



Nuffield Canada
AGRICULTURAL SCHOLARSHIPS

Developing Soil Type Maps into Management Zones

Tony Balkwill
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NUFFIELD CANADA

Nuffield Canada Agricultural Scholarships

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3. Achieve personal development through travel and study
4. Deliver long-term benefits to Canadian farmers and growers, and to the industry as a whole

Applications are due annually by April 30th

SCHOLAR PROFILE



Tony Balkwill is an independent agronomy specialist based out of Southern Ontario. As owner of NithField Advanced Agronomy, he manages thousands of acres of cropland across several counties. He is also a third generation farmer who farms in the Oxford and Brant areas. His farming operation is the foundation for NithField's research and development program and consists of 400+ acres of full production field scale research systems. Tony studies the systems of precision agriculture, agronomy and equipment technologies.

ACKNOWLEDGEMENTS

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In the UK, I'd like to acknowledge the team at Rothamsted: Keith Goulding, Dr. Goetz, M. Richter, Sally Murdock and Steve McGrath. To my fellow Nuffielders, Richard Hinchcliffe and Peter Wiggins Davis, I was truly grateful for the hospitality and time spent. I also wish to thank Jake Freestone, again an amazing visit and I appreciate the time together.

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In New Zealand, I'd like to thank Allister Holmes from New Zealand's Foundation for Arable Research (FAR), for opening up all aspects of the research department for me to explore. To Craig McKenzie and Michael Tayler, thanks you for taking the time to tour me and your resilience to my hundred questions a minute. Both of your operations are at the level of professionalism that most growers aspire too.

Finally back here at home, I would like to express my gratitude to my clients and family for your support and patience over the two years. I hope this report and the knowledge gleaned from my travels is a long term benefit for all of our businesses for years to come.

EXECUTIVE SUMMARY

My Nuffield research topic was to take historical soil type maps and look at the challenges to accurately modernize them into field specific management zones. My research explored the methods and technology available to measure the spatial distribution of soils within a field. I studied different farming systems, and how soil variability differed by implementing variable rate farming.

It was challenging to summarize this amazing experience and reduce it to a one page, Executive Summary. However, specifically to the topic at hand, there are some key findings that need to be brought to light within Canadian agriculture. Soils and their variability are a key foundation to any crop grown, animal grazed and land farmed. However, they are seldom understood or even managed specific to their characteristics.

I have been involved in agriculture all my life, having been born and raised on a mixed livestock and cropping farm in Southern Ontario, Canada. Agriculture and its diversity has shaped a lot of my business, social and work ethics over my young adult life. As I started to specialize in agronomy and technology I noticed a trend in the industry that was troublesome. Everyone, myself included, thought that we could farm better using technology and science in a top down approach. Yield maps, sensors, spatial trends in data, you name it we bought it and tried to use it. What did we see? Variability.

The key finding, which was consistent to all the countries discussed in this report, is the demand for remapping the old soil type maps to a new spatially accurate layer for the use of site specific farming. Farmers were investing in these maps because of the confidence they had in using an accurate soils map for their variable rate foundations. This sort of remapping is happening and will be a key platform in the world of modern farming. It is an inventory of soils that a grower is farming with. This idea follows the original plan of soil maps to have an inventory of soil types in a given region, but now it is more specific and accurate to a field by field level. Whether these modern reclassified soil maps are being used for optimizing production or to understand environmental implications, they will be the foundation of utilizing site specific farming technologies.

My study focused on three distinct groups: in field growers, educational institutions, and commercial industry, and what each was doing, developing or building when looking at soil type maps studies. Within these groups, I wanted to understand what value they each placed on historical soil type map. I also was curious to understand the role in which they were used

in modern farming systems. Thanks to this Nuffield scholarship, I was able to travel to the United Kingdom, Australian and New Zealand to explore these questions.

DISCLAIMER

This report has been prepared in good faith but is not intended to be a scientific study or an academic paper. It is a collection of my current thoughts and findings on discussions, research and visits undertaken during my Nuffield Canada Scholarship. It illustrates my thought process and my quest for improvements to my knowledge base. It is not a manual with step-by-step instructions to implement procedures.

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1.0 INTRODUCTION

At one time, the agricultural industry tried to take out soil variability and unify or average it on a whole field basis. This has since been abandoned, and much time and research in technology and data collection has occurred. These field collected data layers consistently show us that all fields have some sort of historical variability. In most cases that variability is a reflection of soil type. The different landscape positions, deposit depth, and ratio of sand, silt and clay are the key pieces that make up a soil type. A soil type's relationship with a seasonal climate or the farming practices, and even the crop grown, can result in different variabilities.

The language of soils is world-wide, and the way soils are classified and determined is similar anywhere there are agriculture soils. When starting my Nuffield journey, this soil science industry standard seemed a great foundation to test, trial and study the platform and bases for variable rate applications. This ambitious idea was soon derailed when a general search showed that most of this international classification took place in the mid 1900's (Can SIS, 2016). Therefore it was completed with limited technology, but with very thorough science. Still I believed soils were the key.

With this, my inquiry evolved. If a field shows yield variability that correlates with different soil types, is there a way or method to reclassify the old maps into more modern spatially accurate foundation maps? The realization of this started my plan, and clarified my Nuffield Scholarship's schedule of what to commit my travel and research to.

A second point to this study was the risk of growers getting outside businesses or retailers to build and execute variable rate applications that were simply wrong. The reality of this was that they physically worked in equipment, but the application science was inaccurate and based on some general data layers like yield data or soil tests that didn't truly reflect the actual field variability. This was shown to me in each country by several growers and will be explained in more detail within the report. This further cemented the goal to have a unified base that everyone from environmental groups to production farmers are working with. But how do we get there?

This report will show some success and challenges across the world and hopefully will be a slight push into the right direction on how to reclassify soils into modern foundations for precision agriculture.

1.1 History of Mapping Soils

To understand the future of soils and their potential, we must first look at the history of how most agricultural-based developed nations mapped soils. Primarily it was an inventory of soils. Countries wanted to know what soils they had for agriculture use and the potential of regions. These were mostly done in the mid nineteen hundreds; therefore, they lack the accuracy and spatial refinement to be used in modern practices. However, the soils were analyzed with amazing detail. These soils were documented into their characteristics, structures, aggregate makeup and profiles. This is where the work ended. Within Canada, the soil maps are considered complete (McKeague J.A. & Stobbe P.C., 1978).

Unfortunately, these original maps are not accurate enough to use as a foundation for precision agriculture. Today in agriculture, we are able to collect spatial data that shows variability. Data such as yield maps, soil tests or simple satellite imagery are all variability maps of one thing: a spatial representation of soil types in the landscape.

All farmers understand that they have variability of soils, but the “what” or “why” was hard to know. With the advancements of technology, mapping and spatial analysis, there has been a slow build of remapping this variability of soil to be used as a platform for the future of farming. Think of that word “platform”- the base structure in which all other agronomics or practices are built off of. This is what has been missing in the world of precision agriculture; a foundation and consistent layer to use for that platform.

1.2 Approach to Study

My first internal look into Canada, and more specifically Ontario, was dismal. From a provincial government point of view, it was expressed that there was no plan to reclassify the existing maps into more accurate layers. The general view I received was that the original, spatially inaccurate maps were seen as good enough. I argue that that they were acceptable for that time period, but not for modern farming practices.

Outside of Canada, I traveled in the United Kingdom, Australia and New Zealand, where I explored and studied direct with growers and the commercial and retail industries. There were some technologies (*See Appendices for technology details*) being used that could map soil texture, so I studied these tools and evaluated them in the field. They had each shown their ability to reclassify fields to more accurate soil type maps, and perhaps this is the future of building momentum for this new undertaking. Time will tell.

Moving forward, I began to see that it was important to get the views and opinions of more than just farmers using the more modern, accurate soil maps. Perspectives from other facets

of agriculture, soil sciences and environmental sciences are important in order to come up with an efficient system to get the most complete overview of each country and region. I had three distinct groups I wished to explore when travelling to each country: i) in-field growers, ii) educational institutions, and iii) commercial industry. I wanted to see what each was doing, developing or building when looking at soil type maps, both historical and modern. The countries I wanted to visit had to be involved in both modern cropping techniques, as well as utilizing technology.

This report and its findings are directed at one demographic of reader – the growers. I didn't want to report on the market share, or the methods of using these types of systems. The findings are targeted as an implementation plan and process for Canadian farmers. The goal is to take real world case study farmers and transfer that knowledge into an action plan for Canadian agriculture. I felt, early on, that the driver of this system will only have success and uptake if it came from the farmers directly.

There is also a hope that this report and study will give some clarity into the world of modern precision agronomy. The industry across Canada isn't using the same language when defining variable rate foundations (e.g. Management Zones, Yield zones, Fields Zones, Yield Potential Indexes, Interpolated Data and Multi Year Averages). These various industry terms are used to describe one basic thing growers were doing - using technology to manage different parts of the field.

2.0 THE NUFFIELD EXPERIENCE

2.1 The United Kingdom (UK)

My first country to visit was the UK. Prior to my visit, I consulted some online geology mapping reviews to familiarize myself for the UK (UKSO UK Soil Observatory, Cranfield Soil and Agrifood Institute, 2017). With such a deep history of agriculture I felt the UK would give me a great start to the project. I was set to first begin my studies at the prestigious Rothamsted Research Institute.

2.1.1 Rothamsted Research

Rothamsted Research is the longest running agricultural research institution in the world, with its foundation dating from 1843 (History of



*Figure 1 Historical Soils of Rothamsted
Photo Tony Balkwill*

Rothamsted, 2017). It only seemed fitting to spend some time at the world’s oldest, most prestigious research center for the initiation of my Nuffield study. I was warmly accepted into the fold of Rothamsted and had the ability to spend almost three days there, which could have been its own Nuffield report in itself.

So why Rothamsted? The traditional foresight into having collected soils annually from the same fields for centuries showed me Rothamsted was looking at the bigger picture and future of agriculture, no matter where technology or science would take it. The founding members understood that agriculture would constantly be changing. Questions about farming methods of the past might arise in the future. That vision led the way to building a historically catalogued vault of soils, grain and straw (Figure 1). So my study began with acquiring an understanding of the soils at Rothamsted.

The understanding of the soils at Rothamsted have been, and are, the key to many of the historical and future research directives at the facility. Moving forward the research directives are looking at not only soil type delineation within fields but also more complex biological diversity among soil types. They are studying the structure and environment of how soil microbes and biologicals live as well as defining how “soil health” would greatly differ between a healthy sand and a healthy clay. This initiative was already underway when I visited the institution. They had begun to core certain long standing trial fields to get a better understanding of the spatial changes within fields (Avery & Catt, 1995). (Figure 2.)



Figure 2 Soil Type Cores of Rothamsted. Photo Tony Balkwill

The summary message from this amazing experience at Rothamsted was that quality, efficient, productive farming has to begin with an understanding of soil type, its associated fertility and the optimal health of that soil. This was no different when the original Rothamsted researchers started collecting soils hundreds of years ago. They might not have known what they could do with the soil data in the future, but they realized it was the foundation for all sciences in agriculture. No matter what technology was added to the overall farming practices, soil was the only constant, non-wavering foundation upon which agricultural revolutions were to be developed from.

2.1.2 UK Field Studies

After the great experience at Rothamsted I then went to see some UK growers who were using soil maps as a foundation for their management.

2.1.2.1 UK Field Study One

My first field study with a UK grower took me to a Nuffield Scholar's estate to meet with his farm manager and get a better understanding of how they were implementing the use of historical soil type maps into modern, accurate foundations for their precision agriculture. This farm has a diversified cropping mix of sugar beets, potatoes, rapeseed, wheat and barley as well as some oats and other small-acre crops. They crop approximately 5000 acres in the East Midlands area.

Figure 3 is a map that was completed for the estate over the course of a few years, in conjunction with rotations. The numbers represent the soil type, texture, and ideal seeding rate within those polygons. Traditional soil tests at 8" were taken to assess fertility. This map was built by using a conductivity machine (See Appendices). The machine spatially classifies the soil into zones by texture and landscape position. Once the zones are determined, those areas are targeted with a physical deep core classification.

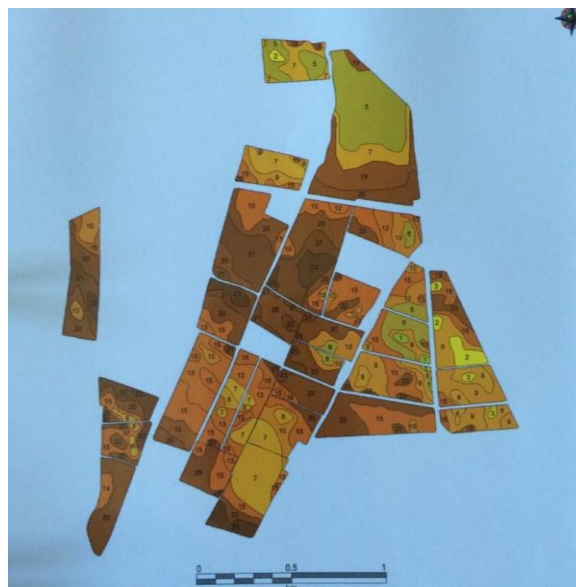


Figure 3 Estate Soil Type Map. Photo Tony Balkwill

The summary was a very unique shift in the estate's operation. The first change they made was that each field had to have certain rotations specific to that field's soil type ranges. There was also a big change in tillage, or type of tillage, based on soil type. Furthermore there was a big change in seeding rate adjustments based on those soils. The main agronomic reason for this was stand establishment (increasing seeding rates for cereal crops on marginal soils and reducing seeding rates on ideal soils). Since there was more stand loss on the marginal soils the increased rate gave the grower a higher harvestable final stand.

2.1.2.2 UK Field Study Two

Grower field study number two took me north to the Lincolnshire region to another mixed arable farming operation. This farm was more focused on high yield specialty wheats (winter and spring), some rapeseed and other small-acre crops. This was a very unique study point that I thought was key to bring up, as the question might be raised among the readers: what about man-made soils? This was one of those situations.

In this grower’s region, the soils are deep fertile silts that were handmade along channels and dykes hundreds of years ago. They would flood and recede the water, over decades, to capture the fertile silt and displace it across the fields once the water was drained away. One glaring similarity with traditional soils is that, even with these soils, there is still field variability, changes in depth, and even, different textures. I was curious and had my hopes that this would be farmed in a “blanket” broadcast approach, but I was taught a different system that was very successful for them.



Figure 4 Lincolnshire Silty Clays. Photo Tony Balkwill

These growers, some of the best in the UK, still fine-tuned every soil change, even within these fertile silts. That wasn’t always the historical case in the family. However, now with mapping and site specific goals, they have self-assessed their soils into productive ranges, or into management ranges, based on how they were built and the variability. It seemed that no matter if it was man-made or glacially made, variability is everywhere and addressing the agronomics of that variability is the way towards productive agriculture. (Figure 4).

2.1.2.3 UK Field Study Three

Field study grower number three was a large farming estate in the South West region of the UK. This region has unique undulating terrain with mixed livestock and arable farming enterprises. Again, with this certain operation, there had been a significant investment in the reclassification of the farm estate. The direct action of this investment had several long term goals. Firstly, the operation wanted to analyze the cost of production and the financial

return of each soil type. These soil types were then evaluated and agronomic systems were put in place based on that soil type's revenue potential (Figure 5). One take-home quote from the farm manager was "Not all soil types will produce the same, but we want all soil types profitable". I felt this was a mission statement of sorts when looking at these operations with extremely high value land. Where there are challenges in expanding your land base, the only option is to improve on the land you're currently farming with more in depth work.

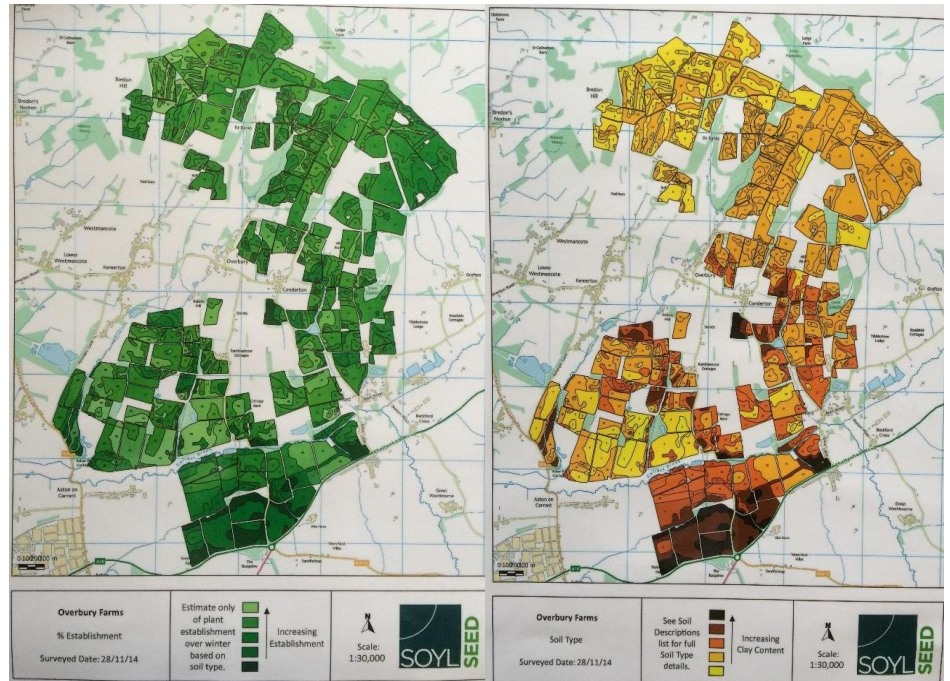


Figure 5 Agronomics based off of Soil Type Maps. Photo Tony Balkwill

2.1.3 Summary of Observations in the UK

My summary of the United Kingdom is as follows:

1. All the case study farms that were using reclassified soil maps as their foundation had the maps completed by an outside company. Company A would use a Veris Machine (see Appendix 1) as the platform to isolate soil texture variability. They would site specifically test and classify those soils. Then they produced not only a soil type map, but also an agronomic system. I particularly liked seeing the action plan part of the process. This plan included the actual seeding recommendations, fertility and management direction of the soils.
2. The growers in the two case studies that had purchased the soil mapping were confident and had already evaluated the return of the investment. I will admit that the cost CDN\$45 per acre was significant but it was sold as a one-time investment and when amortized over multiple years for farming, the return was easy to predict.
3. I left the UK, the first stop of my study tour, with a great understanding on the systems using reclassified soil type maps, as well as the opportunities for industries in Canada to capitalize on this need. The full circle of the research (Rothamsted), the growers and the commercial entity offering the service, and to see it used in field,

showed me how using the reclassified soil maps was being used as a platform of precision agronomics.

2.2 Field Studies in Australia

I arrived in Australia with enthusiasm to see more technology and soil mapping systems being used in multiple regions. Surely with such an extreme climate and diverse cropping regions, there was bound to be a resource that could be uncovered.

2.2.1 Australia Field Study One

My first in-field case study was with a grower in South Australia near the city of Loxton, a highly diversified growing region. The type of crops grown changed based on the ability to source water. In the area where I spent most of my time, the crops were mostly dry land farming of cereals. Wheat and barley were the dominant crops and the annual rainfall was the driver of most of the crops' potential. Having researched the areas soils extensively beforehand, I



*Figure 6 Southern Australia dry land soils.
Photo Tony Balkwill*

was amazed at the landscape and soil formation of the region (Digital Atlas of Australian Soils, 2016) (Figure 6).

This particular area was, predominantly, windblown deposits after the recession of the ocean tens of thousands of years ago (McKenzie, N.J., et al., 2000).

Since Australia would be classified as a young farming region, with less than 200 years of agriculture in most areas, it was quite amazing to see the uptake of precision-based agronomics. As a few growers mentioned, this was a natural evolution from the start-up of using the guidance technology to drive straight. The average farm size in the region is over twenty thousand acres. Most started using guidance, as soon as it came into the market, for efficiency purposes. Having gained confidence in the base technology, the next natural step was to start to look at other improvements like variable rate seeding and variable rate fertilizers.

Of the several growers I spoke with on the first day, many had been variable rating for years, but they also admitted to the fact that they were variable rating because they could, not because they should have been. They were using the technology, and not knowing why. This had led to a crusade of most farmers wanting their fields zoned, and a foundation that was

accurate was needed for the base. The commercial agriculture world in Australia took note, and in the late 1990's and 2000's, some of the first "soil mapping" services were offered.

Their main tool of choice was an EM38 sled (Appendix #2). The standard procedure was to map the field, get the variability zones, and use it forever. The shortcoming with this process was the lack of agronomic support and direction. The grower simply got a map of their fields' soil texture variability. Granted, it was now accurate, but it didn't give the growers a plan or process on how to change their practices to address the new variability maps. It was still up to them to look at historical trends, or work with an agronomist, to come up with new management solutions, specific to the soil zones.

The take-home, from this region and the several growers I spent time with, was very humbling. These growers were truly some of the best farmers I have ever met. They were farming tough, erosion-prone soils, and variable rating all of the applications they could. They were aware of all costs per acre, and embraced technology. They also expressed a clear limit of the potential of that investment. A quote from one that is a great summary of this area, was as such "Technology cannot out-farm mother nature". That was the completion of a few weeks in a very unique farming region of southern Australia. It was quite the contrast to the thought process of Ontario and the UK regions, I had visited previously. While Ontario and the UK showed amazing farming practices and results, they, by no means, had the volatility of this region in Australia. The weather volatility forced them to be more aware of the economics of farming.

2.2.2 Australia Field Study Two

In Swan Hill, Victoria, I met a grower who was intensely managing his farming operation with such success that he had reduced his acres by 30%, and was able to increase his production and revenue by 25%. I had no prior knowledge of how or what his system was for this, but I was curious to see, and naively hoped that it was based on some sort of reclassification of soil foundations.



Figure 7 Wind Blown Sands SA Australia. Photo Tony Balkwill

I noted that the landscape in this region had similar features to that of South

Australia, with lots of windblown soil landscapes. (Figure 7). The term "obvious variability"

would be accurate. After a few days of my relentless questioning, I was able to determine that the process used in this operation was mostly satellite imagery based. A complex summary of crop growth imagery, bare soil imagery, and even infrared layers of green leaf index, were able to show a very accurate reflection of crop performance, or stress by soil type.

This was extremely exciting to see. It started to dawn on me that the similar tools I had seen in use, (e.g. EM 38, Veris) were extremely time consuming and expensive; you had to physically touch every acre to get the map. This grower had devised a system that was able to line up with the economy of scale that those farming in a region like Australia were accustomed to. With some operations in the 20,000 acres or more, this seemed like an essential tool for large scale systems like Western Canada. The process was similar to others I had seen, use the imagery to delineate the variable zones, identify the soil in those zones, and address the variable rate agronomics based on the soil potential. This grower had a simplistic approach to the process. He classified his soils in one of two farming methods: i) highly fertile offensive soils that were farmed proactively, and ii) defensive soils that were farmed with restricted inputs based on their lack of potential. As simple as this was, I think this was a great concept to start the process of farming by soil types. Although this was not as detailed as I had seen in other areas like the UK, it was a great foundation to begin with.

Australia has a landscape of diversified agriculture regions, similar to Canada. Since they are both such large countries, their difference in soils, practices and crops grown vary greatly. With trying to understand soil types and the reclassification in use for precision agriculture in Australia, I specifically targeted both irrigated and non-irrigated regions to determine if they differed in methodology and/or implementation.

2.2.3 Australia Field Study Three

The next area I studied was in New South Wales near the city of Griffith (Australian Soil Classification (ASC) Soil Type Map of NSW, 2016). I had lined up some extensive time to tour irrigated growers with an abundance of high value crops like rice, cotton and vineyards. The city is also host to Deakin University, a field research extension department that works directly with farmer group funded projects and supports PhD students and Masters level thesis work (Deakin University Centre Regional & Rural Futures, Faculty of Sci Eng., 2017).

I was able to base my local case studies out of a fellow Australian Nuffielder's farming operation that consisted of an eclectic mix of crops. Mostly irrigated, it was interesting to see the time and agronomic investment of fine tuning high value crops. They grew seasonal cotton, barley and wheat and had extensive vineyards and olive orchards.

One thing I noticed was the customization of equipment that was unique to this particular farm. They truly believed that commercially available equipment had to be retrofitted to be best utilized for their soils. This was shown time and time again, and I'm afraid I took more pictures of iron than I did of soils during the first two or three days. Over the duration of the stay, I started to study and dig deeper, literally, into the soils, they were working with. It was amazing to see that their family ancestors, back in the 1950's, had specifically placed different grape varieties throughout the farm based on their best understanding of soil types. When looking at the overhead imagery, you can see that the grape species change correlates with the bare soil imagery changes, to match species to their ideal soil type.



Figure 8 Historical Field Change over time - before. Photo Google Earth, Tony Balkwill

Since this region was, historically, a large rice growing area, it was explained to me that when many of the fields or paddocks were built, the soil was moved to build dikes to contain the water that the rice was grown in. This altered the soil into contour topology farming (Figure 8 & 9). The newest method of farming I noticed across tens of thousands of acres was laser levelling of fields, where they would take out the old contours and simply make large flat paddocks that were built with floodable

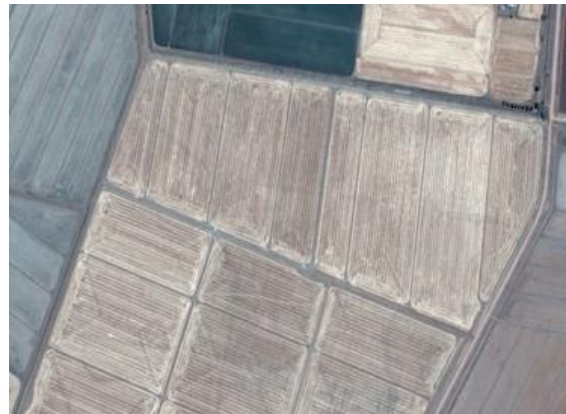


Figure 9 Historical Field Change over time - after.

irrigation channel systems, begging the question of how do you reclassify soil that has been altered? These soils are, technically, not the traditional soil types once classified back in the 1950's, when the states surveyed the landscape into inventory maps.

The value and return of the crops in the region allowed for a lot of re-investment, both in technology and in agronomy for growers. Most growers would laser level a paddock, then reclassify that paddock with the different tools previously mentioned in this report, such as conductivity machines or EM machines. With the large cost associated with the levelling, growers had to get big returns quickly from these new paddocks. The growers were well aware of the soil changes that had occurred. They now needed two things upon completion: i) a new variability map, and ii) a level field for irrigation. Taking this even further, there were

other firms and growers that had the technology to re-level a field, as well as to move soil and reposition it based on soil type to 'even out' the field. They would cut high valued deep soils out of depressions and then re-position a set thickness of topsoil across the paddock once the parent material was level. (Figure 10). It was absolutely amazing to see a highly variable field landscape physically moved to become one unified



Figure 10 Equipment moving soils to level a field for irrigation. Photo Tony Balkwill

field. The result was so accurate that yield maps showed limited variability or historical ties to the original ocean-made soils of that field. This action seemed practical when dealing with crops that had returns of CDN\$2000 or more per acre, but it didn't seem applicable in the majority of the farming regions of Canada. However, it is a truly amazing example of what technology and time can accomplish.

Due to the region's high value crops, there also seemed to be extensive retail soil mapping services. There were several retailers and independent consultants that were selling the re-mapping of soil types. Although it felt great that I was not the only one believing in this as a foundation, it seemed that growers were getting just maps and no agronomics. This was a challenging trend for growers in Australia since most had to then hire outside consultants to interpret the variability and come up with an action plan, or some simply learned on their own, which can take few seasons to do.

2.2.4 Summary of Findings in Australia

Australia reminded me of the western Canada style of farming. Extreme weather and basic logistics were more of the true driver of profit or return rather than the micro-management of zones based on soils. Several growers I had the pleasure meeting agreed that having the most accurate map in the world would be absolutely worthless if you didn't get timely precipitation. Margins were extremely tight most seasons and the reclassification of soils seemed like an unnecessary expense given the tight cost of production. "We know our variability and have it mapped. Why do we need to know anything else?" was a quote of one grower. I agreed with this point but it also got me thinking during one of my many six-hour drives across rural Australia. If you had a complete understanding of soil types that were spatially accurate, would that not allow a person in volatile tight-cost farming regions to be

able to farm with better management specific to the risks associated to those soils? I had to explore this idea further.

My final summary of Australia is as follows:

1. The growers in each region were using precision technology and wanting to get more out of it. This was a recurring comment. They were more technologically advanced than any region or area that I'm aware of in Canada.
2. Growers and agronomists see the need for the reclassification of soil maps as a foundation of successful variable rate farming. They also wanted it completed by third parties, not government, which I thought was interesting. The reason for this was soil mapping and agronomics is such a specialty knowledge base, it needs to be executed by real in-field people with the attention to detail.
3. Soil mapping is successfully being implemented at a commercial level in several regions of Australia. Different regions and different service providers each have their unique products and processes for supporting growers. To conclude, each grower I met expressed a goal to have their soil mapped within a few years, if possible. They felt that reclassified soil maps held so much value that the need to start using them as a foundation was essential.

2.3 Field Studies in New Zealand

The next country I visited was New Zealand. I went to both the North and South islands and spent a large percentage of my time with FAR (Foundation for Arable Research), one of New Zealand's cutting-edge technology research departments (Figure 11). The Northern Island is primarily livestock, sheep and dairy based. Since livestock was the primary focus, after several meetings and field tours, I quickly learned field specifics were not important. In fact, the overall message was that livestock growers wanted cheap feed, by any means necessary. So specific to my study topic there was not a lot I could learn from the growers of the North Islands, or so I thought.



Figure 11 FAR research site. Photo Tony Balkwill

2.3.1 New Zealand Field Study One

An interesting meeting came out of my time with some environmentalists and water conservation directors on the North Island. Since there was such an abundance of livestock across the area, manure was an issue for over-application and potential contamination from point source pollution or runoff. The research department of FAR had a huge focus on soils and their landscape position to help measure and quantify the risk of certain soil types (S-map Online New Zealand soils site, 2016).

I thought this was very interesting. They were working with the older historical maps to begin with, and had ultimately hit a roadblock when they realized the spatial inaccuracies of the original soil maps (Figure 12). I thought this sounded very similar to Canada and the previous

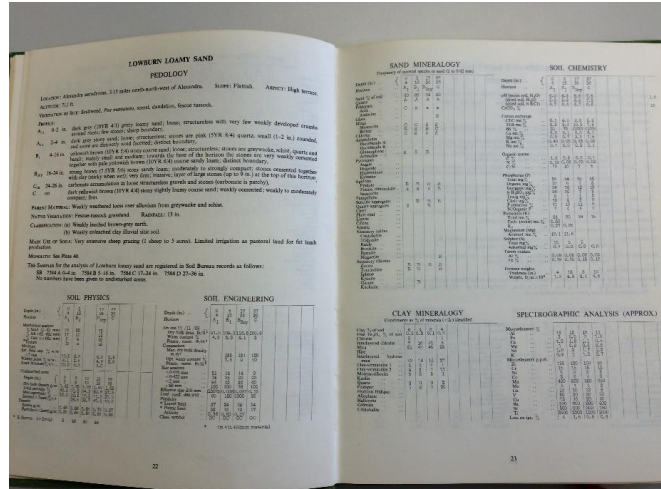


Figure 12 1960's North Island County soil type map text. Photo Tony Balkwill

countries I had visited. In the middle of this intense study project, they had started collecting new soil type cores (4' of depth) near high application manure areas to see what sort of stratification of nutrients was occurring as well as percolation rates amongst the different soils. The overall investment and commitment of this research was staggering, and shows the broad and powerful impact environmental based research has over general agriculture. This sparked an idea for us in Canada to be proactive in our ability to study soils for an environmental as well as agronomical beneficial system; working together with environmental agencies to work with the same accurate layer and overall goal.

After a week in the area, I headed to the South Island, a more arable cropping-dominated region with mixed crops, mostly cereals and maize. I had lined up two growers to spend time with, and use as case studies in my research.

2.3.2 New Zealand Field Study Two

The first farming operation on the South Island, that I visited, grew a range of mixed vegetables, seed crops, barley, wheat and other cereals. They farmed along the south coast near Tamaru and had insight into my topics that was valuable. The region echoed that of the UK with highly overpriced land. Extracting every dollar out of each acre was essential to being a sustainable agricultural business. These particular growers had a complete zone-based system as the platform for their precision agronomy. This had been carefully crafted

and built over decades of yield data collection. This might seem simple but there were learning curves, challenges and unforeseen expenses with this method.

After several years, they realized that the ‘variability’ they wanted to map was soil, but there weren’t commercial services or even skilled industry professionals available for use in the region at that time. Because of the diversified crops they grew, they had to establish yield monitors on each piece of harvesting equipment. These growers had five harvesters, specific to cereals, potatoes, carrots, green beans and rye grass. They needed spatially accurate data based off of productivity.

They started to see early on that it was going to take at least five years of data to collect a big accurate picture of that true spatial change. Once they had several years of collected data, they started to target soil tests based on the soil variability, and address nutrients initially. Once the target levels of soil fertility were reached, they next implemented seeding rate changes based on those base variability map. Products like potassium, phosphates, nitrogen and lime were applied. These applications were site specific to the soil variables they had determined based on their own collected data. There I was in New Zealand seeing one of the most intensely managed farms ever and they weren’t using soil type names, but rather, they had devised their own language and system to define the variability. During our last discussion together, they commented the following: “We are basing all our decisions on soil type, we just have our own language to describe them”.

2.3.3 New Zealand Field Study Three

The next area on the South Island for grower case study number three had similar cropping practices and varieties grown. This particular grower was heavily focused on high value seed crops. His farm was divided into small acre fields that were intensely managed and all irrigated. It seemed only fitting that my final grower case study had his entire operation soil texture mapped and was doing every application, even fungicides and irrigation, based off soil type (Figure 13). The grower felt that this initial investment, in understanding his field variability and his soils, had allowed him to invest in the right layout and capacity of irrigation directed to the soils’ and fields’ variability. He noted that if he was only starting this process, the cost of the improperly placed infrastructure would have been devastating and economically impossible to recoup. At the time, that huge

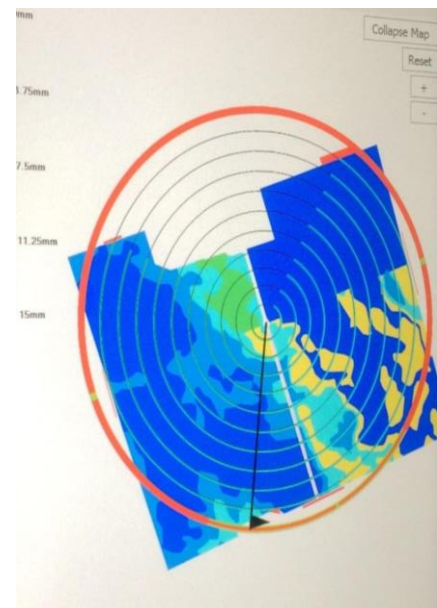


Figure 13 Variable rate Irrigation by Soil Type. Photo Tony Balkwill

undertaking and cost of mapping and coring the soils was a questionable practice. They were not even variable rating one product at the time of the mapping service. However, they felt that they needed this base as a starting point on which to begin the entire variable rate journey. They knew how to build prescription maps, but they didn't have confidence in a base layer until the completion of their first soil map. After several days and field tours, I was ready to take this grower's yields and returns with solid confidence for using reclassified soil type maps as a foundation for successful precision agronomics.

2.3.4 Summary of Finding in New Zealand

My final summary of New Zealand is as follows:

1. You need to have the full field picture variability accurately mapped before beginning the variable rate and precision agronomic farming practices. If you don't, there is no true understanding of the economics return. It can't be lucky farming, it has to be science-based.
2. There is no one or two key variable rate applications that will make a solid return. It needs to be all of them, the math isn't normal. Both growers noted that they were seeing low 2-3% returns when doing one or two compounded variable rate applications, but as they added more and more to each acre, they compounded into 20-30% economic returns. These growers had a theory that there is cohesion to having everything ideal on that soil; to maximize its yield potential and to maximize the economics of that soil from a farming point of view.

3.0 DISCUSSION

It was amazing to see how similar the challenges are in each country that I spent time in and how they all have some sort of comparison to Canadian agriculture. The one big take-home message I can confidently write is that using proper spatially accurate soil maps of field variability will allow us as growers to farm better. This is true for two key reasons - firstly, for productive economically viable farming, and secondly, for environmentally sustainable farming. At some point in the future, these two reasons will become one, and this will be how farming is practiced. Is it naive to think that some proactive foresight should come into play as growers head down this path? Once I had looked at the overall experience, I came to a few realizations.

The need for emphasising every acre was evident in any agriculture region I visited. The increasing cost of land compounded with higher operating costs is driving growers to get more production and efficiency out of each acre. There was also unified agreement that

addressing field variability was the starting point to increasing that production and efficiency.

There were only a handful of growers farming by soil type. Those were growers that understood their variability, either by self-assessment of historical trends, or by investing in outside reclassification. Then there was a larger group who were addressing the variability of their fields, but didn't manage their zones by soil type. These farmers were technically addressing their soil type variability, but simply referred to the zones in regards to the yield potential. Most of these growers didn't have language or knowledge of soil types, even though they were accomplishing similar results as the group that had complete soil maps.

There is a mixed collection of technology, practices and systems across the world that can remap soils. Each of them has merit. The critical observations would be the following:

- a. The true value of developing soil type maps into management zones comes from the agronomy derived from the new soil type map - meaning the recommendations from an agronomy professional who understands the soils and can help a grower execute precision agronomy by soil type. The challenge is the future training or retraining of local agronomists to understand new soil type systems. Growers need management decisions that help their farm, not just maps (Bruggemen & Clay 2017). Maps are simply the tools used to get us there.
- b. Understanding the limits of a soil type (e.g. fertility capacity, rotational restrictions and environmental capacity) allows growers to farm that soil to its maximum potential (Havline, 2010). The industry advisors (Certified Crop Advisors, agronomists, Agrologists) need a better understanding of soil sciences to complement their expertise in crop sciences.
- c. Soil science, plus agronomic knowledge, is the basis for this to succeed. All case studies presented in this report had agronomists that took the soil maps and worked with the grower to succeed in shifting his/her farming practices to that foundation.
- d. Developing soil type maps into management zones can be done in more than one way. Maps could be built using calibrated multiple year data, or with new technology collecting new data layers. Both got the same spatial result. This was a sobering realization but a welcome one to see. We don't need to invest in new technology to move this forward. Simply working with our growers' existing data was also an option to begin this process. What we need to invest

in is the training and education of those professionals who work with growers on a daily basis.

Any grower having invested in the practice, who was using reclassified soil type maps, was successful. They had evaluated the cost, and in some situations, they felt that they hadn't yet recouped the investment, but also believed the return would be spread across future growing years.

4.0 CONCLUSION

All of us farm soil. There is variability in that soil in every field and we have the technology to map it and the equipment capabilities to adjust agronomics to each soil's needs. It truly is that simple to the point that this is how land should be farmed. I think that those growers that adapt to this platform of farming will not only succeed, but will surpass those who don't, both economically and environmentally.

From Prince Edward Island to British Columbia, the foundation of any agricultural operation revolves around its soils. Livestock, arable grains, specialty crops, even small market garden micro-farming, has soil as the foundation. The recommendations I suggest can be adapted to most agricultural regions across Canada. Remapping soil variability with accurate spatially usable maps has a big-picture benefit for both growers and government. Some of those key benefits are to farm more efficiently with higher economic returns, and more site-specific environmentally responsible use of nutrients.

Government also has a lot to gain from this investment. As a long term plan, it can be the foundation for sustainable, environmentally responsible agriculture. If we have an accurate map of our soils along with solid soil science understanding, we can safely and responsibly maximize each soil within its environmental boundaries. As an example, consider the systems that could be placed on soils defined as sands that are located near watersheds. That soil type would have ideal tillage practices, soil-test fertility targets and best management practises. A grower receiving government support could use the best practices and programs for the soil they work. The government would benefit from a normally environmentally risky soil being rehabilitated into a stable, sustainable soil. As well, the grower now has a usable spatiality accurate map of their lands and soils to base agronomic and variable rate foundations upon.

The final conclusion and recommendation is a list of text, websites and documents that although outside of the project references (see Foundation References), are excellent to help

take an agronomist to a sufficient level of understanding the language of soils and their use in modern precision agriculture. These resources can be fine-tuned to your geography and growing region. Most importantly, once familiar with the language of soils, the investment of a shovel to physically examine and study soils and their landscape position will be the most valuable investment you make. The best way to learn about soils is to dig, and keep digging. Examining the colors, textures and handling the soils in field conditions will solidify the texts and resources into a real skill set. You have to get dirty to learn about soils.

5.0 RECOMMENDATIONS

Based on what I learned in the UK, Australia and New Zealand, I came up with the six most basic steps to reflect upon when wanting to work with soil type maps as your management zones. This applies to growers, agronomists and academics - the three industry areas I studied. The goal here is to present a clear and simple outline of recommendations that apply for all three groups.

1. Growers need to start collecting all the data they can. All data is good data. There is no predicting what the value of that data could be useful for down the road.
2. There is more than one system to map soil spatial trends. There are satellite images, soil texture maps, or even historical collected data maps. All of these formats work, and over time, professionals will become more efficient in understanding the limits and systems in which to use them. This gives the industry and growers many options to take direction and action.
3. Of the three mapping systems mentioned above, there needs to be support and training on the most efficient way of interpolating that data into soil type maps. This is where the three industry areas need to work together to implement the big picture.
4. Certified Crop Advisors (CCA) and other agronomic industry personnel need to train and develop a better understanding of soil sciences. This will allow them to support and grow this service to agriculture. This can be accomplished with simple professional development certificates, provincially or federally, and overseen by academics or agronomic institutions. The foundation training and certification of any agronomist should have a base line of soil sciences included in the curriculum.
5. The cost of has to be supported by any stakeholder that can gain from the reclassification (e.g. retail industry, government and farmers).
6. Finally, the language of variable rate farming needs to be taught and used by growers, service providers and consultants. Referring to the soils and soil types, will provide a common language for variable rate farming.

REFERENCES

Avery and Catt, "The soil at Rothamsted". 1995.

<http://www.era.rothamsted.ac.uk/index.php?area=home&page=papers&SearchAuthor=avery&SearchTitle=&startyear=&stopyear=&output=NO&submit=Search>

Australian Soil Resource Information system. Accessed June 12 2016.

<http://www.asris.csiro.au/>

Australian Soil Classification (ASC) Soil Type Map of NSW. Accessed June 12 2016.

<http://data.environment.nsw.gov.au/dataset/australian-soil-classification-asc-soil-type-map-of-nsweaa10>

Bruggeman, Stephanie and Clay, David. 2017. *Practical Mathematics for Precision Agriculture*. Madison WI. American Society of Agronomy.

Can SIS Government of Canada CAN SIS soil reports by province. Accessed Sept 2016.

<http://sis.agr.gc.ca/cansis/publications/surveys/index.html>

Deaken University Centre Regional & Rural Futures, Faculty of Sci Eng. Accessed Aug 2017.

<http://www.deakin.edu.au/homepage>

Digital Atlas of Australian Soils. Accessed June 16 2016.

<https://data.gov.au/dataset/9e7d2f5b-ff51-4f0f-898a-a55be8837828>

Havlin, John L. North Carolina State University. 2010. *Soil Fertility and Fertilizers 7th Edition*. New Delhi. PHI Learning Ltd.

History of Rothamsted, Accessed October 2017

<https://www.rothamsted.ac.uk/history-and-heritage>

King, Carolyn, "Mapping Variability: An on-farm study at soil sensor data for identifying variable rate management zones" *Top Crop Manager*. March 07 2016.

www.topcropmanager.com/precision-ag/mapping-variability-18722

McKeague J.A. & Stobbe P.C. 1978 *The History of Soil Survey in Canada 1914-1978*. Ottawa. Minister of supply and services Canada.

McKenzie, N.J., Jacquier, D.W., Ashton L.J. and Cresswell, H.P. 2000. Estimation of Soil Properties Using the Atlas of Australian Soils. CSIRO Land and Water Technical Report 11/00.

New Zealand Online Soils Data site: S-map Online New Zealand soils data. Accessed May 2

2016. <https://smap.landcareresearch.co.nz/>

OzDSM Collaborative Workspace for Australian Digital Soil Mapping. Accessed July 2 2016.
www.ozdsm.com.au

UKSO UK Soil Observatory. Accessed July 1 2017. <http://www.ukso.org/maps.html>

FOUNDATION REFERENCES

Clayton, J.S., Ehrlich, W.A., Cann, D.B, Day, J.H. and Marshall, I.B. 1977. *Soils of Canada*. Agriculture Canada Publication.

[Government of Canada. 2018. "Canadian Soil Information Service".
<http://sis.agr.gc.ca/cansis/> Modified March 18, 2018.](http://sis.agr.gc.ca/cansis/)

Kirkwood, V., J. Dumanski, A. Bootsma, R.B. Stewart and R. Muma. 1989. The [Land Potential Data Base for Canada](#) Users' Handbook. Land Resource Research Centre Technical Bulletin 1983-4E, Research Branch, Agriculture Canada, Ottawa.

Soil Classification Working Group. 1998. The Canadian System of Soil Classification, 3rd ed. Agriculture and Agri-Food Canada Publication 1646

The Canada Soil Information System. *Manual for describing soils in the field*. 1982.
https://uwaterloo.ca/library/geospatial/sites/ca.library.geospatial/files/uploads/files/canada_soilinformationsystem.pdf

University of Saskatchewan. No date. <https://www.soilsofcanada.ca/>

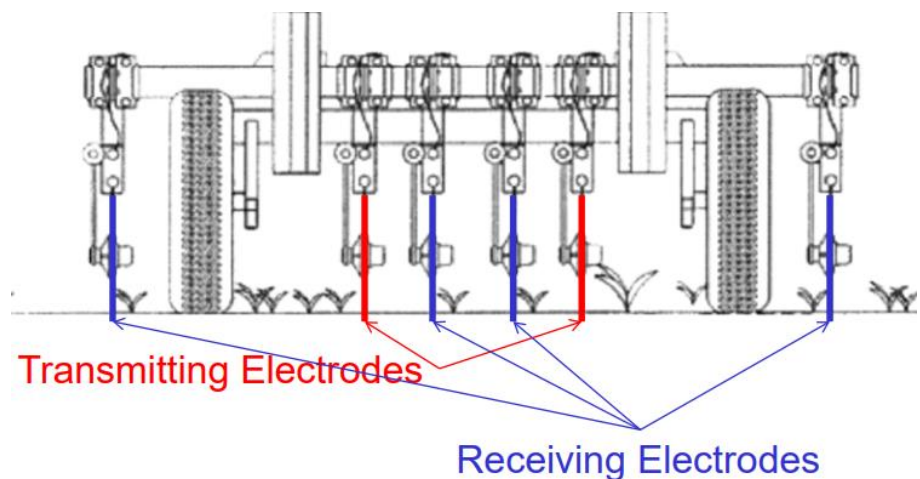
APPENDICES

Appendix #1

Veris <https://www.veristech.com/>

The Veris machine is pulled across a field and measures soil electrical conductivity. It is contact based, meaning it needs to slice into the soil several inches. The machine is designed with coulters to penetrate into the soil. This is pulled by a truck or all-terrain vehicle which also supplies the power and GPS signal.

The machine uses decisiemens as a measurement of how much electrical current a soil can conduct. It's an effective way to map soil texture because smaller soil particles such as clay conduct more current than larger silt and sand particles. This process measures the speed of conduciveness to determine the spatial differences of soils across a field. Since a clay soil has more conductivity, the number is high. While sands have a low number since their conductivity is low.



Appendix #2

EM 38 <http://www.geonics.com/html/em38.html>

An EM38-MK2 is a non-contact sensor for use in soil mapping. The instrument sends an electromagnetic signal through the ground. This signal measures the conductive anomalies within the soil and sends it to a receiver. This signal is spatially logged and then converted to electrical conductivity. The machine is designed as a sled to slide across the soil. This is pulled by a truck or all-terrain vehicle which also supplies the power and GPS signal.

