Horticulture Innovation Australia

Final Report

Understanding spatial variability in potato cropping to improve yield and production efficiency

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Precision Agriculture Laboratory

Project Number: PT13000

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The University of Sydney and Simplot Australia Pty Ltd

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Summary

This research project aimed to pioneer an understanding of the extent and causes of within-field spatial variation in Tasmanian potato yield using a range of new sensing technologies and provide a preliminary determination on the potential for variable-rate management responses to improve profitability. To achieve this goal, soil apparent electrical conductivity (ECa) and high resolution elevation data were used to first define the variation in soil and landscape resources over two growing seasons. Variation in crop production was estimated using in-season aerial reflectance measurements and then measured using a first generation on-harvester yield monitoring system. During the season, soil and crop physical and chemical properties were measured to groundtruth/calibrate the sensor-derived data.

The project wasn't without its technical issues, primarily related to the on-harvester yield monitoring system combined with logistical issues associated with the physical harvest operation and the contractual obligations around harvest timing for individual fields. However, the project successfully documented substantial within-field and between field variation in soil physical and chemical properties, elevation and crop yield. The average potato yield for the study fields was 64 t/ha, but within fields the yield was recorded to vary over three-fold (from 28 t/ha to 96 t/ha on average).

The in-season aerial crop reflectance was shown to significantly correlate to soil physical variability when gathered early in the season and to variation in plant physical and chemical properties, as well as important soil nutrient properties and crop yield when gathered from week 14 onwards.

During the project, collaborating farmers were provided with maps of variability and involved in discussing results and implications. A wider group of growers and advisors were updated on progress through an Industry meeting organised by Simplot Pty Ltd, two articles in Potatoes Australia and PA news, and a poster presentation at a Tasmanian PA Expo.

The results have highlighted that at this early stage, the most appropriate option for exploring SSCM in potato production appears to be the pursuit of individual field-based decision rules within broad recommendations for gathering useful field-scale data and sampling/analytical operations. To this end a short set of general rules for instigating SSCM in potato production has been devised based initially on nutrient management with irrigation management as an option.

A number of recommendations have been distilled to follow up this pilot program.

They are:

- Greater than 3-fold variation in potato yield within fields (mean 64.3 t/ha, S.D. 17 t/ha) translates into significant variation in gross margin within uniformly treated fields. This warrants continued and more detailed investigation into improvements in the allocation of inputs to the potato production system.
- Accurate, easy to gather yield data will be essential for the development of site-specific management in potato production. Improvements to existing retrofit systems should continue and harvester manufacturers encouraged by industry to develop factory-fitted systems.
- The use of mid-season aerial imagery should be encouraged for the early detection of within-field deficiencies in the major macronutrients (N,P,K). Reflectance measurements other than NDVI (e.g. red edge NDVI, thermal) should be explored.
- The use of early-season aerial imagery to detect areas where a build-up of soil-borne pathogen load may be occurring should be further investigated.
- Variable-rate irrigation should be explored based on the changes in soil type identified using ECa surveys or early-season aerial imagery. Results here suggest there may still be a significant negative impact on yield from temporary waterlogging caused by within-field variation in soil water holding capacity.

Keywords

Precision Agriculture, soil conductivity, potato yield, spatial variability, crop reflectance, NDVI

Introduction

Site-specific crop management (SSCM), where inputs and agronomic practices are matched to soil properties and crop requirements as they vary across a field, aims to improve the efficiency and profitability of crop production. Gaining a quantified understanding of how crop production varies spatially within a field should provide the opportunity to improve diagnosis of agronomic issues and eventually apply inputs at variable-rates to meet variation in crop requirement. The manner in which inputs may be distributed would be determined by the goal of production (e.g. is the aim uniform quality or optimal yield at each site in the field) and requires an understanding of the agronomy of production. However variable-rate management of inputs should achieve the triple aims of better input use efficiency, profit maximisation and lower environmental impact.

To begin exploring the potential for implementing this 'site-specific' agronomy, the magnitude and spatial scale of variation in important components of crop production need to be quantified and any production limiting factors in the field identified. For vegetable crops, information across the industries on the scale of within-field variation in important components of production have received little research attention, which means there is minimal information on how/where traditional management could be modified to optimise production.

This project was devised to help bridge this knowledge gap on within-field production variability for potato crops and provide some information on what data may be useful to stimulate the adoption of SSCM by potato growers. The general aim is to provide an assessment as to whether the pattern and size of observed production variability would warrant varying input rates (nutrients, irrigation water etc.) within a field to produce a more profitable result than uniform input application.

The potato industry in Tasmania was chosen for this project because it is the dominant contributor to Tasmanian vegetable production but Tasmania is also the region with the highest costs for potato production worldwide. Production costs for ware potatoes of approximately $14,000/ha, and current potato prices, mean that breakeven yield is around 42 t/ha. The average production estimate for Tasmania is 54 t/ha, meaning that profit margins are tight, with some farms inevitably running close to breakeven. An ability to reduce or optimise the use of inputs should see this situation improve across the industry and increase the ability to compete against international production. Such a strategy would also provide an indicator that the industry is moving towards a more sustainable management system and bring marketing benefits associated with increased environmental awareness.

To achieve these goals, relevant information on crop yield or production surrogates, soil properties and landscape variables needs to be gathered at both a fine spatial resolution and within financially realistic cost bounds. Physical manual sampling of these attributes at the scale required would not pass the financial test. To solve this issue within other cropping industries, there have been a number of sensor systems developed for mapping these soil, landscape and crop properties, and their application in broadacre cropping, viticulture and fruit orchards has shown that there is considerable variability that impacts on crop yield and quality. The sensors include harvester-mounted yield monitors, soil apparent electrical conductivity (ECa) instruments, crop reflectance sensors and high accuracy DGPS-gathered elevation. In many of these production systems the ability to include the information from these sensors into management decisions, as opposed to accepting traditional uniform management to field averages, has produced gains in outputs and/or production efficiencies.

Adoption of these sensor systems in vegetable production has been slow, and a significant reason may well be found in a scoping study commissioned by HAL (Project VG05060) which showed that many fresh vegetable industries would benefit from significant improvements in mechanisation of labour intensive processes before significant gains can be made by improved production information systems. However the scoping study also recommended that there are several industries that are already highly mechanised and suitable for spatial sensing systems. These included potatoes, tomatoes, onions and sweet corn.

The benefits of using a harvester-mounted sensor system to map in-field variation in potato yield needs little explanation. The potential benefits of the soil ECa sensors may be less obvious, but a major cause of yield variation in potato crops would be any variability in available soil water and this is often linked to changes in soil physical parameters. Cotching et al., (2004), using point sampling, found that soil structure and depth to rooting resistance in Tasmanian soils were positively correlated with potato yield. Being able to map soil physical properties, or a correlated surrogate, at fine spatial scales would appear to be advantageous in establishing the true extent of any links to crop production. Soil ECa sensors that employ electromagnetic induction principles and can be vehicle-mounted to provide soil maps, have been correlated to physical properties of soil in other cropping industries.

Where these links can be established, and the cause and extent of financial impact quantified, then management changes can be considered. Variable-rate application of irrigation water and/or nutrient supplies to match soil-induced variability in crop yield/quality are the main options for consideration. Once the interactions are understood at this scale using yield and soil maps, obtaining information on production variability during the growing season would broaden the options for when variable-rate applications could be implemented (especially with irrigation). Crop reflectance sensors, which can be calibrated to biomass production, should serve to indicate areas where production variability may require differential intervention as the current season unfolds. With enough data, decision rules for varying management based on the timing, extent, pattern and cause of spatial variability in potato yield could then be constructed.

The main outcome of this project would therefore be to enable the potato industry to move towards more efficient use of fertiliser and irrigation inputs and thereby increase profitability and sustainability. However, potato production in Tasmania is also strongly vertically integrated, which apart from assisting with the adoption of new technologies and techniques that show trial success, also offers opportunities to use the spatial variation observed to improve harvesting and processing logistics. This may be as simple as providing better estimations of the tonnage being delivered to the processing plant or more complex differential harvesting strategies to segregate quality grades in-field and present a more uniform product to the processing plant. Alternatively the identification of low productivity areas may permit the area under production, and thus production costs, to be diminished with little effect on total production (tonnage).

A preliminary set of decision rules for moving towards the spatial management of inputs based on the sensor data will be constructed to permit potato growers to begin accessing the expected significant gains in yield and production efficiency to be made through SSCM. The insights gained may also be used as a template for exploring SSCM in other mechanised vegetable crops.

Methodology

The project had four main sections to achieve the aims of quantifying the amount of variation in potato production systems and identify any opportunities for the application of differential management strategies.

1. Collection of spatial environmental data (soil, landscape);

2. Collection of spatial information related to crop production during the growing season;

3. Collection of crop yield maps; and

4. Synthesis and data analysis of the environmental and crop data

The study area covered potato producers that are contracted to Simplot Australia Pty Ltd in the Midlands and Northern regions of Tasmania. These regions are the main contributors to the contracted tonnage of potatoes. The Midlands region of Tasmania has duplex soils that at times are difficult to manage, particularly the application of irrigation water across variable soils. The North/North west regions of Tasmania contain Ferrosol loams and are historically the traditional production regions for Tasmania’s vegetable and allied crops.

Steps involved in the four main sections of this project were:

Build an understanding of the spatial variation of the production environment

Collection of soil apparent electrical conductivity (ECa) and elevation data via an on-ground survey on 16 paddocks across the two regions in each season. ECa has been shown to provide corroboration to the spatial yield pattern observed in many broadacre and viticulture fields, and correlation with a number of deterministic physical soil parameters such as soil texture and moisture (Jaynes, 1996; Bramley, 2001; Whelan & McBratney, 2003). Field topography has also been shown to provide an indirect indication of variability in soil physical and chemical attributes - again usually due to a high correlation with a deterministic attribute such as soil texture (Sudduth et al., 1996). Topography also provides indirect information on microclimate attributes and water movement that influence crop production potential (Moore et al., 1993).

The survey was carried out on ~15m swaths using an ATV fitted with an electro-magnetic induction instrument (EM38DD®) to measure soil ECa and a carrier-phase DGPS to gather high quality elevation data (Figure 1). These spatial data layers were used to describe the pattern of soil/landscape variation in the target fields. Once gathered, the method of Taylor et al. (2007) was used to clean the data and map each layer to a common grid for each field. With the layers on a common grid, a multivariate k-means clustering process was employed (Hartigan and Wong, 1979) to delineate potential management classes (PMC). This is an iterative method that creates disjoint classes by estimating cluster means which maximise the Euclidean distance between the means and minimise the distances within the cluster groupings.

In this instance, the process created a single map that stratified the variation in each field into three areas (classes) that have average combinations of elevation and ECa that are as different from each other as possible. A stratified random sampling procedure, with the three classes used as strata, was employed to identify sites for directed sampling. Directing sampling in this manner allows the full range of landscape variability across the fields to be incorporated in the physical groundtruthing and production variability investigations in a time and cost efficient manner. At these identified sampling sites, soil physical and chemical properties along with soil disease pathogen loads were measured.

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Figure 1. Field survey vehicle and instruments to measure soil ECa (electro-magnetic induction (EMI) unit), and elevation (differential GPS).

Measure variation in crop production throughout the growing season

During the growing season the crop was monitored using biomass reflectance imaging sensors mounted on an aircraft. The sensors measured passive reflectance in the red and infra-red bands of the electromagnetic spectrum to form an image of the crop. The reflectance measured in the two bands was used to calculate the Normalised Difference Vegetation Index (NDVI) (Equation 1)

$$NDVI = \frac{IR - red}{IR + red} \qquad (1)$$

Converting the reflectance to NDVI produces a measure of crop greenness, vigour/health that accentuates the differences in crop performance between different areas of the field. Aerial imaging was undertaken at week 8, 12, 14, 16 and close to harvest (week 19). On-ground NDVI was trialled using a prototype tractor-based sensor with real-time data streaming that was to be used during normal spraying operations to limit operational costs related to time and extra field passes. It ultimately proved unsuccessful due to technical issues with the sensor and data capture and low survey opportunity due to the relatively wide spacing of tractor swaths compared to aerial imaging.

Physical crop measurements and tissue samples were taken, as crops approached maturity, to ground-truth the information obtained from the aerial sensors and also compare to crop yield measurements. The samples were taken at the previously identified soil observation sites to enable a full landscape to yield analysis.

Map crop yield using harvester-mounted sensors

The project aimed to measure potato yield at strategic sites using Simplot harvesters fitted with a sensor and monitoring system (YM1) developed by ATV[1]. The system involved the mounting of an active weighing scale under the final grading belt, a GPS on the harvester roof, with both connected to a monitor in the cabin (Figure 2). The system recorded tared weight from the belt, along with field position information, which when combined with harvesting width could be used to calculate a yield in tonnes/ha every second of the operation.

[1] Advanced Technology Viticulture, 118 First Ave., Joslin, SA, 5070, Australia

(a) (b)

Figure 2. Yield monitoring system components (a) active weighing scale (b) in–cabin monitor.

Data analysis

Correlation analysis was used to identify relationships between individual landscape and production properties. For correlation analysis of whole-field survey, NDVI and yield data where sample numbers were high (thousands of observations) a conservative level for significance testing was implemented (Pearson correlation coefficient n =100 p<0.01 =0.25).

Spatial analysis of the whole-field survey and yield data was used to provide quantitative information on how the landscape and production varies within a field.

Within-field spatial analysis

Global semivariograms of soil ECa and crop yield were calculated, and best-fit models determined, using VESPER (Minasny et al., 2005). The semivariogram is used to describe and parameterise the spatial variation of a densely sampled attribute across a field. A global semivariogram model provides information on the amount of short-range or random variation (C0), and the variation contributed by systematic influences, known as the structural component of variation (C). Total variation is the sum of C and C0 (the sill). The distance over which this systematic spatial dependence holds (a) is, in effect, the maximum distance between two samples within a field where a modeled relationship can be expected to hold and the larger the value, the more coherent the observed spatial pattern.

In this process a suite of four models (spherical, exponential, stable, linear with sill) were compared using the Akaike Information Criteria (AIC) (Akaike, 1974). The exponential model predominated in preliminary assessment and was used exclusively for final analysis. Median semivariogram models were also calculated following the procedure of McBratney and Pringle (1997) to provide generalized models for comparison of attributes and regions where practical. The strength of the spatial dependence of the median semivariograms was assessed using the nugget ratio (NR) as applied by Cambardella et al. (1994) (Equation 2).

$$NR = \frac{C0}{CO + C} \times 100 \qquad (2)$$

Where: C0 = nugget, C0 + C = sill of each semivariogram. When NR≤ 0.25 = strong spatial dependence; 0.25≤NR≥0.75 = moderate spatial dependence; NR ≥ 0.75 = weak spatial dependence.

Sample point analysis

Incorporating the landscape data into the sampling design through the PMC clustering process is aimed at improving the potential identification of any agronomically significant relationships in the point sample data. At the individual field level this process has been successfully employed in viticulture (Bramley 2001) and broadacre applications (Whelan & McBratney, 2003). Student's t-test and analysis of variance (ANOVA) can be used to assess each field individually.

However in this project the goal is a preliminary general assessment of factors influencing production variability across the Tasmanian potato industry. At each sample point, ECa, elevation, NDVI and yield data were extracted from the whole-field data sets and combined with the soil and plant data. Correlation analysis on the entire set of point samples was undertaken to identify significant relationships and build an understanding of the importance of measured factors on production variability.

Outputs

1) Preliminary decision rules for describing spatial variability in potato production and determining any suitable variable-rate management interventions built from existing data and the more detailed data gathered over the two years of this project (see outcomes).

2) Hardcopy and digital maps of variability data for each season from each field provided for farmers. In each season, soil maps and in-season crop monitoring images were provided to the respective farmers. Yield maps were discussed at the end of each season where full field harvest was successful.

3) Oral presentations: at the annual Symposium on Precision Agriculture in Australasia – 31/09/2014. Paper presented by Brett Whelan at the Simplot Australia Research and Development Seminar on 16th July 2014 at Ulverstone, Tasmania

4) Two articles raising awareness in the Potato Industry and the Precision Agriculture communities were published and a poster/booth presentation at a PA EXPO delivered:

- Using Precision Agriculture Tools to Understand Potato Yield Variability. *Potatoes Australia,* April/May 2015, pp22-23
- Early PA for Potatoes. *Precision Ag News*, SPAA Society of Precision Agriculture Australia. Spring/Summer 2015, Vol 12:1, pp14-15.
- Mapping to Monitor and Manage Production Variability in Potato Cropping. *Precision Agriculture Expo,* Deloraine, 23rd April 2015, Australian Institute of Agricultural Science & Technology, Tasmanian Division.

5) A peer-reviewed scientific paper on the spatial variability in potato production, causal relationships and preliminary decision rules is in preparation for submission to the Precision Agriculture Journal (impact factor = 1.929)

Outcomes/Results

ECa and elevation survey data

An example of the data gathered during the field surveys is shown in Figure 3. The surveys confirmed that in both the North and Midland regions there was extensive variation in ECa within fields. Tables 1 and 2 show the basic descriptive statistics for the project fields in the two regions. A comparison of the median coefficient of variation (CV%) for the two depths of investigation in each field shows that the ECa (0-1.5m) is generally more variable around the mean in each field than the shallower (0-0.75m) and that the difference more pronounced for the Northern region.

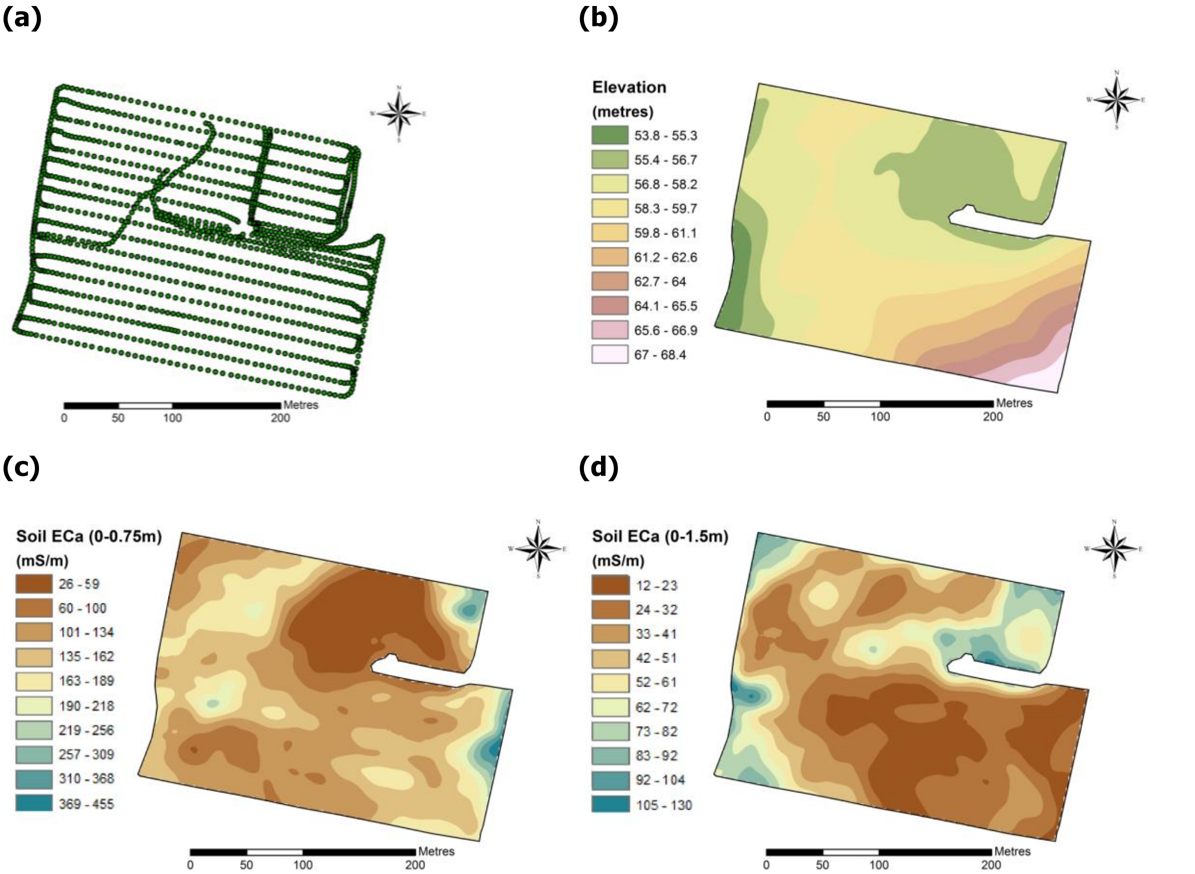

Figure 3. An example of field survey data gathered using an ATV equipped with EM38DD and DGPS. (a) survey path, (b) mapped elevation, (c) soil ECa (0-0.75m), (d) soil ECa (0-1.5m).

Table 1. Descriptive statistics for ECa measured to two depths (0-0.75m and 0-1.5m) and elevation for fields in the two regions in 2014.

	ECa (0-0.75m) (mS/m)			ECa (0-1.50m) (mS/m)			Elevation (m)		
Field	**mean**	**S.D.**	**CV%**	**mean**	**S.D.**	**CV%**	**mean**	**S.D.**	**CV%**
North									
BP	71	10	14	16	5	31	208	7	3
FH	84	12	14	27	17	63	229	5	2
TI	48	8	17	14	10	71	241	1	1
MA	70	12	17	20	11	55	178	1	1
P1	63	15	24	23	8	35	144	1	1
PP	102	19	19	11	7	64	152	4	3
WI	82	13	16	12	8	67	171	4	2
RA	34	16	47	10	5	50	94	4	4
RB1	102	10	10	15	5	33	74	4	5
RB2	119	12	10	32	5	16	69	7	10
Median	77	12	17	16	8	53	162	5	3
Midlands									
BA	34	12	35	45	18	40	18	2	1
BU	40	13	33	55	18	33	18	1	1
DP	75	42	56	87	38	44	36	2	1
HV	82	17	21	108	22	20	19	1	1
SY	19	12	63	33	17	52	17	1	1
Median	40	13	35	55	18	40	18	1	1

Table 2. Descriptive statistics for ECa measured to two depths (0-0.75m and 0-1.5m) and elevation for fields in the two regions in 2015.

	ECa (0-0.75m) (mS/m)			ECa (0-1.50m) (mS/m)			Elevation (m)		
Field	**mean**	**S.D.**	**CV%**	**mean**	**S.D.**	**CV%**	**mean**	**S.D.**	**CV%**
North									
B1	97	39	40	55	34	62	72	7	10
G3	147	76	52	56	29	52	59	3	5
RO	210	74	35	42	13	31	187	3	2
NW	81	10	12	31	13	42	221	6	3
BA	83	14	17	37	4	11	146	6	4
CH	80	10	13	27	9	33	171	3	2
DO	85	9	11	27	10	37	145	3	2
TA	93	17	18	11	6	55	171	5	3
Median	89	16	18	34	12	40	159	4	3
Midlands									
BU	453	134	30	455	193	42	158	3	2
OSB	570	201	35	814	272	33	171	2	1
GA	258	65	25	346	86	25	177	2	1
RP2	360	256	71	431	244	57	154	3	2
RP4	175	113	65	302	161	53	163	4	2
VC	295	171	58	460	220	48	181	2	1
RB	342	161	47	533	190	36	147	1	1
Median	342	161	47	455	193	42	163	2	1

The results of the more sophisticated spatial analysis of the ECa are shown in the individual and regional median semivariograms for the two depths in Figures 4 to 7. Table 3 documents the model parameters for the median semivariograms fitted using all relevant ECa data for each category.

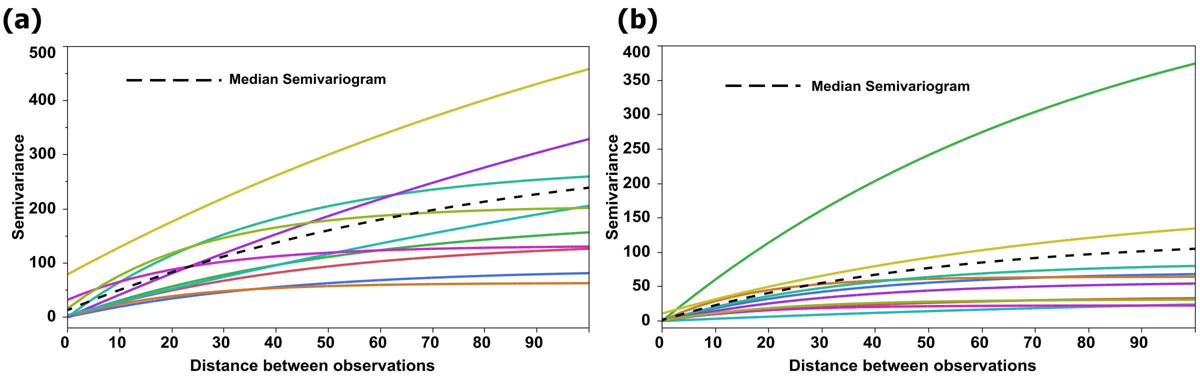

Figure 4. 2014 Semivariograms for whole field ECa – North: (a) 0-75cm depth median semivariogram properties: C0=13, C1=370, a'=80 (effective range=240m); (b) 0-150cm depth median semivariogram properties: C0=1.3, C1=120, a'=50 (effective range=150m).

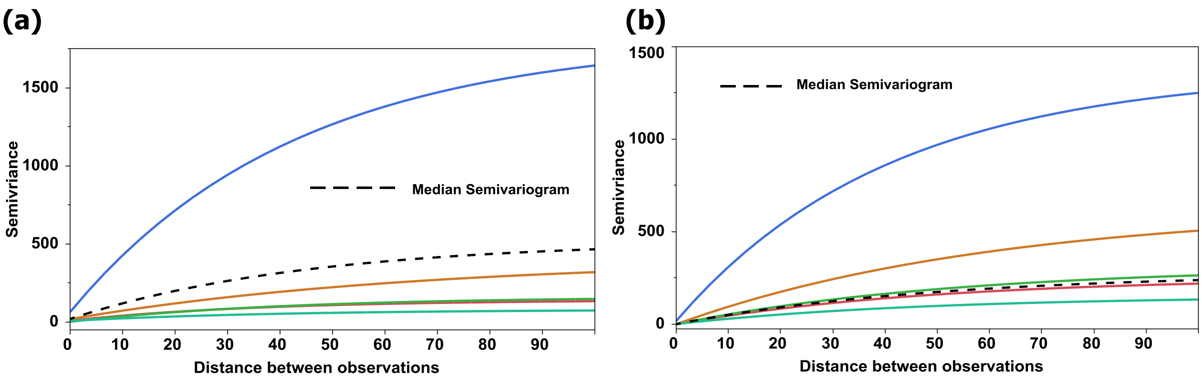

Figure 5. 2014 Semivariograms for whole field ECa – Midlands: (a) 0-75cm depth median semivariogram properties: C0=20, C1=500, a'=45 (effective range=135m); (b) 0-150cm depth median semivariogram properties: C0=0.8, C1=275, a'=50 (effective range=150m).

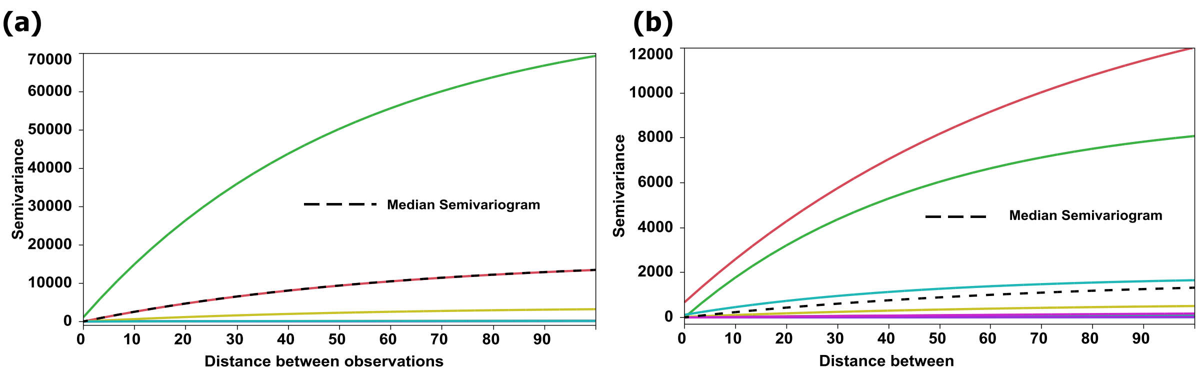

Figure 6. 2015 Semivariograms for whole field ECa – North: (a) 0-75cm depth median semivariogram properties: C0=0, C1=16618, a'=60 (effective range=180m); (b) 0-150cm depth median semivariogram properties: C0=4, C1=1729, a'=69 (effective range=210m).

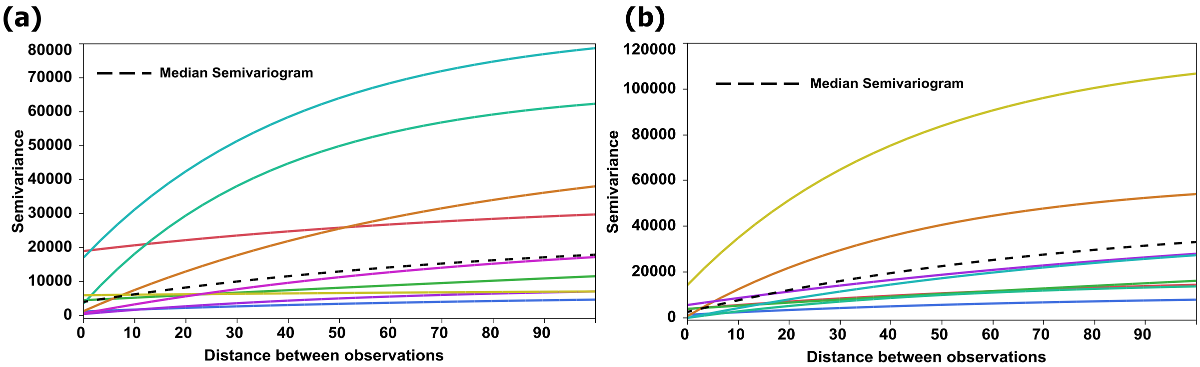

Figure 7. 2015 Semivariograms for whole field ECa – Midlands: (a) 0-75cm depth median semivariogram properties: C0=3905, C1=19993, a'=84 (effective range=250m); (b) 0-150cm depth median semivariogram properties: C0=2598, C1=42305, a'=78 (effective range=240m);

Table 3. Median semivariogram model parameters for ECa measured to two depths (0-0.75m and 0-1.5m) for the two regions and two seasons. The range (a') for an exponential model equates to 1/3rd effective range for a transitive model. NR = nugget ratio analysis where NR≤ 0.25 = strong; 0.25≤NR≥0.75 = moderate; NR ≥ 0.75 = weak.

	C0	C1	a'	Effective range (a) (metres)	NR
2014 ECa North (0-0.75m)	13	317	80	240	4
2014 ECa North (0-1.50m)	1.3	120	50	150	1
2014 ECa Midland (0-0.75m)	20	500	45	135	4
2014 ECa Midland (0-1.50m)	0.8	275	50	150	0
2015 ECa North (0-0.75m)	0	16618	60	180	0
2015 ECa North (0-1.50m)	4	1729	69	210	0
2015 ECa Midland (0-0.75m)	3905	29682	149	450	12
2015 ECa Midland (0-1.50m)	2598	42305	78	240	6

The data confirms that the total variation in ECa changes between fields and regions but also shows that the total variance in ECa (not the variance relative to the mean as depicted in the CV%) is actually larger in the shallow measurement. This suggests that the topsoil is more variable in soil type than the subsoil. The total variance (C0 + C) and the short range variation (C0) are both larger in the Midlands. In both regions, the large effective ranges (a) and low NR values for the median semivariogram parameters provide evidence for strong spatial structure and cohesive patterns in the ECa data at both depths of investigation. These qualities can be seen in the maps in Figure 3c and 3d.

The elevation data varies much more smoothly, however the Northern region fields display more within-field variation in elevation than the Midlands. Using the standard deviations (SD) recorded in Table 1, and assuming a normal distribution, the median changes in elevation within field can range from 8m in the Midlands to 20m in the North.

An example of the results of the k-means clustering process that combined the ECa and elevation data layers into PMC to direct physical sampling sites is shown in Figure 8.

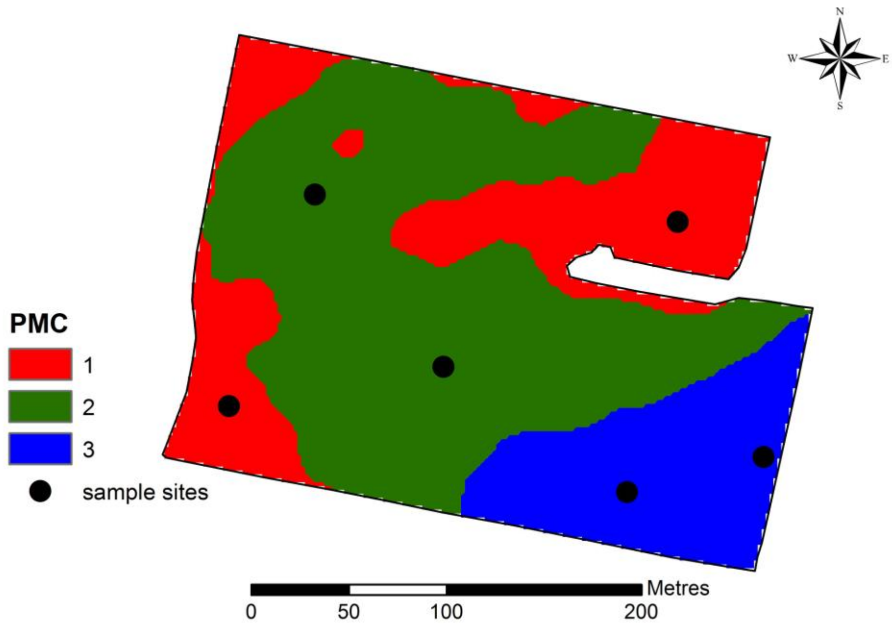

Figure 8. An example of the ECa and elevation survey data shown in Figure 1 being combined into a potential management class map (PMC) using k-means clustering. Physical sample sites randomly allocated within each class.

Remote sensing data

An example of the aerial NDVI data gathered for the project is shown in Figure 9. This is data for the same field as Figure 1 and 8.

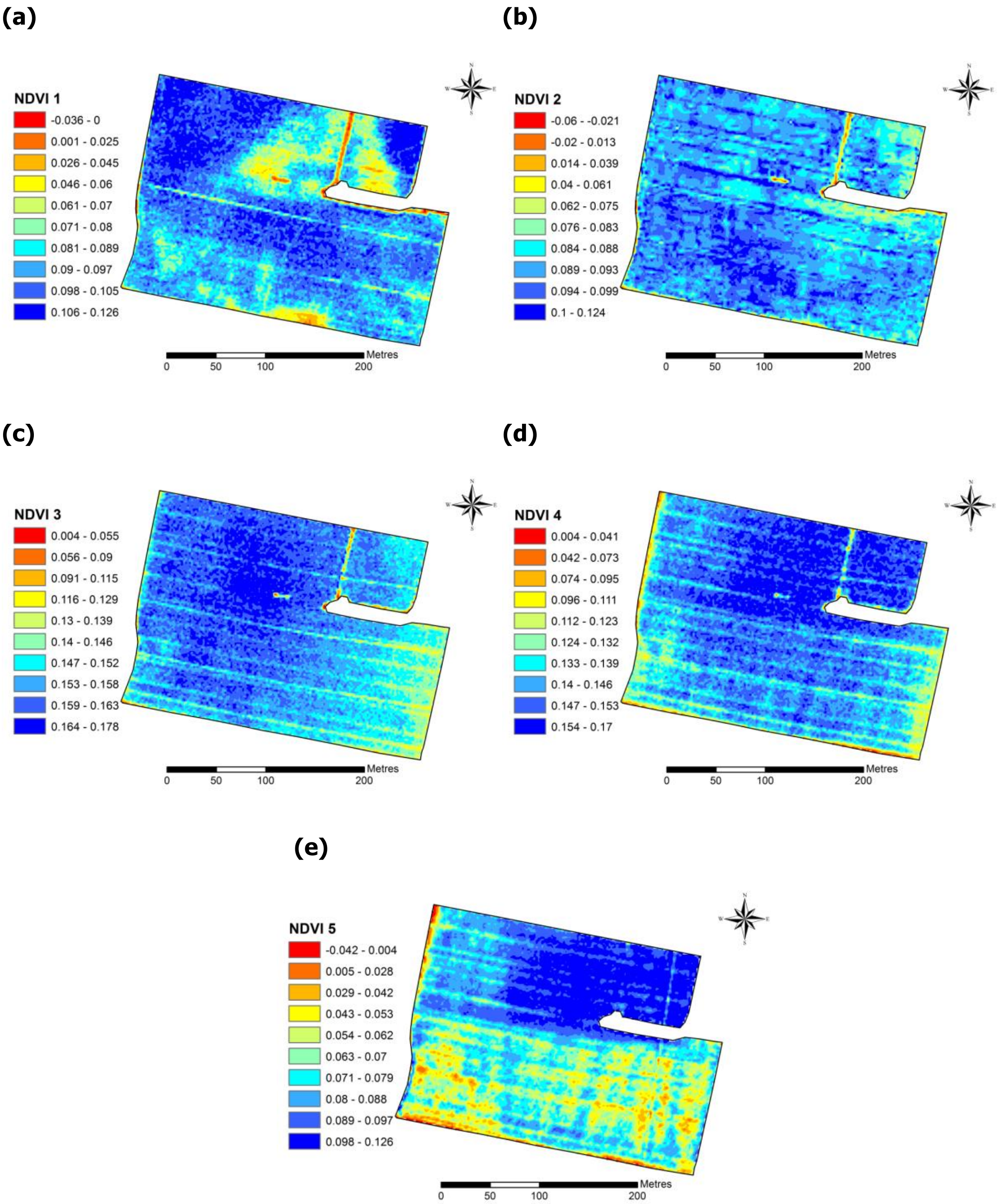

Figure 9. An example of the aerial NDVI imagery gathered during the growing season for the field in Figure 1 (a) week 8, (b) week 12, (c) week 14, (d) week 16, (d) week 19.

On-harvester potato yield data

Table 4 documents the potato yield data from fields where the yield in the entire field was successfully monitored by the on-harvester systems. This includes fields that were not included in the original project surveys. Unfortunately, not all fields in the project were yield mapped due to technical issues with the monitor, crop disease and some logistical issues. Technical issues with the ATV YM1 monitor are being progressively resolved and a new version released for 2016 (www.atv.net.au/ATV_YM2.html). Another first generation, non-OEM monitoring system built by Greentronics (www.greentronics.com) is available, but the lack of OEM yield monitors for vegetable harvesters remains a significant industry issue.

There are a number of logistical issues connected to the harvesting operation that make the monitoring more complicated than a grain harvesting operation. Each harvest operation will usually be undertaken in blocks that may not be harvested adjacent in time, meaning that gathering whole field yield data can be problematic, especially if weather intervenes or where contract harvesting of the fields and contractual delivery agreements mean that a field is harvested as two or more subsections with a significant time separation. The more physical nature of the combined digging, lifting and transport operation also raises issues when soil conditions or blockages result in frequent stopping/reversing of the harvester.

However, access to data from the harvesters on successfully harvested fields outside the project, combined with project fields with full yield data, provided a substantial database. Table 4 compares the actual receival total with the raw data recorded by the monitoring systems. The discrepancy in each field and the all-field summary statistics are shown. Potato yields vary substantially between fields (54 t/ha to 78 t/ha; avg = 64.3 t/ha, med = 64.5 t/ha) with an average 3.5-fold yield variability within a field (28 t/ha to 96 t/ha. The data shows that the yield monitoring system as operated to manufacturer's instructions results in an average absolute error of 10%. The receival yield data was used to post calibrate the yield monitor data to reflect actual field average yield prior to further analysis.

The semivariogram models for potato yield in the individual fields and the median model for potato yield across both regions are displayed in Figure 10 and show that the within-field total variance, like the ECa, also varies widely between fields. Changes in both the short range variation and the spatial structure of the variation contribute to the variation between the fields. Table 5 compares the model parameters of the median semivariagram for potato yield with the parameters for median semivariograms calculated for soil ECa in the two depths for all fields. It is evident that the short range variation is substantially higher as a proportion of total variation (i.e. high NR) for the potato yield. This manifests in yield data with greater 'noise' and yield maps with less spatial coherence than the related soil ECa maps, as shown in Figure 11.

Table 4. Potato yield data from whole fields. Summary statistics on field area, receival totals, monitored yields and discrepancy.

Field	Area	Received Total		Monitored Yield (t/ha)			Discrepancy	
		(t)	(t/ha)	Mean	S.D.	CV%	(t/ha)	(t)
B1	6.8	362.4	54	57	15	26	3	20.4
G3	6.8	494.0	73	66	17	26	9	61.2
No Water	7.4	446.0	60	63	21	33	3	22.2
Beans	5.2	301.6	58	63	17	27	5	26.0
Rocky	4.6	272.8	59	54	13	24	5	23.0
Dons	6.2	395.3	64	67	19	28	3	18.6
Don	2.4	177.7	74	64	19	30	10	24.0
Tank A	5.6	393.1	70	64	16	25	6	33.6
Tank B	1.6	93.5	58	67	16	24	9	14.4
Exchange	4.8	343.3	71	61	16	26	10	48.0
Paddock 4	8.2	492.7	60	58	17	29	2	16.4
Spurs	11.8	925.8	78	71	19	27	7	82.6
Gayfield	17	1148.0	66	60	17	28	6	102.0
Woodrising 1	6.5	422.5	65	55	16	29	10	65.0
Woodrising 2	8.5	578	68	53	18	34	15	127.5
Topivories	2.9	162.4	56	59	20	34	3	8.7
Front House	4.5	301.5	67	69	20	29	2	9.0
Highway	7.5	502.5	67	70	15	21	3	22.5
Redpath	9.5	522.5	55	52	15	29	3	28.5
Beveridge1	5.9	401.2	68	73	19	26	5	29.5
Robinson 1	5.5	346.5	63	61	20	33	2	11.0
Radford	8.7	522	60	62	16	26	2	17.4
Average	**6.7**	**436.6**	**64.3**	**62**	**17**	**28**	**6**	**31.8**
Median	**6.4**	**398.3**	**64.5**	**63**	**17**	**28**	**5**	**23.5**

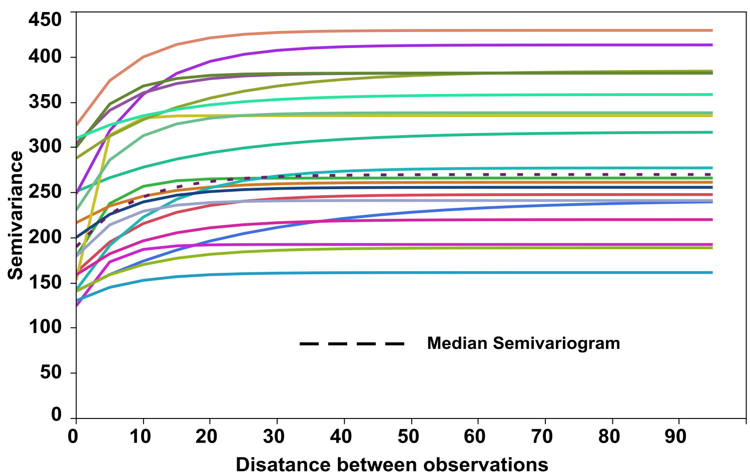

Figure 10. Semivariograms for whole field yield data. Median semivariogram properties – C0 = 190, C1 = 80, a' = 9 (effective range = 30m).

Table 5. Median semivariogram model parameters for ECa measured to two depths (0-0.75m and 0-1.5m) for all fields and potato yield for all whole-field data. The range (a′) for an exponential model equates to 1/3rd effective range for a transitive model. NR = nugget ratio analysis where NR≤ 0.25 = strong; 0.25≤NR≥0.75 = moderate; NR ≥ 0.75 = weak.

	C0	C1	a′	Effective range (a) (metres)	NR
ECa (0-0.75m)	16.5	8559	70	210	0
ECa (0-1.50m)	2.7	1002	60	180	0
Potato yield	190	80	9	30	70

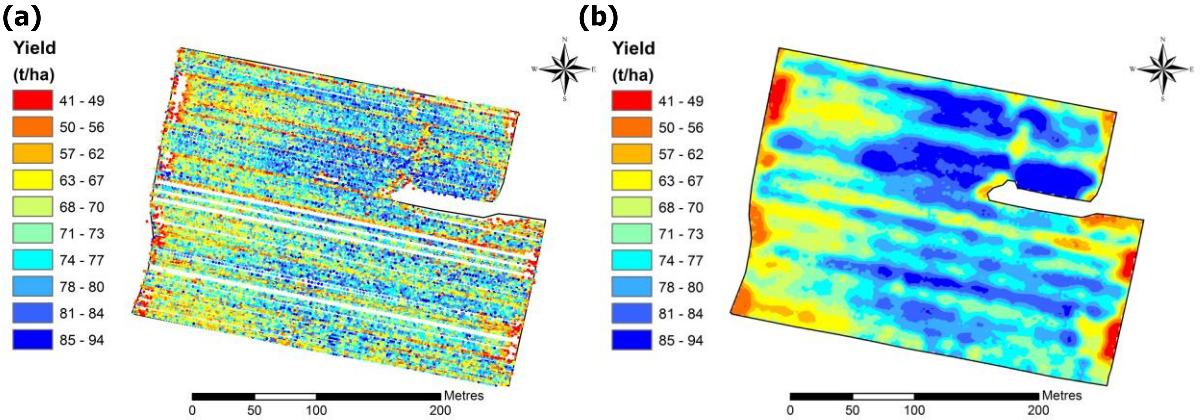

Figure 11. On-harvester yield data. (a) raw yield information, (b) yield map interpolated onto a regular grid using local kriging as per Taylor et al. (2007).

Soil physical data

Particle size analysis of the soil in the study fields shows that the potato fields located in the Ferrosol loams of the North and the duplex soils of the Midlands display an extensive variation in soil texture. Figure 12 plots the results from the farms/fields in a texture triangle which documents an extensive range from Sands to Clays.

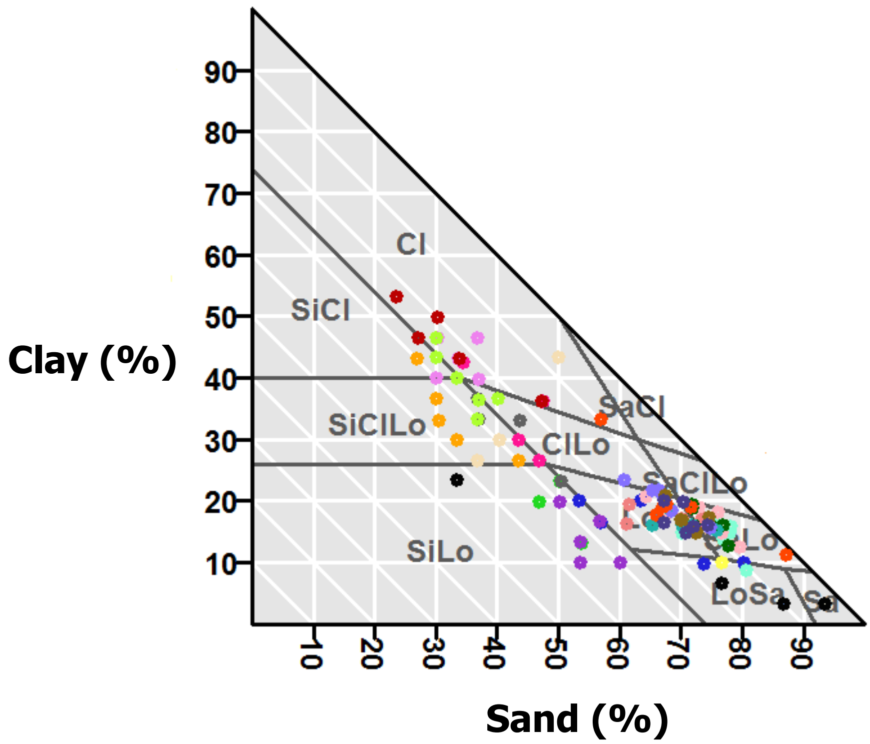

Figure 12. Variability in soil texture across the potato growing paddocks in the project. Soils growing potato in Tasmania range from Sands to Clays. Texture component symbols are: Cl = clay, Si = silt, Sa = sand, Lo = loam.

Whole-field data analysis

Correlation analysis of the different data layers gathered in the whole-field surveys is shown in Tables 6 and 7. The two ECa measurements are predominantly significantly negatively related in the North and positively related in the Midlands. This indicates greater changes in physical properties of the soil with profile depth in the North. The descriptive statistics for ECa in Tables 2 and 3 corroborate this observation. This difference in ECa response for the two regions influences the relationship between elevation and ECa. In the North the significant relationships are predominantly positive for the shallow depth (0-0.75m) and predominantly negative for the 0-1.5m depth. In the Midland region, the significant relationships are predominantly negative for both measurement depths. A positive relationship means that as elevation rises or falls in a field, the ECa value behaves similarly. A negative relationship is observed when the ECa declines as elevation increases and vice versa.

The data here suggests that the soil profiles in the Midlands follow a relatively traditional catena linkage whereby soil at higher elevation in a field is lighter in texture, shallower with a lower water holding capacity and therefore registers a lower ECa than soil at lower elevations. The response of the soil in the North suggests that while the subsoil follows an expected catena pattern, the shallower EC measurement may indicate a potential structural issue in the topsoil that is restricting water holding capacity at lower elevations. In all, the implications are that the influence of soil and landscape position on production variability will vary widely within and between regions, providing an indication that site-specific management information will be required at the field level.

Table 6. Correlation coefficients for 2014 whole-field analysis of relationships between elevation and measurements of ECa at two depths (0-0.75m & 0-1.5m), and between the two depth measurements of ECa. Significant values (p<0.01) highlighted yellow.

	North										Midlands				
Fields	**BP**	**FH**	**TI**	**MA**	**P1**	**PP**	**WI**	**RA**	**RB1**	**RB2**	**BA**	**BU**	**DP**	**HV**	**SY**
Elevation \ ECa (0-0.75m)	0.17	-0.67	0.56	-0.04	0.43	0.40	0.16	0.65	-0.14	-0.23	0.57	-0.07	-0.40	-0.41	0.21
Elevation \ ECa (0-1.5m)	-0.50	-0.36	0.62	0.32	0.02	-0.36	-0.13	0.64	-0.48	-0.53	0.65	-0.01	-0.48	-0.38	0.21
ECa (0-0.75m) \ ECa (0-1.5m)	-0.41	-0.23	0.72	-0.76	-0.24	-0.74	-0.83	0.85	-0.08	0.27	0.96	0.98	0.95	0.96	0.96

Table 7. Correlation coefficients for 2015 whole-field analysis of relationships between elevation and measurements of ECa at two depths (0-0.75m & 0-1.5m), and between two depth measurements of ECa. Significant values (p<0.01) highlighted yellow.

	North								Midlands						
Fields	**BB1**	**BG3**	**RO**	**NW**	**BA**	**CH**	**DO**	**TA**	**BU**	**OSB**	**GA**	**RP2**	**RP4**	**VC**	**RB**
Elevation \ ECa (0-0.75m)	-0.35	0.44	-0.70	-0.08	0.87	-0.25	0.37	-0.59	-0.38	0.72	0.08	-0.53	-0.75	-0.24	-0.68
Elevation \ ECa (0-1.5m)	-0.62	-0.56	-0.60	0.44	-0.90	-0.17	0.15	0.08	-0.42	0.77	-0.05	-0.48	-0.72	-0.23	-0.71
ECa (0-0.75m) \ ECa (0-1.5m)	-0.05	-0.15	0.94	-0.58	-0.80	-0.60	-0.24	-0.76	0.67	0.97	0.95	0.96	0.99	0.99	0.99

Analysis of the relationship between elevation and NDVI data gathered at different times during the season (Table 8) shows that a predominantly significant positive relationship is achieved by the 3rd aerial survey (week 14). The relationships between NDVI and ECa at both survey depths are also maximized at the 3rd aerial survey (Tables 9 and 10) with the relationships being dominantly negative at this stage. These results show that crop performance (greenness/vigour/health) is more likely to be greater in areas of higher elevation across the fields, and the negative relationship with ECa follows the ECa/elevation relationship (lower ECa; higher elevation), certainly for the Midlands. Together this suggests that elevation and the related soil physical changes are generally working in concert to influence crop greenness/vigour/health, however the higher NDVI at higher elevation may infer the elevation/soil interaction is actually combining with rainfall/irrigation quantities to create a production restriction during the first 2/3 of the season.

Table 8. Correlation coefficients for whole-field analysis of relationships between NDVI gathered over the growing season and elevation. Significant values ($p<0.01$) highlighted yellow.

	North								**Midlands**					
Field \ Date	**BB1**	**BG3**	**RO**	**NW**	**BA**	**CH**	**DO**	**TA**	**BU**	**OSB**	**GA**	**RP2**	**RP4**	**RB**
1		0.04		0.29	-0.64	-0.02	-0.11	-0.09			0.2		-0.62	0.19
2	0.08	0.04	-0.23		-0.37	-0.06	0.14	0.24	0.05		0.18	0.24	0.21	0.25
3	0.33	-0.36	0.39	-0.03	0.21	0.05	0.22	0.17	-0.39		0.1	0.33	0.25	0.25
4	0.12	-0.3	0.23	0.05	-0.07	0.09	-0.12	0.25	-0.37	0.15	-0.07		0.43	0.3
5	-0.35	-0.37	-0.1	-0.19		0.23	-0.08	0.03	0.09	-0.28	-0.22		0.37	0.39

Table 9. Correlation coefficients for whole-field analysis of relationships between NDVI gathered over the growing season and ECa (0-0.75m). Significant values ($p<0.01$) highlighted yellow.

	North								**Midlands**					
Field \ Date	**BB1**	**BG3**	**RO**	**NW**	**BA**	**CH**	**DO**	**TA**	**BU**	**OSB**	**GA**	**RP2**	**RP4**	**RB**
1		0.4		0.26	-0.56	-0.02	-0.07	0.19			-0.07		0.46	-0.34
2	0.09	-0.03	-0.13		-0.42	0.04	0.17	-0.17	0.04		-0.05	-0.55	-0.26	-0.3
3	0.06	-0.25	0.68	-0.08	0.04	0.13	0.16	-0.09	0.23		-0.03	-0.62	-0.36	-0.33
4	0.04	-0.3	-0.27	-0.14	-0.22	0.18	0.11	-0.26	0.33	0.11	0		-0.5	-0.38
5	-0.2	-0.31	0.29	-0.07		0.14		0.13	0.24	-0.2	-0.06		-0.38	-0.36

Table 10. Correlation coefficients for whole-field analysis of relationships between NDVI gathered over the growing season and ECa (0-1.5m). Significant values (p<0.01) highlighted yellow.

	North								Midlands					
Field \ Date	**BB1**	**BG3**	**RO**	**NW**	**BA**	**CH**	**DO**	**TA**	**BU**	**OSB**	**GA**	**RP2**	**RP4**	**RB**
1		-0.16		0.15	0.64	0.08	-0.15	-0.22			-0.13		0.45	-0.36
2	-0.22	-0.13	0.09		0.32	0	0.18	0.04	0.02		-0.06	-0.42	-0.25	-0.34
3	-0.43	0.04	-0.3	0.1	-0.3	-0.1	0.2	0.05	0.09		-0.01	-0.49	-0.35	-0.32
4	-0.25	0.01	-0.07	0.23	-0.06	-0.22	0.03	0.2	0.22	0.15	0		-0.5	-0.37
5	0.29	0.27	-0.2	0.21		-0.24	-0.03	-0.16	0.06	-0.25	-0.02		-0.37	-0.32

At the end of the seasons however, the relationships between whole-field yield and elevation was significant in only 36% of fields with both positive and negative outcomes (Table 11). The same statistics are found for the relationship between yield and ECa (0-0.75m). A lesser number of fields (29%) recorded a significant relationship between yield and the deeper ECa measurement. However the relationship as predominantly negative, indicating a tendency to lower yield with higher ECa readings with depth. Combining these results with the earlier data on soil and elevation indicates that the higher ECa in the subsoil in both regions can be linked to a production restrictive condition, potentially waterlogging or increased soil salinity.

Table 11. Correlation coefficients for whole-field analysis of relationships between final crop yield, elevation and measurements of ECa at two depths (0-0.75m & 0-1.5m). Significant values (p<0.01) highlighted yellow.

Field	**BB1**	**BG3**	**RA**	**RO**	**NW**	**DO**	**TA**	**RB1**	**RB2**	**FH**	**TI**	**HS**	**BU**	**GA**
Yield \ Elevation	-0.16	-0.02	-0.01	0.01	-0.08	-0.41	0.25	0.07	-0.49	0.14	0.02	0.45	-0.35	0.47
Yield \ ECa (0-0.75m)	-0.10	-0.41	0.28	0.36	-0.21	0	-0.04	0.15	0.21	0.09	-0.13	-0.29	0.29	-0.10
Yield \ ECa (0-1.5m)	-0.02	-0.13	0.27	-0.40	0.06	-0.30	-0.11	-0.22	0.4	-0.25	-0.12	-0.08	0.13	-0.16

In Table 12 the relationship between on-harvester yield and NDVI gathered during the season shows a distinct trend to increasingly significant positive relationships by the 4th survey (week 16). This is an encouraging result for the use of NDVI as a predictor of potato yield at the whole-field scale. It suggests that it is more useful to gather aerial imagery from mid-season onwards if the prediction of variability in crop yield or the identification of potentially low production areas is desired during the season.

Table 12. Correlation coefficients for whole-field analysis of relationships between NDVI gathered over the growing season and final crop yield as measured on-harvester.

Field \ Date	BB1	BG3	EX	RO	NW	DO	TA	BU	GA
1		-0.12			-0.01	0.24	0.41		0.26
2	0.2	0.1	0.13	0.03		0.11	0.22	0.18	0.24
3	0.13	0.25	0.13	0.17	0.04	0.17	-0.17	0.26	0.17
4	0.25	0.42	0.11	-0.02	0.13	0.42	-0.49	0.3	0.18
5	0.41	0.32		0.38	0.05	0.29	-0.28	0.11	0.04

Sample site data analysis

The full correlation analysis of the sample point data for the combined two seasons is recorded in Appendix 1. A range of interactions are identified, but of greatest relevance to the outcomes of this project is identifying the soil and plant properties that are significantly related to the variability in production measures of NDVI and on-harvester yield data.

Table 13 shows the results of the analysis for each aerial survey date. The coefficients for relationships with all the physical plant and soil measurements are included to illustrate any trends in significance with time. All other significant coefficients are recorded for each survey date.

Firstly, the NDVI observations from each survey are significantly correlated ($p<0.05$) with the observations at least 2 surveys later or early in time. This provides evidence that even at the sample site observation scale, the NDVI is representing a smooth change in plant conditions through the season.

It is also obvious from Table 13 that the first NDVI survey is significantly influenced by soil physical and chemical parameters, is positively related to the soil-borne disease pathogen load, and is not responding to physical or chemical plant parameters.

Table 13. Correlation coefficients from the analysis of relationships between NDVI gathered over the growing season and soil and plant physical and chemical measurements. All coefficients for physical plant and soil measurements are recorded along with all significant correlations. (* = p<0.10, ** = p<0.05, *** = p<0.01).

Attribute	NDVI 1	NDVI 2	NDVI 3	NDVI 4	NDVI 5
plants_3m	-0.32	0.24	0.27	0.48*	0.00
stems_3m	0.53*	-0.77**	-0.63*	-0.47*	0.00
av_stem_length (cm)	-0.00	0.01	0.14	0.37*	0.17
wet_weight (g)	-0.37	0.49	0.30	0.51*	0.00
specific_gravity	-0.41	0.42	0.36	0.57*	0.00
average_weight (g)	-0.13	0.23	0.21	0.46	0.00
Pratylenchus penetrans /g soil				-0.34**	-0.48***
Pratylenchus crenatus Copies / g sample	0.56***	0.78***	0.48***	0.25*	
Powdery Scab pgDNA/g Sample	0.43***	0.40***			
Common Scab pgDNA/g Sample	-0.39***				0.28
Clay (%)	0.76***	0.85***	0.36***	0.03	-0.02
silt (%)	0.86***	0.78***	0.27**	-0.04	0.14
sand (%)	-0.87***	-0.88***	-0.34**	-0.00	-0.08
em38v (mS/m)	-0.48***	-0.39***	-0.26**	-0.08	0.38
em38h (mS/m)	-0.32**	-0.43***	-0.15	0.03	0.29
plant_Total N (%)			0.46**	0.40*	0.61***
plant_P(%)			0.51***	0.44**	0.73***
plant_Ca(%)	0.55**				
plant_Zn (mg/kg)					-0.37*
plant_B (mg/kg)					-0.46**
plant_S (%)			0.34*	0.44**	0.54**
plant_Cu (mg/kg)					0.49**
plant_Fe (mg/kg)			-0.35*	-0.47**	
plant_Mn (mg/kg)					
plant_Al (mg/kg)		-0.43**	-0.35*	-0.48**	
plant_Na (%)					-0.81***
plant Cl (%)			-0.61***	-0.50**	-0.93***
soil_ammonium (mg/kg)	-0.52***	-0.58***			
soil_nitrate (mg/kg)	-0.28*	-0.32**			
soil_P_colwell (mg/kg)	0.36**				-0.34**
soil_K_Colwell (mg/kg)	0.36**				
soil_Sulphur (mg/kg)	-0.31*				0.33**
soil_OC (%)	0.35**			0.27*	
soil_Conductivity (dS/m)		-0.32**	-0.43***		
soil_pH_CaCl	-0.55***				
soil_pH_H2O	-0.48***				
soil_Cu (mg/kg)					-0.28*
soil_Fe (mg/kg)					
soil_Mn (mg/kg)	0.41**				
soil_Zn (mg/kg)	0.31*				
soil_Al (meq/100g)					
soil_Ca (meq/100g)	0.33*		0.34**		
soil_Mg (meq/100g)		-0.34**			
soil_K (meq/100g)	0.36**				
soil_Na (meq/100g)		-0.45***	-0.50***		
CEC (meq/100g)	0.31*		0.26*		
ndvi1	1.00	0.88***	0.52***	0.18	-0.00
ndvi2	0.88***	1.00	0.66***	0.29**	0.40**
ndvi3	0.52***	0.66***	1.00	0.73***	0.51***
ndvi4	0.18	0.29**	0.73***	1.00	0.55***
ndvi5	-0.00	0.40**	0.51***	0.55***	1.00

The second NDVI survey (NDVI 2) is still influenced by the physical soil parameters but the soil chemical and soil-borne disease pathogen load relationships are reducing while relationships with the physical plant parameters are beginning to increase. At the NDVI 3 survey, the influence of the soil physical and soil-borne disease pathogen loads are declining further and the relationships with plant chemical properties increases. By the 4th aerial survey (NDVI 4) the relationships with soil physical parameters have become non-significant, relationships with plant physical and chemical properties have peaked. At the last aerial survey (NDVI 5), the significant relationships are concentrated on the plant chemical properties.

These results offer significant support to the conclusion from the whole-field analysis that variation in aerial reflectance surveys from mid-season onwards are significantly responding to differences in plant related physical and chemical properties. It is worth noting that differences in both plant N and plant P, the two major elements applied in fertilizer management regimes, are significantly influencing NDVI. Early season surveys are responding significantly to differences in soil properties and disease pathogen load.

Table 14 shows the results of the general analysis of the relationships between harvester-gathered yield and the same site-measured soil and plant parameters. Of the soil physical properties, increasing clay and decreasing silt content have the most significant effect on raising crop yield. Soil Nitrogen and Potassium show a significant positive relationship with yield and the results suggest that when the exchangeable cations Al, Ca and Mg increase as a portion of CEC then yield can be negatively impacted. The concentration of key micronutrients Boron and Iron in plant tissue are negatively related to yield indicating a potential for toxicity. Increased Iron concentration in the soil also records a negative impact on yield. Manganese concentrations in the plant tissue show a positive relationship with yield which may indicate an important tendency towards deficiency in both regions.

The relationship with yield and the soil-borne disease pathogen load show a negative correlation with Pratylenchus penetrans and Pratylenchus crenatus suggesting a tendency for the present loads to be negatively impacting yield. Positive correlations with Pratylenchus neglectus, Meloidogyne hapla and Powdery Scab may indicate that where yield is highest, the conditions and increased plant material is causing pathogen loads to build but they are not yet at damaging levels.

From a plant physiological view, increasing the average stem length of the plants within a 3 metre length of row is recorded as the most significant plant parameter positively effecting crop yield compared to the number of plants or numbers of stems.

Table 14. Correlation coefficients from the analysis of relationships between yield data and soil and plant physical and chemical measurements. All significant correlations shown. (* = p<0.10, ** = p<0.05, *** = p<0.01).

Attributes	Yield
plants_3m	-0.46*
av_stem_length	0.56***
Pratylenchus neglectus__nematodes /g soil	0.30***
Pratylenchus penetrans__/ g soil	-0.22*
Pratylenchus crenatus__Copies / g sample	-0.42***
Meloidogyne hapla__pgDNA/g Sample	0.21*
Powdery Scab__pgDNA/g Sample	0.27**
Clay (%)	0.27**
silt (%)	-0.25**
em38h (%)	0.22*
plant_B (mg/kg)	-0.30*
plant_Fe (mg/kg)	-0.39**
plant_Mn (mg/kg)	0.33*
plant_Al (mg/kg)	-0.48***
soil_ammonium (mg/kg)	0.46***
soil_nitrate (mg/kg)	0.33**
soil_K_Colwell (mg/kg)	0.56***
soil_Sulphur (mg/kg)	-0.31**
soil_Conductivity (dS/m)	-0.27*
soil_pH_CaCl	-0.26*
soil_Fe (mg/kg)	-0.34**
soil_ exch_Al (meq/100g)	-0.49***
soil_ exch_Ca (meq/100g)	-0.50***
soil_ exch_Mg (meq/100g)	-0.48***
soil_ exch_K (meq/100g)	0.44***

Preliminary rules for exploring SSCM in potato production

The data gathered in this project has identified substantial between-field and within-field variability in the soil ECa used for growing potatoes in the North and Midlands of Tasmania. The variability is substantially driven by significant variation in soil texture, with changes in the clay and silt contents displaying the most influence. Coupled with the identified within-field variation in terrain, especially in the Northern region, the most appropriate option for exploring SSCM appears to be the pursuit of individual field-based decision rules within broad recommendations for useful field-scale data and sampling/analytical operations. This result mirrors findings in a range of other cropping industries (Bramley, 2001; Robertson et al., 2011; Koshla et al., 2008).

In that context, a general set of preliminary rules is distilled here that could be used to initiate exploration of SSCM at the within-field scale across the potato production regions of the North and Midland regions of Tasmania. The results here indicate that a simple focus on managing spatial variability in the main macronutrients should be the first target. That this may bring financial benefits in potato production has been previously shown by Simard et al. (1998) for variable-rate application of P and K. It may also bring improvements in quality and uniformity (Widjmark at al. 2005). This is also a well adopted management target in other cropping industries so technology for operations is widely commercialised.

The second area for consideration is the use of soil ECa, elevation and NDVI imagery to manage irrigation water. Previous work by Rud et al. (2013) has shown potential for such management in potato production.

General rules for instigating SSCM in potato production

1. Pre-season survey for soil ECa and elevation. Early season aerial NDVI could be substituted for ECa to minimize cost. This step is most important if irrigation management is likely to be a target

2. Midseason aerial NDVI imagery used to detect areas of potential N and P deficiency and yield limitations.

3. Use midseason imagery or combine with ECa/early imagery and elevation to stratify fields into PMC and direct targeted sampling. Methods could range from simple distribution stratification to multivariate clustering.

4. Sample top soil in each PMC for crop and soil chemical properties to determine potential for variable-rate nutrient management options based on measured concentrations in each PMC. N, P, K and Mn are priorities to target and avoid deficiency. Toxicity issues to assess include B and Fe. If irrigation management is also a target, sampling topsoil and subsoil for particle size analysis and soil conductivity is recommended.

5. Rectify any easily managed issues. Collect yield data to build a dataset for the field to use in quantifying impact of in-season management changes on production and to refine any future changes to nutrient or water management.

Recommendations

- Greater than 3-fold variation in potato yield within fields (mean 64.3 t/ha, S.D. 17 t/ha) translates into significant variation in gross margin within uniformly treated fields. This warrants continued and more detailed investigation into improvements in the allocation of inputs to the potato production system.

- Accurate, easy to gather yield data will be essential for the development of site-specific management in potato production. The manufacturer of the yield monitoring system used in this project has updated the system for data recording and feedback should continue to be provided to continue to improve the system. Alternative monitoring systems should also be investigated, including encouraging harvester manufacturers to develop factory-fitted systems.

- The use of mid-season aerial imagery should be encouraged for the early detection of within field deficiencies in the major macronutrients (N,P,K). Reflectance measurements other than NDVI (e.g. red edge NDVI, thermal) should be explored.

- The use of early-season aerial imagery to detect build-up of soil-borne pathogen load should be further investigated.

- Variable-rate irrigation should be explored based on the changes in soil type identified using ECa surveys or early-season aerial imagery. At present in the industry, small volume, regular applications of water are doing a reasonable job of negating the impact of spatial variability in soil water holding capacity within fields but results here suggest there may still be a significant negative impact on yield from temporary waterlogging.

Scientific Refereed Publications

Journal article

Whelan, B.M. and Mulcahy, F. (in prep.) Mapping and investigating the causes of spatial variation in potato production. *Precision Agriculture Journal* (impact factor = 1.549)

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APPENDIX 1: Correlation analysis for all sample site data

	Row	yield	plants_3m	stems_3m	av_stem_length	tuber_number	weight	wet_weight	specific_gravity	average_weight	R. solani AG2.1__pgDNA/g Sample*	R. solani AG3 __pgDNA/g Sample*	Pratylenchus neglectus__nematodes /g soil	Pratylenchus penetrans__/ g soil	Pratylenchus crenatus__Copies / g sample	Meloidogyne fallax__pgDNA/g Sample*	Meloidogyne hapla__pgDNA/g Sample*
1	Yield (t/ha)	1.00	-0.46	-0.04	0.56	0.03	0.36	0.31	0.00	0.01	0.10	0.12	0.30	-0.22	-0.42	0.17	0.21
2	plants_3m	-0.46	1.00	0.50	-0.09	0.61	-0.22	-0.15	0.05	-0.33	0.14	-0.23	-0.19	0.23	0.12	-0.19	-0.06
3	stems_3m	-0.04	0.50	1.00	-0.01	0.43	-0.39	-0.40	-0.37	-0.57	0.07	0.09	-0.17	0.22	-0.22	-0.07	-0.10
4	av_stem_length (cm)	0.56	-0.09	-0.01	1.00	-0.21	0.16	0.13	0.01	0.19	0.11	0.08	0.25	-0.19	0.02	0.09	-0.00
5	tuber_number	0.03	0.61	0.43	-0.21	1.00	0.14	0.06	-0.32	-0.74	-0.37	0.00	0.26	0.44	-0.01	0.00	0.04
6	Weight (g)	0.36	-0.22	-0.39	0.16	0.14	1.00	0.97	0.15	0.49	-0.27	0.00	0.22	-0.25	-0.21	0.00	0.10
7	wet_weight (g)	0.31	-0.15	-0.40	0.13	0.06	0.97	1.00	0.37	0.51	-0.26	0.00	0.30	-0.33	-0.10	-0.16	0.15
8	specific_gravity	0.00	0.05	-0.37	0.01	-0.32	0.15	0.37	1.00	0.45	-0.02	0.00	0.27	-0.39	0.14	-0.06	0.14
9	average_weight (g)	0.01	-0.33	-0.57	0.19	-0.74	0.49	0.51	0.45	1.00	0.12	0.00	-0.10	-0.36	0.04	-0.14	-0.04
10	R. solani AG2.1 pgDNA/g Sample	0.10	0.14	0.07	0.11	-0.37	-0.27	-0.26	-0.02	0.12	1.00	-0.04	0.02	-0.04	-0.07	-0.05	-0.01
11	R. solani AG3 pgDNA/g Sample	0.12	-0.23	0.09	0.08	0.00	0.00	0.00	0.00	0.00	-0.04	1.00	0.03	-0.04	-0.08	-0.04	-0.02
12	Pratylenchus neglectus nematodes /g soil	0.30	-0.19	-0.17	0.25	0.26	0.22	0.30	0.27	-0.10	0.02	0.03	1.00	-0.09	-0.08	0.15	-0.02
13	Pratylenchus penetrans / g soil	-0.22	0.23	0.22	-0.19	0.44	-0.25	-0.33	-0.39	-0.36	-0.04	-0.04	-0.09	1.00	0.04	-0.03	-0.02
14	Pratylenchus crenatus Copies / g sample	-0.42	0.12	-0.22	0.02	-0.01	-0.21	-0.10	0.14	0.04	-0.07	-0.08	-0.08	0.04	1.00	-0.03	-0.05
15	Meloidogyne fallax pgDNA/g Sample	0.17	-0.19	-0.07	0.09	0.00	0.00	-0.16	-0.06	-0.14	-0.05	-0.04	0.15	-0.03	-0.03	1.00	-0.03
16	Meloidogyne hapla pgDNA/g Sample	0.21	-0.06	-0.10	-0.00	0.04	0.10	0.15	0.14	-0.04	-0.01	-0.02	-0.02	-0.02	-0.05	-0.03	1.00
17	Powdery Scab pgDNA/g Sample	0.27	-0.17	0.02	0.38	-0.34	0.05	0.07	0.07	0.27	-0.01	-0.08	0.02	-0.09	0.11	0.02	-0.05
18	Common Scab pgDNA/g Sample	-0.05	0.15	0.26	0.09	0.22	0.05	0.05	0.03	-0.13	-0.02	-0.05	0.26	-0.05	-0.10	-0.06	0.02
19	Colletotrichum coccodes pgDNA/g Sample	-0.12	0.19	0.20	-0.11	0.31	-0.07	-0.05	0.04	-0.20	-0.04	0.03	0.01	-0.07	-0.12	-0.11	-0.06
20	Verticillium dahliae pgDNA/g Sample	0.15	-0.20	-0.11	0.17	-0.12	-0.02	0.13	0.18	-0.02	0.16	0.02	0.11	-0.03	-0.07	-0.06	-0.04
21	Clay (%)	0.27	-0.24	0.02	-0.15	-0.40	-0.02	0.07	0.26	0.30	-0.04	-0.04	0.14	-0.04	-0.09	-0.04	-0.02
22	silt (%)	-0.25	-0.24	0.02	-0.15	-0.13	0.44	0.37	0.13	0.28	-0.04	-0.04	0.14	-0.04	-0.09	-0.04	-0.02
23	sand (%)	0.03	0.34	0.16	-0.18	0.38	-0.22	-0.25	-0.28	-0.38	0.15	0.15	0.09	0.23	-0.30	-0.08	0.18
24	em38v (mS/m)	0.12	0.45	0.32	-0.12	0.10	-0.15	-0.21	-0.28	-0.24	0.08	-0.09	0.04	-0.08	-0.23	-0.14	-0.00
25	em38h (mS/m)	0.22	-0.22	0.25	-0.04	-0.07	-0.14	-0.14	-0.00	-0.02	0.14	-0.01	0.06	-0.10	-0.27	-0.13	-0.06
26	Elev (m)	0.05	-0.22	-0.14	-0.16	-0.17	0.14	0.28	0.39	0.34	-0.23	-0.09	0.30	0.04	0.01	0.00	-0.01
27	plant_Total N (%)	0.28	0.20	-0.46	-0.20	-0.34	0.72	0.80	0.48	0.56	0.15	-0.10	0.19	-0.31	-0.11	0.20	0.24
28	plant_P(%)	-0.04	0.45	-0.22	-0.02	-0.26	0.73	0.70	0.14	0.52	0.44	-0.16	0.10	-0.15	0.21	-0.08	0.27
29	plant_K(%)	0.25	0.52	-0.12	0.08	-0.44	0.71	0.55	-0.39	0.65	0.08	0.01	-0.03	-0.13	0.07	-0.36	0.02
30	plant_Ca(%)	-0.04	-0.71	-0.25	-0.04	-0.42	-0.45	-0.32	0.35	0.06	-0.06	-0.07	0.23	-0.03	0.21	0.32	-0.10
31	plant_Mg(%)	-0.22	-0.13	0.08	0.09	0.41	0.22	0.29	0.36	-0.23	-0.16	0.01	-0.00	0.04	0.20	0.42	-0.16
32	plant_Zn (mg/kg)	-0.02	-0.53	-0.21	0.01	0.58	-0.64	-0.60	-0.19	-0.67	-0.11	-0.04	0.17	0.02	0.27	0.16	-0.07
33	plant_B (mg/kg)	-0.30	-0.02	0.74	0.02	0.68	-0.83	-0.84	-0.26	-0.91	-0.16	-0.18	0.11	0.37	0.27	0.15	0.07
34	plant_S (%)	0.14	-0.21	0.41	0.07	0.37	-0.65	-0.57	0.22	-0.59	-0.09	0.09	0.10	0.04	0.12	0.13	0.19
35	plant_Cu (mg/kg)	-0.02	0.32	0.18	-0.02	-0.30	0.31	0.52	0.93	0.35	0.20	-0.05	0.08	-0.02	-0.24	-0.06	0.10
36	plant_Fe (mg/kg)	-0.39	0.17	-0.10	-0.15	-0.31	-0.15	0.01	0.38	0.17	-0.07	-0.09	-0.17	0.39	0.41	0.14	-0.14
37	plant_Mn (mg/kg)	0.33	-0.37	-0.33	0.19	0.11	0.47	0.48	0.04	0.13	-0.07	0.16	0.39	-0.04	-0.01	0.56	-0.09
38	plant_Al (mg/kg)	-0.48	0.11	0.01	-0.07	-0.38	-0.16	0.02	0.53	0.19	0.02	-0.13	-0.17	0.30	0.42	0.04	-0.10
39	plant_Na (%)	-0.14	-0.21	-0.05	-0.33	0.44	-0.30	-0.37	-0.58	-0.45	-0.25	-0.16	-0.14	0.45	-0.04	0.02	-0.19
40	soil_ammonium (mg/kg)	0.46	-0.14	0.06	0.02	-0.16	0.20	0.07	0.04	0.15	0.20	0.14	0.08	-0.15	-0.41	0.05	-0.04
41	soil_nitrate (mg/kg)	0.33	-0.24	-0.02	-0.03	-0.51	0.09	0.01	-0.07	0.21	0.14	-0.04	-0.15	-0.22	-0.17	0.14	-0.03
42	soil_P_colwell (mg/kg)	0.09	0.05	0.15	0.23	-0.07	-0.35	-0.45	-0.63	-0.14	0.04	0.22	-0.01	0.16	0.02	-0.20	-0.01
43	soil_K_Colwell (mg/kg)	0.56	0.15	0.04	0.25	0.21	0.01	-0.09	-0.38	-0.19	0.14	0.14	0.11	-0.04	-0.20	0.17	-0.08
44	soil_Sulphur (mg/kg)	-0.31	0.00	-0.12	-0.07	0.11	0.03	-0.09	-0.48	-0.15	-0.06	-0.11	-0.12	0.25	0.40	-0.07	0.01
45	soil_OC (%)	0.19	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	-0.13	0.21	0.08	-0.07	-0.43	0.29	-0.26
46	soil_Conductivity (dS/m)	-0.27	0.08	-0.07	-0.16	0.15	-0.06	-0.20	-0.58	-0.22	-0.07	-0.14	-0.21	0.17	0.34	-0.02	-0.03
47	soil_pH_CaCl	-0.26	0.11	-0.18	-0.23	0.27	0.40	0.42	0.38	-0.02	-0.10	0.07	0.12	-0.10	-0.02	-0.16	0.07
48	soil_pH_H2O	-0.10	0.10	-0.14	-0.12	0.22	0.39	0.43	0.45	0.02	-0.11	0.15	0.15	-0.17	-0.13	-0.17	0.04
49	soil_Cu (mg/kg)	-0.01	-0.04	-0.14	0.06	-0.12	0.50	0.62	0.83	0.30	-0.10	0.08	0.17	-0.19	-0.11	0.04	-0.12
50	soil_Fe (mg/kg)	-0.34	0.42	0.23	-0.43	0.06	-0.13	-0.18	-0.30	-0.22	-0.13	-0.20	-0.29	0.19	0.45	-0.10	-0.09
51	soil_Mn (mg/kg)	-0.01	-0.45	-0.23	0.46	-0.43	0.18	0.28	0.55	0.51	0.10	0.06	0.07	-0.15	-0.15	-0.08	-0.13
52	soil_Zn (mg/kg)	-0.13	0.30	0.08	-0.24	-0.08	0.03	0.01	0.07	0.05	-0.17	-0.01	-0.09	0.02	0.14	0.13	-0.16
53	soil_Al (meq/100g)	-0.49	-0.20	-0.16	-0.14	-0.27	0.48	0.62	0.90	0.48	-0.09	-0.13	-0.09	0.14	0.19	-0.08	-0.00
54	soil_Ca (meq/100g)	-0.50	0.01	-0.21	-0.26	0.06	0.48	0.54	0.59	0.18	-0.09	-0.12	-0.10	0.08	0.22	-0.07	-0.01
55	soil_Mg (meq/100g)	-0.48	0.09	-0.18	-0.30	0.22	0.45	0.46	0.39	0.00	-0.08	-0.11	-0.09	0.06	0.17	-0.07	-0.02
56	soil_K (meq/100g)	0.44	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10	-0.04	-0.53	0.17	-0.09
57	soil_Na (meq/100g)	0.11	0.00	0.00	-0.06	0.00	0.00	0.00	0.00	0.00	-0.07	0.03	-0.10	-0.03	-0.11	0.02	-0.09
58	CEC (meq/100g)	0.21	0.03	-0.18	0.04	0.01	0.50	0.57	0.66	0.21	-0.12	0.33	0.15	-0.18	-0.12	0.09	-0.18
59	soil_B (mg/kg)	0.15	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.13	0.14	0.19	0.03	-0.45	0.07	-0.16
60	ndvi1	-0.06	-0.32	0.53	-0.00	0.00	0.00	-0.37	-0.41	-0.13	-0.12	0.05	0.01	-0.17	0.56	-0.14	-0.18
61	ndvi2	0.01	0.24	-0.77	0.01	0.00	0.00	0.49	0.42	0.23	-0.06	-0.07	-0.03	-0.14	0.78	-0.09	-0.09
62	ndvi3	-0.01	0.27	-0.63	0.14	0.00	0.00	0.30	0.36	0.21	-0.01	-0.14	0.08	-0.18	0.48	-0.02	-0.02
63	ndvi4	0.14	0.48	-0.47	0.37	0.00	0.00	0.51	0.57	0.46	0.03	0.04	0.02	-0.34	0.25	0.03	0.03
64	ndvi5	0.21	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.06	0.01	-0.07	-0.48	0.19	0.04	0.02

APPENDIX 1: Correlation analysis for all sample site data

	Powdery Scab_ pgDNA/g Sample*	Common Scab_ pgDNA/g Sample*	Colletotrichum coccodes__pgDNA/g Sample*	Verticillium dahliae__pgDNA/g Sample*	clay	silt	sand	em38v	em38h	elev	plant_Total N (%)	plant_P(%)	plant_K(%)	plant_Ca(%)	plant_Mg(%)	plant_Zn(mg/kg)	plant_B(mg/kg)	plant_S(%)	plant_Cu(mg/kg)	plant_Fe(mg/kg)	plant_Mn(mg/kg)	plant_Al(mg/kg)
1	0.27	-0.05	-0.12	0.15	0.27	-0.25	0.03	0.12	0.22	0.05	0.28	-0.04	0.25	-0.04	-0.22	-0.02	-0.30	0.14	-0.02	-0.39	0.33	-0.48
2	-0.17	0.15	0.19	-0.20	-0.24	-0.24	0.34	0.45	-0.22	-0.22	0.20	0.45	0.52	-0.71	-0.13	-0.53	-0.02	-0.21	0.32	0.17	-0.37	0.11
3	0.02	0.26	0.20	-0.11	0.02	0.02	0.16	0.32	0.25	-0.14	-0.46	-0.22	-0.12	-0.25	0.08	-0.21	0.74	0.41	0.18	-0.10	-0.33	0.01
4	0.38	0.09	-0.11	0.17	-0.15	-0.15	-0.18	-0.12	-0.04	-0.16	-0.20	-0.02	0.08	-0.04	0.09	0.01	0.02	0.07	-0.02	-0.15	0.19	-0.07
5	-0.34	0.22	0.31	-0.12	-0.40	-0.13	0.38	0.10	-0.07	-0.17	-0.34	-0.26	-0.44	-0.42	0.41	0.58	0.68	0.37	-0.30	-0.31	0.11	-0.38
6	0.05	0.05	-0.07	-0.02	-0.02	0.44	-0.22	-0.15	-0.14	0.14	0.72	0.73	0.71	-0.45	0.22	-0.64	-0.83	-0.65	0.31	-0.15	0.47	-0.16
7	0.07	0.05	-0.05	0.13	0.07	0.37	-0.25	-0.21	-0.14	0.28	0.80	0.70	0.55	-0.32	0.29	-0.60	-0.84	-0.57	0.52	0.01	0.48	0.02
8	0.07	0.03	0.04	0.18	0.26	0.13	-0.28	-0.28	-0.00	0.39	0.48	0.14	-0.39	0.35	0.36	-0.19	-0.26	0.22	0.93	0.38	0.04	0.53
9	0.27	-0.13	-0.20	-0.02	0.30	0.28	-0.38	-0.24	-0.02	0.34	0.56	0.52	0.65	0.06	-0.23	-0.67	-0.91	-0.59	0.35	0.17	0.13	0.19
10	-0.01	-0.02	-0.04	0.16	-0.04	-0.04	0.15	0.08	0.14	-0.23	0.15	0.44	0.08	-0.06	-0.16	-0.11	-0.16	-0.09	0.20	-0.07	-0.07	0.02
11	-0.08	-0.05	0.03	0.02	-0.04	-0.04	0.15	-0.09	-0.01	-0.09	-0.10	-0.16	0.01	-0.07	0.01	-0.04	-0.18	0.09	-0.05	-0.09	0.16	-0.13
12	0.02	0.26	0.01	0.11	0.14	0.14	0.09	0.04	0.06	0.30	0.19	0.10	-0.03	0.23	-0.00	0.17	0.11	0.10	0.08	-0.17	0.39	-0.17
13	-0.09	-0.05	-0.07	-0.03	-0.04	-0.04	0.23	-0.08	-0.10	0.04	-0.31	-0.15	-0.13	-0.03	0.04	0.02	0.37	0.04	-0.02	0.39	-0.04	0.30
14	0.11	-0.10	-0.12	-0.07	-0.09	-0.09	-0.30	-0.23	-0.27	0.01	-0.11	0.21	0.07	0.21	0.20	0.27	0.27	0.12	-0.24	0.41	-0.01	0.42
15	0.02	-0.06	-0.11	-0.06	-0.04	-0.04	-0.08	-0.14	-0.13	0.00	0.20	-0.08	-0.36	0.32	0.42	0.16	0.15	0.13	-0.06	0.14	0.56	0.04
16	-0.05	0.02	-0.06	-0.04	-0.02	-0.02	0.18	-0.00	-0.06	-0.01	0.24	0.27	0.02	-0.10	-0.16	-0.07	0.07	0.19	0.10	-0.14	-0.09	-0.10
17	1.00	-0.08	0.04	-0.03	-0.08	-0.08	-0.30	-0.19	-0.15	0.11	0.21	0.01	0.12	0.20	-0.03	0.15	0.02	-0.02	-0.20	-0.04	0.16	-0.12
18	-0.08	1.00	0.07	-0.08	-0.06	-0.06	0.12	0.51	0.19	-0.02	0.21	0.37	0.10	-0.19	-0.11	-0.12	0.10	0.25	0.43	-0.19	-0.24	-0.11
19	0.04	0.07	1.00	0.08	-0.09	-0.09	0.03	-0.01	0.02	-0.09	0.21	0.17	0.13	-0.06	-0.12	-0.11	0.07	-0.07	-0.06	-0.19	-0.07	-0.18
20	-0.03	-0.08	0.08	1.00	-0.07	-0.07	0.15	-0.06	0.36	-0.29	0.29	0.18	-0.10	-0.21	-0.11	-0.21	-0.51	-0.26	0.06	-0.25	0.08	-0.28
21	-0.08	-0.06	-0.09	-0.07	1.00	1.00	-0.89	-0.14	-0.13	0.27	-0.41	-0.31	-0.32	0.76	0.19	0.57	0.36	0.32	-0.31	-0.07	-0.15	0.13
22	-0.08	-0.06	-0.09	-0.07	1.00	1.00	-0.83	-0.14	-0.13	0.27	-0.33	-0.31	-0.32	0.76	0.19	0.57	0.36	0.32	-0.31	-0.07	-0.15	0.13
23	-0.30	0.12	0.03	0.15	-0.89	-0.83	1.00	0.33	0.39	-0.15	0.42	0.27	0.14	-0.44	-0.49	-0.37	-0.46	-0.13	0.15	-0.39	0.00	-0.42
24	-0.19	0.51	-0.01	-0.06	-0.14	-0.14	0.33	1.00	0.67	-0.12	0.29	0.31	0.35	-0.44	-0.36	-0.38	-0.25	-0.03	0.54	-0.34	-0.18	-0.32
25	-0.15	0.19	0.02	0.36	-0.13	-0.13	0.39	0.67	1.00	-0.19	0.38	0.28	0.18	-0.42	-0.37	-0.42	-0.59	-0.30	0.38	-0.40	-0.12	-0.42
26	0.11	-0.02	-0.09	-0.29	0.27	0.27	-0.15	-0.12	-0.19	1.00	0.23	0.04	-0.26	0.54	0.21	0.52	0.27	0.28	-0.31	0.22	0.02	0.20
27	0.21	0.21	0.21	0.29	-0.41	-0.33	0.42	0.29	0.38	0.23	1.00	0.73	0.44	-0.14	-0.66	-0.10	-0.49	0.18	0.20	-0.37	-0.00	-0.42
28	0.01	0.37	0.17	0.18	-0.31	-0.31	0.27	0.31	0.28	0.04	0.73	1.00	0.35	-0.39	-0.42	-0.38	-0.32	0.20	0.33	-0.16	-0.25	-0.16
29	0.12	0.10	0.13	-0.10	-0.32	-0.32	0.14	0.35	0.18	-0.26	0.44	0.35	1.00	-0.47	-0.72	-0.30	-0.33	-0.19	0.06	-0.28	-0.08	-0.33
30	0.20	-0.19	-0.06	-0.21	0.76	0.76	-0.44	-0.44	-0.42	0.54	-0.14	-0.39	-0.47	1.00	0.46	0.83	0.54	0.36	-0.51	0.20	0.17	0.32
31	-0.03	-0.11	-0.12	-0.11	0.19	0.19	-0.49	-0.36	-0.37	0.21	-0.66	-0.42	-0.72	0.46	1.00	0.28	0.41	-0.03	-0.17	0.39	0.22	0.33
32	0.15	-0.12	-0.11	-0.21	0.57	0.57	-0.37	-0.38	-0.42	0.52	-0.10	-0.38	-0.30	0.83	0.28	1.00	0.50	0.40	-0.47	0.19	0.13	0.36
33	0.02	0.10	0.07	-0.51	0.36	0.36	-0.46	-0.25	-0.59	0.27	-0.49	-0.32	-0.33	0.54	0.41	0.50	1.00	0.52	-0.26	0.40	-0.18	0.51
34	-0.02	0.25	-0.07	-0.26	0.32	0.32	-0.13	-0.03	-0.30	0.28	0.18	0.20	-0.19	0.36	-0.03	0.40	0.52	1.00	0.08	0.09	-0.24	0.30
35	-0.20	0.43	-0.06	0.06	-0.31	-0.31	0.15	0.54	0.38	-0.31	0.20	0.33	0.06	-0.51	-0.17	-0.47	-0.26	0.08	1.00	-0.08	-0.20	-0.05
36	-0.04	-0.19	-0.19	-0.25	-0.07	-0.07	-0.39	-0.34	-0.40	0.22	-0.37	-0.16	-0.28	0.20	0.39	0.19	0.40	0.09	-0.08	1.00	-0.05	0.90
37	0.16	-0.24	-0.07	0.08	-0.15	-0.15	0.00	-0.18	-0.12	0.02	-0.00	-0.25	-0.08	0.17	0.22	0.13	-0.18	-0.24	-0.20	-0.05	1.00	-0.18
38	-0.12	-0.11	-0.18	-0.28	0.13	0.13	-0.42	-0.32	-0.42	0.20	-0.42	-0.16	-0.33	0.32	0.33	0.36	0.51	0.30	-0.05	0.90	-0.18	1.00
39	0.33	-0.37	-0.15	0.01	0.18	0.18	0.30	-0.02	0.07	-0.07	-0.08	-0.40	0.14	0.21	-0.02	0.24	0.04	-0.33	-0.36	0.03	0.25	-0.09
40	-0.19	0.01	0.00	0.35	-0.54	-0.58	0.62	0.22	0.53	-0.07	0.46	0.18	0.05	-0.08	-0.20	-0.14	-0.80	-0.32	-0.08	-0.50	0.44	-0.56
41	0.25	-0.10	0.05	0.15	-0.14	-0.19	0.18	0.21	0.32	-0.21	0.57	0.24	0.37	-0.30	-0.42	-0.34	-0.62	-0.28	0.14	-0.51	0.24	-0.57
42	0.24	-0.14	0.00	0.36	-0.22	-0.04	0.14	-0.36	0.03	-0.02	-0.20	-0.11	-0.17	0.03	0.25	0.22	0.16	-0.05	-0.20	0.25	-0.11	0.13
43	0.25	-0.24	-0.03	0.40	-0.20	-0.23	0.25	-0.36	0.25	-0.09	0.16	0.01	0.19	-0.20	-0.15	-0.01	-0.39	-0.26	-0.10	-0.22	0.32	-0.30
44	-0.21	0.08	-0.07	-0.14	-0.06	0.46	-0.25	0.05	-0.13	0.01	-0.37	-0.19	-0.09	-0.24	0.43	0.13	0.47	-0.08	0.03	0.32	-0.24	0.25
45	0.11	-0.36	-0.19	0.13	-0.11	-0.04	0.09	-0.47	0.09	0.21	-0.02	-0.11	-0.41	0.10	0.21	0.07	-0.70	-0.07	-0.01	0.42	0.17	0.32
46	-0.18	0.17	-0.09	-0.14	-0.03	0.30	-0.17	0.41	0.19	-0.05	-0.21	-0.12	0.06	-0.36	0.29	0.04	0.37	-0.07	0.16	0.18	-0.24	0.12
47	-0.26	0.38	0.13	-0.15	0.11	0.17	-0.16	0.22	-0.03	0.23	0.15	0.37	-0.11	-0.09	-0.01	-0.01	0.10	0.46	0.40	-0.17	-0.46	-0.08
48	-0.13	0.34	0.12	-0.08	0.06	0.06	-0.07	0.15	0.02	0.23	0.26	0.39	-0.09	-0.02	-0.08	-0.04	-0.12	0.39	0.35	-0.28	-0.31	-0.22
49	0.03	-0.27	0.04	0.16	0.15	0.25	-0.24	-0.53	-0.08	0.12	-0.06	-0.08	-0.35	-0.02	0.16	-0.04	-0.26	-0.04	0.01	-0.05	0.03	0.01
50	-0.26	-0.09	-0.15	-0.26	0.13	0.45	-0.35	0.12	-0.16	0.06	-0.46	-0.38	-0.03	-0.14	0.31	0.01	0.36	-0.16	-0.12	0.32	-0.13	0.29
51	0.17	-0.25	-0.01	0.51	0.11	0.13	-0.14	-0.43	0.15	-0.38	-0.16	-0.28	-0.27	0.13	0.12	0.07	-0.20	-0.17	-0.09	0.12	0.13	0.17
52	-0.03	-0.22	-0.04	0.06	0.25	0.40	-0.38	-0.28	-0.12	0.07	-0.38	-0.35	-0.30	-0.06	0.51	0.33	0.16	-0.21	-0.08	0.35	0.04	0.32
53	-0.24	-0.08	0.03	-0.19	0.28	0.59	-0.52	-0.25	-0.41	-0.04	-0.74	-0.44	-0.45	0.19	0.52	0.24	0.80	0.29	-0.04	0.69	-0.41	0.78
54	-0.22	-0.08	0.10	-0.18	0.29	0.56	-0.50	-0.25	-0.39	-0.04	-0.71	-0.42	-0.43	0.12	0.57	0.23	0.75	0.25	-0.03	0.59	-0.39	0.68
55	-0.20	-0.08	0.15	-0.17	0.28	0.53	-0.48	-0.23	-0.36	-0.03	-0.69	-0.42	-0.40	0.06	0.60	0.22	0.73	0.19	-0.03	0.55	-0.36	0.62
56	0.18	-0.35	0.01	0.37	-0.20	-0.06	0.15	-0.58	0.05	-0.12	-0.09	-0.13	0.03	-0.04	-0.11	0.05	-0.38	-0.12	-0.14	0.04	0.21	-0.01
57	-0.08	0.06	-0.15	-0.01	0.13	0.10	-0.14	0.39	0.43	-0.01	-0.13	-0.17	-0.25	-0.07	0.17	0.01	-0.64	0.03	-0.04	0.39	0.03	0.23
58	0.01	-0.21	-0.05	0.19	-0.01	0.04	-0.02	-0.39	0.19	0.23	0.12	0.08	-0.33	0.03	0.14	0.04	-0.41	0.01	0.07	-0.08	0.05	-0.11
59	0.13	-0.16	-0.07	0.61	-0.20	0.00	0.11	-0.42	0.35	-0.16	0.16	0.14	-0.26	-0.08	-0.06	-0.09	-0.55	0.04	0.12	0.12	-0.09	0.13
60	0.43	-0.39	-0.04	-0.02	0.76	0.86	-0.87	-0.48	-0.32	0.03	-0.13	-0.37	-0.20	0.55	0.28	0.43	0.07	-0.07	-0.38	-0.26	0.70	-0.28
61	0.40	-0.19	-0.04	-0.05	0.85	0.78	-0.88	-0.39	-0.43	0.09	0.13	0.01	-0.02	0.24	0.03	0.17	-0.01	0.18	-0.10	-0.30	0.31	-0.43
62	0.20	-0.09	0.03	0.00	0.36	0.27	-0.34	-0.26	-0.15	0.17	0.46	0.51	-0.17	-0.05	-0.25	-0.23	-0.20	0.34	0.09	-0.35	-0.22	-0.35
63	-0.03	-0.09	0.17	0.06	0.03	-0.04	-0.00	-0.08	0.03	-0.02	0.40	0.44	-0.05	0.09	-0.18	-0.07	-0.03	0.44	-0.08	-0.47	0.11	-0.48
64	-0.15	0.28	-0.01	-0.06	-0.02	0.14	-0.08	0.38	0.29	-0.22	0.61	0.73	-0.15	-0.32	-0.29	-0.37	-0.46	0.54	0.49	-0.15	-0.23	-0.09

APPENDIX 1: Correlation analysis for all sample site data

	plant_Na(%)	soil_ammonium	soil_nitrate	soil_P_colwell	soil_K_Colwell	soil_Sulphur	soil_OC	soil_Conductivity	soil_pH_CaCl	soil_pH_H2O	soil_Cu	soil_Fe	soil_Mn	soil_Zn	soil_Al	soil_Ca	soil_Mg	soil_K	soil_Na	CEC	soil_B	ndvi1	ndvi2	ndvi3	ndvi4	ndvi5
1	-0.14	0.46	0.33	0.09	0.56	-0.31	0.19	-0.27	-0.26	-0.10	-0.01	-0.34	-0.01	-0.13	-0.49	-0.50	-0.48	0.44	0.11	0.21	0.15	-0.06	0.01	-0.01	0.14	0.21
2	-0.21	-0.14	-0.24	0.05	0.15	0.00	0.00	0.08	0.11	0.10	-0.04	0.42	-0.45	0.30	-0.20	0.01	0.09	0.00	0.00	0.03	0.00	-0.32	0.24	0.27	0.48	0.00
3	-0.05	0.06	-0.02	0.15	0.04	-0.12	0.00	-0.07	-0.18	-0.14	-0.14	0.23	-0.23	0.08	-0.16	-0.21	-0.18	0.00	0.00	-0.18	0.00	0.53	-0.77	-0.63	-0.47	0.00
4	-0.33	0.02	-0.03	0.23	0.25	-0.07	0.11	-0.16	-0.23	-0.12	0.06	-0.43	0.46	-0.24	-0.14	-0.26	-0.30	0.20	-0.06	0.04	0.23	-0.00	0.01	0.14	0.37	0.17
5	0.44	-0.16	-0.51	-0.07	0.21	0.11	0.00	0.15	0.27	0.22	-0.12	0.06	-0.43	-0.08	-0.27	0.06	0.22	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
6	-0.30	0.20	0.09	-0.35	0.01	0.03	0.00	-0.06	0.40	0.39	0.50	-0.13	0.18	0.03	0.48	0.48	0.45	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00
7	-0.37	0.07	0.01	-0.45	-0.09	-0.09	0.00	-0.20	0.42	0.43	0.62	-0.18	0.28	0.01	0.62	0.54	0.46	0.00	0.00	0.57	0.00	-0.37	0.49	0.30	0.51	0.00
8	-0.58	0.04	-0.07	-0.63	-0.38	-0.48	0.00	-0.58	0.38	0.45	0.83	-0.30	0.55	0.07	0.90	0.59	0.39	0.00	0.00	0.66	0.00	-0.41	0.42	0.36	0.57	0.00
9	-0.45	0.15	0.21	-0.14	-0.19	-0.15	0.00	-0.22	-0.02	0.02	0.30	-0.22	0.51	0.05	0.48	0.18	0.00	0.00	0.00	0.21	0.00	-0.13	0.23	0.21	0.46	0.00
10	-0.25	0.20	0.14	0.04	0.14	-0.06	-0.13	-0.07	-0.10	-0.11	-0.10	-0.13	0.10	-0.17	-0.09	-0.09	-0.08	0.10	-0.07	-0.12	0.13	-0.12	-0.06	-0.01	0.03	0.06
11	-0.16	0.14	-0.04	0.22	0.14	-0.11	0.21	-0.14	0.07	0.15	0.08	-0.20	0.06	-0.01	-0.13	-0.12	-0.11	0.10	0.03	0.33	0.14	0.05	-0.07	-0.14	0.04	0.01
12	-0.14	0.08	-0.15	-0.01	0.11	-0.12	0.08	-0.21	0.12	0.15	0.17	-0.29	0.07	-0.09	-0.09	-0.10	-0.09	0.10	-0.10	0.15	0.19	0.01	-0.03	0.08	0.02	-0.07
13	0.45	-0.15	-0.22	0.16	-0.04	0.25	-0.07	0.17	-0.10	-0.17	-0.19	0.19	-0.15	0.02	0.14	0.08	0.06	-0.04	-0.03	-0.18	0.03	-0.17	-0.14	-0.18	-0.34	-0.48
14	-0.04	-0.41	-0.17	0.02	-0.20	0.40	-0.43	0.34	-0.02	-0.13	-0.11	0.45	-0.15	0.14	0.19	0.22	0.17	-0.53	-0.11	-0.12	-0.45	0.56	0.78	0.48	0.25	0.19
15	0.02	0.05	0.14	-0.20	0.17	-0.07	0.29	-0.02	-0.16	-0.17	0.04	-0.10	-0.08	0.13	-0.08	-0.07	-0.07	0.17	0.02	0.09	0.07	-0.14	-0.09	-0.02	0.03	0.04
16	-0.19	-0.04	-0.03	-0.01	-0.08	0.01	-0.26	-0.03	0.07	0.04	-0.12	-0.09	-0.13	-0.16	-0.00	-0.01	-0.02	-0.09	-0.09	-0.18	-0.16	-0.18	-0.09	-0.02	0.03	0.02
17	0.33	-0.19	0.25	0.24	0.25	-0.21	0.11	-0.18	-0.26	-0.13	0.03	-0.26	0.17	-0.03	-0.24	-0.22	-0.20	0.18	-0.08	0.01	0.13	0.43	0.40	0.20	-0.03	-0.15
18	-0.37	0.01	-0.10	-0.14	-0.24	0.08	-0.36	0.17	0.38	0.34	-0.27	-0.09	-0.25	-0.22	-0.08	-0.08	-0.08	-0.35	0.06	-0.21	-0.16	-0.39	-0.19	-0.09	-0.09	0.28
19	-0.15	0.00	0.05	0.00	-0.03	-0.07	-0.19	-0.09	0.13	0.12	0.04	-0.15	-0.01	-0.04	0.03	0.10	0.15	0.01	-0.15	-0.05	-0.07	-0.04	-0.04	0.03	0.17	-0.01
20	0.01	0.35	0.15	0.36	0.40	-0.14	0.13	-0.14	-0.15	-0.08	0.16	-0.26	0.51	0.06	-0.19	-0.18	-0.17	0.37	-0.01	0.19	0.61	-0.02	-0.05	0.00	0.06	-0.06
21	0.18	-0.54	-0.14	-0.22	-0.20	-0.06	-0.11	-0.03	0.11	0.06	0.15	0.13	0.11	0.25	0.28	0.29	0.28	-0.20	0.13	-0.01	-0.20	0.76	0.85	0.36	0.03	-0.02
22	0.18	-0.58	-0.19	-0.04	-0.23	0.46	-0.04	0.30	0.17	0.06	0.25	0.45	0.13	0.40	0.59	0.56	0.53	-0.06	0.10	0.04	0.00	0.86	0.78	0.27	-0.04	0.14
23	0.30	0.62	0.18	0.14	0.25	-0.25	0.09	-0.17	-0.16	-0.07	-0.24	-0.35	-0.14	-0.38	-0.52	-0.50	-0.48	0.15	-0.14	-0.02	0.11	-0.87	-0.88	-0.34	-0.00	-0.08
24	-0.02	0.22	0.21	-0.36	-0.36	0.05	-0.47	0.41	0.22	0.15	-0.53	0.12	-0.43	-0.28	-0.25	-0.25	-0.23	-0.58	0.39	-0.39	-0.42	-0.48	-0.39	-0.26	-0.08	0.38
25	0.07	0.53	0.32	0.03	0.25	-0.13	0.09	0.19	-0.03	0.02	-0.08	-0.16	0.15	-0.12	-0.41	-0.39	-0.36	0.05	0.43	0.19	0.35	-0.32	-0.43	-0.15	0.03	0.29
26	-0.07	-0.07	-0.21	-0.02	-0.09	0.01	0.21	-0.05	0.23	0.23	0.12	0.06	-0.38	0.07	-0.04	-0.04	-0.03	-0.12	-0.01	0.23	-0.16	0.03	0.09	0.17	-0.02	-0.22
27	-0.08	0.46	0.57	-0.20	0.16	-0.37	-0.02	-0.21	0.15	0.26	-0.06	-0.46	-0.16	-0.38	-0.74	-0.71	-0.69	-0.09	-0.13	0.12	0.16	-0.13	0.13	0.46	0.40	0.61
28	-0.40	0.18	0.24	-0.11	0.01	-0.19	-0.11	-0.12	0.37	0.39	-0.08	-0.38	-0.28	-0.35	-0.44	-0.42	-0.42	-0.13	-0.17	0.08	0.14	-0.37	0.01	0.51	0.44	0.73
29	0.14	0.05	0.37	-0.17	0.19	-0.09	-0.41	0.06	-0.11	-0.09	-0.35	-0.03	-0.27	-0.30	-0.45	-0.43	-0.40	0.03	-0.25	-0.33	-0.26	-0.20	-0.02	-0.17	-0.05	-0.15
30	0.21	-0.08	-0.30	0.03	-0.20	-0.24	0.10	-0.36	-0.09	-0.02	-0.02	-0.14	0.13	-0.06	0.19	0.12	0.06	-0.04	-0.07	0.03	-0.08	0.55	0.24	-0.05	0.09	-0.32
31	-0.02	-0.20	-0.42	0.25	-0.15	0.43	0.21	0.29	-0.01	-0.08	0.16	0.31	0.12	0.51	0.52	0.57	0.60	-0.11	0.17	0.14	-0.06	0.28	0.03	-0.25	-0.18	-0.29
32	0.24	-0.14	-0.34	0.22	-0.01	0.13	0.07	0.04	-0.01	-0.04	-0.04	0.01	0.07	0.33	0.24	0.23	0.22	0.05	0.01	0.04	-0.09	0.43	0.17	-0.23	-0.07	-0.37
33	0.04	-0.80	-0.62	0.16	-0.39	0.47	-0.70	0.37	0.10	-0.12	-0.26	0.36	-0.20	0.16	0.80	0.75	0.73	-0.38	-0.64	-0.41	-0.55	0.07	-0.01	-0.20	-0.03	-0.46
34	-0.33	-0.32	-0.28	-0.05	-0.26	-0.08	-0.07	-0.07	0.46	0.39	-0.04	-0.16	-0.17	-0.21	0.29	0.25	0.19	-0.12	0.03	0.01	0.04	-0.07	0.18	0.34	0.44	0.54
35	-0.36	-0.08	0.14	-0.20	-0.10	0.03	-0.01	0.16	0.40	0.35	0.01	-0.12	-0.09	-0.08	-0.04	-0.03	-0.03	-0.14	-0.04	0.07	0.12	-0.38	-0.10	0.09	-0.08	0.49
36	0.03	-0.50	-0.51	0.25	-0.22	0.32	0.42	0.18	-0.17	-0.28	-0.05	0.32	0.12	0.35	0.69	0.59	0.55	0.04	0.39	-0.08	0.12	-0.26	-0.30	-0.35	-0.47	-0.15
37	0.25	0.44	0.24	-0.11	0.32	-0.24	0.17	-0.24	-0.46	-0.31	0.03	-0.13	0.13	0.04	-0.41	-0.39	-0.36	0.21	0.03	0.05	-0.09	0.70	0.31	-0.22	0.11	-0.23
38	-0.09	-0.56	-0.57	0.13	-0.30	0.25	0.32	0.12	-0.08	-0.22	0.01	0.29	0.17	0.32	0.78	0.68	0.62	-0.01	0.23	-0.11	0.13	-0.28	-0.43	-0.35	-0.48	-0.09
39	1.00	0.15	0.37	0.13	0.15	0.10	-0.03	0.16	-0.59	-0.55	-0.25	0.30	-0.10	0.10	-0.23	-0.26	-0.19	-0.02	0.17	-0.22	-0.22	-0.22	-0.00	-0.28	-0.33	-0.81
40	0.15	1.00	0.40	0.37	0.63	-0.42	0.53	-0.31	-0.32	-0.13	0.06	-0.47	0.33	-0.09	-0.73	-0.69	-0.64	0.53	-0.16	0.32	0.58	-0.52	-0.58	-0.16	0.10	0.19
41	0.37	0.40	1.00	-0.11	0.32	-0.25	0.13	-0.05	-0.37	-0.35	-0.17	-0.14	0.04	-0.08	-0.54	-0.50	-0.45	0.11	-0.17	0.00	0.02	-0.28	-0.32	-0.15	-0.07	0.17
42	0.13	0.37	-0.11	1.00	0.54	0.15	0.23	0.03	-0.25	-0.12	0.09	-0.24	0.28	0.12	-0.26	-0.30	-0.30	0.50	-0.02	0.22	0.57	0.36	-0.01	0.00	0.03	-0.34
43	0.15	0.63	0.32	0.54	1.00	-0.15	0.67	-0.13	-0.35	-0.21	0.30	-0.43	0.48	0.17	-0.44	-0.42	-0.38	1.00	-0.04	0.50	0.75	0.36	0.02	0.07	0.17	-0.11
44	0.10	-0.42	-0.25	0.15	-0.15	1.00	-0.45	0.72	0.03	-0.16	-0.12	0.59	-0.24	0.26	0.38	0.38	0.37	-0.44	-0.04	-0.16	-0.37	-0.31	-0.04	0.03	-0.15	0.33
45	-0.03	0.53	0.13	0.23	0.67	-0.45	1.00	-0.24	-0.29	-0.19	0.76	-0.15	0.52	0.62	0.37	0.81	0.66	0.68	0.01	0.85	0.65	0.35	0.01	0.23	0.27	0.13
46	0.16	-0.31	-0.05	0.03	-0.13	0.72	-0.24	1.00	0.17	0.01	-0.31	0.46	-0.30	0.19	0.15	0.15	0.15	-0.25	0.80	-0.21	-0.17	-0.10	-0.32	-0.43	0.07	0.30
47	-0.59	-0.32	-0.37	-0.25	-0.35	0.03	-0.29	0.17	1.00	0.95	0.08	-0.11	-0.27	-0.17	0.21	0.31	0.36	-0.33	0.38	0.17	-0.15	-0.55	-0.17	-0.09	-0.06	0.24
48	-0.55	-0.13	-0.35	-0.12	-0.21	-0.16	-0.19	0.01	0.95	1.00	0.15	-0.33	-0.17	-0.21	0.04	0.15	0.22	-0.22	0.40	0.29	-0.02	-0.48	-0.20	-0.10	-0.07	0.12
49	-0.25	0.06	-0.17	0.09	0.30	-0.12	0.76	-0.31	0.08	0.15	1.00	-0.11	0.62	0.49	0.37	0.44	0.45	0.68	-0.07	0.76	0.73	0.23	-0.07	0.18	-0.03	-0.28
50	0.30	-0.47	-0.14	-0.24	-0.43	0.59	-0.15	0.46	-0.11	-0.33	-0.11	1.00	-0.33	0.44	0.58	0.56	0.51	-0.34	-0.02	-0.25	-0.42	-0.03	-0.01	-0.08	0.04	0.19
51	-0.10	0.33	0.04	0.28	0.48	-0.24	0.52	-0.30	-0.27	-0.17	0.62	-0.33	1.00	0.24	0.07	0.03	-0.01	0.66	-0.06	0.44	0.78	0.41	0.12	0.13	0.12	-0.12
52	0.10	-0.09	-0.08	0.12	0.17	0.26	0.62	0.19	-0.17	-0.21	0.49	0.44	0.24	1.00	0.40	0.44	0.44	0.42	0.10	0.38	0.38	0.31	-0.17	-0.11	0.13	-0.02
53	-0.23	-0.73	-0.54	-0.26	-0.44	0.38	0.37	0.15	0.21	0.04	0.37	0.58	0.07	0.40	1.00	0.96	0.88	0.36	-0.15	0.03	0.15	0.22	0.07	0.03	0.19	-0.02
54	-0.26	-0.69	-0.50	-0.30	-0.42	0.38	0.81	0.15	0.31	0.15	0.44	0.56	0.03	0.44	0.96	1.00	0.98	0.57	0.02	0.10	0.71	0.33	0.05	0.34	0.20	0.06
55	-0.19	-0.64	-0.45	-0.30	-0.38	0.37	0.66	0.15	0.36	0.22	0.45	0.51	-0.01	0.44	0.88	0.98	1.00	0.44	0.25	0.13	0.50	0.03	-0.34	-0.11	0.04	-0.11
56	-0.02	0.53	0.11	0.50	1.00	-0.44	0.68	-0.25	-0.33	-0.22	0.68	-0.34	0.66	0.42	0.36	0.57	0.44	1.00	-0.05	0.63	0.76	0.36	0.02	0.09	0.18	-0.12
57	0.17	-0.16	-0.17	-0.02	-0.04	-0.04	0.01	0.80	0.38	0.40	-0.07	-0.02	-0.06	0.10	-0.15	0.02	0.25	-0.05	1.00	0.10	0.11	0.08	-0.45	-0.50	0.04	-0.06
58	-0.22	0.32	0.00	0.22	0.50	-0.16	0.85	-0.21	0.17	0.29	0.76	-0.25	0.44	0.38	0.03	0.10	0.13	0.63	0.10	1.00	0.74	0.31	-0.03	0.26	0.20	0.02
59	-0.22	0.58	0.02	0.57	0.75	-0.37	0.65	-0.17	-0.15	-0.02	0.73	-0.42	0.78	0.38	0.15	0.71	0.50	0.76	0.11	0.74	1.00	0.28	-0.05	0.17	0.17	-0.09
60	-0.22	-0.52	-0.28	0.36	0.36	-0.31	0.35	-0.10	-0.55	-0.48	0.23	-0.03	0.41	0.31	0.22	0.33	0.03	0.36	0.08	0.31	0.28	1.00	0.88	0.52	0.18	-0.00
61	-0.00	-0.58	-0.32	-0.01	0.02	-0.04	0.01	-0.32	-0.17	-0.20	-0.07	-0.01	0.12	-0.17	0.07	0.05	-0.34	0.02	-0.45	-0.03	-0.05	0.88	1.00	0.66	0.29	0.40
62	-0.28	-0.16	-0.15	0.00	0.07	0.03	0.23	-0.43	-0.09	-0.10	0.18	-0.08	0.13	-0.11	0.03	0.34	-0.11	0.09	-0.50	0.26	0.17	0.52	0.66	1.00	0.73	0.51
63	-0.33	0.10	-0.07	0.03	0.17	-0.15	0.27	0.07	-0.06	-0.07	-0.03	0.04	0.12	0.13	0.19	0.20	0.04	0.18	0.04	0.20	0.17	0.18	0.29	0.73	1.00	0.55
64	-0.81	0.19	0.17	-0.34	-0.11	0.33	0.13	0.30	0.24	0.12	-0.28	0.19	-0.12	-0.02	-0.02	0.06	-0.11	-0.12	-0.06	0.02	-0.09	-0.00	0.40	0.51	0.55	1.00