# CLIMATE CHANGE
# ADAPTATION PROGRAM

## Improving On-Farm Drainage Management to Reduce the Impacts of Climate Change in Delta, BC

Funding for this project has been provided by the Governments of Canada and British Columbia through Growing Forward 2, a federal-provincial-territorial initiative. The program is delivered by the Investment Agriculture Foundation of BC.

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# Improving On-Farm Drainage Management to Reduce the Impacts of Climate Change in Delta, BC

Final Report for the Farm Adaptation Innovator Program (FAIP), British Columbia Project

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# Improving On-Farm Drainage Management to Reduce the Impacts of Climate Change in Delta, BC

## Final Report for the Farm Adaptation Innovator Program (FAIP), British Columbia Project

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**Acknowledgements:** This project would not have been possible without the immense support of the Delta Farmers' Institute who helped to facilitate workshops, field days, and the participation of agricultural producers. We would like to acknowledge the contributions of the 15 agricultural producers who volunteered their fields to allow us access to their land, install equipment, and in some cases, have their drains cleaned, and to Todd Barnes of Valley Farm Drainage who performed the cleaning for us. A special thank you to Brent Harris, who installed drains at various spacings and allowed us increased access to this field for the duration of the study.

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# List of Abbreviations

BC – British Columbia
C - carbon
Delta – The District Municipality of Delta
DEM – digital elevation model
DFI – Delta Farmers’ Institute
DF&WT – Delta Farmland and Wildlife Trust
DGPS – differential global positioning system
EC – electrical conductivity (dS/m)
GDD – growing degree days
GIS – geographic information systems
GLSA - grassland set-aside
GPS – global positioning system
LPL – lower plastic limit of soil (gravimetric)
N – nitrogen
PTF – pedotransfer function
RGB – red-green-blue spectrum
RMSE – root mean squared error
SOC – soil organic carbon (%)
SOM – soil organic matter (%)
TDR – Time Domain Reflectometry
UBC – University of British Columbia
UPL – upper plastic limit of soil (gravimetric)
UAV – unmanned aerial vehicle
VWC – volumetric water content (% v/v)
Wopt – optimum soil water content (gravimetric)
YVR – Vancouver International Airport

# Executive Summary

To enhance farmer capacity in Delta to adapt to the expected changes in shoulder season precipitation, a two year project was launched in collaboration between the University of British Columbia and the Delta Farmers Institute. This project's specific objectives were to:

1. Demonstrate and evaluate new on-farm strategies for addressing drainage and salinity problems
2. Improve producer understanding of existing drainage and salinity management options
3. Increase producer access to drainage and salinity management information and tools and promote promising strategies

In the fall of 2015, we established a trial on a field in Delta with known drainage and salinity problems to demonstrate and evaluate the benefits of various drainage management practices. To assess the efficacy of current drainage systems we sampled and monitored fields across Delta with different drainage systems for two of the most prominent crops. Twenty-six fields (15 vegetables, 11 blueberry) were included in this study. These field data were then used to parameterize and validate both field and landscape level digital soil maps and a drainage model to predict soil workability for expected future rainfall patterns.

In our field-scale trial we found that both increasing drainage spacing and planting grassland set-asides (GLSAs) had a moderate impact on soil moisture that did not immediately translate into additional workable days. In the cropped fields (fields without GLSA), decreasing drainage spacing from 60 to 30 feet had a small impact on soil moisture; installing a GLSA with 30 ft drains had a small impact, and decreasing spacing in the GLSA from 30 to 15 ft had a moderate impact. Tilling in a one-year GLSA in the fall had a large impact on soil moisture compared to fields which remained in GLSAs at the same drain spacing.

Analysis of vegetable and blueberry fields sampled across Delta's landscape highlighted the variability in soil properties across the region and current conditions and performance of drainage management. No differences were observed in bulk density regardless of drainage management, indicating that at least at the soil surface, fields without drainage are not having more problems with compaction. Nor were there differences observed in soil organic carbon (SOC) indicating that drainage is not yet contributing to SOC losses. The fields that were monitored across the landscape in Delta showed that current drainage systems increased 'observed workable days' by 8% in vegetable fields (14% with pumps) but did not decrease ponding. In blueberry fields drainage systems lowered water table by 14% (22% with pumps) and decreased ponding by 39% (83% with pumps). Across both vegetable and blueberry fields we saw no impacts of drains on salinity. Based on our results however, we can clearly recommend pumps if they can be installed to effectively remove water from the hydraulic system of the field.

After one year, drain cleaning *tended* to increase workable days by 7% (although not significantly) and lowered the water table by 13% (marginally significant). Drain cleaning did not reduce salinity after one year. Additional sites and longer monitoring would be required to

determine for how long this drain cleaning benefit is effective and under what conditions it is most likely to improve tile performance.

Modelling, based on parameterization from one year of field data from the field-scale trial, predicted important differences between tile spacings for current and future precipitation. In 2030, based on predicted rainfall from climate models, our drainage model predicted many fewer workable days than 2016 in general, and a much larger impact of drainage. Fields with drains spaced at 15 ft had 64% more workable days and drains spaced at 30 ft had 46% more workable days than fields without drains; a difference of 11 days gained from 15 vs. 30 feet. Modeling clearly indicates the increased importance of drainage under an expected scenario of increased shoulder season rainfall.

# Introduction

The District Municipality of Delta (Delta), located within the delta of the lower Fraser River, is one of the most productive agricultural regions in the British Columbia (BC). The deep, fertile soils, and relatively mild climate, makes for highly conducive growing conditions for a wide range of crops. Currently the majority of the farmland is used to produce blueberries, cranberries, forage for dairy production and vegetables (Metro Vancouver 2012). Delta produces more than half of the province's potatoes and green beans. The growing conditions for agriculture in Delta are some of the best in Canada and may improve in some ways as the climate changes. Growing degree days (GDD), for example, are forecasted to increase by 224 days by 2020, potentially increasing the cropping season. Unfortunately, at the same time precipitation is also forecasted to increase (4% by 2020 and 7% by 2050) (BC Agriculture & Food Climate Action Initiative 2013). While increased precipitation during the cropping season would be beneficial, the production season is actually expected to become drier, while the rest of the year becomes wetter. In the fine-textured and poorly-drained soils of Delta (Luttmerding 1981), increases in precipitation may exacerbate an already challenging drainage situation.

Increased precipitation during the spring, particularly in March and April, when farmers in Delta are beginning their field preparation operations, can hamper the timing of planting or force farmers to use heavy equipment on moist fields. Similarly, in the fall, if precipitation occurs before the harvest, usually in late August, September, or early October, farmers will likely be forced to use their equipment on moist soils (**Figure 1**). If farmers begin operation with heavy equipment when the soil is too wet, the pressure of the tires from the equipment is likely to cause compaction (Voorhees et al. 1986). Compaction results in reduced soil pore space, which can impede water infiltration, seed germination, root penetration, increase runoff and erosion and can ultimately lead to severe yield reductions (Raper 2005). Reduced drainage in the wintertime can also prevent the flushing of salts that accumulate with summertime irrigation. This is a problem of particular concern for the farmers in Delta who rely on irrigation water from the neighboring Fraser River where the salinity of the water is tidally influenced. Increasing salinity through irrigation further increases the salinization of soils that may be inherently high in salt and may be at risk of salt water intrusion in high water tables. Reducing compaction can be managed by lowering tire pressure on equipment (Soehne 1958), avoiding the use of equipment when soils are too wet, maintaining soil structure and soil organic matter (SOM), and improving field drainage. While these management options are well known, their relative efficacy in Delta in the context of a changing rainfall patterns in the spring and fall shoulder seasons is not.

A better understanding of when a soil is "too wet" can help with management and planning of field operations or even large infrastructure investments such as the installation of tile drains. While being too wet can lead to compaction, when a soil is too dry, tillage can cause the creation of large clods (Tisdall and Adem 1986), which in turn can contribute to compaction. There is therefore an optimum soil water content (Wopt) to till soils, where it is not too wet or too dry for that particular soil. This Wopt has been defined by Dexter and Bird (2001) as the water content where tillage is likely to produce the greatest proportion of small aggregates. Given that water content above this Wopt can results in compaction if equipment is used, it can thus be seen as a threshold for “workability.” A particular soil’s Wopt or workability threshold is largely determined by its’ texture and SOM content. Texture is unlikely to change without major soil moving activities (e.g. soil infill or erosion). SOM, however, is a dynamic property that can be altered by soil management practices. Increasing organic inputs on a field, through cover cropping, grassland set-asides and compost or manure additions can maintain or even improve SOM. Alternatively, extensive tillage can lead to the microbial oxidation of SOM; drainage improvement may be hypothesized to also increase microbial oxidation of SOM (Baker et al. 2007). In organic, wetland soils, installing drainage increases microbial access to oxygen and can lead to so much SOM oxidation that subsidence can occur (Baker et al. 2007). The same mechanisms may, in the frequently-saturated soils of Delta, result in the oxidation of SOM if periods of saturation are reduced. The installation of infrastructure to improve field drainage therefore could have a long-term negative feedback on the capacity for farmers to operate effectively during the shoulder seasons.

***Figure 1*** Soil compacted by use of heavy machinery during harvest in November 2016

Although there has been substantial research into on-farm drainage management in Delta, on-farm drainage problems seem to be increasing, and could increase further as climate patterns shift (Thiel et al. 2015). Some concerns with past research may be that it was done in the context of past climate, farm management, or economic conditions, which may have changed. In a recent survey in the region, 76% of farmers responded that they were experience drainage and/or soil salinity problems; 59% responded that they would consider investing in drainage management infrastructure (of this, 50% considered tile drain improvements, 30% considered closed system conversion, and 20% considered ditch maintenance) (Thiel et al. 2015). The responding farmers were unsure about the efficacy of current drainage management options. The survey also highlighted concerns that the information that farmers need to make drainage management decisions may not be readily available or available in a useful format.

To enhance farmer capacity in Delta to adapt to the expected changes in shoulder season precipitation, a two year project was launched in collaboration between the University of British Columbia and the Delta Farmers Institute. This project's specific objectives were to:

1. Demonstrate and evaluate new on-farm strategies for addressing drainage and salinity problems
2. Improve producer understanding of existing drainage and salinity management options
3. Increase producer access to drainage and salinity management information and tools and promote promising strategies

# Methods

## Objective 1 – On-Farm Demonstration Trial

### *Trial Establishment*

In the fall of 2015, we established a trial on a field in Delta with known drainage and salinity problems to demonstrate and evaluate the benefits of various drainage management practices. With the help of a collaborating farmer, perforated plastic tile drain ("Big-O") was installed at 15, 30, 45, or 60 ft, in different plots (**Figure 2**). In addition to the tile spacing, various vegetation options for improving soil surface conditions were explored. The control, 15, and 30 ft Big-O spacings were planted in a grassland set-aside (GLSA) to explore if the changes soil structure and SOM resulting from a GLSA would impact field drainage. Tile treatments in the GLSA included 15 ft spacing (GLSA 15), 30 ft spacing, (GLSA 30) and a control. In the summer of 2016, the 30, 45, and 60 ft treatments not in GLSA were planted with either potatoes, peas or corn, (Cropped 30, Cropped 45, and Cropped 60). In the fall of 2016, part of the 15 and 30 ft GLSA plots were tilled to create a one-year post-GLSA treatments (Post-GLSA 15 and Post-GLSA 30, not shown in **Figure 2**; tilled portion was the eastern portion of the 15 and 30 ft GLSA treatments).

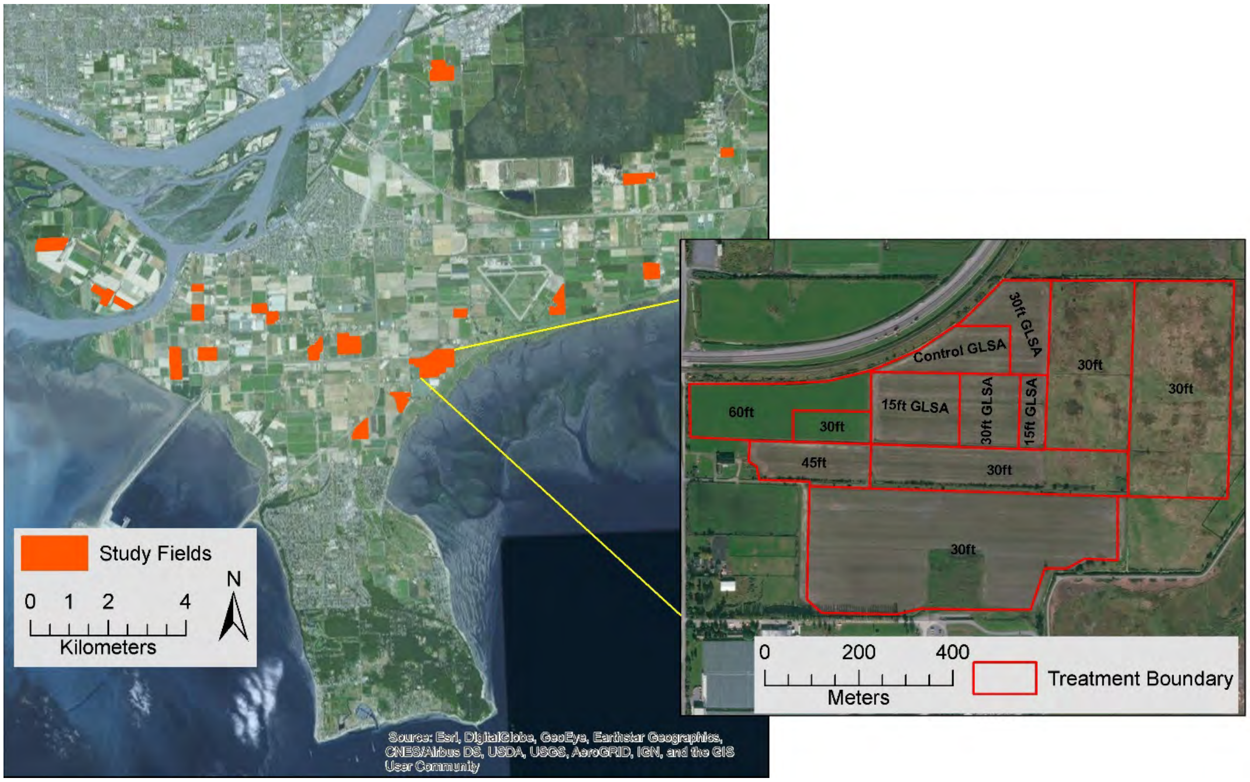


***Figure 2*** Schematic of Landscape-Scale Monitoring Fields and Field-Scale Demonstration Trial Treatment Breakdown

***Figure 3*** Tile drainage installation by collaborating farmer at the field-scale demonstration and research site

### *Baseline Soil Analysis and Mapping*

Prior to trial establishment in September-October 2015, we sampled and analyzed soils to develop a baseline. We sampled soils using a gridded pattern across the field at a spacing of 40 m for a total of 308 samples. Of these samples, 66 were taken to a depth of 100 cm and the rest to 30 cm. Each sample location was recorded with a high-accuracy DGPS system (post-processing accuracy ~10 cm) in order to create accurate soil maps.

***Figure 4*** Baseline soil sampling within the grassland set-aside after the tile drainage was installed

Soil samples were assessed for soil texture, bulk density (0-15 cm only), total carbon (C), nitrogen (N), salinity (EC) and pH. Salinity was measured as electrical conductivity (EC) in a 1:2 solution, and a conversion factor of 5 was applied in order to compare these numbers with the more common ‘saturated paste’ method (Hanlon et al. 2002).

We used the baseline soil samples to develop digital maps across the field for soil properties including SOC, bulk density, clay, EC and the workability threshold. In July of 2016, an unmanned aerial vehicle (UAV) was flown over the study field to capture images in the visible spectrum (red-green-blue: RGB). Two covariates at 5 m resolution were derived from this RGB imagery – the green band reflectance was directly used as one covariate and another covariate was generated by averaging the reflectance of each image pixel for each band. These data along with predictor variables derived from a digital elevation model (DEM) were included in geostatistical interpolation using a universal kriging model to produce continuous digital soil maps of the entire field for SOC, bulk density, clay, and EC. The workability threshold map was produced using the SOC and clay map with the pedo-transfer function (PTF) described below.

### *Field Condition Monitoring*

Soil moisture was monitored on an approximately bi-weekly basis during the spring and fall of 2016, and the spring of 2017 to assess differences among the treatments. We determined soil moisture using Time Domain Reflectometry (TDR) soil probes at depths of 3” (7.6 cm) and 8” (20.3 cm) to measure volumetric water content (VWC). These values were compared with our workability threshold in order to determine if a point was `workable` on any particular day.

Further soil sampling was carried out for EC analysis in April 2016, September 2016, and April 2017 to a depth of 15 cm. These samples were taken in a variety of sampling schemes to best account for observed salinity patterns across the field.

## *Soil Workability*

### Workability Threshold

In this study, the optimum water content (Wopt) for tillage was calculated using a series of pedo-transfer functions (PTF) (Mueller et al. 2003). We used this Wopt as a soil workability threshold to predict the upper limit of soil water content above which soil structure is likely to be negatively impacted from field preparation and harvest with heavy equipment. This threshold is highly dependent on the concentration of SOM % and Clay % in the soil and was calculated using the equations:

*Equation 1* $UPL = 11.9 + 0.92 * Clay\% + 0.16 * SOM\%$ *(Olson 1975)*

*Equation 2* $LPL = 7.15 + 0.199 * Clay\% + 3.914 * SOM\%$ *(Olson 1975)*

*Equation 3* $Wopt = LPL - 0.15 * (UPL - LPL)$ *(Mueller et al. 2003)*

Where UPL is the Upper Plastic Limit, LLP the Lower Plastic Limit, and SOM % = 1.72 * SOC %.

Given our monitoring of soil moisture was done using a TDR reporting VWC, the optimum gravimetric water content was then converted into a volumetric soil workability threshold by multiplying by bulk density. We used volumetric workability thresholds to compare with our volumetric soil moisture measurements; however, all mapping was done with gravimetric workability thresholds, in order to minimize error in the maps that would be introduced by using another variable (bulk density) in the geospatial mapping environment. This gravimetric threshold is reported throughout as Wopt.

Total soil workable days in 2016 were estimated by calculating the days between our first observed workable day in the spring and our final observed workable day in the fall of 2016. A field scale drainage model, DRAINMOD (Skaggs 1978), was used to predict these workable days at a higher temporal resolution.

### Soil Workability Modelling

DRAINMOD is a computer simulation model for the hydrology of poorly drained, high-water-table soils on a daily scale. The model predicts the effects of drainage on the soil water regime. DRAINMOD requires inputs of daily weather (precipitation and max/min temperatures), crop characteristics (rooting depths, wilting point), drainage design (depth, spacing and size of tile drains), and soil hydraulic characteristics. For soil hydraulic characteristics, we used the PTF model Rosetta to estimate saturated hydraulic conductivity, residual and saturated water contents, and other soil hydraulic parameters from the input variables of bulk density and soil texture (% sand, silt and clay).

We estimated soil hydraulic properties using Rosetta for 3 different points under each drainage regime in the field-scale plots, and ran DRAINMOD using the same weather, crop, and drainage characteristics for each soil point. Outputs were then averaged to obtain a ‘treatment’ effect. We used data from two drainage treatments with 15 and 30 ft spacing to parameterize the model. Daily weather information was taken for 2016 (January – December) from the Vancouver International Airport (YVR) weather station (~25 km away). The model was then validated with observed soil moisture data from 2016. We performed a sensitivity analysis on the validated model by changing the drainage spacings and related drainage design parameters. The model simulation was performed for 60 ft and again at 90 ft spacing as a ‘no-drainage’ scenario.

We took DRAINMOD’s output of VWC and compared this on a day-by-day basis to our soil workability threshold to calculate the total number of workable days predicted by the model. Using this, we were able to compare estimated workable days in 2016 between treatments in this field.

Finally, we re-ran the model for simulated daily weather information from 2030. This daily weather information was obtained from downscaled (BCSD) ANUSPLIN300+CanESM2 Global Climate Model (GCM) projections under RCP2.6 emission scenarios, which allows for regional daily predictions of precipitation and temperatures (PCIC 2014). The RCP2.6 emission scenario is a relatively conservative scenario, assuming net negative anthropogenic greenhouse gas emissions after the year 2070, and with a likely global temperature increase of 1$^{o}$C by 2065. We ran the model under this simulated daily 2030 weather for all of the drain spacings mentioned above, and calculated the total workable days predicted for 2030 to investigate the effectiveness of tile drains in a changing climate.

# Objective 2 – Existing Drainage Management Options

## *Site Selection*

To assess the efficacy of current drainage systems we sampled and monitored fields across Delta with different drainage systems for two of the most prominent crops. Twenty-six fields (15 vegetables, 11 blueberry) were included in this study. For vegetables, we chose 5 fields each with Big-O tile with pumps in the adjacent ditches (Drains + Pump), Big-O tile only (Drains) and laser levelling only (No Drains). We identified 3 blueberry fields with (each) Drains + Pump, Drains, No Drains, and one field with old clay/wooden tiles.

## *Drain Maintenance/Cleaning*

In 8 fields with Drains (5 blueberry fields (3 pumped) and 3 vegetable fields), a portion of the drainage system was cleaned by a contractor in the winter/spring of 2016. In the fall of 2016, we cleaned 2 more fields, bringing the total of fields with a cleaned system to 10.

***Figure 5*** Contractor cleaning tile drains in a blueberry field

### *Baseline Soil Analysis and Mapping*

Baseline soil analysis was carried out in the summer of 2016. We took soil samples from 4 plots per field, randomly located within each of the 4 quarters of the field. Soil samples were taken to a depth of 1 m (0-15 cm, 15-30 cm, 30-60 cm, and 60-100 cm) at 4 points within each plot and composited. Bulk density samples were taken at 0-7.5 cm and 7.5-15 cm. Soil samples were assessed for soil texture, C, N, EC and pH.

For landscape scale mapping, Landsat satellite data of multiple dates ranging from early growing season to harvesting season (e.g. May to August in 2016) were acquired for Delta. The satellite images were processed and clipped to include only the agricultural land reserve in this area. Data from soil samples taken in Delta from previous projects were added to our summer 2016 baseline, for a total of 310 field-verified, spatially explicit, data points. These included soil samples from annual and perennial croplands, grassland set-asides, and hedgerows. In addition to the environmental covariates derived from the DEM, a group of soil and vegetation indices was developed from the satellite images and all of them were used in a Random Forest machine learning model to produce maps of SOC % and Clay %. These maps were used in the PTF equations to generate landscape scale workability maps as described above.

### *Field Condition Monitoring*

Starting in March 2016, we assessed each field bi-weekly for soil moisture and excess moisture (ponding). Ponding was assessed by estimating the % coverage of standing water in a field on a specific day.

After a season of monitoring soil moisture in blueberry fields and discussing the results with farmers we determined that this was not likely the most useful metric for their operations.

Instead of monitoring soil moisture, in the fall of 2016, we installed piezometers in the blueberry fields to a depth of 2 m in order to monitor water table levels to estimate the depth and period of root saturation the blueberries were experiencing under each drainage management treatment.

### *Statistical Analysis*

Data was analyzed primarily using linear mixed-effects models with treatment and cleaning as fixed effects and the field as a random effect. Models were considered significant when $p < 0.05$, and 'marginally significant' when $p < 0.1$. Where models were significant, a Tukey post-hoc test was carried out to determine which treatments were different. Ponding, a categorical variable, was analyzed using chi squared tests for the frequency of ponding in each season (spring 2016, fall 2016, and spring 2017). We used a principal components analysis (PCA) to explore the relationship between measures of drainage performance (e.g. workable days, water table) across all the vegetable and blueberry farms in the study, soil properties and drainage management options, including the spacing of title, which varied from 30 to 60 ft.

## Objective 3 – Knowledge Transfer

We engaged in a number of different strategies to facilitate the sharing of results from our field and regional scale monitoring and analysis. These strategies targeted knowledge dissemination among producers, technical experts, and the scientific community at field days, producer meetings, conferences and public workshops.

# Results

## Rainfall

As rainfall was very different between the two years of the study (2016 and 2017), and had similar impacts in both the on-farm demonstration trial and the regional study, we have presented a summary of precipitation results in 2016 and 2017.

The rainfall patterns for the project period were highly variable (**Figure *6***). In the fall shoulder season (September to November) of 2015, rainfall totaled 256 mm which was slightly below the historic average (1960-2014) of 353 mm for the season. In the fall of 2016, the rainfall was 526 mm, more than 1.5 times the historic averages. During the first spring season (March to May) in 2016 rainfall was 201 mm, which was below the historic average (1960-2014) rainfall of 258 mm.   In the spring of 2017 rainfall was 462 mm, almost twice the historic average.

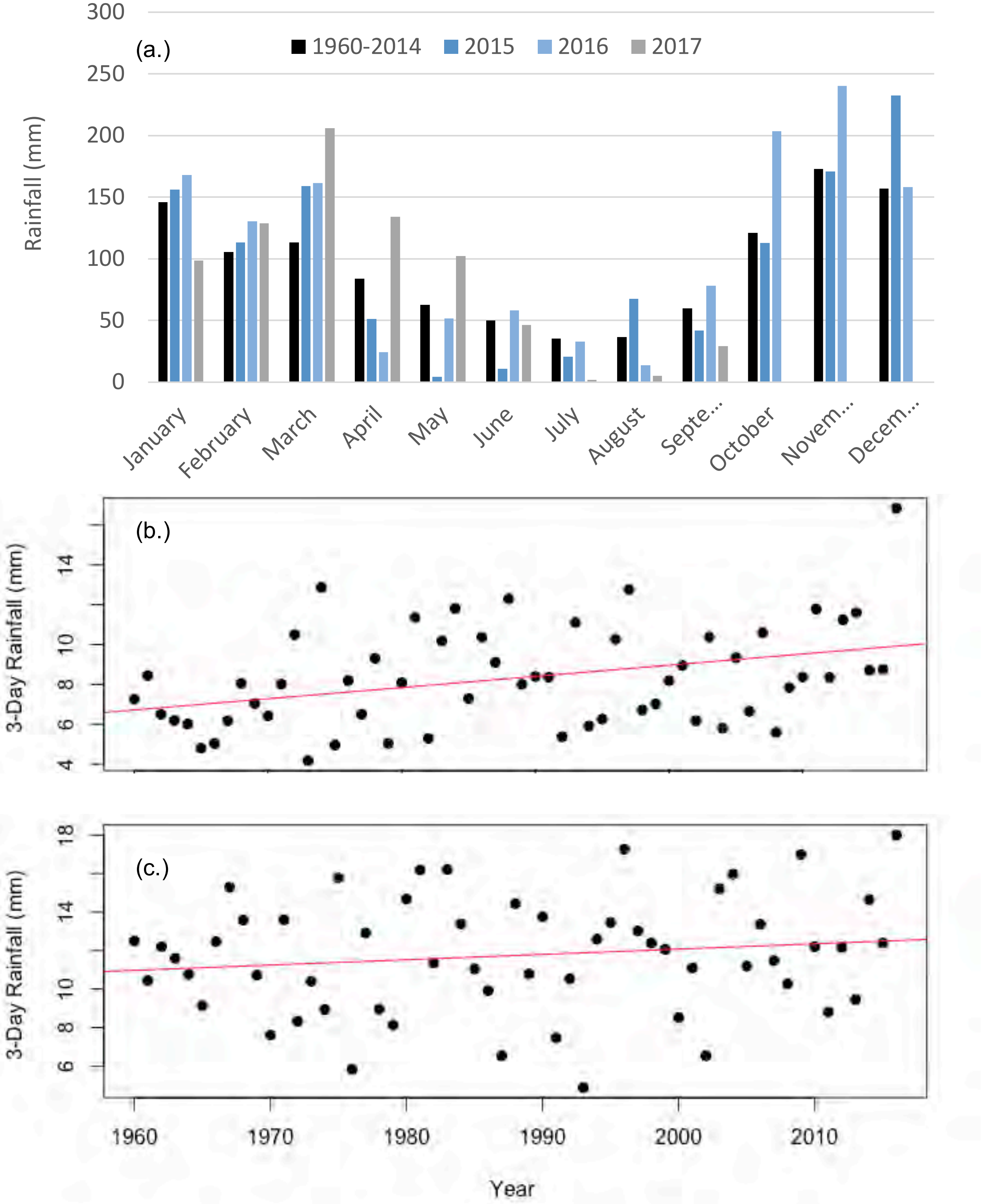


***Figure* 6** Monthly rainfall for Delta showing historic average from 1960 to 2014 and for the project years 2015-2017 (a.), average 3-day total rainfall from 1960 to 2017 for the spring shoulder season (March to May) (b.) and for the fall shoulder season (September to November) (c.). Red line indicates linear trend.

# Objective 1 – On-Farm Demonstration Trial

## *Soil Moisture*

Across all seasons, soil moisture content in our demonstration plots was generally highest in the Control (no drainage installed), especially in the early spring and late fall. In the grassland set-asides, closer drain spacing (15 vs 30 ft) tended to improve soil drainage resulting in lower soil moisture at the surface (7.5 cm) (**Figure 7**). The differences among treatments were most apparent at higher soil moisture; below 45% VWC, the variability within each treatment plot was generally larger than between the treatments. Thus, the differences in water content were not likely to result in changes in workability given most of them occurred at water contents well above the workability threshold. In all cases, plots were first observed to be workable on April 7, 2016 but not until June 7, 2017.

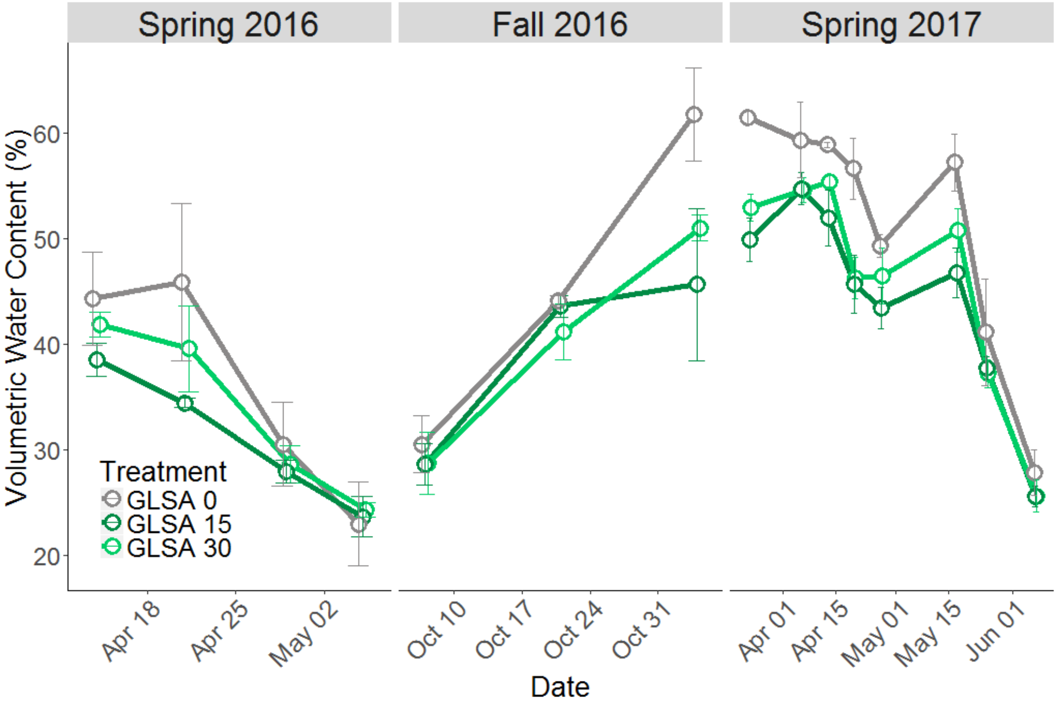


***Figure 7*** Soil Volumetric Water Content (VWC%) in the demonstration trial plots in spring 2016, fall 2016, and spring 2017. All plots have grassland set-aside (GLSA), and drain spacings are no drains (GLSA 0), 15 ft spacing (GLSA 15), and 30 ft spacing (GLSA 30). Error bars represent ± one standard error.

In the cropped plots (no GLSA), drain spacing had a much smaller effect, although VWC was highest under 60 ft drain spacing (**Figure 8**). The spring of 2016 is anomalous due to tillage occurring before monitoring began, on April 7, 2017. Directly after tillage, soil moisture content was quite low (25-30%), but did increase slightly as the soil settled. Differences between treatments were evident again later in the spring of 2016. Similarly, 60f ft drain spacing had a higher soil moisture in the early season of spring 2017 (before May 15), but again, this was most evident above 45 % VWC.

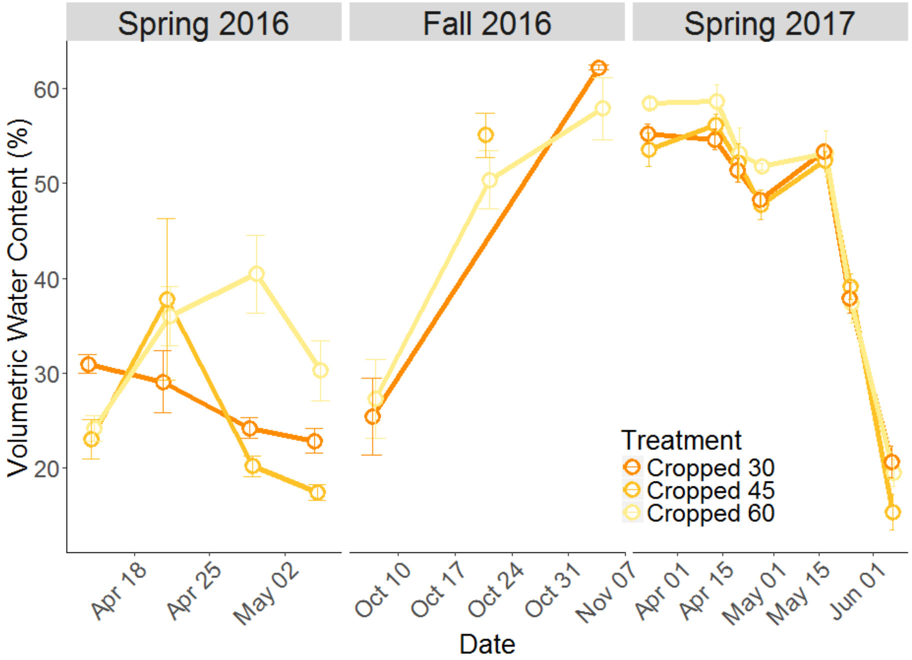


***Figure 8*** Soil Volumetric Water Content (VWC%) in the Field-Scale Trial from 2016-2017. All plots are cropped, and drain spacings are 30 ft, 45 ft, and 60 ft. Error bars represent ± one standard error.

The impacts of the GLSA, compared with cropped plots, varied between wet and dry years. In the spring of 2016, soil moisture was lower in the cropped plots than in the GLSA fields, though this was a very early and dry spring, and all treatments were workable by April 7, 2016. Additionally, cropped plots had already been tilled during our monitoring after April 7, 2016, temporarily increasing aeration and infiltration. Thus, neither the GLSA treatment nor the drain spacing would have allowed farmers into their fields much earlier in this dry year.

In the much wetter spring of 2017 while cropped and GLSA moisture contents were similar, the GLSA tended to have a slightly lower moisture content than the cropped field (**Figure 9**). The post-GLSA plots (tilled in the fall of 2016) were markedly drier than either the GLSA or the cropped plots. As a result, the first observed workable day in the post-GLSA field was April 20, 2017, while for both the GLSA and the cropped field, the first workable day did not occur until June 7, 2017.

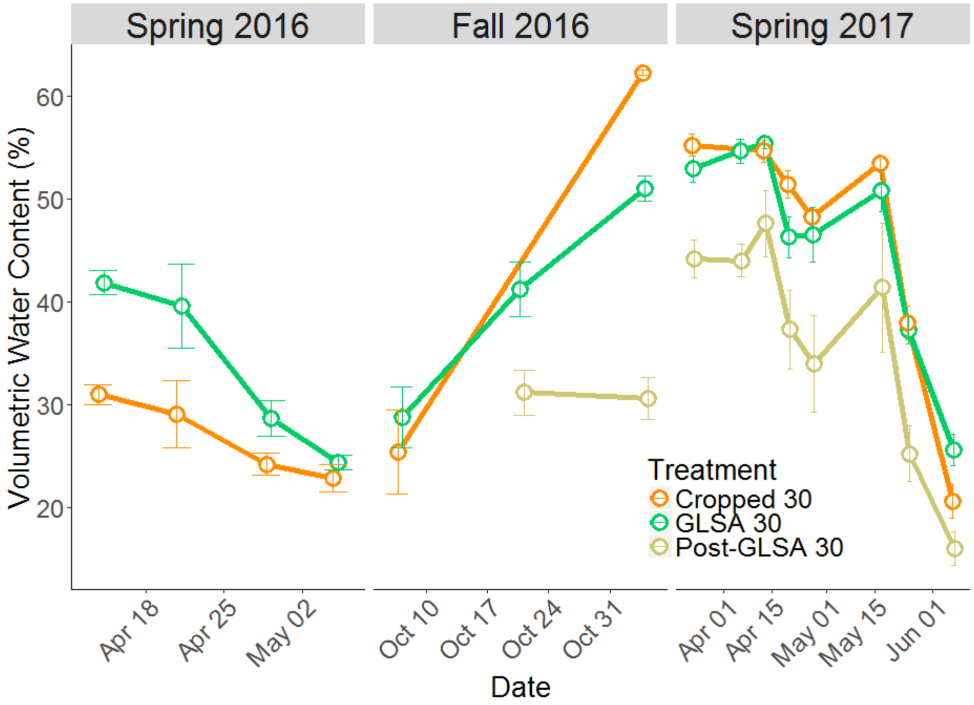


***Figure 9*** Soil Volumetric Water Content (VWC%) in the Field-Scale Trial from 2016-2017. All plots have drain spacings at 30 ft, and treatments are cropped, grassland set-aside (GLSA), or post-GLSA (tilled in fall 2016). Error bars represent ± one standard error.

### *Workability*

Other than the post-GLSA plot, differences in water content did not reflect different workability between treatments. Upon investigation of workability thresholds, we found a trend in the workability threshold, where the control and 60 ft drain spacing had a higher workability threshold than other treatments (**Figure 10**). Thus, some of the observed differences among treatments are likely due to the inherent soil properties of the two fields, illustrating the limitations of a field scale trial without replication.

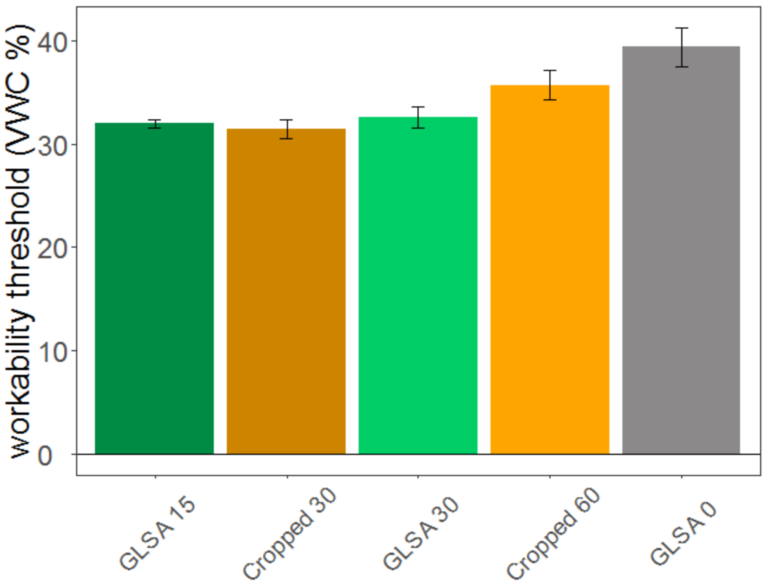


***Figure 10*** Soil Workability Limit (maximum VWC% for workability) in different treatments in the Field-Scale Trial. Error bars represent ± one standard error.

However, the mapping of the soil properties in the demonstration field showed the distribution of soil properties to be highly variable even within each treatment. Mapping of the soil properties across the Field-Scale Trial was successful with high $R^2$ values ranging from 0.71 to 0.9 and low root mean squared error (RMSE) (**Table 1**). The SOC across the field ranged from 0.50% to 4.50% (**Figure 11**a) with the southern and western portion of the field having relatively higher concentrations of SOC%. The variation in soil clay was also high, with values ranging from 7% to 27%, highest in the south-eastern part of the field (**Figure 11b**). As a result of the variation in both SOC and clay, the soil workability thresholds varied greatly from 12.0 to 41.5% (**Figure 11c**). The majority of the field (54%) had a Wopt between 30-35%, with another 33% of the field ranging from 25-30% (**Figure 11d**) which is typical of the distribution of Wopt we observed across Delta (see the next section).

***Table 1*** Goodness-of-fit results for Field Data vs. Predicted soil properties for digital soil mapping of the Field-Scale Trial

| Soil Property | $R^2$ | RMSE |
|---|---|---|
| Clay | 0.71 | 1.66 |
| Soil Organic Carbon | 0.89 | 0.36 |
| Optimum soil water content (gravimetric; Wopt) | 0.9 | 1.59 |

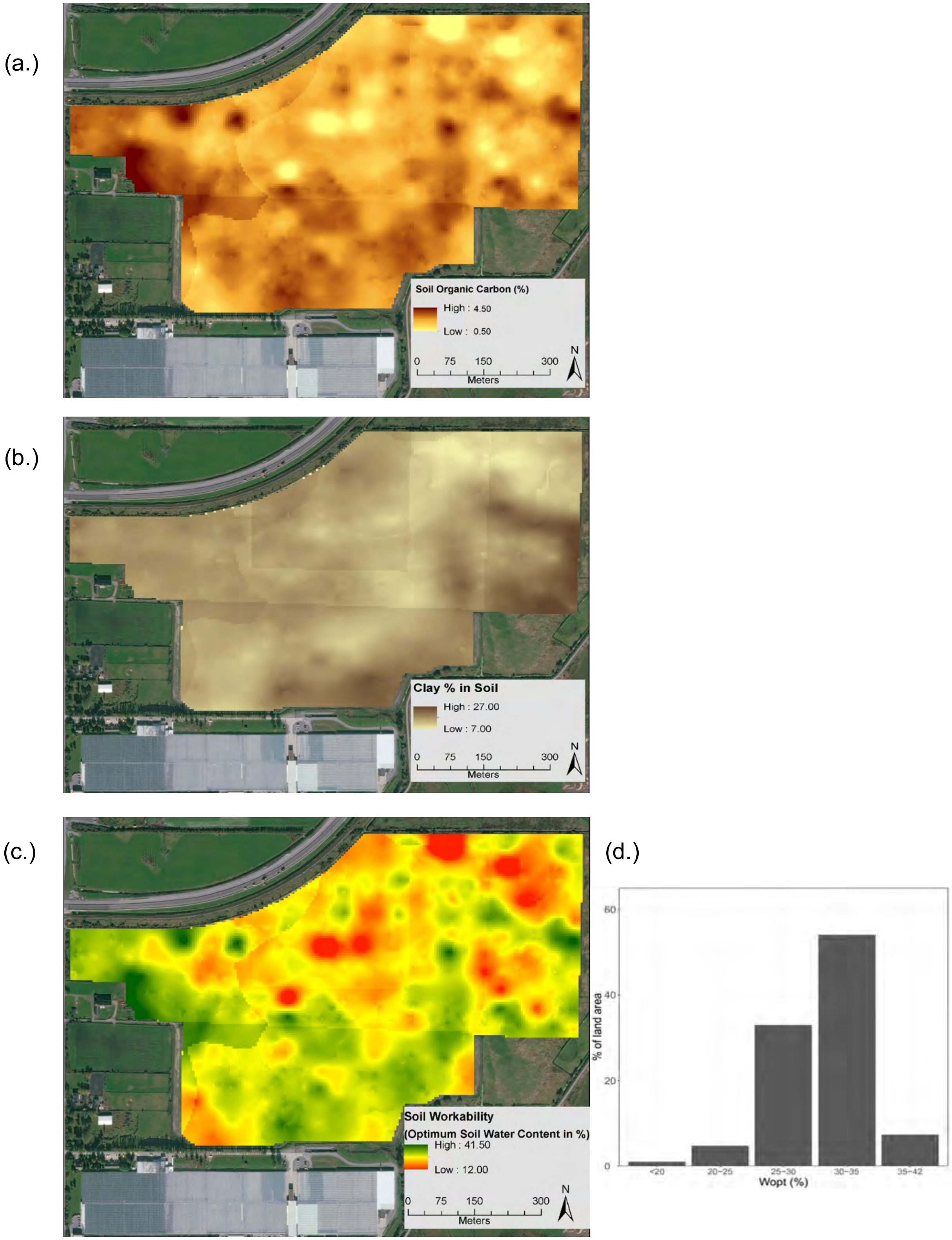
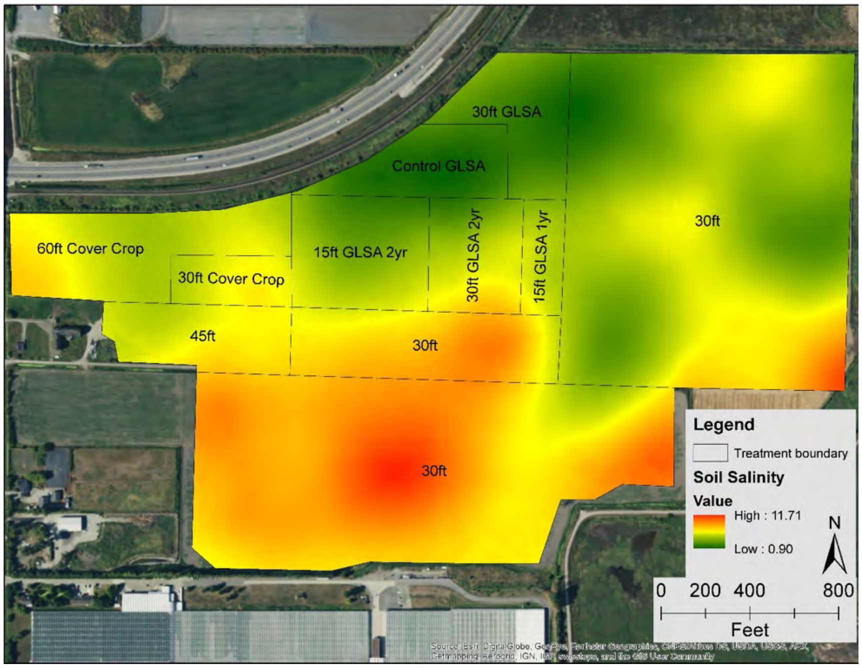


***Figure 11*** Digital map of Soil Organic Carbon (%) (a.) clay (%) (b.) and soil workability (gravimetric moisture %) at the Field-Scale Demonstration Trial (c.); the distribution of optimum soil water content for workability (d.)

### *Salinity*

There were some pockets of very high soil salinity found in our baseline assessment carried out in the fall of 2015. Salinity in the field ranged from 0.9 to 11.7 ds/m (**Figure 12**). In the spring of 2015 and 2016, salinity dropped in the plots that had tile installed. In contrast, salinity in the control treatment (no drainage) increased. Comparing fall 2015 and fall 2016, all treatments including 30, 45 and 60 ft spacing saw decreased salinity after 1 year of drainage (Figure 13). The trend observed suggests that, as expected, the spacing decreased so too did the reduction in salinity.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

***Figure 12*** Digital map of baseline soil Electrical Conductivity (dS/m) at the Field-Scale Demonstration Trial

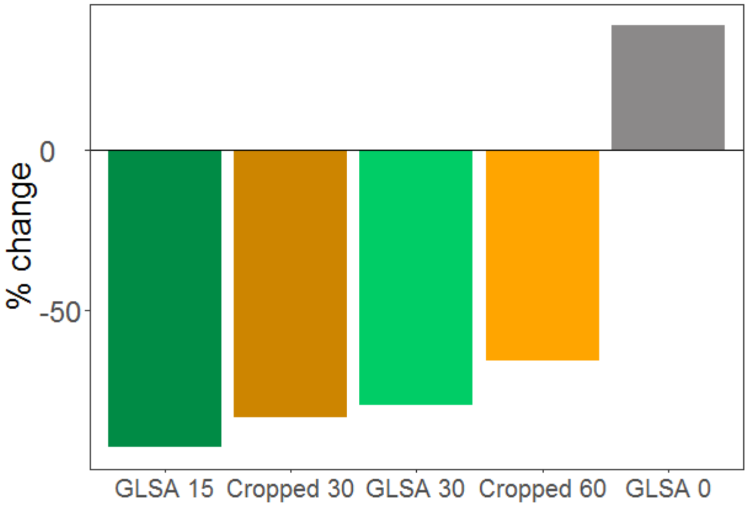


***Figure 13*** Percent change in salinity (Electrical Conductivity, dS/m) in the Field-Scale Trial after one year (baseline fall 2015, to fall 2016) in grassland set-asides (GLSA) and cropped fields (Cropped) with either 15, 30 or 60 ft drain spacings.

### *Workable Day Modelling*

Model performance for DRAINMOD based on the validation of soil sampling points taken within the 15 ft and 30 ft spacing in the field-scale trial was reasonable (**Figure 14**). The $R^2$ of the model for 15ft drainage spacing was 0.62 while the model with 30 ft spacing had a $R^2$ of 0.57. Given that the modeling was entirely focused on predicting shoulder season precipitation, the inclusion of data from the winter and summer and parameterization with irrigation and crop information would likely improve the performance further.

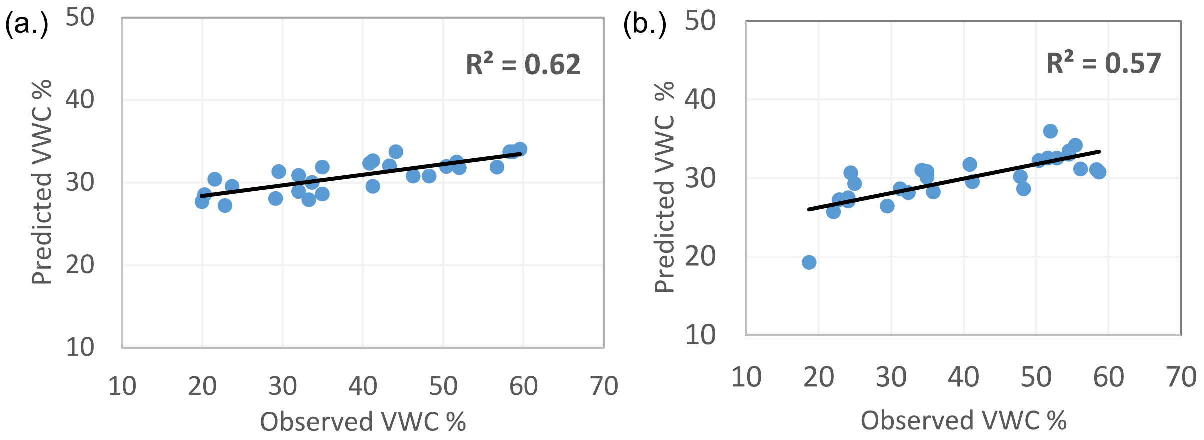
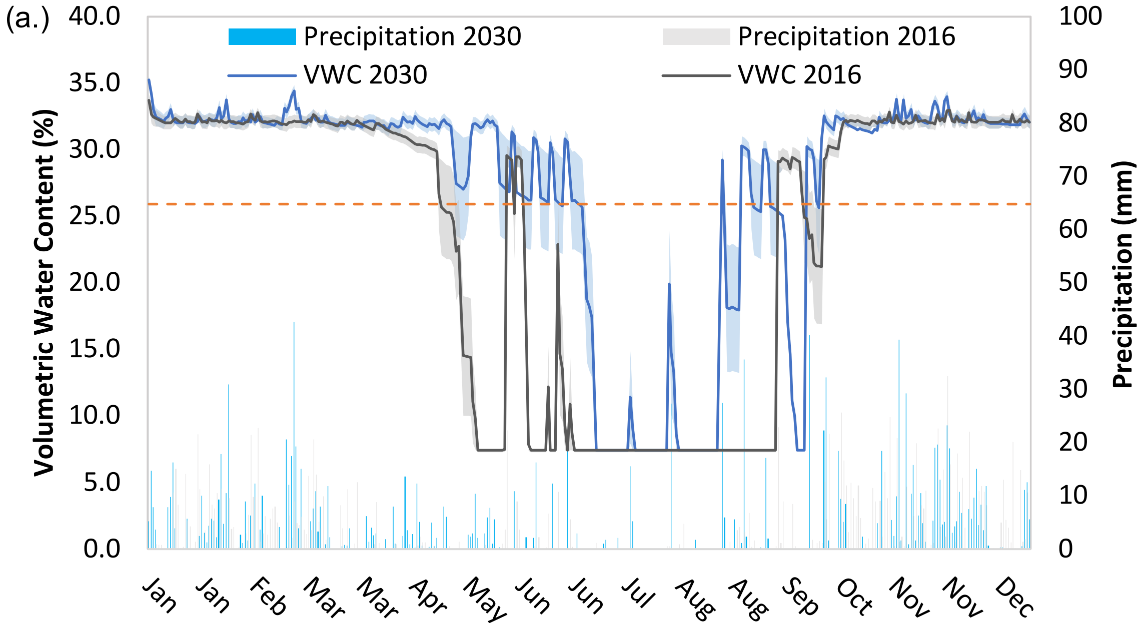


***Figure 14*** Accuracy assessment of DRAINMOD predicted Volumetric Water Content (VWC %) with vs. observed VWC% for 15 ft (a.) and 30 ft (b.) at the Field-Scale Demonstration Trial

The rainfall predictions used in the modelling indicate a 13 % increase in overall rainfall with an expected 9 % in the spring and 27 % in the fall shoulder season compared to the historic average (1960 to 2014). The results of the DRAINMOD simulations clearly show that soil VWC % is predicted to increase along with increased precipitation in 2030 for both treatments (**Figure 15**). Modelled VWC % remains above the workability threshold for an extended period in 2030 compared to 2016 largely due to increased predicted rainfall for 2030 for April and May. The predicted rainfall for the fall season in 2030 is actually 8 % lower than what was observed in the fall of 2016 which was an extremely wet year.

Modelling for 2016 predicted that installing drains with15 ft spacing would result in 49 % more workable days as compared to fields without drainage (**Table 2**). The results for 2030 predict a gain of 64 % over fields without drainage given the increased shoulder season precipitation. If we compare the predicted results for the differences between 15 ft spacing and 30 ft spacing, the gain in number of workable days is only 6 % in 2016 and more than doubles to 13 % in 2030. However when looking at the variability associated with the model, reported here, as the standard error of the mean of the predictions of the three points in each field, we see that the variability within each field is largely greater than that between tile spacing. So while there is a clear expected pattern of an increase in the number of workable days as the tile drainage spacing decreases, our confidence in these differences is low. Based on the infield variability, we would not expect that there would be meaningful differences between any spacing other than the 15 ft and no drainage at all.



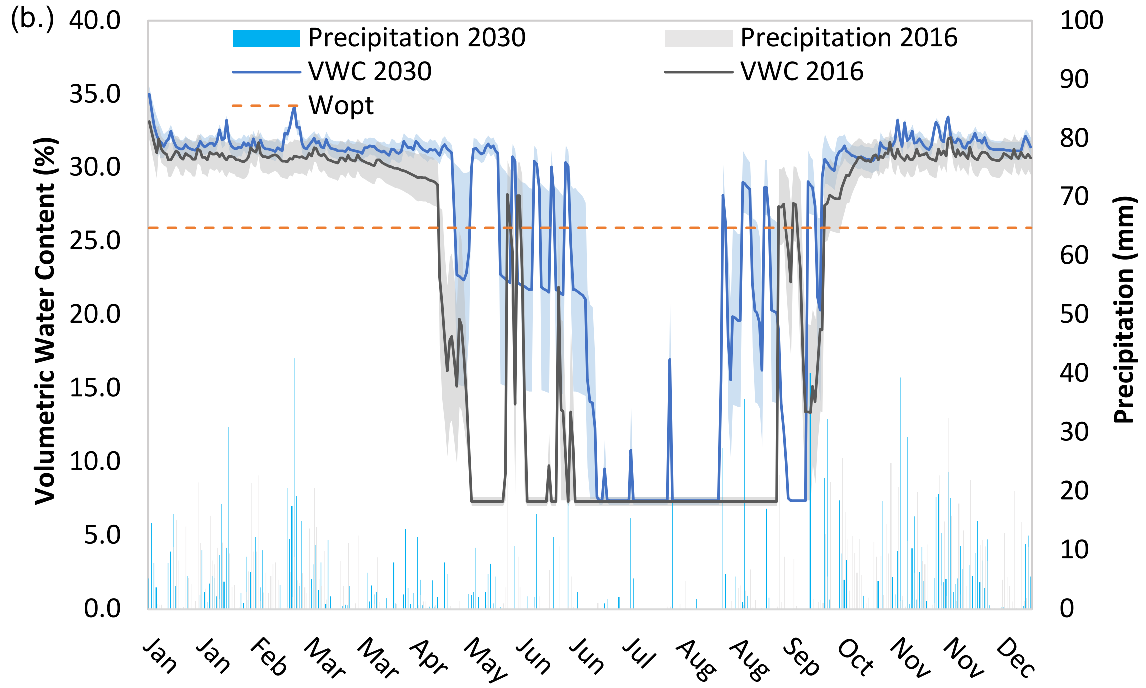


***Figure 15*** DRAINMOD-Modeled Volumetric Water Content (VWC %) in 2016 and 2030 for 15 ft drainage treatment (a.) and in 2016 and 2030 for 30 ft drainage treatment (b.). Shades represent ± one standard error.

While it is possible that the accuracy of the model could be improved to reduce the variability, there are other components of the modeling that could have been included that actually might increase the variability. The rainfall predictions for example, come with their own variability that can depend highly on what climate scenario is being used.

***Table 2*** Total predicted workable days in 2016 and 2030 determined by DRAINMOD simulations of the Field-Scale Demonstration Trial

| | ***Number of Workable days*** | | | |
|---|---|---|---|---|
| ***Drainage Spacing*** | ***2016*** | ***Std Err*** | ***2030*** | ***Std Err*** |
| 15 | 143 | 7.37 | 97 | 19.17 |
| 30 | 135 | 8.84 | 86 | 18.56 |
| 60 | 122 | 16.33 | 84 | 17.02 |
| 90 | 109 | 17.17 | 77 | 18.88 |
| No drain | 96 | 13.58 | 59 | 7.77 |

Based on our DRAINMOD outputs we compared the costs of the additional workable days per acre ($/AWD/acre) that would be expected by installing tile drainage at various spacings for a period between 2016 and 2030. Our economic analysis was done for a 40 acre field, assuming an installation cost of $0.80 per ft for the tile, an initial cost of $5,000 for a pump and $200 per year to operate it, as well as $72 per hour every 5 years for tile cleaning and a real interest rate of 3 %. The analysis was done for the predicted increase in the number of workable days as modelled by DRAINMOD for the rainfall of 2030. Given that we have not modeled the additional workable days that would be achieved between 2016 and 2030, we have assumed either the benefits would accrue gradually at a linear rate over the 14 years or at an extreme, immediately. The results show that the costs for additional days is similar for 60 and 90 ft spacing but then increases substantially for 30 ft spacing and more than doubles for 15 ft spacing (**Figure 16**). When the benefits are accrued immediately the costs are reduced by half. Interpreting these costs and benefits is challenging as it is hard to estimate what the actual economic benefit of an additional workable day translates to for individual farmers. The benefits of additional workable days depends on the number of fields the farmer is managing and the differences in these field's soil properties. The results, however, indicate the range of costs farmers are likely to encounter to improve their capacity to effectively adapt to even small changes in weather patterns.

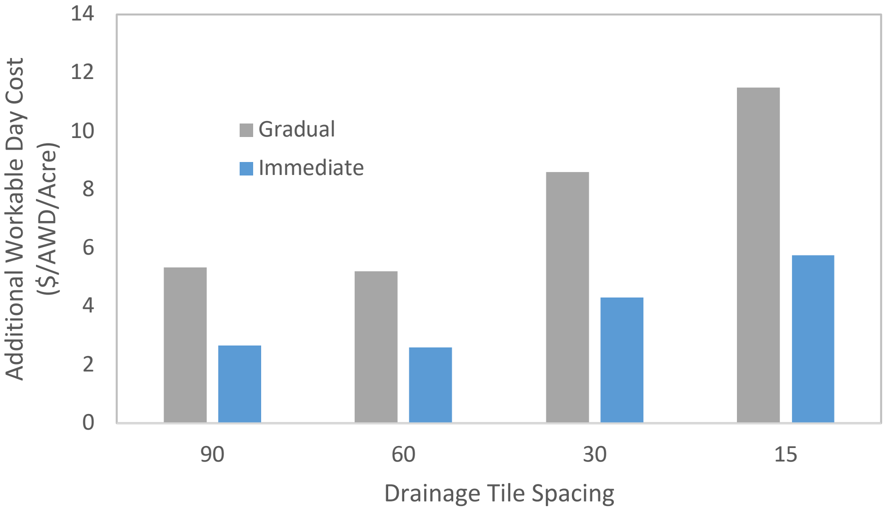


***Figure 16*** Estimated costs for each additional workable day per acre ($/AWD/Acre) for tile drainage spacings of 90, 60, 30 and 15 ft for a scenario where additional days are accrued gradually from 2016 to 2030 (Gradual) or immediately after installation (Immediate).

# Objective 2 - Existing Drainage Management Options

## Soil properties

### *Bulk Density*

There were no significant differences between bulk density at the 0-15 cm depth across treatments for either blueberry of vegetable fields (**Figure 17**). This was unexpected given a primary hypothesis of this study was field operations during periods of soil saturation lead to compaction. These results would suggest that if compaction is indeed occurring because of farm operations, drainage management options are not influencing this change. It should be noted, however, that bulk density is a dynamic soil property and varies by depth. Fields that are being tilled annually, and at different times of the year, may have higher or lower bulk densities depending on when the tillage happened. We sampled soils for this study during the production season, and in the vegetable fields this would have been after tillage, which can reduce bulk density and mask overall compaction. Furthermore, because tillage, roots and organic inputs are generally at the soil surface, differences in bulk density between the treatments could be more pronounced at deeper depths.

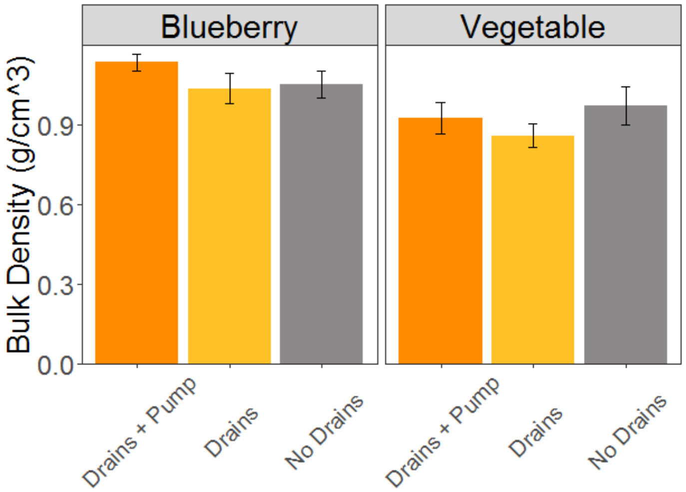


***Figure 17*** Bulk Density (g/cm$^3$) across existing drainage management options (Drains + Pump, Drains, or No Drains) in vegetable fields in 2016. Error bars represent ± one standard error.

### *Soil Organic Carbon*

SOC tended to be lowest in fields with Drains + Pump, both in vegetables and in blueberries (**Figure 18**). In blueberries, the highest SOC was found in fields with No Drains (especially at depth), while in vegetables the highest SOC was in fields with Drains only. Vegetable fields tended to have more SOC at 20 cm depth than blueberry fields, likely due to repeated tillage in vegetable fields creating a deeper Aph horizon. While there were significant differences in SOC by depth (p<0.001) but the differences among treatments were not significant.

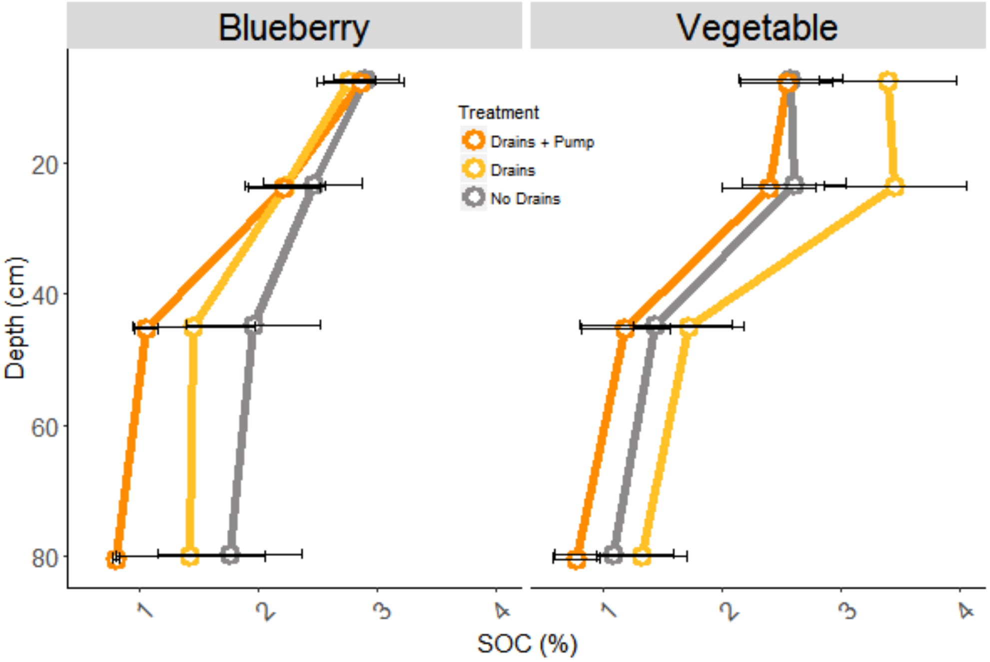


***Figure 18*** Soil Organic Carbon (SOC %) across existing drainage management options (Drains + Pump, Drains, or No Drains) in blueberry and vegetable fields in 2016. Error bars represent ± one standard error.

### *Landscape Soil Mapping*

Digital mapping of soil properties across Delta illustrated clear benefits in terms of providing more accurate soils information compared to what was previously available in soil survey maps. As part of the accuracy assessment, the predicted values of SOC %, clay %, and Wopt % were compared with field data using a linear regression model. For validation, 70% of the data were used for training, and 30% were used for testing the model. It is important to note that the soil maps are validated using field data that was designed for sampling treatment and crop differences (vegetables and blueberries, and Drains + Pumps, Drains, and No Drains), and not spatially distributed for soil mapping purposes. Validation tests were also performed between field data and Canadian Soil Survey data, where survey data were considered as the dependent variables. The landscape maps predicting soil properties were much more closely correlated with field data than the soil survey (**Table 3** and **Figure 19**). The $R^2$ of clay, SOC, and Wopt was found to be 73 %, 91 %, and 92 % respectively for predicted and field data. In contrast, $R^2$ of the same properties was below 5 % for survey and field data. Root mean square error (RMSE) were far lower for predicted soil properties than for the survey. For example, the RMSE of Wopt was only 1.2 % for the predicted maps whereas the RMSE was 28.93 % for the soil survey. While it is expected that some soil properties are likely to have changed since the soil survey was completed (e.g. SOC), other properties should not (e.g. clay content) yet the correlation between survey and field data was extremely low. This highlights the limitation of using soil survey data, even at a regional scale, for analysis and planning and the benefits of developing and maintaining digital soil maps.

***Table 3*** Goodness-of-fit variables for Field Data vs. Predicted soil properties, and Field Data vs. Soil Survey-derived Soil Properties

| *Map Data* | *Soil Properties* | *$R^2$* | *RMSE* |
|---|---|---|---|
| Predicted | Clay% | 0.73 | 2.07 |
| | SOC% | 0.91 | 0.15 |
| | Wopt% | 0.92 | 1.2 |
| Survey | Clay% | 0.03 | 3.05 |
| | SOC% | 0.04 | 3.76 |
| | Wopt% | 0.05 | 28.93 |

The digital soil maps of the region provide high resolution information that can be used for current planning and to provide an important baseline for tracking changes in soil conditions. Maps of of SOC % (**Figure 20**a) ranged from 1.5 – 4.5 % and show higher concentrations in agricultural fields in the north-eastern part of Delta. Clay % values range from 8 – 29%, with higher contents observed in fields mainly in the western part of the region ( **Figure 20**b). Sixty percent of the landscape was observed to have a gravimetric workability threshold (Wopt %) in the range of 30-35% whereas areas with low SOC% and/or high clay % had lower thresholds (e.g. Westham Island, **Figure 20**c).

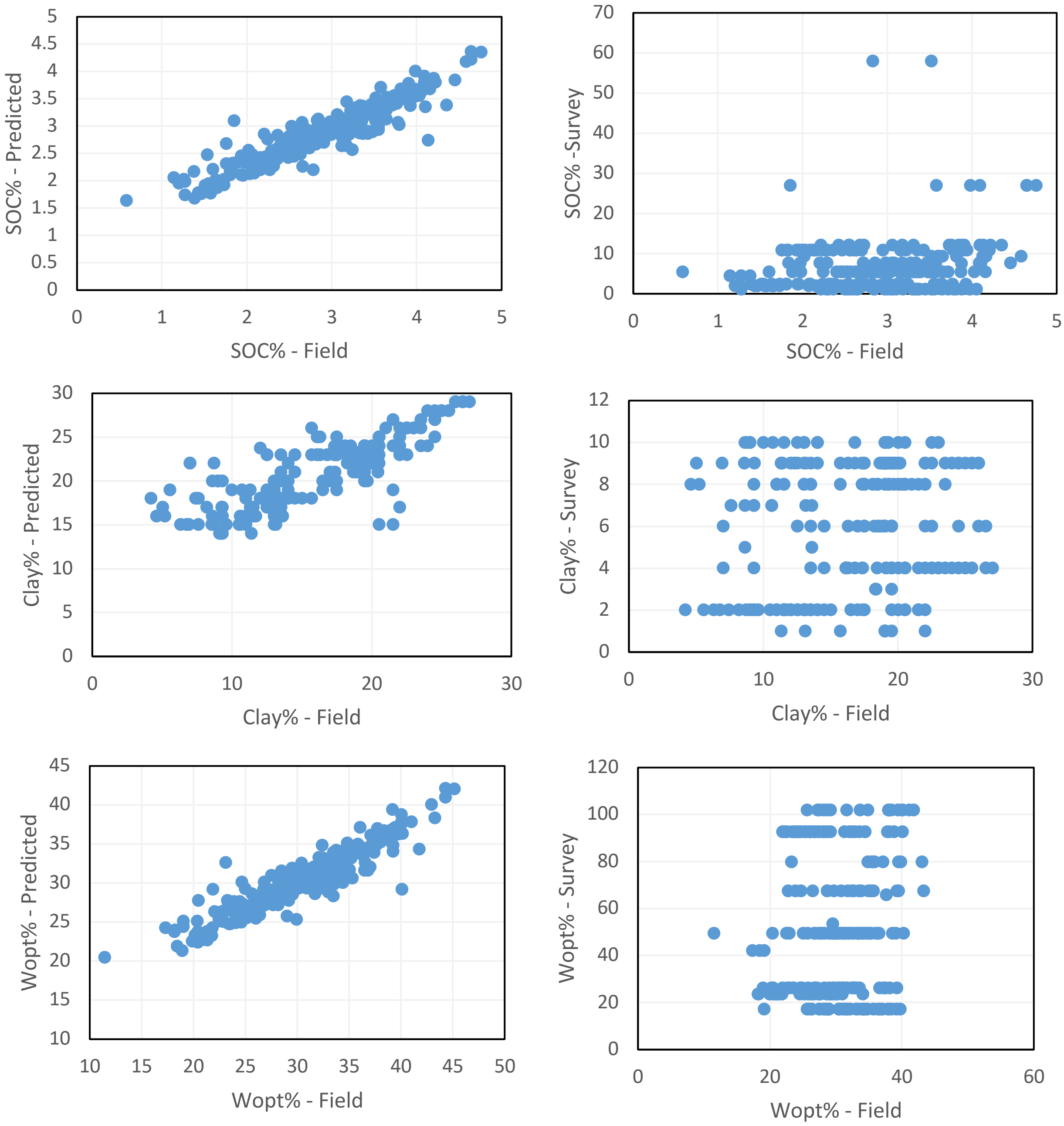
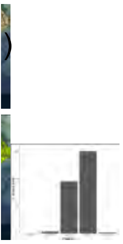


***Figure 19*** Scatterplots comparing predicted and soil survey data with field data for soil properties – Soil Organic Carbon (SOC %), Clay (%), and soil gravimetric workability threshold (Wopt %)

Unfortunately, landscape-scale information of field-level drainage conditions was not available, and thus any mapping which would reflect drainage treatment effects (e.g. number of workable days by region) was not possible.

(a.)



(b.)

(c.)

(d.)

*__Figure 20__* Digital map of Soil Organic Carbon (%) (a.) clay (%) (b.) and soil workability (gravimetric moisture %) at the landscape-scale (c.); the distribution of optimum soil water content for workability (d.)

## Vegetables

### *Soil Moisture*

We observed a consistent trend where soil moisture was highest in fields with No Drains, particularly in the dry spring of 2016. Alternatively, in the much wetter fall of 2016 and spring of 2017, the trend showed Drains + Pump treatments were consistently the driest, especially in the early spring 2017; however, differences were not evident between Drains and No Drains (**Figure 21**). While these trends were fairly consistent, the differences among treatments was not large and the variability within the fields was high, thus no statistical differences were found.

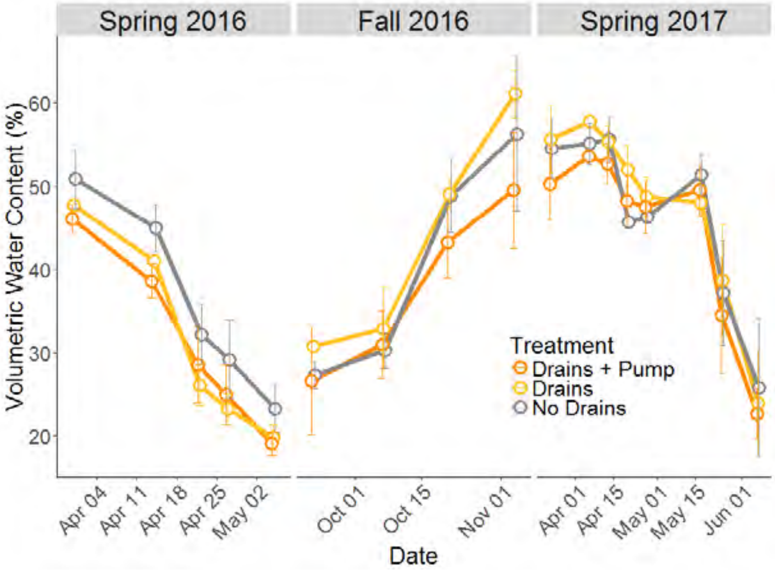


***Figure 21*** Soil Volumetric Water Content (VWC%) across existing drainage management options (Drains + Pump, Drains, or No Drains) in vegetable fields from 2016-2017. Error bars represent ± one standard error.

### *Workability*

The observed workable range (first observed workable day in the spring to last observed workable day in the fall) in 2016 was significantly (p=0.07) lower in fields without drainage than those with drainage but there were no differences observed in the type of drainage system (Drains vs. Drains + Pump) (**Figure 22**). The average first workable day in 2016 was April 23, while in 2017 the average first workable day was June 4. This is a difference of 41 days between an unusually dry spring and a more typical one.

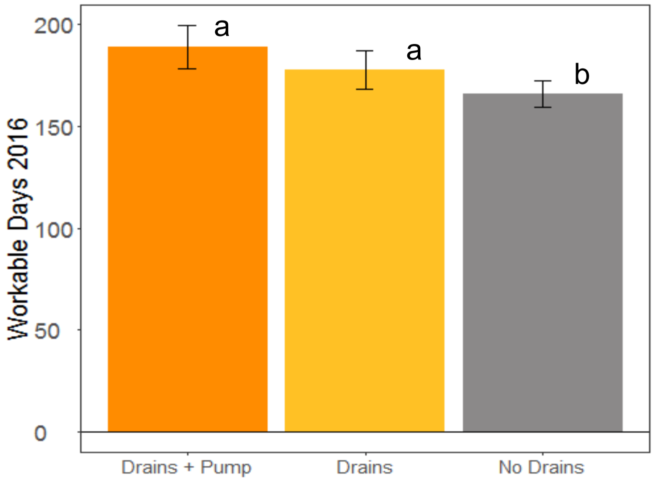


***Figure 22*** Observed workable range (number of days between first observed workable day and final observed workable day) across existing drainage management options (Drains + Pump, Drains, or No Drains) in vegetable fields in 2016. Error bars represent ± one standard error. Letter indicate statistical differences among treatments ($p = 0.07$).

### *Ponding*

In 2016, there were no observed differences in ponding across the fields monitored in this study. In the spring of 2017, drained fields had a significantly higher amount of ponding ($p<0.01$). This difference however, was entirely driven by one Drained field, and excluding this field from the analysis resulted in no significant differences among the treatments. There are several factors which may have impeded the drain tiles' functioning in this field: the outfall of the drainage tile appeared to be buried by sediment, so it is possible the tiles were blocked; and the field is also closer in proximity to Boundary Bay than most of the other fields and may have been impacted by a higher water table. Thus, there is some doubt as to whether this field is representative of drained fields but illustrates the variability in performance seen across the region and potentially the need for tile/ditch maintenance.

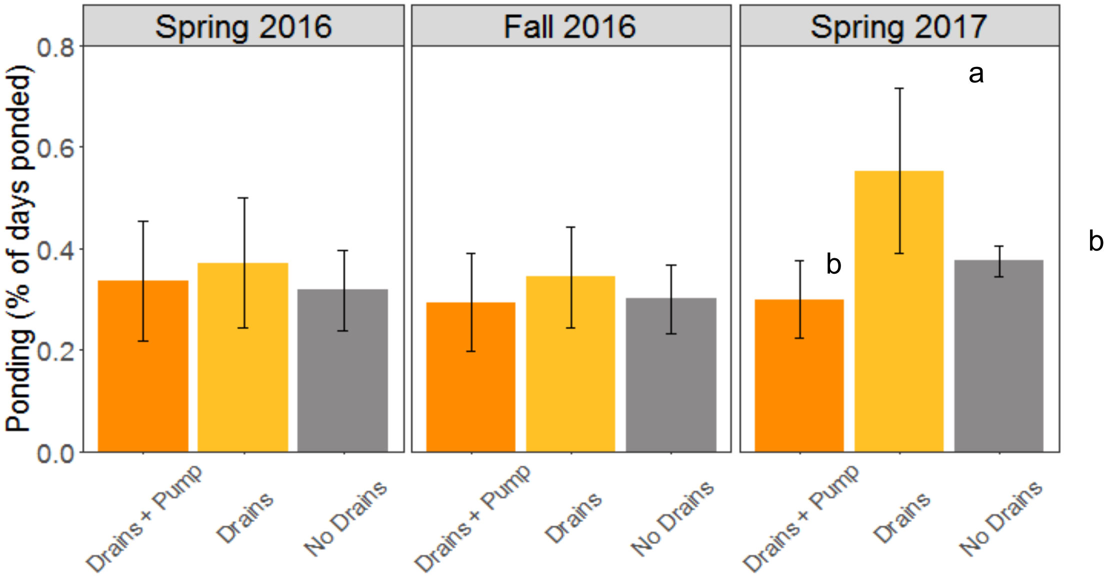


***Figure 23*** Ponding (intensity X average duration, reported as % of days ponded) across existing drainage management options (Drains + Pump, Drains, or No Drains) in vegetable fields from 2016-2017. Error bars represent ± one standard error. Letter indicate statistical differences among treatments ($p < 0.01$)

### *Salinity*

We found that drained fields were significantly higher in salinity ($p<0.01$) than other treatments. However, after removing the same outlier field mentioned above, again there were no significant differences.

This is another analysis that illustrates the challenge with our observational study site selection. While the selection of farms was largely random, some farmers may have chosen to install drainage specifically on their most salt effected fields. This was evidenced by several Drained fields having extremely high salinity resulting in the high variability seen for this analysis. Salinity was generally higher in the fall than in the spring season, before rains have a chance to flush out the salt – this is a process which would be aided by drainage. These data, however, serve as an important baseline for tracking soil salinity over time. It is possible that although there were no differences among the treatments in this study, that over time the rate of change will depend on the type of drainage. We would expect to see salt concentrations go down in fields that had drains and pumps or that had been cleaned, compared to those that had not.

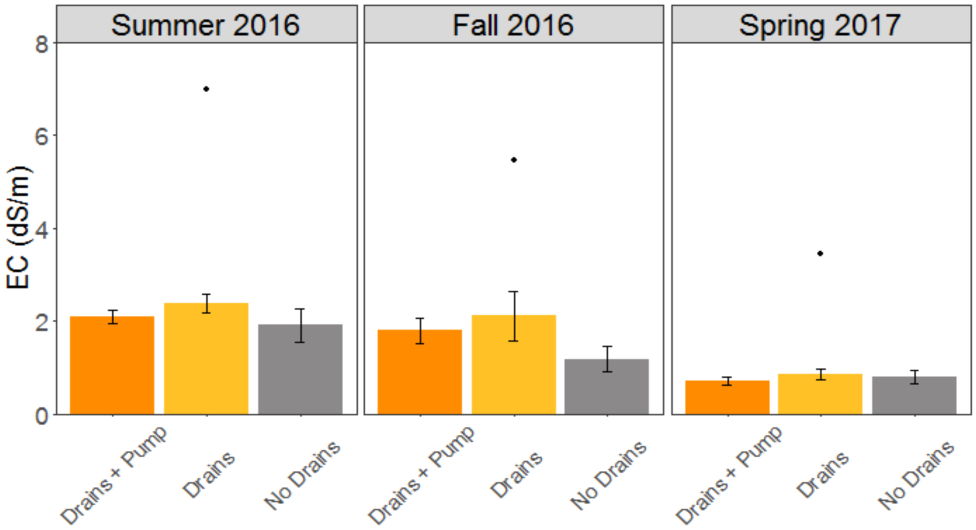


***Figure 24*** Salinity (Electrical Conductivity, dS/m) across existing drainage management options (Drains + Pump, Drains, or No Drains) in vegetable fields from 2016-2017. Error bars represent ± one standard error, and black points represent one outlier field which was removed from the bar graphs in the Drains treatment.

### *Tile Cleaning*

Tile cleaning had a non-significant impact on the observed workable range in 2016 (**Figure 25**), though the cleaned field sections tended to have more workable days (**Figure 26**). The tile cleaning appeared to be the most effective in the spring of 2016, immediately after cleaning. It may also be that the effect of cleaning is observable under more typical rainfall than was observed in the fall of 2016 and spring of 2017.

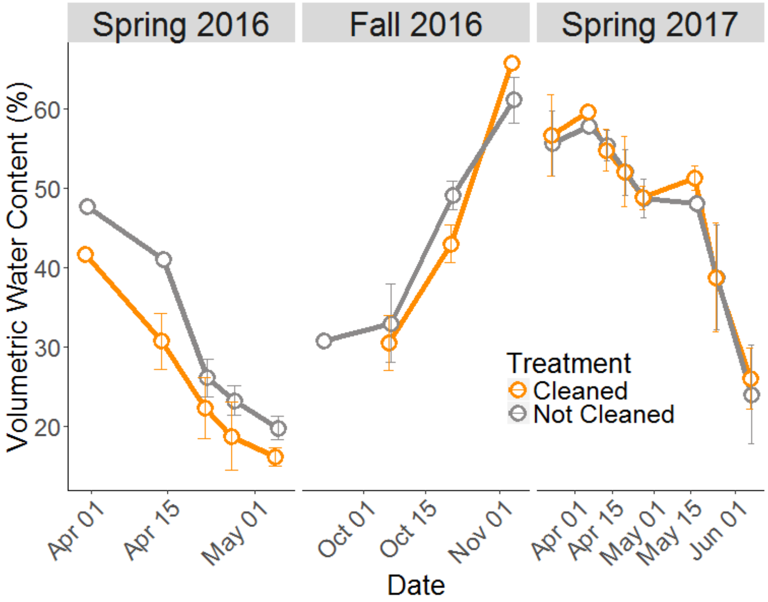


***Figure 25*** Soil Volumetric Water Content (VWC%) in fields with Drains which have been Cleaned (in fall 2015/spring 2016) or Not Cleaned in Vegetable Fields from 2016-2017. Error bars represent ± one standard error.

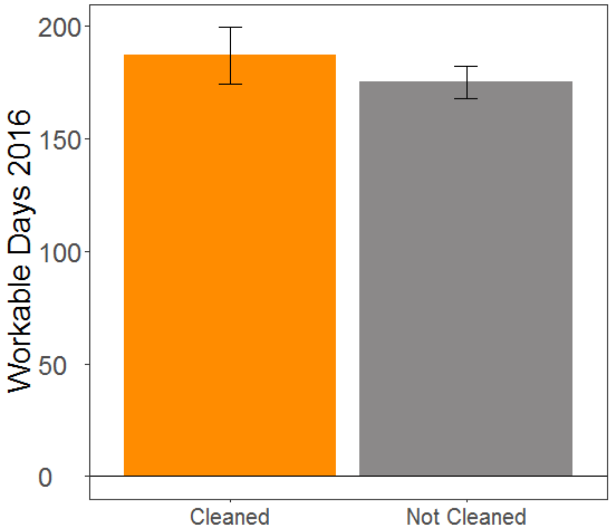


***Figure 26*** Observed workable range (number of days between first observed workable day and final observed workable day) in fields with Drains which have been Cleaned (in fall 2015/spring 2016) or Not Cleaned in vegetable fields in 2016. Error bars represent ± one standard error.

### *Vegetable Drainage System Variation*

The principal components analysis (PCA) of the vegetable fields illustrated some key points of the overall performance of the current drainage systems. While it is unclear whether drainage systems were installed specifically in problematic fields, the PCA indicates that the variation of drainage performance (i.e. Wopt, workable days, ponding, EC) and soil properties was not distinctly determined by the three types Drains + Pump, Drains, and No Drains (as indicated by the overlapping ellipses in **Figure 27**). This suggests that factors aside from the selection of these three types of drainage system are more likely to explain differences in drainage performance. The PCA provides a number of interesting relationships that should be noted. As the tile spacing increases in dimension 1 we see an increase in bulk density. In the opposite direction of these vectors, i.e. as tile spacing decreases, workable days, soil, carbon, and Wopt increase. Interestingly so too does sand, EC and ponding, largely driven by one field. It may be that given soil texture and SOC are more important determinants of drainage management outcomes than the type or even the spacing of drainage system.

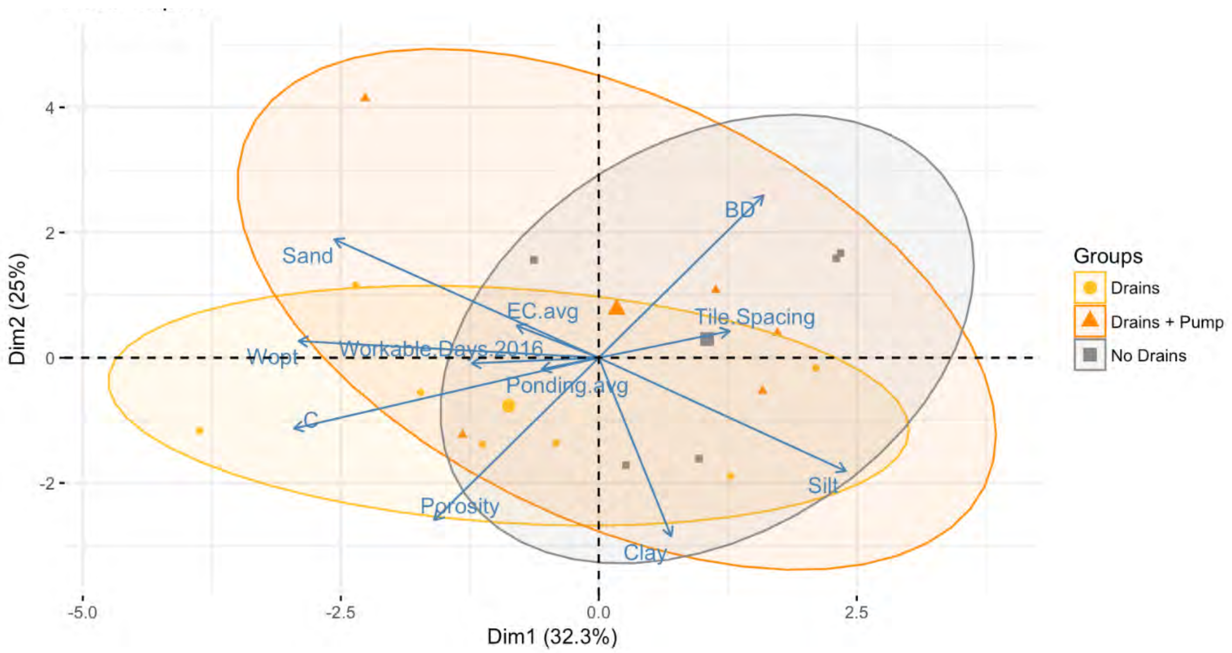


***Figure 27*** Principal Components Analysis (PCA) of fields across existing drainage management options (Drains + Pump, Drains, and No Drains) in vegetable fields. Arrows represent soil parameters and hydraulic variables and points represent individual fields.

## Blueberries

### *Ponding*

In blueberries, there were clear differences in ponding among the treatments. Fields with Drains + Pump were significantly less ponded ($p<0.01$) on average than other fields; this was likely due to the very effective ditches in the Drained + Pumped fields. The reduced ponding in these fields would likely improve the farmers' capabilities to conduct management options throughout the winter.

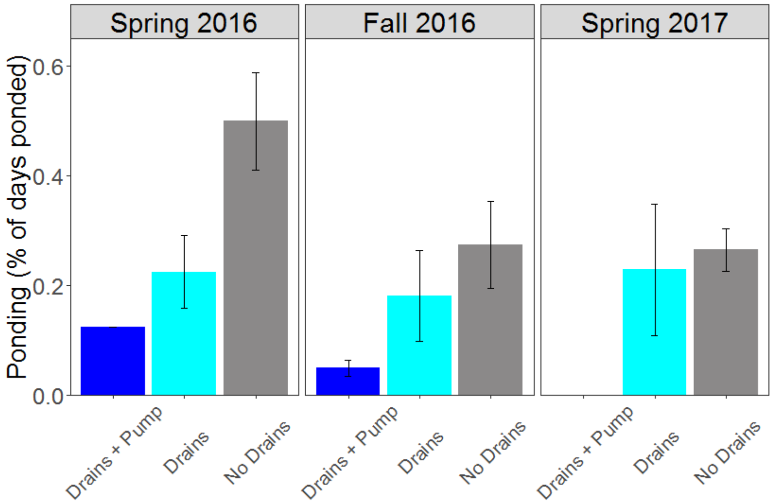


***Figure 28*** Ponding (intensity X average duration, reported as % of days ponded) across existing drainage management options (Drains + Pump, Drains, or No Drains) in blueberry fields from 2016-2017. Error bars represent ± one standard error.

### Water Table

Similarly to the ponding, blueberry fields that had Drains + Pump had a significantly lower water table (50 ± 6 cm) than fields with No Drains (42 ± 8 cm, p<0.01) during the 2016-2017 winter season. With only Drains, the water table was intermediate (47 ± 6 cm). This suggests that drains do help but ditch management makes the drains even more effective.  Pumps are clearly key to keeping ditch water levels below the level of the drains but it may also contribute to the overall hydrology of the field by moving water out of the system.

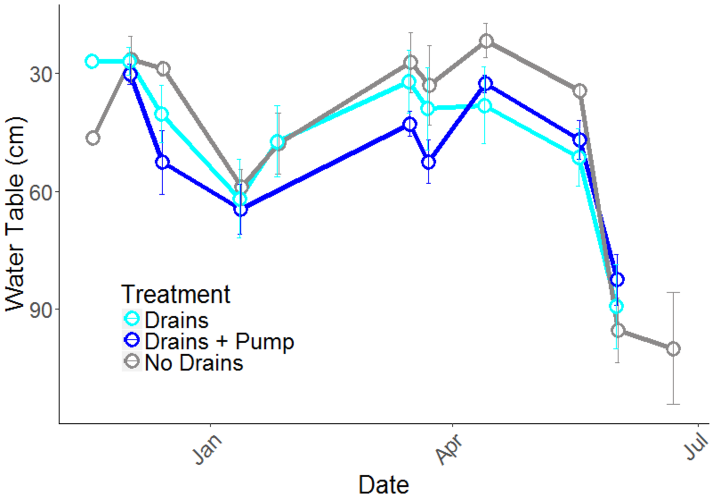


***Figure 29*** Water table (depth below surface, cm) across existing drainage management options (Drains + Pump, Drains, or No Drains) in blueberry fields in Winter/spring 2017. Error bars represent ± one standard error.

### Salinity

There were no differences in salinity among blueberry fields, though in the summer of 2016, one field in the Drains + Pump treatment had a very high salinity. This salinity was reduced by the spring of 2016, minimizing any trends in this area.  Overall, despite the stated concerns of the farmers, salinity levels were fairly low in the beginning of the season (<1 dS/m) indicating that, at least at the soil surface, salts are being leached out of the profile.

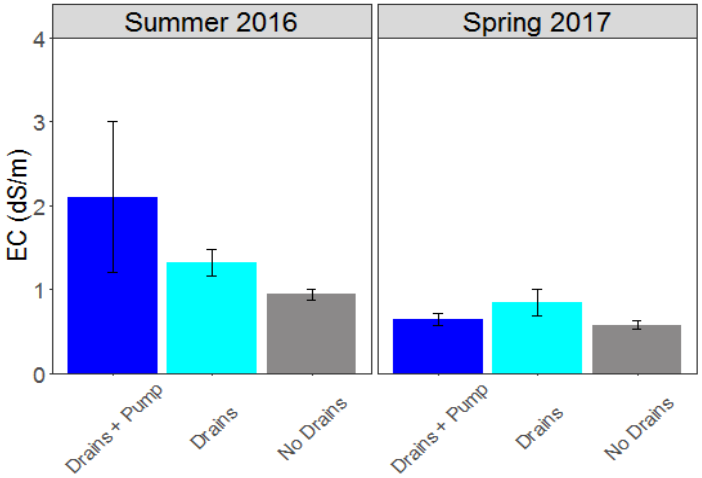


***Figure 30*** Salinity (Electrical Conductivity, dS/m) across existing drainage management options (Drains + Pump, Drains, or No Drains) in blueberry fields from 2016-2017. Error bars represent ± one standard error, and black points represent one outlier field which was removed from the bar graphs in the Drains treatment.

## *Tile Cleaning*

Blueberry fields had a marginally lower water table due to drain cleaning (p=0.06). During the unusually wet fall of 2016, when the water table was greater than 40 cm for both cleaned and uncleaned, we observed some of the largest differences. In the spring, as the fields began to dry down, these differences were not observed. We did not see any differences in salinity one year following drain cleaning in the blueberries.

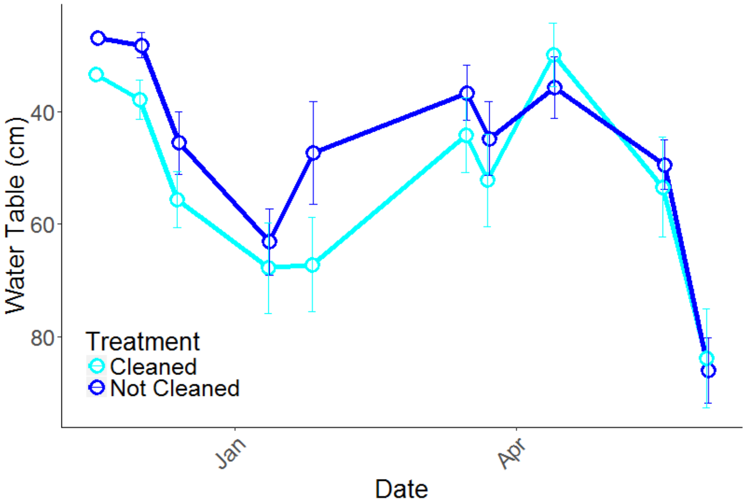


***Figure 31*** Water table (depth below surface, cm) in fields with Drains or Drains + Pump which have been Cleaned (in fall 2016/spring 2016) or Not Cleaned, in blueberry fields in Winter/spring 2017. Error bars represent ± one standard error.

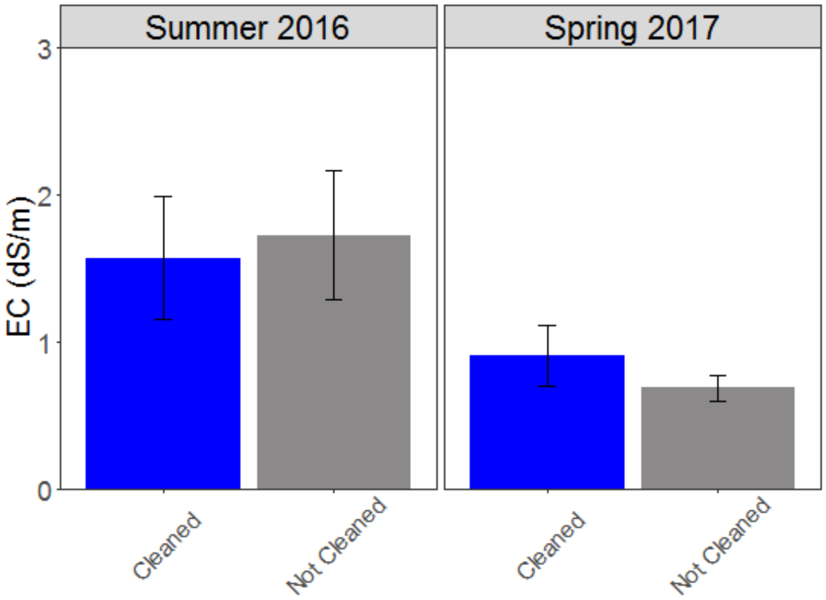


***Figure 32*** Salinity (Electrical Conductivity, dS/m) in fields with Drains which have been Cleaned (in fall 2015/spring 2016) or Not Cleaned, in blueberry fields from 2016-2017. Error bars represent ± one standard error.

### *Blueberry Drainage System Variation*

The principal components analysis (PCA) of the blueberry fields showed distinct separation between fields with Drains + Pump and fields with No Drains, in both drainage management outcomes (e.g. ponding, water table) and soil properties (as indicated by the ellipses in **Figure 33**). Fields with Drains overlapped the two. Ponding was clearly correlated with increased tile spacing and clay content. Interestingly, SOC was correlated with higher EC and bulk density. Fields that had higher ponding intensity had lower water table which appeared to be most correlated with silt content.

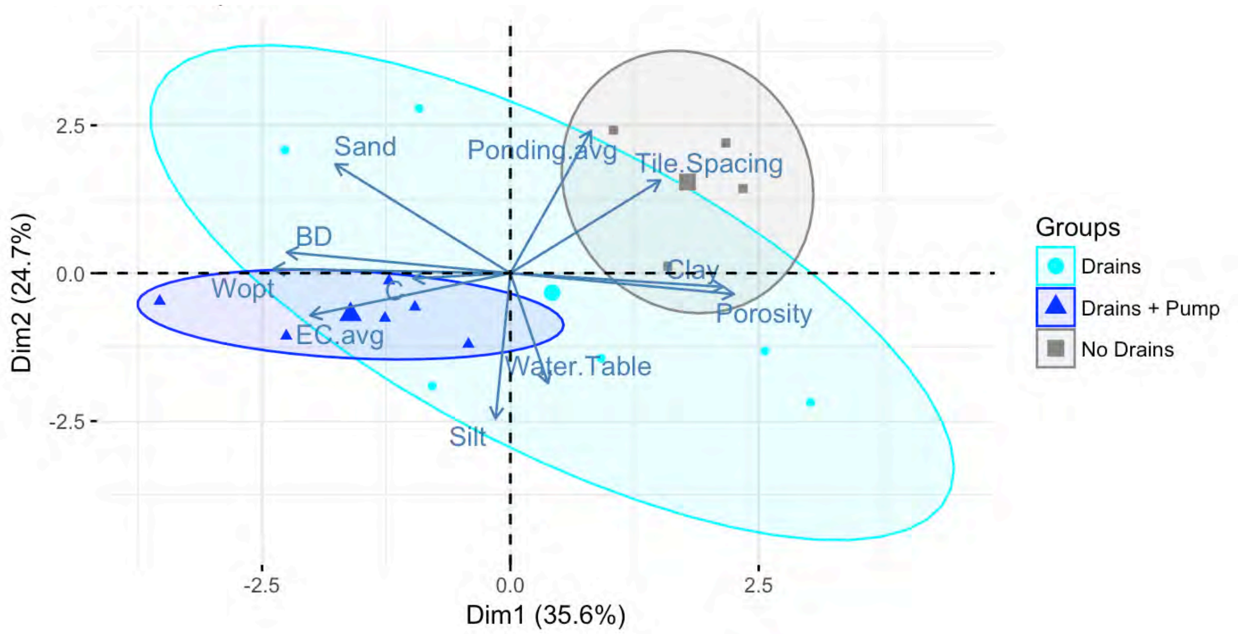


***Figure 33*** Principal Components Analysis (PCA) of blueberry fields across existing management options (Drains + Pump, Drains, and No Drains) in vegetable fields. Arrows represent soil parameters and hydraulic variables and points represent individual fields.

# Objective 3 – Knowledge Transfer

Over the course of the project our team has been engaged in wide range of knowledge transfer activities targeting scientists, technicians and farmers.

Geared towards academics and technical professionals, we have given six presentations: one at the Canadian Society of Soil Science AGM & Workshop (Kamloops, 2016), one at the Fraser Valley Water Management Symposium (Abbotsford, 2016), one at the BC Agri-food and seafood conference (Kelowna 2016), another at the Canadian Society of Soil Science AGM (Peterborough, 2017) and two at the Ecological Society of America's Annual Meeting (Portland, 2017). We have two manuscripts that are currently in preparation that will be submitted to peer reviewed journals by the end of the year.

Geared towards producers, we held two presentations at Delta Farmers' Institute (DFI) events (one in fall of 2015, which attracted ~32 growers, and one in the fall of 2016, which attracted ~27 growers). We have produced one fact-sheet sent to producers highlighting field-specific results (January 2017), and four outlining more general and region-applicable results from this study. Digital soil maps from the study have been posted online and are available at [http://sal-lab.landfood.ubc.ca/](http://sal-lab.landfood.ubc.ca/).

Our April 2017 workshop & field tour was organized with the Delta Farmers' Institute (DFI). In the morning, we gave a presentation detailing results of the project, and split into three focus groups: 1. Field-Scale Analysis – discussion of field variability and how this impacts the effectiveness of Big-O drain tiles; 2. Modelling – what climactic changes are we expecting by 2030/2050, and how can drainage strategies help to mitigate these challenges; 3. Future – what other beneficial management options can we use to increase the effectivity of drainage and to look at other benefits – increased soil carbon, nutrient use efficiency, etc. In the afternoon, we took a field tour to our on-farm demonstration site where we showed visual ponding, water table, and dug a soil pit to look at soil water content.

# Conclusions and Recommendations

### *Drain Spacing and Grassland Set-Asides*

In our field-scale trial we found that both increasing drainage spacing and planting GLSAs had a moderate impact on soil moisture that did not immediately translate into additional workable days. In the cropped fields (fields without GLSA), installing closer drainage spacing (from 60 to 30 feet) had a small impact on soil moisture; installing a GLSA with 30 ft drains had a small impact, and installing closer spacing in the GLSA (from 30 to 15 ft) had a moderate impact. Tilling in a one-year GLSA in the fall had a large impact on soil moisture compared to fields which remained in GLSAs at the same drain spacing. All of these impacts were most evident when VWC was greater than 45%, mainly earlier in spring and later fall. Although we observed a greater reduction in soil salinity with decreased tile spacing after only one year we have low confidence in these results due to the lack of replication. Overall conclusions from the observed results of the field-scale trial are limited primarily by this lack of replication but also because we anticipate that the performance of the drains may change as the system settles. Recommendations in terms of spacing and GLSAs should be made once the site has been re-evaluated for changes to soil salinity and workability in a few years.

### *Modelled workable days – current and future*

Modelling, based on parameterization from one year of field data from the field-scale trial, predicted important differences between tile spacings. Using DRAINMOD to model the full year, we were able to predict soil moisture on *all* days (not just measured days). Based modelling of the field-scale trial with 2016, the field with drains spaced at 15 ft would gain 49 % more workable days and the field with drains spaced at 30 ft would gain 40 % more workable days than the field without drainage. In 2030, based on modeled rainfall, DRAINMOD predicted many fewer workable days than 2016 in general, and a much larger impact of drainage. Fields with drains spaced at 15 ft had 64 % more workable days and drains spaced at 30 ft had 46% more workable days than fields without drains; a difference of 11 days gained from 15 vs. 30 ft. Our modeling clearly indicates the increased importance of drainage under an expected scenario of increased shoulder season rainfall.

### *Drainage with pumps at the landscape scale*

Analysis of vegetable and blueberry fields sampled across Delta's landscape highlighted the variability in soil properties and current conditions and performance of drainage management. No differences were observed in bulk density regardless of drainage management indicating that, at least at the soil surface, fields without drainage are not having more problems with compaction. Nor were there difference observed in SOC, indicating that drainage is not yet contributing to SOC losses. The fields that were monitored across the landscape in Delta showed that current drainage systems increased 'observed workable days' by 8% in vegetable fields (14% with pumps) but did not decrease ponding. In blueberry fields drainage systems lowered water table by 14% (22% with pumps) and decreased ponding by 39% (83% with pumps). Across both vegetable and blueberry fields we saw no impacts of drains on salinity, likely due to differing soil conditions, drain spacing, age of drains, and position relative to the dikes. The conclusions that can be made from this study are somewhat limited by the treatments as they were not randomly assigned, but merely observational. It is possible that fields with poor drainage are those which preferentially had drains installed. Finally, we were not able to track a number of management factors that could contribute to differences in performance: pump time, water flow in the ditches, to name two examples. Based on our results however, we can clearly recommend pumps if they can be installed to effectively remove water from the hydraulic system of the field.

### *Drain Cleaning*

After one year, drain cleaning *tended* to increase workable days by 7% (not significant) and lowered water table by 13% (marginally significant). Drain cleaning did not reduce salinity after one year. Additional sites and longer monitoring would be required to determine for how long this drain cleaning benefit is effective and under what conditions it is most likely to improve tile performance.

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