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1 Assessing the value of cover crops in vineyards using proximal sensing  
2 approaches.

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8

9 **Service of the interest of On-Farm Experimentation :** Illustration of how a grower has engaged to  
10 test innovations on-farm using agri-tech

11 Innovations in Agri-tech and in cover cropping were introduced into the juice grape industry in NY in  
12 the early 2010s. To test the effectiveness of cover crops in a grower's commercial vineyard, a  
13 stratified design was implemented to minimise the effort needed and the potential effect of the  
14 experiment on production. Agri-tech was used to assess the impact of the presence or absence of a  
15 cover crop on yield and vine size. The yield sensor and canopy sensors indicated that over four years  
16 there was no impact on production from the cover crops, but the grower did notice that the cover  
17 crops provided soil and management benefits. The results reinforced the grower's desire to increase  
18 the use of cover cropping in vineyard management.

19 Introduction:

20 In 2012, a National Grape and Wine Initiative (NGWI) project brought investment in vineyard sensing  
21 to the Lake Erie viticulture region via a Crop Load project at Cornell's Lake Erie Research and  
22 Extension Laboratory (CLEREL). Financial support was made available to growers interested in  
23 installing yield monitoring technology (ATV grape yield monitor (GYM), Roslin, South Australia,  
24 Australia) on their harvesters. One commercial contract operator and one family-run enterprise in  
25 the region took advantage of this offer. In addition to the yield monitoring technology, terrestrial-  
26 mounted canopy sensors (N-Tech Greenseeker RT100 (N-Tech Industries Inc, Ukiah, CA, USA) and an  
27 apparent soil electrical conductivity (EC<sub>a</sub>) surveying service (DualEM-1s, DualEM, Milton, Ontario,  
28 Canada) were also made available to the growers free of charge through Cornell's Cooperative  
29 Extension (CCE) service. Therefore, these two growers very rapidly gained access to information from  
30 on-the-go sensors providing high-resolution information on yield, vine size (canopy) and soil  
31 variability within their vineyard blocks (while all local growers had access to the vine size and soil  
32 data if they wanted to engage with the extension service).

33 In addition to the interest in agri-tech and precision viticulture at this time, there was a growing  
34 interest in the role of cover crops within cool-climate vineyards in North America (Messiga et al.  
35 2015). Interrow cover crops planted mid-summer were being advocated to improve soil quality,  
36 particularly by breaking up compaction layers, and to improve trafficability during harvest  
37 (September/October) when the soil may be saturated. However, this is offset by a concern among  
38 growers that the interrow cover crop may compete with the vines to the detriment of production  
39 (yield). By chance, the same family-run vineyard enterprise that had invested in the yield-monitoring  
40 technology was also interested in using cover crops. In this case, the younger generation was  
41 interested in possibilities of the agri-tech innovation, whilst it was the older generation who was  
42 interested in the cover crop innovation. These two innovations are complementary in nature, there is  
43 no trade-off between them, and the agri-tech sensors provided a potential way of assessing the local

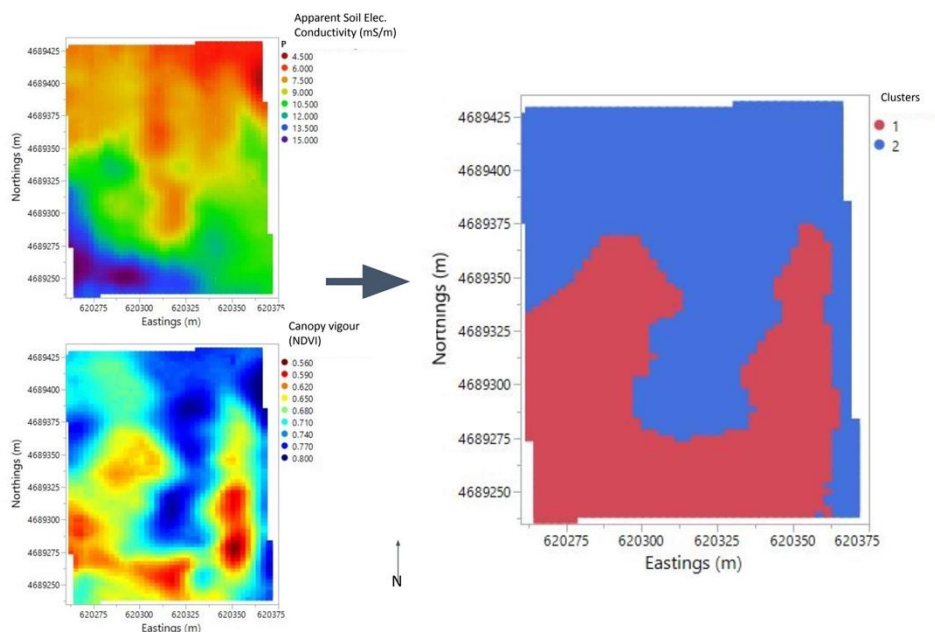
44 site-specific effect of the cover crop on production. To this end an on-farm experiment was designed  
45 using precision viticulture technologies to establish and monitor cover crop effects.

## 46 Materials and Methods:

47 The experiment was performed from 2013 to 2017 in a 2.2 ha Concord (*Vitis Labrusca*) vineyard near  
48 Westfield, NY. The vineyard is a single high-wire cordon managed by machine pruning with hand  
49 follow up. Vineyard layout is 2.74 m between rows and 2.44 m between vines within rows.  
50 Management was done using best management practices as recommended by CCE (Jordan et al.  
51 1981)

### 52 2.1 Sensing

53 Grape yield monitoring was performed at harvest with a load-cell sensor embedded in a false weigh-  
54 bridge on the discharge conveyor belt, that has been shown to be accurate and reliable with regular  
55 calibration in these vineyards (Taylor et al. 2016). However, the system was not perfect and yield  
56 data in 2015 were not able to be retrieved. Canopy sensing in mid to late July was done to map vine  
57 size using a side-on approach where cane length in the canopy side wall relates well to vine size in  
58 these vineyards(Taylor et al. 2017). Soil surveys were performed in late spring (full soil moisture  
59 profile) by CLEREL with a DualEM-1s mounted on a PVC sled and dragged along the inter-rows behind  
60 an all terrain vehicle. The Dual-EM recorded the  $EC_a$ , which is indicative of soil texture differences  
61 when performed at field capacity soil moisture. The between row distance (2.74 m) meant that there  
62 was little interference from the trellis wires on the  $EC_a$  response if the sled was kept central in the  
63 inter-row. All these production data layers (canopy and yield)were collected automatically and  
64 routinely by the grower during routine vineyard operations. It did not require specialised surveys or  
65 additional time.



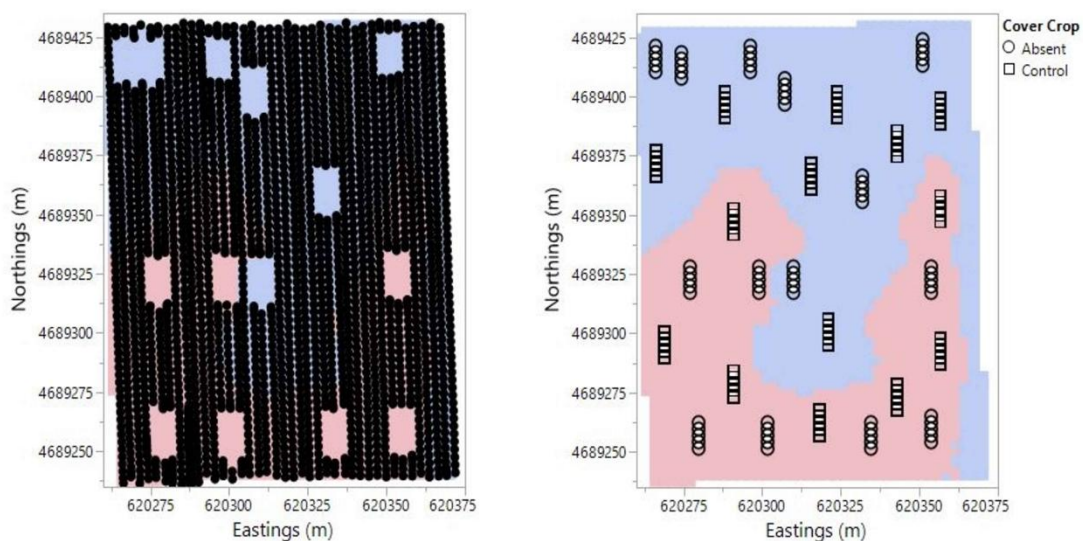
66  
67 Figure 1: Vineyard maps of soil apparent electrical conductivity ( $EC_a$ ; mS/m) and NDVI (Normalised  
68 Differences Vegetation Index) values derived from terrestrial-mounted soil and canopy sensors  
69 respectively. These have been fused and classed into two potential management zones (right) using  
70 *k*-means clustering. Cluster 1 (red) is a zone of lower vigour associated with a heavier soil texture  
71 (higher  $EC_a$ ) while Cluster 2 has higher vigour on a lighter texture soil.

72 All sensor data were cleaned and interpolated using local block kriging onto a common 2.74 m grid  
73 and collated into a spreadsheet for analysis using the general protocol of Taylor et al. (2007).

## 74 2.2 Experimental Design.

75 The interpolated 2013 canopy and EC<sub>a</sub> data were clustered by staff at CLEREL to form two  
76 management classes using *k*-means clustering (see Taylor et al. (2007)). This separated the vineyard  
77 block into an area of relatively large vine size on a medium texture soil type and an area of smaller  
78 vine size associated with a heavier soil texture (higher EC<sub>a</sub>).

79 The vineyard managers were convinced that the cover crop would be beneficial to soil quality in the  
80 long-term, even if there was a short-term effect on production, so the default position in the  
81 vineyard was to plant the cover crop. Several possible experimental designs were discussed with the  
82 two vineyard managers (owners), including a simple half and half split and a complex chequerboard  
83 arrangement over the entire field, as well as strip trials and subplots stratified on the management  
84 classes. The managers were asked to propose alternative designs as well, but did not feel  
85 comfortable doing this at this time (i.e. at their first experience with this form of digitally-enabled  
86 experimentation). Based on their desire to have as much as the vineyard as possible under a cover  
87 crop and to understand the response in the lighter and heavier soil texture classes, the managers  
88 opted for the sub-plot approach of Whelan et al. (2012) that minimises the treatment area relative to  
89 a full strip approach.



90

91 Figure 2: Left: The as-applied prescription map indicating the subplots where the cover crop was not  
92 sown each year and; Right: the centre pixels within each subplot (circles) and the paired pseudo  
93 subplot cover crop treatment pixels (squares) used for the analysis.

94 To implement this design, seven sub-plots were identified in each management class where the  
95 cover crop was omitted (see Whelan et al. 2012 for full details of the design). These subplots were  
96 three panel lengths long (~21 m) and incorporated two interrows, such that the central vine trellis  
97 had no cover crop on either side. Three panels was considered long enough to have the sensors pick  
98 up any treatment effects. A prescription map was developed and applied that simply omitted sowing  
99 the cover crop in the absent treatments (Fig. 2). The remaining area of vineyard inter-row was  
100 planted to a predominantly radish cover crop mix (forage and tillage radish; *Brassica sp.*), to help  
101 break up the subsoil. Consequently, there was no predefined cover crop treatment area in the

102 design. Instead, seven additional 'pseudo' subplots were randomly selected and the data extracted at  
103 these sites to complement the absent cover crop treatments. Having paired treatments like this a)  
104 ensured a balanced design for subsequent analysis using classical statistical techniques, and b) made  
105 it simple for the grower to understand the comparison. The treatment design was extracted to the  
106 spreadsheet containing all the interpolated sensor data. In total there were 35 'pixels' of interpolated  
107 data associated with each treatment (Fig 2). Treatment subplot location were kept constant each  
108 year (2013-17) to avoid inter-annual effects.

## 109 2.3 Experimental Analysis

110 The design above was a balanced stratified block design. Treatment means were calculated and  
111 plotted for the period 2013-17 (note that the yield data for 2015 was not available) using JMP (v13,  
112 SAS Inc, CA, USA). ANOVA was not performed at this point as the intent was to illustrate trends to the  
113 grower for their satisfaction, rather than apply a rigorous scientific analysis.

## 114 Results and Discussion

### 115 3.1 Experiment implementation and data collection

116 The growers had a generally positive experience with the agri-tech innovations. As noted, yield data  
117 were lost in one of the four years; however the canopy data was routinely collected by the grower  
118 during general vineyard operations with little issue (only once running the sensor by accident into a  
119 fence post, which it survived). This is not to say that the technology was perfect or that it did not  
120 require care in acquisition. However, the younger manager was engaged with the technology, which  
121 made acquisition reliable. The sowing of the cover crops was also a positive experience using the  
122 prescription map and a variable rate actuator on the planter. It is noted that this was fairly simple, as  
123 it was just a binary cut-off system, and more complex rate changes may introduce more problems.

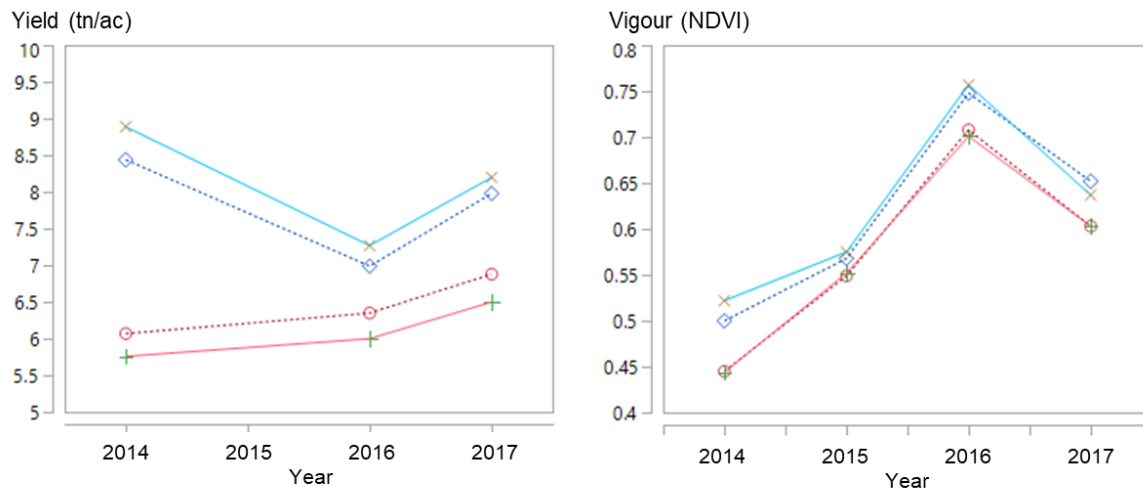
### 124 3.2 Data Analysis

125 The preprocessing and mapping (interpolation) of the data was performed by a trained research  
126 associate at CLEREL. Data processing tools are not yet at the stage where the growers themselves  
127 could easily engage with the analysis itself. However, simply plotting the trends and response curves  
128 was accessible to the grower and useful to their decision process. These plots are shown in Fig. 3.

129 Firstly, the difference between the high (blue) and low (red) vigour areas was clear in both the yield  
130 response and the NDVI response. It was also clear that the difference between subplots, with or  
131 without cover crop, was very consistent over the four years (2014-17). The high vigour subplots with  
132 cover crop had ~0.5 tn/ac (~1.1 Mg/ha) higher yield than the absent cover crop subplots at the start  
133 of the experiment. Conversely, in the low vigour area, the absent cover crop area started with ~0.5  
134 ton/ac (~1.1 Mg/ha) advantage. In both cases, this advantage was maintained regardless of the  
135 treatment type. This indicated, based on the sensor data, that the cover crop was having very little  
136 impact on production potential. The same conclusion can be drawn from the canopy vigour (NDVI)  
137 plots.

138 So, the experiment clearly indicated that the cover crop was not adversely competing with the vines.  
139 There did not appear to be a negative effect on vine size or on yield from adding the cover crop to  
140 the vineyard management. However, anecdotally, the cover crop was providing an ecosystem service  
141 by improving soil structure (less compaction noted), both through the action of the roots and by  
142 reducing the impact of farm machinery trafficking in the vineyards. In the latter case, there were also  
143 other benefits reported by the grower associated with improved vehicular access and trafficability.

144 This reassured the growers that extending cover cropping to all their vineyards (i.e. upscaling from  
145 2.2 ha to ~90 ha) would not result in any major financial setback to production.



146

147 Figure 1: Plot of treatment means over time for the real (absent cover crop) and pseudo (present)  
148 treatment pixels in Figure 2. Line colour follows the zone delineation in Fig. 1 - red = low vigour and  
149 blue = high vigour. Dashed lines indicate where the cover crop was absent and the solid line indicates  
150 that the cover crop was present (pseudo treatments) (Note imperial units as provided to a US grower.)

151 Conclusion:

152 A grower's interest in the effect of inter-row cover crops on the bottom-line of the vineyard's  
153 production was assessed using an experimental design that was monitored using embedded routine  
154 sensing systems. The design allowed the grower to define the question and test their belief (i.e. the  
155 default was a presence of cover crop, not an absence). Monitoring using sensors showed that vine  
156 size and yield did not appear to be affected by the presence of the cover crop. Implementing the  
157 experiment and collecting data was relatively straightforward; however the analysis and the design  
158 still requires expert intervention. The skills needed for this would be a limitation to wider application  
159 of this approach. The agri-tech required is not a limitation provided care is taken with the use of the  
160 agri-tech.

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