



RESEARCH FOCUS

Sensors Provide Information to Guide Variable-Rate Mechanical Fruit Thinning and Prevent Overcropping of Concord Grapes

Terence Bates¹, Jackie Dresser², Rhiann Eckstrom³, Golnaz Badr⁴, Thom Betts⁵, and James Taylor⁶

¹Cornell University, Horticulture Section, Cornell Lake Erie Research and Extension Laboratory, Portland, NY ^{2,3,4}Cornell Lake Erie Research and Extension Laboratory, Portland, NY ⁵grower cooperator in Westfield, NY ⁶ITAP, Montpellier, France



Grower-cooperator Thom Betts performs mid-season crop estimation and variable-rate mechanical fruit thinning in his Concord vineyard to improve vine balance and increase vineyard uniformity

Photo courtesy of Terry Bates

The overarching goal of the *Efficient Vineyard* project is to spatially measure vineyard soil, canopy, and crop characteristics; to validate and integrate the data layers to understand vineyard crop load patterns; and to apply variable-rate management to improve vineyard uniformity. We used spatial sensor data collected one month after bloom and stratified manual vineyard samples to estimate vine size and crop size in a Lake Erie region Concord vineyard. Under consultation with the cooperating grower, we generated a digital crop thinning prescription map with the goal of balancing overall vineyard crop load. We then used currently available precision agriculture hardware and software to integrate the digital prescription map with the mechanical shaker head on a commercial grape harvester, and applied on-the-fly variable-rate fruit thinning. Spatial-data-driven variable-rate fruit thinning improved the overall crop load balance in the block, as measured by Ravaz Index, and improved vineyard uniformity, as measured by spatial data distribution.

KEY CONCEPTS

- Vineyard soil, vegetative growth, and crop potential vary across blocks. The *Efficient Vineyard* project uses digital agriculture technologies to measure, model, and manage vineyard variation to improve overall vineyard balance, fruit quality, and uniformity.
- *Measure*: Mobile soil, canopy, and crop sensors are used to collect high density spatial data. Directed in-field manual measurements are used to translate sensor data into viticulture information, such as yield and pruning weight.
- *Model*: Multi-layer spatial data are processed to identify different vineyard regions or "management classifications." Digital prescription management maps are created based on past viticulture research, the growers' strategy, and desired economic outcomes.
- *Manage*: Prescription maps are integrated with precision ag hardware and software for on-the-fly variable-rate applications. This technology has been demonstrated with mechanical shoot thinning, mechanical fruit thinning, and variable-rate fertilizer applications.



Figure 1. Equipment used for sensing and variable-rate crop thinning (clockwise from bottom left): Modified Morris-Oldridge mechanical pruning machine, Crop Circle NDVI sensor, DualEM soil sensor, and Gregoire mechanical harvester.

Photos courtesy of Terry Bates

Methods. In 2017, a 6.01 ha (14.8 acre) commercial Concord vineyard in the Lake Erie region was used to investigate the use of variable-rate mechanized fruit thinning for vineyard crop load balance. The Concord vines were own-rooted, planted at a 2.74m row by 2.13m (9 by 8 ft) vine spacing, and trained to a 1.83m (6 ft) high bilateral cordon. Vines were mechanically cane pre-pruned with a modified Morris-Oldridge machine (Fig. 1) with light manual follow-up pruning to maintain vine structure.

Soil electrical conductivity (a proxy for soil productivity based on nutrients, soil texture, cation exchange capacity, etc.) was measured in May, and canopy NDVI (normalized difference vegetation index) (Fig. 2) was measured in late May, early June, and mid-June. The data were processed and layered over a map of the vineyard to create three management classes (MCs) (Fig. 2, lower right). These MCs divided the vineyard into three levels of canopy size (NDVI), and were used to generate maps to guide variable-rate crop thinning by the grape harvester.

Crop estimation and variable rate crop thinning with grape harvester. Clusters from each MC were sampled 30 days after bloom for crop estimation (the point at which Concord is roughly one-half of its expected harvest weight). Yield was estimated at 17.7, 22.2, and 26.2 t/ha (7.2, 9.0, and 10.6 t/ac) for MC 1, 2, and 3, respectively. Based on the Concord crop load model and input from vineyard managers, acceptable target yield levels were determined for each MC.

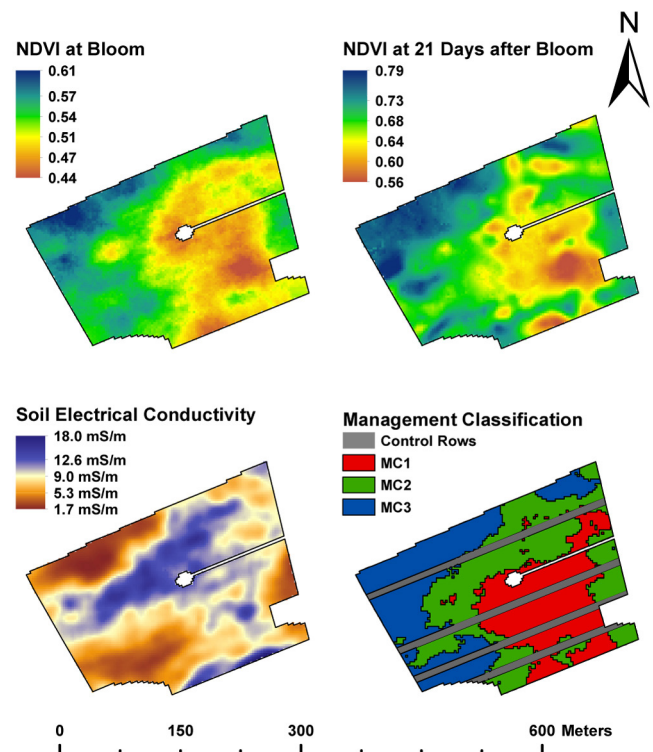


Figure 2. Proximal sensor scans in a 6.01 ha Concord vineyard for canopy NDVI (top, left and right) and soil apparent electrical conductivity (bottom left). Cluster analysis (*k*-means) was performed to generate the three management classifications (MC) (bottom right) used for variable rate fruit thinning. The grey strips were pairs of control rows where no crop adjustment was performed.

Table 1. Crop Load (Ravaz Index) for NY Concord Grapevines

Ravaz Index (kg/kg)	Category	Description
0-5	Severely under-cropped	Vines will gain 0.23 kg pruning weight and reach maximum soluble solids
5-10	Undercropped	Vines will gain 0.11 kg pruning weight and reach maximum soluble solids
10-14	Balanced (normal bloom year)	Vines will have no change in pruning weight and have a 0-0.5 reduction in soluble solids
14-18	Balanced (early bloom year)	Vines will have no change in pruning weight and have a 0.5-1.0 reduction in soluble solids
18-23	Overcropped	Vines will lose 0.11 kg pruning weight and have a 1-1.5 reduction in soluble solids
>23	Severely over-cropped	Vines will lose 0.23 kg or more pruning weight and have a 1-1.5 reduction in soluble solids

Table 2. Crop load and juice soluble solids of thinned and unthinned vines in three spatially derived management classifications. * indicates significant difference at $p < 0.05$

Management Classification	Treatment	Crop Load (Ravaz Index)	Juice Soluble Solids (Brix)
1	Control	25.5	15.2
	Thinned	21.3*	16.8*
2	Control	23.7	15.1
	Thinned	19.9*	17.0*
3	Control	19.5	15.6
	Thinned	17.1*	16.4*

Digital map to guide thinning intensity. A spatial prescription shapefile (map delineating different zones) was generated in ArcGIS, programmed using SMS™ precision agriculture software, and exported to a field computer. This spatial prescription map controlled the hydraulic flow to the mechanical harvester shaker head through a pulse-width modulation valve. Test rows were used to determine the correct shaker head speed to achieve thinning rates of approximately 4.5 t/ha (~1.75 t/acre) harvest equivalent (0.2 t/ha more in MC1 and 0.2 less in MC3).

Three thinning rates. Once thinning rates were determined, three different rates were programmed into the prescription map on the field computer, and the cooperating grower drove while the machine adjusted thinning rates on-the-go. The mass of fruit removed was collected with a harvester mounted grape yield monitor. Four control strips per MC were not thinned.

Spatial crop load map and management classifications. Juice soluble solids, yield, and pruning weights were col-

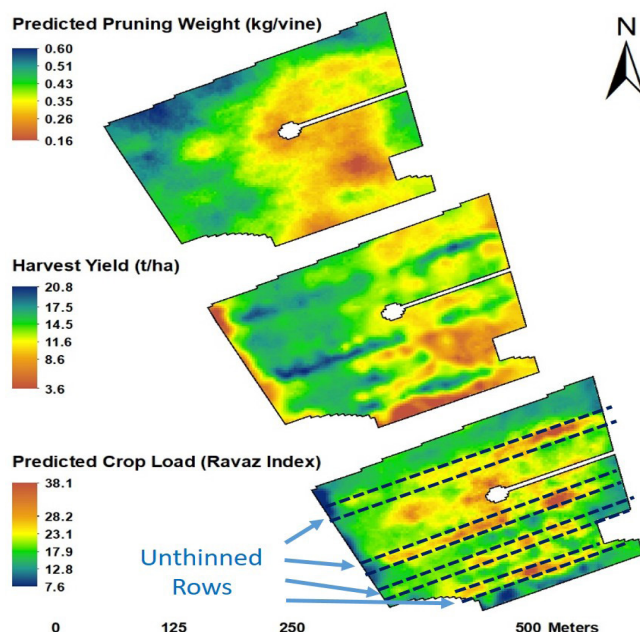


Figure 3. Spatial vine size (pruning weight), crop size (fruit yield), and calculated crop load (Ravaz Index) of a 6.01 ha Concord vineyard in New York. Mid-season variable-rate fruit thinning reduced crop load to values more indicative of balanced vines. Un-thinned control strips (dotted lines, bottom figure) had higher over-cropped Ravaz Index values.

lected manually from 30 locations across the MCs. Spatial crop size at harvest was mapped with the grape yield monitor and validated with actual truck delivery weights from the blocks. Spatial vine size was mapped by projecting the NDVI at bloom x pruning weight relationship to the NDVI at bloom data. The predicted spatial crop load map was generated by dividing yield by pruning weight (Fig 3).

The MCs were established based on relationships that existed between soil conductivity, NDVI, and manual pruning weights specific to this vineyard. There was a negative correlation between shallow soil and canopy NDVI at the four collection times. Soils with higher clay content had less canopy growth. All of the NDVI data layers taken at different times were positively correlated, indicating a relatively stable season-long pattern in canopy growth. The best correlation between NDVI and manual pruning weights was at bloom; therefore, we used this layer (Fig. 2, top left) to make the spatial vine size map.

Impact of mechanical thinning on crop load. From the 30 manually collected measurements, the crop loads in the unthinned control vines were considered over-cropped in MC3 to severely over-cropped in MC1 and MC2 (Table 2).

The harvest juice soluble solids in control vines ranged from 15.1 to 15.6 °Brix. In the Concord juice industry, the desired harvest juice soluble solids are 16.0 ± 0.5 °Brix with a minimum cut-off at 15.2. Therefore, the delayed sugar accumulation in the control vines was of lower market quality and close to the harvest minimum. Mid-season fruit thinning reduced the crop load to values more indicative of balanced crop loads in an early season (bloom

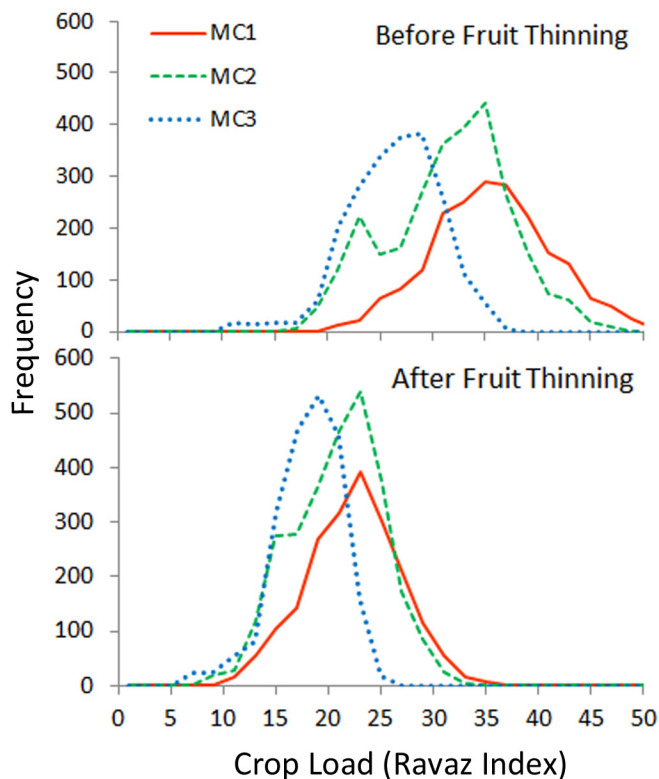


Figure 4. Histogram of 8,013 grid crop load values in a 6.01 ha Concord vineyard before and after variable rate fruit thinning. Target crop load values for this vineyard and season were 14-18. VR fruit thinning brought the vineyard into crop load balance and increased crop load uniformity.

was early in 2017) to just slightly over-cropped. Juice soluble solids in fruit thinned vines were between 16.4-17.0 °Brix. Spatially, the control strips (**Fig. 1 bottom-right**) in the crop load map (**Fig 3, bottom**) can be clearly seen as having over-cropped crop load values.

Discussion. The goal in variable-rate vineyard crop load management is to both improve the overall vineyard crop load and make the vineyard more uniform. In this study, the crop that was removed mid-season was measured and mapped with a yield monitor. For comparison, the thinned yield map was multiplied by 2 (to predict its equivalent harvest weight) and added back to the actual harvest yield to estimate what the block yield would have been without any fruit thinning. A before and after fruit thinning crop load was then calculated for each MC (**Fig. 4**).

The population distributions of crop load grid points indicate that the entire vineyard would have been over-cropped without fruit thinning. MC1 had the smallest vine size and the lightest crop compared to the other MCs; however, the crop load ratio was the highest indicating the vines were the most over-cropped.

Variable rate fruit-thinning reduced the crop load in all three MCs. The mean Ravaz Index for the whole vineyard was reduced from 30.1 to 19.8. Interestingly, the standard deviation of the whole block was also reduced from 6.5 to

4.6, indicating a more uniform crop load.

Practical Importance. This study demonstrated that we could use a variety of proximal (close-range) sensors to measure how vine growth and cropping levels vary within a vineyard block. By using spatial sensor data to model vineyard crop load through multi-layer data analysis, we were then able to delineate different spatial management classifications and use on-board maps to guide a grape harvester to apply variable-rate crop adjustment to improve vineyard balance and yield/quality uniformity.

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Authors



***Terry Bates** is senior research associate with the section of horticulture in the School of Integrative Plant Science and director of the Cornell Lake Erie Research and Extension Laboratory in Portland, NY*



***Dr. Golnaz Badr** is a former post-doctoral research associate, Cornell Lake Erie Research and Extension Laboratory, Portland, NY*



***Jackie Dresser** is research technician at the Cornell Lake Erie Research and Extension Laboratory in Portland, NY.*



***Dr. James Taylor** is senior researcher, National Research Institute of Science and Technology for Environment and Agriculture – UMR ITAP, Montpellier, France*



***Rihann Eckstrom** is research aide at the Cornell Lake Erie Research and Extension Laboratory in Portland, NY.*

