Variable rate irrigation to manage vineyard variability in California







U.S. wine production (million gallons)





California Wine Institute

Vineyard development and management

- Vineyards are <u>developed</u> uniformly:
 - Variety
 - Rootstock
 - Planting distances
 - Irrigation layout
- Vineyards are <u>managed</u> uniformly:
 - Pruning

– Leaf removal

- Irrigation
- Fertilization

- Fruit thinning
- Harvesting

Vineyard development and management

- However soils are variable:
 - Topography
 - Aspect
 - Elevation
 - Slope
 - Chemical and physical properties
 - Texture
 - Water holding capacity
 - pH
 - Nutrient content



How can we manage vineyard variability?

Through Precision Viticulture:

- Management to optimize vineyard performance
 - Responding to intra-field variability
 - Maximizing grape yield and quality
 - Minimizing environmental footprint



To be replaced with video at final presentation (exceeds file upload size)

Long/Lat Lon: 121

d [km/h]

on: 121 15' 0 24" W Lat: 38 21' 14.69" N

04:20

WWW 20501 2011 652693 North: 4246576 Zone: 10S

Statistics

21-Oct-201

17:04:14 0.33 0.241

From point to surface data



Significant Correlations with Yield per Acre								
Parameter	Correlation (r ²)							
Subsurface K ⁺	0.903							
Soil rooting depth	0.774							
Subsurface pH	- 0.805							
Subsurface P	- 0.805							
Subsurface organic matter	- 0.882							
Subsurface K/Mg ratio	- 0.890							

Significant Correlations with Grape Quality

Parameter	Correlation (r ²)
Soil rooting depth	- 0.673
Surface CA	- 0.506
Subsurface CA / Mg ratio	- 0.510
Surface CEC	- 0.554

Variable Rate Irrigation Study

Objective:

Develop and operate a proof-of-concept VRI system prototype and validate it by:

- Decreasing vineyard variability
- Optimizing fruit yield and quality
- Increasing water use efficiency.

Modular vs. Zonal Irrigation

















Experiment location



2012 yield map

Colony 2A Cabernet Sauvignon

- Wilton, California
- 31.5 acres
- 5 x 11 feet
- 17-year old
- Teleki 5C
- Hand-pruned
- Drip-irrigated



Yield (t/ac) High : 14

Low : 0

- San Joaquin silt loam (~ 75%)
- San Joaquin-Galt complex (~ 25%)
- 20 inches annual rainfall
- Highly variable



Block area: 31.5 acres VRI & CI: 10.0 acres Field average: 9.17 tons/acre

For each high density variable: 140 data points in VR Irrigation 140 data points in Conventional Irrigation



Landsat data

System design

- IBM First Of A Kind (FOAK) program
- Variable flow submersible pump
- Underground piping to experiment
- Main and sub-main valves
- Flow meters
- Power/electronics/central computer
- Double-hose irrigation tubing
- Solenoid and check valves

General layout



Power layout



Communication layout



System design



System design





Irrigation zone control

- Computer network with single master coordinating operation
- Master-slave messaging protocol based on MODBUS
- High speed over the 3,000+ feet cable
- PC and master control are accessed remotely through cell link to load irrigation schedules

Irrigation scheduling

- METRIC (Mapping evapotranspiration at high resolution and internalized calibration)
- ET residual of surface energy balance

Rn + LE + G + H = 0

- Inputs
 - Landsat (visible & infrared)
 - CIMIS weather data
- Outputs
 - ETc
 - Kc (f/NDVI)
- Watering of each zone:

ETc = ETref * Kc * Km



2013 irrigation management

2012	# of	Irrigation management factor						
yield tons/acre (average = 8.9)	irrigation zones	May 4 weeks	June 4 weeks	July - Oct 16 weeks				
< 8.9	76	1.2	0.5	0.7				
> 8.9	64	no irrigation	0.5	0.7				

2014 irrigation management

# of	Irrigatio	n managemen	t factor
irrigation zones	May 4 weeks	June 4 weeks	July - Oct 16 weeks
140	0.0 - 0.7	0.5 – 0.8	0.6 – 1.0

Vine performance data

- High density:
 - Yield
 - NDVI
- Fruit composition
 - 43 analytes
 - GQI
- Wine composition
 - 45 analytes
 - Sensory





VRI Yield - Normalized

8.82	7.07	7.37	6.62	7.09	8.16	8.77	7.59	7.61	8.07	7.93	7.68	7.94	7.73	7.76	7.98	8.52	8.19	8.27	8.18	12.8	12.17	13.99	10.92	12.25	11.68	12.58	11.07	11.45	12
8.24	7.13	6.65	6.99	7.27	8.87	9.0 <mark>4</mark>	8.93	7.84	8.04	7.48	7.01	7.37	7.84	8.12	8.26	7.61	7.98	8	8.05	-11.3	11.28	11.47	12.5	12.88	12.66	11.5	10.79	10.56	11
8.87	6.9	6.4	7.2	8.12	8.84	9.04	8.68	7.56	8.57	7.1	6.44	7.18	7.63	7.9	7.98	7.12	8.16	8.18	7.99	10.8	12.48	11.8	12.11	12.02	13.27	11.87	11.77	10.45	11
8.66	7.15	6.14	6.83	7.83	7.77	8.1	8.55	9.05	8.74	6.92	6.5	6.77	7.13	7.84	7.81	7.27	7.95	8.17	7.96	11.8	7 13.06	11.55	12.83	13.2	11.92	10.23	12.98	11.39	10
8.65	7.8	7.4	6.9	8.86	8.44	7.9	8.16	9.64	9.4	7.53	7.31	6.96	6.98	8.14	7.79	7.86	8.38	8.21	7.5	11.8	7 11.92	11.18	12.04	13.11	11.02	10.25	12.24	10.35	10
<mark>9.2</mark> 2	8.21	7.61	8.24	8.97	7.9	8.28	9.08	8.98	8.71	7.55	7.88	7.63	7.13	7.79	7.46	7.7	7.98	7.73	7.51	11.1	5 11.71	10.53	10.39	10.39	9.35	10.3	9.51	8.62	10
9.67	9.1	8.48	7.89	8.73	8.15	8.17	8.17	8.35	8.51	7.96	7.48	7.36	7.26	7.56	7.25	7.41	8.34	7.51	7.27	10.9	10.16	9.89	9.44	9.46	10.14	10.5	10.05	10.98	11
10.45	9.32	7.93	7.89	8.94	8.9	8.16	7.64	7.69	7.73	7.36	7.34	6.97	6.64	7.34	8.12	7.99	7.64	8.3	7.47	10.7	10.41	8.57	8.87	7.87	9.73	10.09	10.12	10.42	11
10.53	9.81	<mark>8.9</mark> 7	10.15	10.19	9.77	9.55	9.54	9.63	9.23	8.09	7.54	6.69	8	7.55	7.74	8.05	7.86	7.83	6.74	10.:	8.74	7.97	8.95	8.49	9.22	9.33	8.69	8.56	8
9.84	9.06	8.59	8 <mark>.5</mark> 3	9.4	10.44	10.19	11.03	10.55	9 .45	7.39	6.81	6.91	6.27	6.75	7.27	7.65	7.75	7.91	6.85	9.1	7.85	7.73	7.55	6.7	6.71	7.8	7.98	8.01	7
<mark>8.57</mark>	8.83	8.28	9.2	<mark>9.57</mark>	9.6	10.41	10	9.65	9.18	7.24	7.25	7.78	8.3	8 <mark>.1</mark> 5	7.71	8.39	8.43	8.07	7.48	9.12	8.55	7.86	7.71	7.41	6.21	7.08	8.53	9.78	8
8.4	9.08	8.3	9.59	9.42	10.09	11.45	11.46	11.47	11.86	7.09	8.17	7.2	7.5	7.49	7.83	8.31	8.57	8.79	7.52	10.8	10.69	9.07	7.66	6.24	7.02	7.4	9.78	9.67	9.
9.44	9.47	9.91	10.17	10.09	10.53	10.92	11.45	11.53	11.51	7.01	8.01	8.25	8.15	8	7.94	8.28	7.83	8.46	7.78	10.4	10.2	9.27	8.87	9.12	8.68	8.97	9.14	9.1	9
9.86	9.85	9.44	9.97	10.08	10.2	10.17	10.74	11.84	12.38	7.23	8.15	8.95	8.72	7.84	7.68	7.66	8.37	8.88	8.72	10.1	9.98	9.81	9.27	8.93	8.36	9.22	9.99	9.41	9

2012 Yield: Mean = 8.9 t/ac 6.1 – 12.4 t/ac Range = 6.3

2013 Yield: Mean = 7.7 t/ac 6.3 – 8.9 t/ac Range = 2.6 2014 Yield: Mean = 10.2 t/ac 6.2 – 14.0 t/ac Range = 7.8

CI Yield - Normalized

9.31	9.18	9.41	9.85	9. <mark>7</mark> 8	8.81	8.8	9.46	10.17	10.46
9.11	9.38	9.99	9.52	<mark>9.1</mark> 3	9.76	9.28	9.88	9.63	10.82
9.95	10.23	10.02	10.32	<mark>9.4</mark> 3	9.48	9.73	10.31	10.52	10.22
9.05	9.25	9.82	9.76	9.99	9.38	9.59	9.88	9.85	10
8.16	7.23	7.86	8.67	9.72	10.07	10.51	10. <mark>24</mark>	10.26	9.88
<mark>8.</mark> 81	7.97	7.9	8.31	9.29	9.53	<mark>9.87</mark>	10.29	10.89	10.55
8.41	8.65	7.3	7.69	8.59	9.24	8.6 <mark>3</mark>	<mark>8.7</mark> 4	9.96	9.91
8.64	7.85	7.53	8.02	8.67	9.14	9.23	9.3	9.41	9.48
10.13	8.64	7.97	7.79	8. <mark>16</mark>	8.06	7.93	8.61	8.13	9.18
9.14	8.3	8.86	8.76	8.28	7.95	8.06	9.09	10	10.0 <mark>3</mark>
10.94	9 <mark>.1</mark> 3	9.4	8.36	8.32	8.17	7.53	7.1	7.81	8.34
10.74	9.58	7.89	7.01	7.64	7.83	7.25	7	7.46	7.74
						<mark>9.53</mark>	10.04	8.99	8. <mark>56</mark>
	20	12	Yie	eld:		7.05	6.67	7.53	7.79
Μ	ea	n =	8.9	9 t/	ac	7.84	8.67	7.73	7.17
6.4 – 10.9 t/ac 6.5 7.19								6.8	6.72
	Range = 4.5								
								8.36	7.66

6.26	7.06	7.59	7.71	7.07	6.63	7.45	7.53	7.95	7.65
6.16	6.65	7.24	6,91	6.26	6.09	5.75	6.13	6.79	7.3
7.07	7.50	7.04	7.47	0.00	6.47		7.40	7.25	7.00
1.07	1.56	7.91	1.41	6.66	6.17	6.8	7.19	1.35	7.06
7.19	6.94	7.07	6.93	7.12	<mark>6.</mark> 29	6.82	6.99	7.58	7.39
7.04	6.65	7.04	7.5	7.91	8.16	8.84	8.72	8.99	8.81
7.94	7.71	7.52	7.78	8.49	8.6	8.96	9.53	9.84	10.65
6.94	6.65	6.94	7.47	7.95	7. <mark>97</mark>	8.05	8.25	9.13	9.98
7.38	6.34	6.19	6.63	7.4	8	8.01	8.27	8.41	8.75
7.01	6.44	<mark>6.48</mark>	6.98	7.31	7.11	7.38	7.65	7.08	7.17
6.26	6.26	6.9	<mark>6.9</mark> 8	7.06	6.72	6.27	6.74	7.52	7.48
7.73	6.8	6.98	6.8	7.02	6.85	6.24	6.62	7.29	8.14
8.96	8.79	7.57	6.56	7.31	7.38	6.77	6.59	7. <mark>4</mark> 2	7.77
				•	•	8.9	9.4	9.22	9.02
	20:	13 `	Yie	ld:	_	6.76	6.37	7.01	7.87
Me	ean	9.68	7.28	7.54					
5.8 – 10.7 t/ac 6.79 6.75									6.24
	7.11	7.25							
								7 14	6.47

9.82	10.37	10.57	9.96	9.53	8.79	8.9	9.85	10.72	10.02	
9.24	9.68	<mark>9.17</mark>	9.99	7.66	8.6	8.24	<mark>8.2</mark> 6	8.49	9 <mark>.61</mark>	
10.48	9.76	8.76	8.79	7.82	7.61	8.43	9.3	9.52	10.08	
7.52	7.21	7.23	7.95	9.02	7.56	7.41	8.28	9.14	9.65	
7.32	6.68	7.6	7.5	8.87	9.28	9. <mark>44</mark>	8.88	9.62	10 <mark>.0</mark> 6	
8.58	7.78	8.04	7.64	8.19	8.65	9.2	9.68	10.92	14.26	
<mark>7.64</mark>	7.27	6. <mark>48</mark>	6.09	6.96	8.83	7.57	7.4	10.1	12.02	
7.6	7.94	7.18	6.44	7.78	7.92	8.39	9 .1 9	10.35	11.27	
9 <mark>.2</mark>	7.15	6.95	6.32	6.75	7.41	7.36	7.48	7.84	9.52	
9.06	8.73	8.69	8.12	7.18	7.59	7.31	8.16	8.93	10.01	
9.91	9.4	9.36	7.76	7.05	7.88	7.82	8.08	9 .4 4	9.67	
10.61	10	8.83	8.18	7.47	7.63	7.67	7.05	7.92	8.02	
						7.33	7.81	9.65	10.16	
	20	14	Yie	ld:		9.28	8.13	8.96	10.22	
M	Mean = 8.7 t/ac 9.52									
6.	6.1 – 14.3 t/ac 9.67 9.14									
	Range = 8.2									
								8.84	9.19	

2013 applied water



2014 applied water



Scheduled 2014 Variable Rate and Conventional Irrigation Areas

2013 water use efficiency



2014 water use efficiency



Non-spatial statistics

Irrigation	Yield class	Leaf Area Index	clusters per vine	cluster weight (g)	berry weight (g)
	high	6.0 a	147.7 a	76.0 a	0.9 ab
Variable rate	medium	5.3 a	127.7 a	84.7 a	0.8 b
	low	5.2 a	127.7 a	71.6 a	0.7 c
	high	6.1 a	151.6 a	81.9 a	1.0 a
Conventional	medium	6.1 a	155.6 a	75.7 a	0.8 b
	low	6.1 a	130.2 a	66.1 a	0.7 bc
	· · · · · · · · · · · · · · · · · · ·				

Different letters are significantly different at p<0.05

Spatial statistics

MCD, Mean Correlation Distance
 Cambardella Index

Measures of spatial dependence and structure

Variable Rate Irrigation:

- Decreased spatial structure in 2013
- Increased spatial structure in 2014

Fruit Yield and Quality



2013 Wine Composition

	Irrigation							
_	Conventional	Variable rate						
A420	4.2 b	4.7 a						
A520	8.0 b	9.3 a						
MALC	14.4 b	15.1 a						
Malic acid	2,062.8 a	1 <i>,</i> 806.5 b						
IBMP	1.8 a	1.2 b						
Pigmented_polymers	27.8 b	33.5 a						
Polymeric_tannins	611.6 b	761.5 a						
Quercetin glycosides	2.7 b	4.1 a						
Dimethyl_sulfide	12.8 a	11.3 b						

Conclusions

- First season:
 - Successful VRI system prototype implementation
 - VRI decreased vineyard variability
 - VRI increased water use efficiency
- Second season:
 - Increased yield in low yielding vines
 - Maintained high water use efficiency
- Opportunity for commercial development

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