The Response of 'Concord' Grapevines to Soil pH

Final Report to Viticulture Consortium and New York Wine and Grape Foundation

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Experimental Plot

An experimental vineyard block was planted in 1999 to investigate the effect of mineral nutrient availability on Concord growth and productivity. Three factors (soil pH, supplemental fertilizers, and irrigation) were used alone and in combination to manipulate soil nutrient availability (figure 1). At planting, four soil pH treatments were randomly established in four experimental blocks with lime and sulfur soil amendments. In 2003, each block was split in two equal sub-blocks where one sub-block received additional fertilizers based on soil and petiole tests and the other sub-block received no additional fertilizers. In addition, each block was again spit into sub-block for irrigation or no irrigation; however, sufficient precipitation in 2003 and 2004 prohibited the need for additional soil moisture through irrigation. Irrigation treatments were applied in 2005.

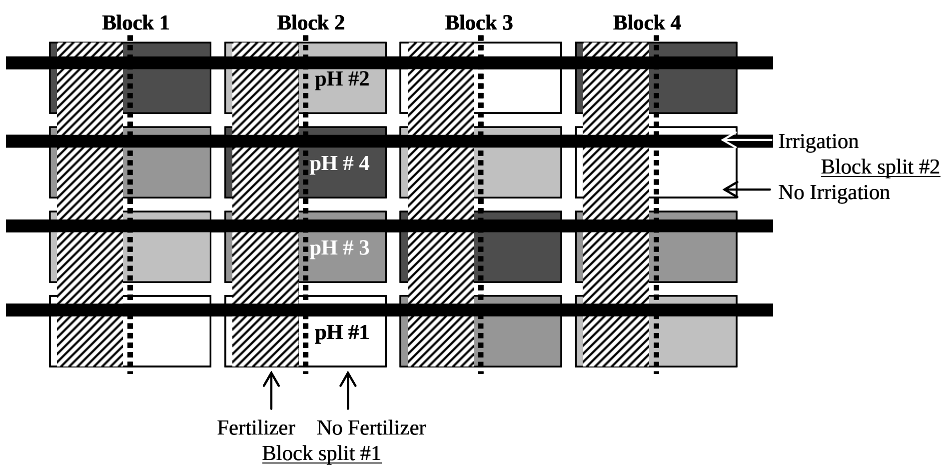

Figure 1: Diagram of the Concord/Soil pH block at the Cornell Vineyard Laboratory in Fredonia. Each soil pH plot was split for fertilizer and irrigation. Therefore, each block had 16 treatment combinations (4 soil pH x 2 fertilizer x 2 irrigation) replicated in four blocks.

Applied soil amendments and their effect on soil pH

Ground sulfur was applied in 1999 and in 2000 to decrease soil pH (Soil pH treatment 1, table 1 and figure 2). The applied treatment dropped the soil pH to between 4.2 and 4.6 for the length of the experiment. No amendments were applied in Soil pH treatment 2 where the soil pH averaged 5.4 through 2002. From 2003 to 2005 the measured soil pH in treatment 2 showed a steady decline to 4.8 in 2005. Soil pH treatments 3 and 4 received 5.9 and 10.9 equivalent tons of dolomitic limestone per acre, respectively, over a seven year period. Initially, treatment 3 reached a soil pH of 6.3 and treatment 4 reached 6.5. However, despite repeated surface lime applications, both treatments showed a steady decline in soil pH from 2000 to 2005. The decline in soil pH in treatments 2, 3, and 4 are most likely a result of ammonium nitrate fertilizer (yearly split applications of 50 + 30 pounds actual N to the entire experiment), parent material buffering to a lower soil pH, and cropping.

Table 1: Spring applied soil amendments in the Concord/Soil pH experiment.

Soil pH Treatment	1999	2000	2001	2002	2003	2004	2005
1	0.26 t/a sulfur	0.25 t/a sulfur	–	–	–	–	–
2	–	–	–	–	–	–	–
3	1.9 t/a lime	1.0 t/a lime	–	1.0 t/a lime	–	–	2.0 t/a lime
4	2.9 t/a lime	2.0 t/a lime	2.0 t/a lime	2.0 t/a lime	–	–	2.0 t/a lime

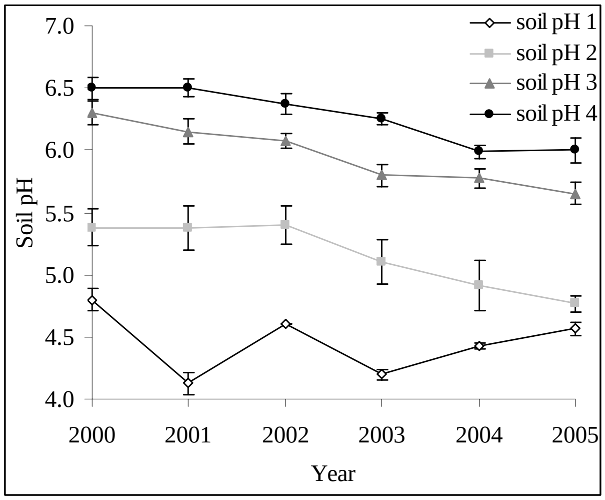

Figure 2: Average soil pH of the base treatments from 2000-2005. Soil samples were taken in the spring from 0-6 inch and from 6-12 inch depth (0-6 inch reported here). n = 4, bars = ± st. error.

Applied fertilizer treatments and their effect on soil nutrient availability

Soil pH treatments were split and various fertilizers were applied in 2003 and 2004 based on soil and vine tissue analysis (table 2). The percent base saturation of K, Mg, Ca, and H shows the effect of both soil amendments and fertilizer treatments on the balance of these elements in the soil (figure 3).

Table 2: Applied fertilizers in the Concord/Soil pH experiment.

Soil pH Treatment	2003	2004
1	250#/a calcium	250#/a calcium 200#/a phosphorus 200#/a potassium
2	200#/a phosphorus	200#/a phosphorus
3	200#/a potassium	200#/a potassium
4	200#/a potassium	200#/a potassium

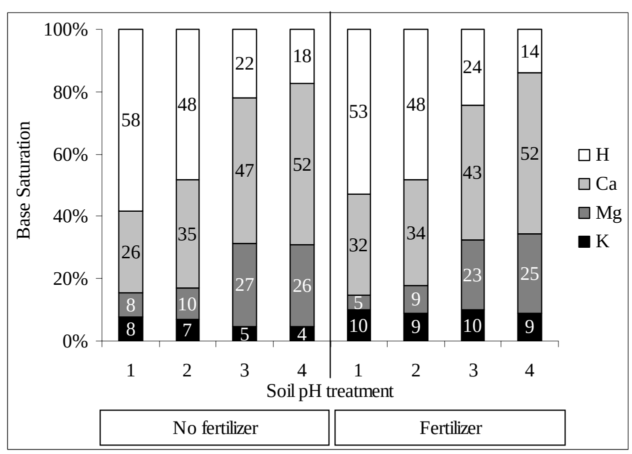

Figure 3. Relative amounts of H, Ca, Mg, K in 2005 soil samples in the four soil pH treatment plots without and with additional fertilizer.

Raising the soil pH decreased the relative availability of H (by definition) and increased the availability of other base cations (Ca and Mg). The base saturation of H decreased from 58% in treatment 1 to 18% in treatment 4. In unfertilized plots, soil pH treatments 3 and 4 increased the relative amounts of both Ca and Mg but decreased the relative amount of K (meq Ca:Mg:K = 10:6:1). Application of K fertilizer to treatments 3 and 4 was able to hold the base saturation percentage of K constant between all soil pH treatments (changing the meq Ca:Mg:K = 5:3:1)

Suggested milliequivalent ratios of Ca:Mg:K in row crops is typically 20:4:1. Interestingly, none of the soil samples were close to this ratio indicating a possible difference in managing Concord grapevines with a high fruit K requirement. Soil pH treatment 2 (the highest producing treatment) had a Ca:Mg:K of 4.5:1.25:1.

<u>Applied irrigation and comparison to 2005 precipitation</u>

Drip irrigation was used in 2005 from June 3rd to August 25th (table 3). The 2005 growing season was warm and relatively dry in comparison to the long term average until heavy precipitation in August from hurricane remnants (figure 4). Irrigation was used early and often to maintain adequate soil moisture in the irrigated plots and keep the vines out of water stress. For most of the growing season (until the heavy fall precipitation) the water accumulation in the irrigated plots (irrigation + precipitation) was within +/- 2.0 inches of the long term average.

Soil moisture, mid-day stem potential, and leaf gas exchange measurements were taken during July and August between irrigated and unirrigated plots. In general, non-irrigated vines had 38% higher stem potential readings (greater water stress) and 30% lower leaf gas exchange during the dry summer months when compared to irrigated vines.

Table 3. 2005 irrigation schedule.

	Supplemental Irrigation	
2005 Date	gal/vine	equivalent inches/acre
6/3	9.6	0.21
6/6	11.2	0.25
6/9	10.4	0.23
6/14	10.4	0.23
6/23	13.6	0.30
6/27	24.0	0.53
6/30	12.8	0.29
7/1	6.4	0.14
7/6	24.0	0.53
7/7	17.6	0.39
7/12	24.0	0.53
7/14	12.8	0.29
8/8	115.2	2.57
8/25	24.0	0.53

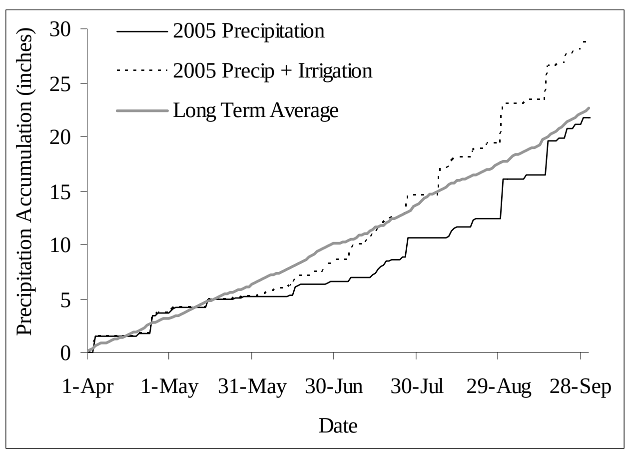

Figure 4: Comparison of 2005 accumulated precipitation with and without supplemental irrigation and the long term precipitation average from April 1 to October 1.

<u>The effect of soil pH treatments on vine size, yield, and juice soluble solids</u>

Vine size remained moderate between 2001-2003 because of dry weather and/or relatively large crops for the young vines (figure 5). 2004 was a wet growing season with a moderate crop level. As a result, 2004 grown pruning weights were large and averaged between 2.9 and 3.7 pounds/vine. Soil pH treatment 1 vines were consistently lower than the other treatments for the length of the experiment. Soil pH treatment 2 vines were consistently the largest and clearly separated from the other treatments in 2004. Soil pH treatments 3 and 4 were intermediate in size.

Analysis of individual vines illustrates the relationship between vine size – yield and yield – juice soluble solids from 2002-2005 (figure 6). The positive relationship between vine size and yield of balanced pruned Concord is well documented. Increasing vine size leads to greater retained nodes/vine and/or increased clusters/node. Yield differences from year to year at a given vine size and bud number (i.e. why all lines in fig 6 are not the same) are because of additional yield component factors of berry weight and berries/cluster. The negative relationship between yield and juice soluble solids was also consistent from 2002-2004. The high JSS at a given yield in 2005 was due to smaller than normal berry weight in non-irrigated vines which concentrated soluble solids.

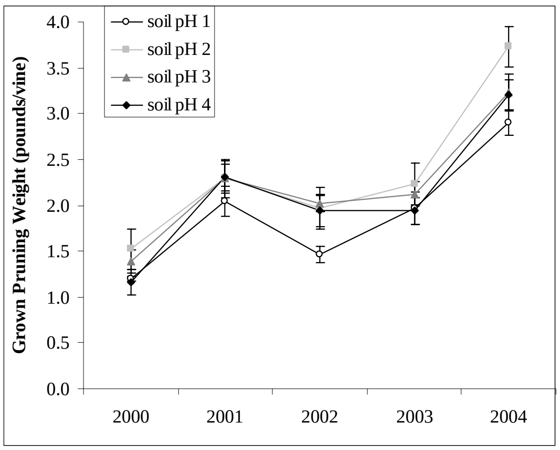

Figure 5: Mean vine size (pounds of dormant cane pruning weight) of Concord under four soil pH treatments. n = 4 blocks, bars = ± st. error.

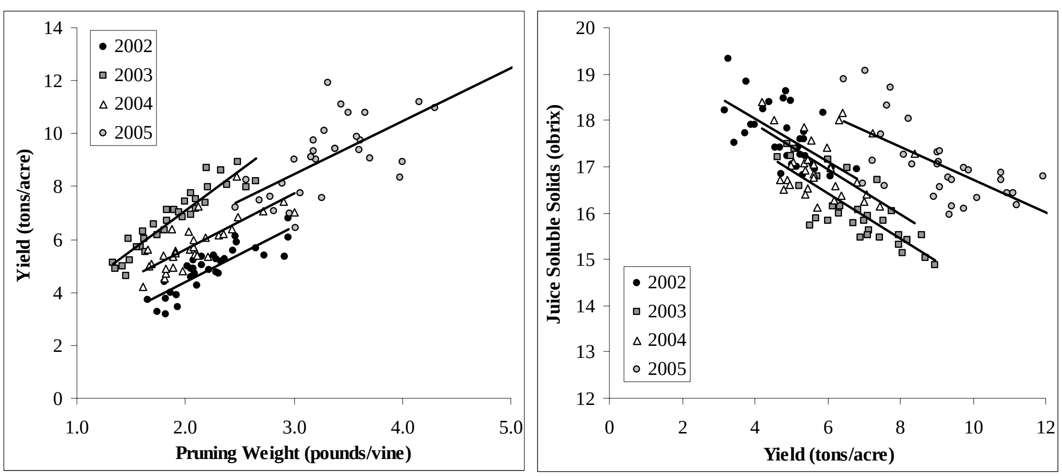

Figure 6: Pruning weight, yield, and juice soluble solids of non-irrigated, non-fertilized Concord under four soil pH treatments from 2002-2005.

<u>The effect of soil pH treatments, irrigation, and fertility on 2005 vine performance</u>

Soil pH treatment and irrigation both had an effect on Concord yield and juice soluble solids in 2005; however, their effect was on separate yield components (table 4). Soil pH influenced pruning weight which influenced nodes/vine and clusters/vine. Irrigation, on the other hand, increased cluster weight by increasing berry weight (or) dry weather produced smaller than average berries in non-irrigated vines. Treatment combinations with high crop size and large berry weight had lower juice soluble solids than low crop size and low berry weight.

2005 grown pruning weight will be measured over the winter to finalize the experiment. Visual observations indicate there will be a large effect of irrigation and soil pH on final vine size.

Table 4: Vine size, yield, and juice soluble solids of 2005 Concord in the soil pH experiment. Letters indicate mean separation by Duncans' new multiple range at the 5% level. ANOVA * = p-value < 0.001, ** = p-value < 0.0001.

					Components of Yield						
Soil pH category	**Irrigation**	**Supplemental Fertilizers**	**2004 pruning weight (pounds/vine)**	**2005 Yield (tons/acre)**	**nodes/vine**	**clusters/node**	**clusters/vine**	**cluster weight (g)**	**berries/cluster**	**fresh berry weight (g)**	**Juice Soluble Solids (°brix)**
1	no	no	2.9 c	7.7 d	58.0 c	2.3 ns	132.2 c	86.8 ef	33.5 ns	2.6 def	18.3 a
1	no	yes	3.3 bc	8.8 bcd	66.0 abc	2.3 ns	151.5 abc	87.4 ef	33.5 ns	2.6 def	17.8 ab
1	yes	no		11.2 ab	66.9 abc	2.5 ns	164.3 abc	102.7 abcd	36.0 ns	2.9 abc	16.5 c
1	yes	yes		11.2 ab	70.9 abc	2.5 ns	179.6 ab	95.3 bcde	40.4 ns	2.7 cde	16.2 cd
2	no	no	3.7 ab	9.6 abcd	73.6 abc	2.3 ns	170.9 abc	86.1 ef	33.6 ns	2.6 def	16.7 c
2	no	yes	4.0 a	10.9 abc	79.7 ab	2.4 ns	186.7 ab	88.4 f	34.7 ns	2.6 ef	16.5 c
2	yes	no		11.5 a	67.7 abc	2.4 ns	160.4 abc	106.2 abc	36.5 ns	2.9 abc	15.9 cd
2	yes	yes		11.9 a	80.0 a	2.4 ns	191.7 a	93.8 def	32.9 ns	2.9 abc	15.4 d
3	no	no	3.2 abc	8.5 cd	63.5 bc	2.4 ns	152.5 abc	85.6 ef	33.5 ns	2.6 def	16.6 c
3	no	yes	3.4 abc	9.6 abcd	68.1 abc	2.5 ns	170.7 abc	86.2 ef	34.4 ns	2.5 f	16.7 c
3	yes	no		11.3 a	63.1 c	2.6 ns	161.8 abc	106.7 ab	36.0 ns	3.0 ab	16.2 cd
3	yes	yes		10.4 abc	64.4 abc	2.3 ns	147.1 bc	106.4 abc	35.6 ns	3.0 a	16.4 cd
4	no	no	3.2 abc	8.6 cd	64.1 abc	2.4 ns	154.5 abc	82.2 ef	33.2 ns	2.5 f	16.9 bc
4	no	yes	3.1 bc	9.9 abcd	62.1 c	2.6 ns	162.8 abc	94.7 cde	37.9 ns	2.5 f	16.7 c
4	yes	no		11.1 ab	66.3 abc	2.5 ns	165.7 abc	101.1 abcd	36.8 ns	2.8 bcd	16.1 cd
4	yes	yes		11.2 ab	64.4 abc	2.4 ns	154.2 abc	110.3 a	37.1 ns	3.0 ab	16.3 cd
Soil pH			*	*	*		*				*
Irrigation				**				**		**	**
Fertility											

Non-irrigated vines without supplemental fertilization tended to be the smallest vines with the lowest crop and highest juice soluble solids (figure 7). Adding supplemental fertilizers to these vines increased vine size and yield and decreased juice soluble solids. Soil pH treatment 2 had the highest yield of the non-irrigated vines. Irrigation increased yield and lowered juice soluble solids but it also appeared to eliminate the effect of soil pH. Therefore, the most stressed vines at the lowest soil pH benefited the most from irrigation and the already strong vines in soil pH treatment 2 benefited the least from irrigation. The positive relationship between vine size and yield and the negative relationship between yield and juice soluble solids was again measured in 2005.

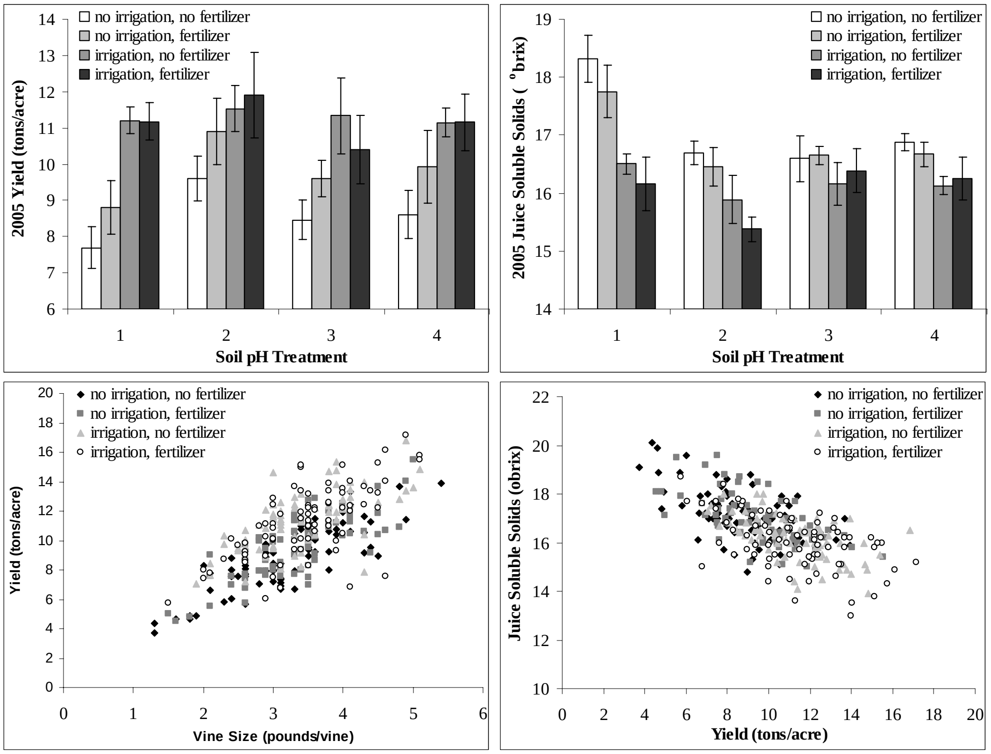

Figure 7: Comparison of irrigation and supplemental fertilizers on Concord vines grown at different soil pH in 2005. Bar charts: n = 4 blocks, bars = ± st. error. Scatter plots: individual count vines.

The effect of soil pH treatments, irrigation, and fertility in 2005 on tissue mineral nutrients

Petioles were collected at bloom and veraison and analyzed for mineral nutrient content at A&L Eastern Agricultural Labs in Richmond, VA. There was an effect of soil pH on bloom tissue P, K, Ca, Mg, Mn, Cu, and Zn (table 5). Supplemental fertilizers also showed an effect on bloom tissue K and Mg. Little irrigation was applied by bloom; therefore, water was not a factor on tissue nutrient concentrations.

Table 5: 2005 Bloom Concord petiole tissue concentrations. * = p-value<0.001, **<0.0001.

			Bloom Petiole												
Soil pH category	Irrigation	Fertilizers	N%	P%	K%	S%	Ca%	Mg%	Na%	Fe ppm	Al ppm	Mn ppm	Cu ppm	Zn ppm	B ppm
1	no	no	1.35	0.51	2.29	0.26	0.85	0.25	0.03	56.00	27.00	1084.50	9.00	44.25	28.25
1	no	yes	1.41	0.45	2.14	0.26	0.84	0.23	0.03	64.25	27.25	1238.50	8.50	40.25	28.75
1	yes	no	1.40	0.53	2.45	0.27	0.88	0.23	0.02	45.50	28.25	1158.75	9.00	46.00	30.50
1	yes	yes	1.41	0.54	2.83	0.27	0.93	0.22	0.02	53.50	29.75	1226.25	9.00	48.50	32.00
2	no	no	1.29	0.45	2.33	0.28	0.94	0.32	0.02	40.00	26.75	558.75	7.75	42.50	30.50
2	no	yes	1.32	0.47	2.43	0.28	1.00	0.30	0.02	41.50	27.00	568.75	7.75	46.25	32.25
2	yes	no	1.33	0.44	2.28	0.30	0.99	0.34	0.03	48.50	29.00	505.75	8.50	48.50	31.50
2	yes	yes	1.38	0.42	2.36	0.29	0.99	0.34	0.02	44.25	27.00	445.75	8.00	46.00	32.50
3	no	no	1.29	0.38	1.67	0.26	0.89	0.39	0.03	52.25	25.25	366.50	7.75	41.25	32.00
3	no	yes	1.28	0.40	1.84	0.26	0.86	0.38	0.03	47.50	25.75	393.75	7.25	40.00	28.00
3	yes	no	1.31	0.39	1.64	0.29	0.93	0.50	0.02	50.75	29.25	290.75	7.25	40.50	29.25
3	yes	yes	1.31	0.41	2.23	0.29	0.90	0.42	0.02	47.00	27.25	401.00	7.50	39.00	30.50
4	no	no	1.31	0.38	1.30	0.26	0.87	0.48	0.03	44.50	26.00	263.25	7.25	38.75	28.25
4	no	yes	1.33	0.39	1.88	0.26	0.84	0.39	0.03	46.25	25.75	314.25	7.50	37.50	27.75
4	yes	no	1.39	0.37	1.69	0.28	0.90	0.50	0.02	47.00	29.25	287.00	8.25	45.25	32.50
4	yes	yes	1.38	0.38	2.34	0.28	0.91	0.44	0.02	43.75	25.25	329.50	7.25	39.25	30.25
soil pH				**	**		*	**				**	*	**	
Irrigation															
Fertilizers					*			*							
soil pH x Irrigation															
soil pH x Fertilizers															
Irrigation x Fertilizers															
soil pH x Irrigation x Fertilizers															

All of the same treatment effects measured at bloom were again measured in veraison petiole samples; however, with greater significance (table 6). In addition, irrigation had additional effects on tissue N, P, K, Mg, Na, and Zn.

Table 6: 2005 Veraison Concord petiole tissue concentrations. * = p-value<0.001, **<0.0001.

			Veraison Petiole												
Soil pH category	Irrigation	Fertilizers	N%	P%	K%	S%	Ca%	Mg%	Na%	Fe ppm	Al ppm	Mn ppm	Cu ppm	Zn ppm	B ppm
1	no	no	0.81	0.29	0.80	0.10	1.48	0.51	0.02	80.75	43.00	3046.25	3.75	69.75	27.25
1	no	yes	0.80	0.29	1.31	0.10	1.47	0.33	0.02	64.75	39.75	3202.00	4.00	74.25	30.50
1	yes	no	0.79	0.25	1.16	0.09	1.44	0.44	0.04	68.25	42.25	3133.00	4.25	56.50	29.50
1	yes	yes	0.84	0.29	1.96	0.10	1.47	0.27	0.04	64.25	42.00	3171.75	4.75	63.25	29.50
2	no	no	0.89	0.20	1.17	0.09	1.38	0.62	0.02	42.00	38.25	1350.50	4.00	71.25	26.75
2	no	yes	0.85	0.18	1.32	0.10	1.59	0.68	0.02	53.25	42.25	1353.75	4.50	81.75	29.25
2	yes	no	0.84	0.24	1.44	0.10	1.53	0.57	0.03	50.25	39.50	1551.00	4.00	54.50	28.50
2	yes	yes	0.83	0.22	1.49	0.09	1.50	0.57	0.04	47.00	40.25	1449.75	4.75	58.00	28.25
3	no	no	1.00	0.20	0.74	0.10	1.48	1.27	0.02	56.00	40.00	524.00	4.75	57.75	23.50
3	no	yes	1.01	0.18	1.80	0.11	1.45	0.99	0.02	48.00	38.75	689.75	4.25	68.00	25.75
3	yes	no	0.84	0.26	0.90	0.09	1.42	1.12	0.03	45.00	38.75	542.50	3.00	44.25	25.25
3	yes	yes	0.83	0.20	2.03	0.11	1.28	0.79	0.03	52.50	37.25	705.25	4.50	46.50	25.75
4	no	no	1.01	0.23	0.68	0.09	1.31	1.33	0.02	42.00	36.75	465.75	3.00	55.75	23.00
4	no	yes	1.05	0.17	1.80	0.10	1.39	1.00	0.02	48.25	38.00	529.50	3.25	62.50	23.25
4	yes	no	0.92	0.26	0.98	0.09	1.42	1.09	0.03	41.75	37.00	434.25	3.50	41.50	26.75
4	yes	yes	0.91	0.22	2.02	0.10	1.37	0.89	0.03	38.75	36.75	576.75	4.00	48.50	28.00
soil pH			**	**				**		**		**		**	**
Irrigation			**	*	**			**	**					**	
Fertilizers				*	**			**							
soil pH x Irrigation			*												
soil pH x Fertilizers					**			**							
Irrigation x Fertilizers															
soil pH x Irrigation x Fertilizers															

The effects of soil pH on micronutrient metals and the effect of irrigation on N were expected. Since the soil amendments, supplemental fertilizers, and soil moisture all target K and since there was an interaction of soil pH and fertilizers on veraison petiole K and Mg, these nutrients were further investigated. Low soil pH vines had low tissue K except for irrigated and fertilized vines (figure 8). All low pH vines had low tissue Mg. In general, increasing soil pH increased tissue Mg and decreased tissue K. However, supplemental K fertilizer at high soil pH increased tissue K and decreased tissue Mg. Irrigation at high soil pH further increased tissue K and decreased tissue Mg.

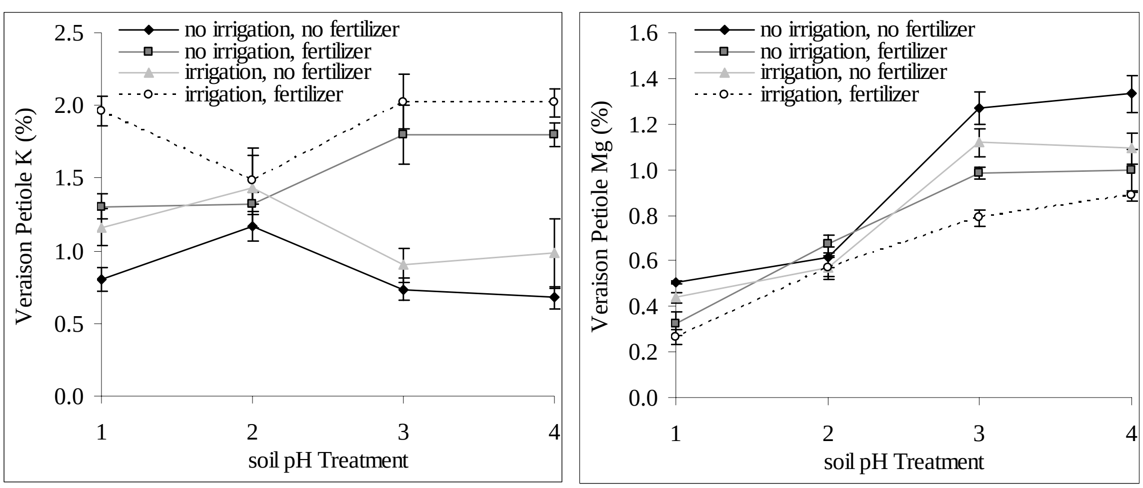

Figure 8: Veraison Concord petiole K and Mg at four soil pH treatments with and without supplemental irrigation and fertilizers.

Conclusions

1. Vine Size: The primary influence of viticulture experiments which manipulate the function of Concord roots is on vine size. Manipulating soil nutrient availability through soil amendments or supplemental fertilizers, changing water availability through floor weed management or irrigation, or altering soil exploration with rootstocks all directly influence vine size. Vine size has a direct influence on yield potential and yield has a direct influence on juice soluble solids through the leaf area to fruit weight ratio. Additional influences of water or nutrients on yield components, such as the effect of irrigation on berry weight, are secondary to the importance of vine size on Concord productivity. In this experiment, nutrient availability through soil pH and supplemental fertilizers changed Concord vine size and productivity. Although 2005 was the first year for irrigation and an effect of irrigation was measured on berry weight which increased yield, the greater impact of irrigation will most likely be on vine size – to be measured this winter.

2. Strongly Acidic Soil: Soil pH treatment 1 had soil pH between 4.2 and 4.6, a common soil pH range in Lake Erie Concord vineyards. At this soil pH, soil cation exchange is dominated by H and Al and is deficient in Ca, Mg, and K. Supplemental Ca and K fertilizers slightly improved vine productivity at this pH. However, it is common for aluminum toxicity to restrict root growth at this soil pH. Vine size and early water stress observations (even in wet years) suggest that Concord root growth was also restricted in this experiment at low soil pH. Therefore, fertilizers may have limited effectiveness in improving vine performance because there is not a strong root system to take up the nutrients. In addition, the inability for the roots to explore the soil profile and absorb water may be more of a limiting factor than nutrient availability. Irrigation had a large effect on yield in the low pH vines by increasing berry weight. We also expect to measure a large increase in vine size through irrigation.

3. K and Mg at all other soil pH: Increasing the soil pH increased the availability of Ca and Mg which decreased the availability of K. Looking at non-irrigated vines, the three top treatments in vine size and yield were <u>soil pH 2 – no fertilizer</u>, <u>soil pH 3 + K fertilizer</u>, and <u>soil pH 4 + K fertilizer</u>. All three of these treatments had similar Mg-K milliequivalent soil ratios and similar Mg-K fall petiole ratios. Soil meq Mg:K were between 1.0-2.5 Mg:1.0 K where K was between 7-10% of the total H, Ca, Mg, K base saturation. Fall petiole tissue values showed a reverse in the Mg-K ratio with roughly 1.0 Mg:1.9 K. Increasing the soil pH with no supplemental K fertilizer changed the soil meq Mg:K to 5.5-6.5 Mg:1.0 K where K was between 4-5% of the total H, Ca, Mg, K base saturation. This situation creates a deficiency in K soil availability and leads to high Mg and low K fall petiole values (1.8 Mg:1.0 K) as well as decreased vine size and yield. Therefore, it is important to supply enough K to the soil to compete with the soil Mg which is influenced by soil pH. (It is important to remember that it is the carbonate in lime that changes the soil pH and the natural availability of soil Ca and Mg. The issue of using calcitic or dolomitic lime is of less importance).

4. Irrigation increased K and decreased Mg petiole values. Effects on vine size will be measured.