Nitrogen Fertilization of White Riesling Grapes in Washington: Nitrogen Seasonal Effects on Bud Cold Hardiness and Carbohydrate Reserves

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A commercial vineyard of White Riesling was used to study the influence of 0, 56, 112, and 224 kg N/ha on bud cold hardiness and carbohydrate reserves of bud and cane tissues over a three-year period. High N had significant effects on cold hardiness of buds, levels of soluble sugars and starches extracted from one-year-old bud or cane samples, only on a limited number of dates during the three years of the study. There was a positive relationship between bud hardiness and soluble sugars from bud or cane samples that was highly significant. Regression analysis of yearly data indicated there was no relationship between nitrogen level and either soluble sugars or starch in buds or canes. There was a positive relationship between air temperature and bud low temperature exotherms during the sampling period of each year, and an inverse relationship between air temperature and soluble sugar levels in both buds and canes. These data show the predominant role of air temperature on bud and presumably vine cold hardiness and the attendant changes in carbohydrate reserves. This study further demonstrates that under otherwise good management practices of pruning, cropload, irrigation, and rootstock selection, there should be little concern regarding a detrimental influence of nitrogen applied before harvest on cold hardiness or carbohydrate reserves of grapevines.

KEY WORDS: bud cold hardiness, carbohydrates, nitrogen fertilization, White Riesling vines

Nitrogen (N) is the predominant nutrient applied on an annual basis throughout most of the grape growing regions of the world. The scheduling of N applications and determination of appropriate levels have been the subject of numerous research projects (1,4,5,6,7 ,9,14,15,16,18,38,39). Additional studies have attempted to establish the uptake, metabolism and storage of nitrogenous compounds and how fruit yield and quality are affected (2,14,15,19,22,24). However, numerous questions regarding the influence of nitrogen on cold hardiness and carbohydrate reserves have been raised as a consequence of these studies and their recommendations (3,9,12,13,16,25,32). Low temperature injury, the stimulus for many of these questions, has not been restricted to northern temperate growing regions (36). Understanding grapevine cold hardiness is further complicated by our limited understanding of trunk, cordon, and cane hardiness as compared to bud hardiness. The interpretation of nitrogen-related cold hardiness studies in grapes is complicated by the use of rootstocks which have specific nutrient uptake characteristics and physiological influences on the scion (7,11,20,21,27,29,33,38). The generally accepted relationship, as stated by Pellet and Carter (25), is that high nitrogen fertilizer rates reduce grapevine cold hardiness, yet these same authors note that few studies have specifically examined this question, and most of the literature is not conclusive. This is in part due to the variability in genetic, environmental and cultural factors.

The purpose of this research was to examine the effect of nitrogen in conjunction with other standard cultural practices on the bud cold hardiness and bud and cane carbohydrate reserves of White Riesling grapevines in south central Washington.

Materials and Methods

Vineyard: The study was conducted from 1985 - 1989 at the Chateau Ste. Michelle's (CSM) Cold Creek vineyard, 25 km north of Sunnyside, Washington. The plot consisted of about 12 ha of own-rooted *Vitis vinifera* L. cv. White Riesling. The soil is a Warden silt loam which has an underlying Caliche layer. Field capacity of the soil was about 28 cm/m (27% to 28% moisture by volume). Permanent wilting point was about 8 to 10 cm/m (8% to 10% by volume). The land had not been cultivated prior to vineyard establishment in 1978. Based on soil sampling, the land was ripped to a depth of 1 m to breakup a caliche layer and fertilized as recommended by Dow *et al.* (8). The vines were planted in 1978 on a 1.8 × 3.0 m spacing and trained to a bilateral cordon system with two catch wires. Maximum and minimum temperatures, precipitation, and relative

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H/LA Paper No. 91-29. Project No. 3519. College of Agriculture and Home Economics Research Center, Washington State University, Pullman, WA 99164

The authors acknowledge support from the Washington Wine Grape Advisory Board, Stimson Lane Wine and Spirits and Washington State University. The assistance of Andy Bary, Alan Kawakami, Barbara Seymour, and Anna Wichers of Washington State University and J. Andersen, G. Ballard, K. Corliss, J. Johnson, A. Litton, and R. Wheeler of Stimson Lane Wine and Spirits is greatly appreciated.

Manuscript submitted for publication 25 October 1991.

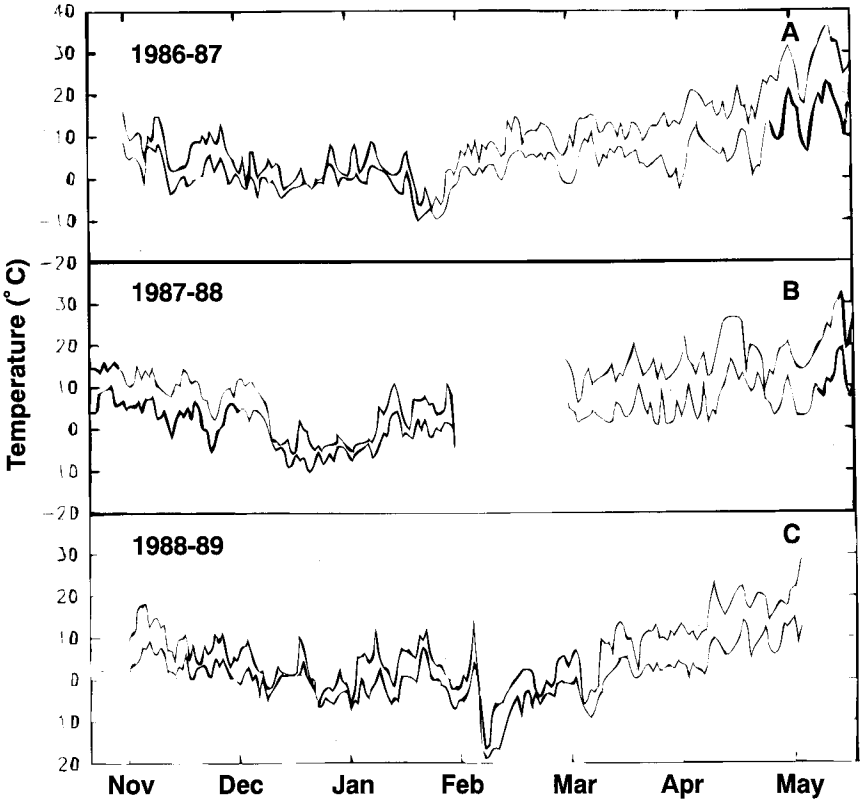

Fig. 1. Maximum and minimum air temperatures for 1986-87 (a), 1987-88 (b), and 1988-89 (c) for the vineyard where the experiments were performed.

humidity were collected daily by on-site weather instruments. Temperature data presented in Figure 1 represent the time periods during which the vines were dormant and samples were taken for cold hardiness and carbohydrate analysis.

Statistical design: The experiment was designed as a randomized complete block with eight replications of rate of nitrogen fertilization. Plots consisted of five rows (>50 vines/row) of which 15 vines from the center row were used to collect data, thereby providing two border rows on either side of the data row.

Data were subjected to analysis of variance, F-tests, and orthogonal polynomial regression analyses using SAS (30).

Irrigation: The vineyard was sprinkle-irrigated during the 1978 - 1981 seasons and converted to trickle irrigation in 1982. The pressure compensating emitters delivered 3.7 L/hr and were equally spaced about 117 to 122 cm down the row. Water was supplied from deep wells and 600 mm to 800 mm of water was applied over the season. Soil moisture status was monitored throughout the growing season at biweekly intervals using neutron probe measurements taken at 30-cm intervals to a depth of 1 m. Four large totalizing flow meters were placed at the delivery points for each vineyard block. Small (1.9 × 1.6 cm municipal type Hays) totalizing flow meters were installed to measure the amount of water applied to each treatment row.

Nitrogen fertilization: Prior to initiation of a full fertilizer treatment program in 1986, the vineyard was uniformly fertilized annually with 65 to 80 kg N/ha. In 1985, the year prior to complete implementation of the study, plots received half (0, 28, 56, or 112 kg actual N/ha) of the experimental rates used in the study. In 1986 - 1988 plots were treated with either 0, 56, 112, or 224 kg actual N/ha in the form of UN-32 (43.3% NH_4NO_3; 35% urea; 21.3% water; representing 32% actual N) which was injected through the drip irrigation system. Fertilizer was applied at pre-bloom (late May to early June) and post-bloom (late June to early July) with no more than 25 kg N/ha applied per day. Nitrogen application was always completed prior to veraison. Whenever N was being applied, the 0 N/ha also received comparable irrigation.

Movement of nitrogen in the soil was monitored by sampling the soil 0.15, 0.75, and 1.5 m from the drip irrigation emitter to a depth of 0.9 to 1.2 m. Soil samples were taken in March prior to budbreak. Petiole samples were taken at bloom, veraison, and harvest. Bloom petiole samples were taken from the leaf directly opposite a cluster, while veraison and harvest petiole samples were taken from the most recently matured leaf on a given shoot. The concentration of nitrate-nitrogen was determined on all three samples.

Pruning: Number of shoots/vine and pruning weights were determined in late February to mid-March. Vines were uniformly pruned to 30 to 35 nodes/vine in 1986, and subsequently balance pruned to 11 nodes/0.45 kg of one-year-old dormant pruning wood in 1987 and 1988. The practice of balance pruning was used to reduce the problems of over- or under-cropping and their possible effects on bud cold hardiness.

Cold hardiness and carbohydrate analysis: Samples for cold hardiness and carbohydrate analysis were collected weekly from November through March. Cold hardiness of excised buds was determined by low temperature exotherm analysis (35). Buds were collected from the basal fourth to the eighth nodes of one-year-old canes. Cane selection was random, thus providing a bud sample that represented the variation of bud cold hardiness within a vine. Buds from vines representing the replicates of each treatment were pooled and subsamples taken to prepare three thermoelectric modules (TEM) per treatment with 10 buds per plate. The median temperature at which 50 percent of the buds froze (T_{50}) was estimated from the average of the temperatures at which the median low temperature exotherm occurred on each of the three TEMs.

Samples for carbohydrate analysis from each of the replicates were frozen, freeze dried, and ground to pass through a 60-mesh screen. Ten-milligram subsamples were extracted according to the procedure of Wample and Bary (34). Reducing sugar quantification was achieved by the Shaffer-Somogyi method as modified by Nelson (23).

Starch was determined on the residue following soluble carbohydrate extraction using the procedure of Loescher and Nevins (17). The results are reported as maltose equivalents.

Additional data from this study regarding soil and petiole nutrient levels, pruning weights, yields, fruit quality, and winemaking characteristics are being prepared for publication but were considered too extensive for a single publication.

Results and Discussion

Nitrogen application increased petiole nitrate-N at bloom (Fig. 2). The variability in the 112 and 224 kg N/ha in 1987 is due to irrigation problems associated with a pump failure. Analysis of variance (ANOVA) for nitrogen treatment gave an F-value of 49.9 (3 degrees of freedom) indicating a high level of significance. ANOVA for the three years of the study for petiole nitrate-nitrogen indicated a significant difference between nitrogen treatments in all three years at $p \leq 0.01$. No symptoms of nitrogen toxicity were noted despite the high petiole nitrate levels. There was an increase in pruning weights associated with higher nitrogen fertilization rates.

The first samples for bud cold hardiness in 1986 - 87 were taken in mid-November and all N treatments had similar T_{50} values of -16°C (Fig. 3a). During the winter of 1986 - 87 only five of the 17 sample dates had T_{50} values which differed due to N treatment with the 0 N treatment always being more hardy than the 224 kg N/ha (Table 1). Differences were less consistent between the 0 N and the 56 or 112 kg N/ha treatments. The 56 or 112 kg N/ha buds were only different on 21 January and different from the 224 kg N/ha on 18 February and 1 March.

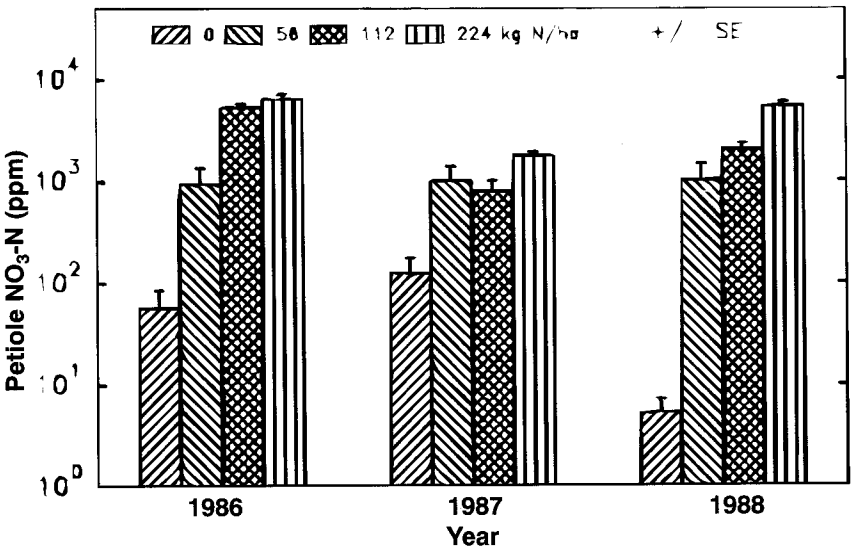

Fig. 2. Nitrate levels from petioles sampled at bloom from White Riesling grapevines given four levels of nitrogen fertilization over a three-year period. Samples were taken opposite clusters. Data represent the mean +/- standard error.

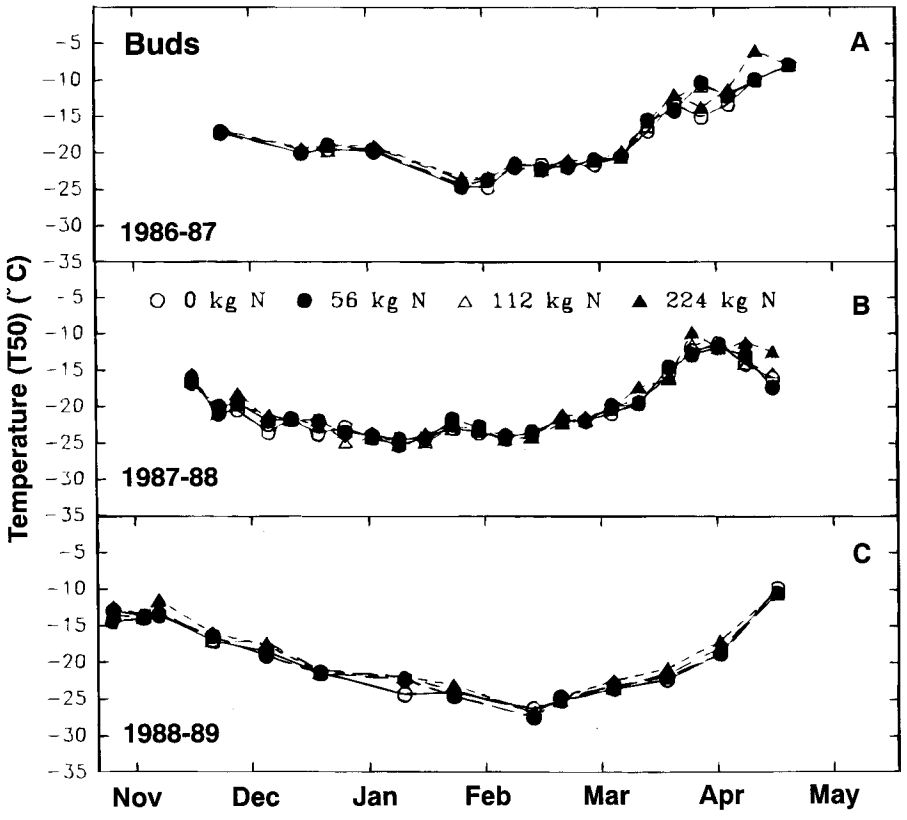

Fig. 3. Cold hardiness of buds collected during the winter of 1986-87 (a), 1987-88 (b), and 1988-89 (c), from the fourth to the eighth nodes of one-year-old wood from White Riesling grapevines given four different nitrogen fertilization rates. Hardiness was determined by low temperature exotherm analysis. Each point represents the mean of three values derived from the median temperature of exotherms from three thermoelectric plates with 10 buds on each plate. Statistical analysis is provided in Table 1.

On the first sampling date in 1987 - 1988, the 56-kg N/ha buds were most hardy, and the 224-kg N/ha the least hardy (Fig. 3b; Table 1). However, samples taken on 18 November the 56-kg N/ha were the least hardy but with no differences between the other three nitrogen levels. On 23 November 1987, buds from 0-, 56-, and 112-kg N/ha were all more hardy than the 224-kg N/ha buds, thus indicating the variability in bud cold hardiness between nitrogen treatments. During late February, March, and early April of 1988, differences occurred with the general trend for the high nitrogen level having the least hardy buds (Fig. 3b and Table 1). On 29 March, the 224-kg N/ha buds were more hardy than either the 0- or 112-kg N/ha buds and no different than the 56-kg N/ha buds. Thus there were only nine out of the 23 samples that showed significant differences in 1987 - 1988, and only six of these showed significantly less hardiness in the 224-kg N/ha compared to the 0-kg N/ha buds.

Sampling began on 20 October 1988, since we suspected that an earlier sampling date might reveal an effect of nitrogen on cold hardiness. Despite the earlier sampling, only three out of the 14 sample dates showed significant differences, and no differences were found until early January 1989, when the 0-N buds were hardier (-23.9°C) than all other nitrogen treatments (*ca.* -22°C) (Fig. 3c; Table 1). On 1 March, the cold hardiness of the 0-, 56-, and 112-kg N/ha buds were not different from one another but were all three more hardy than the 224-kg N/ha buds. A similar, although not identical, situation occurred on 15 March.

Table 1. Effect of nitrogen fertilization on bud cold hardiness of White Riesling grapevines, given four levels of nitrogen fertilization, as measured by low temperature exotherm analysis (T_{50}) of buds sampled from nodes four to eight. Data represent only those presented in Figures 3a-c with significant differences between nitrogen treatments.

		Nitrogen fertilization (kg N/ha)			
Season	Date	0	56	112	224
1986-87	21 Jan	-24.7b[z]	-24.4b	-23.7a	-23.4a
	28 Jan	-24.7b	-23.7a	-23.6a	-23.4a
	18 Feb	-22.0b	-21.7b	-21.9b	-21.0a
	4 Mar	-20.5b	-20.5b	-20.6b	-19.8a
	11 Mar	-17.0b	-15.5a	-16.3ab	-15.6a
1987-88	11 Nov	-16.1b	-16.8c	-16.6bc	-15.5a
	18 Nov	-21.1b	-20.0a	-20.9b	-21.0b
	23 Nov	-20.5b	-19.6b	-19.8b	-18.2a
	1 Dec	-23.5b	-22.0a	-21.2a	-21.8a
	4 Jan	-25.3b	-24.5a	-25.3b	-25.1b
	22 Feb	-22.0b	-22.0b	-21.9b	-21.4a
	22 Mar	-12.4b	-12.9b	-11.0a	-9.8a
	29 Mar	-11.1ab	-11.9bc	-11.1a	-12.0c
	12 Apr	-16.1b	-17.4b	-15.3ab	-12.5a
1988-89	5 Jan	-23.9b	-22.4a	-22.1a	-22.0a
	1 Mar	-23.6b	-23.2b	-23.5b	-22.4a
	15 Mar	-22.4c	-21.9bc	-21.6b	-20.8a

[z]Different letters within a row indicate significant differences (LSD, ANOVA $p < 0.05$) for the corresponding date and nitrogen combination in Fig. 3a-c.

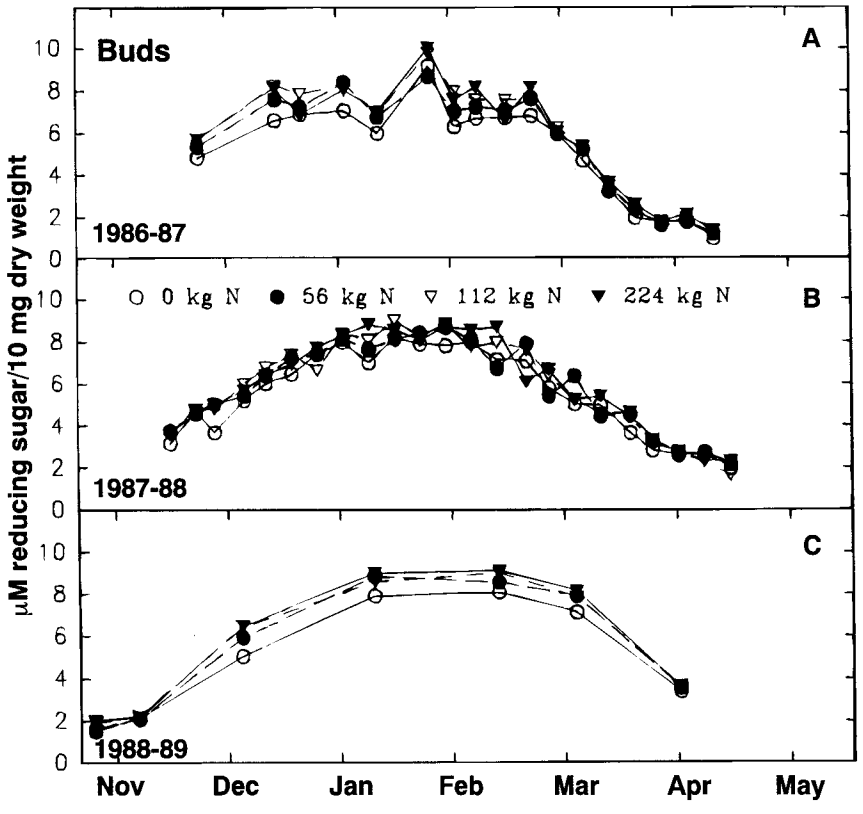

Fig. 4. Soluble sugars extracted from buds collected during the winter of 1986-87 (a), 1987-88 (b), and 1988-89 (c) from the fourth to the eighth nodes of one-year-old wood from White Riesling grapevines given four different nitrogen fertilization rates. Each point represents the mean of three or four replicates. Statistical analysis is provided in Table 2.

These results suggest an influence of N on cold hardiness. However, the variability in the data and the fact that the majority of the sample dates (37/54) showed no significant differences make it difficult to draw a firm conclusion about the effect of nitrogen on cold hardiness. Only 12 out of 54 sample dates showed significant differences between the 0- and the 56- or 112-kg N/ha treatments over the three years. This suggests there is little effect of nitrogen, within the commercially acceptable rates of application, on bud cold hardiness of White Riesling grapes.

Nitrogen fertilization did influence the levels of soluble sugars in buds on specific dates (Fig. 4a-c; Table 2). The seasonal changes are similar to those reported by others (10,26,28,37) and reflect the influence of low temperature and dormancy on the interconversion of sugars and starch. During 1986 - 1987,

Table 2. Effect of nitrogen fertilization on soluble sugar levels extracted from buds sampled from nodes four to eight of White Riesling grapevines given four levels of nitrogen fertilization. Data represent only those presented in Figures 4a-c with significant differences between nitrogen treatments.

Buds		Soluble sugars kg/N/ha			
Season	Date	0	56	112	224
1986-87	19 Nov	4.8b[z]	5.4a	5.6a	5.7a
	28 Jan	6.3b	7.0ab	7.9a	7.6a
	18 Mar	6.0b	6.7a	6.9ab	7.0a
1987-88	11 Nov	3.1b	3.7a	3.6ab	3.7a
	23 Nov	3.7b	5.0a	4.8a	5.0a
	1 Dec	5.2c	5.4bc	6.0a	5.7b
	4 Jan	7.0c	7.6bc	8.1ab	8.8a
	25 Jan	7.8b	8.7a	8.8a	8.7a
	15 Feb	7.1ab	7.9a	7.6a	6.1b
	22 Feb	5.8bc	5.4c	6.4ab	6.7a
	1 Mar	5.0b	6.4a	5.2b	5.2b
	8 Mar	4.9ab	4.4b	4.5b	5.4a
	5 Apr	2.6ab	2.7a	2.2c	2.3bc
	12 Apr	2.0ab	2.2a	1.6b	2.3a
1988-89	21 Oct	1.5b	1.7a	1.9a	2.0a
	30 Nov	5.0c	5.9b	6.3ab	6.4a
	8 Feb	8.1c	8.5bc	9.0ab	9.1a
	1 Mar	7.1b	7.9a	7.8a	8.1a

[z]Different letters within a row indicate significant differences (LSD ANOVA $p < 0.05$) for the corresponding date and nitrogen combination in Fig. 4a-c.

Table 3. Effect of nitrogen fertilization on soluble sugar levels extracted from canes sampled from nodes four to eight of White Riesling grapevines given four levels of nitrogen fertilization. Data represent only those presented in Figures 5a-c with significant differences between nitrogen treatments.

Canes		Soluble sugars kg/N/ha			
Season	Date	0	56	112	224
1986-87	4 Mar	3.5ab[z]	3.2b	3.9a	4.1a
1987-88	11 Nov	3.3ab	2.9bc	3.5a	2.8c
	18 Nov	4.2a	3.7b	4.0ab	3.7b
	5 Apr	1.3c	1.8b	2.0b	2.3a
1988-89	21 Oct	1.3c	1.4b	1.4b	1.6a
	1 Mar	4.5b	5.0a	5.0a	4.8ab

[z]Different letters within a row indicate significant differences (LSD ANOVA $p < 0.05$) for the corresponding date and nitrogen combination in Fig. 5a-c.

the 224-kg N/ha buds had higher levels of reducing sugars than the 0-kg N/ha on three dates. On 19 November and 28 January, the sugar levels in buds from 112 kg N/ha were also higher than those from 0 kg N/ha, as were the sugar levels from buds of 50 kg N/ha on 19 November and 18 March. Despite the effect of the pump failure on petiole nitrate levels in 1987 (Fig. 2), there continued to be a positive relationship between nitrogen rates and extractable sugars in buds. Although there are exceptions during 1987 - 1988, the pattern is for the 224-kg N/ha buds to have the highest and the 0-kg N/ha the lowest sugar levels. Buds from the 56- and 112-kg N/ha treatments generally had intermediate sugar levels. These data show that 224 kg N/ha did not cause a reduction in the level of soluble sugars in dormant bud tissues. This contrasts with the view that high N causes low reserve carbohydrate levels due to increased vegetative growth (25). Regression analysis of yearly data did not demonstrate a significant positive effect of nitrogen on soluble sugar levels in buds. This indicates another level of carbohydrate allocation control and that early to mid-season nitrogen fertilization is not the controlling factor in bud soluble carbohydrate status.

There were fewer differences in the levels of soluble sugars extracted from cane tissues than for buds (Table 3). Seasonal changes in cane sugar concentrations, although slightly lower, were similar to that for bud sugar concentrations (Fig. 5a - c). As was the case for buds, regression analysis did not indicate a significant relationship between cane soluble sugars and nitrogen fertilization level. Despite this, there was an apparent

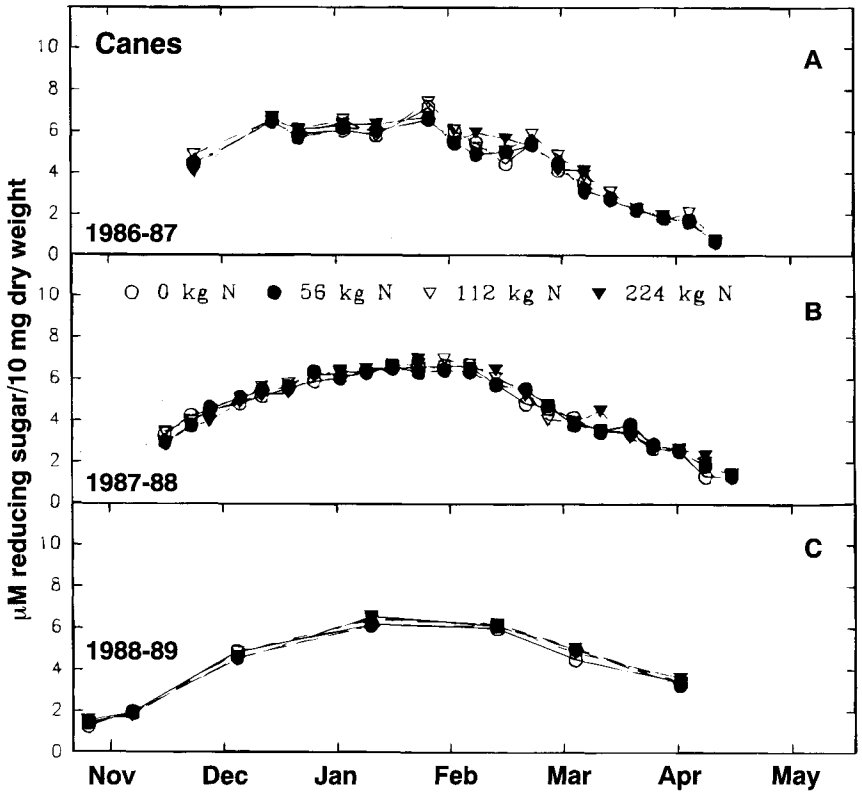

Fig. 5. Soluble sugars extracted from stems collected during the winter of 1986-87 (a), 1987-88 (b), 1988-89 (c), from the fourth to the eighth nodes of one-year-old wood from White Riesling grapevines given four different nitrogen fertilization rates. Each point represents the mean of three or four replicates. Statistical analysis is provided in Table 3.

Table 4. Effect of nitrogen fertilization on starch levels (reported as maltose equivalents) extracted from buds sampled from nodes four to eight of White Riesling grapevines given four levels of nitrogen fertilization. Data represent only those presented in Figures 6a-c with significant differences between nitrogen treatments.

Buds		Starch kg/N/ha			
Season	Date	0	56	112	224
1986-87	19 Nov	5.5a[z]	5.4a	5.8a	4.6b
1987-88	11 Nov	5.9b	6.5b	6.6b	7.6a
	7 Dec	3.2b	2.8b	3.3b	4.9a
	28 Dec	2.3b	2.4b	3.2a	3.3a
	16 Mar	4.2b	5.9a	5.2ab	4.9ab
	29 Mar	4.5b	5.1a	4.7ab	5.0a
	5 Apr	3.5c	3.9bc	4.2b	4.9a
1988-89	2 Nov	3.4c	3.6bc	4.3a	4.1ab
	30 Nov	4.6c	5.2b	5.0bc	5.8a
	5 Jan	2.1b	2.7a	2.6a	2.8a
	8 Feb	B/2.7b	B/2.9b	2.5b	3.4a
	29 Mar	BC/3.6bc	B/3.8b	3.3c	4.3a

[z]Different letters within a row indicate significant differences (LSD ANOVA $p < 0.05$) for the corresponding date and nitrogen combination in Fig. 6a-c.

Table 5. Effect of nitrogen fertilization on starch levels (reported as maltose equivalents) extracted from canes sampled from nodes four to eight of White Riesling grapevines given four levels of nitrogen fertilization. Data represent only those presented in Figures 7a-c with significant differences between nitrogen treatments.

Canes		Starch kg/N/ha			
Season	Date	0	56	112	224
11986-87	4 Mar	3.5ab[z]	3.2b	3.9a	4.1a
1986-87	1 Apr	5.5ab[z]	6.1a	5.8a	4.9b
1987-88	11 Nov	6.0c	6.5b	6.5b	6.9a
	18 Nov	5.2c	5.9bc	7.0a	6.0b
	7 Dec	3.5bc	3.4c	3.8b	4.4a
	28 Dec	2.8c	2.9bc	3.4a	3.3ab
	18 Jan	3.0b	3.4a	3.4a	2.8b
1988-89	8 Feb	2.4a	2.1b	2.6a	2.5a

[z]Different letters within a row indicate significant differences (LSD ANOVA $p < 0.05$) for the corresponding date and nitrogen combination in Fig. 7a-c.

trend for increasing nitrogen fertilization to be associated with higher soluble sugar levels in canes.

Seasonal analysis of dormant buds over the three years of this study showed that starch content was increased by nitrogen fertilization rates on only 10 out of 54 samples taken over the three year period (Fig. 6a - c; Table 4). Starch levels showed an inverse relationship to sugar levels which is consistent with other reports (10,37). On ten of the 12 dates over the three years that showed differences (Table 4), samples from the 224-kg N/ha treatment had the highest starch levels and the 0 kg-N/ha the lowest.

There were only seven dates out of 54 over the three years that showed significant differences in the starch levels extracted from cane tissues (Table 5). Figure 7a - c shows a decline in cane starch levels from the first sampling date to mid-winter followed by a gradual increase to budbreak. This follows the pattern for starch in bud samples with about the same degree of change for individual sample dates and the entire season as seen in buds. This is different than reducing sugars which were higher in buds than in cane tissues.

Soluble sugar and starch concentrations were relatively consistent in bud and cane tissues during the three years of this study. Bud cold hardiness was highly correlated with the level of soluble sugars in buds and cane tissues but not starch in either of these tissues (Fig. 8a - c; Table 6). Diagnosis of colinearity for the regression of bud hardiness against bud

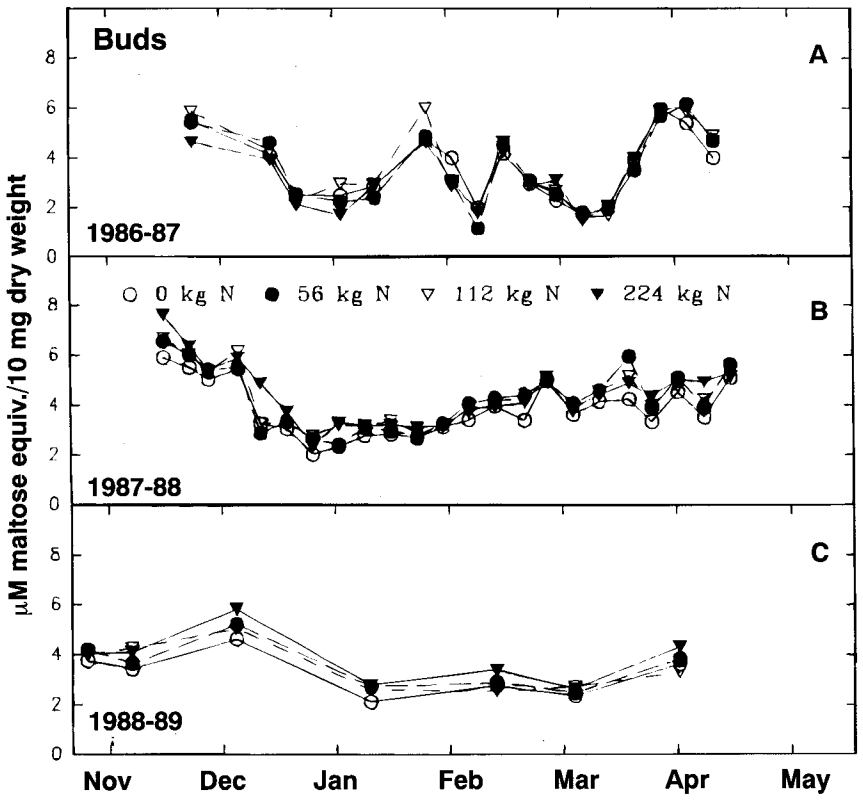

Fig. 6. Starch extracted from buds collected during the winter of 1986-87 (a), 1987-88 (b), and 1988-89 (c) from the fourth to the eighth nodes of one-year-old wood from White Riesling grapevines given four different nitrogen fertilization rates. Each point represents the mean of three or four replicates. Statistical analysis is provided in Table 4.

Table 6. Statistical values for the regressions of bud cold hardiness values (T_{50}) against either soluble sugars or starch extracted from bud or cane tissue over three years.

		Soluble sugars		Starch	
Season	Tissue	P	R^2	P	R^2
1986-87	Buds	.0001	.76	.0008	.17
	Canes	.0001	.76	.0001	.33
1987-88	Buds	.0001	.79	.0001	.22
	Canes	.0001	.81	.0001	.25
1988-89	Buds	.0001	.83	.0001	.35
	Canes	.0001	.80	.0001	.53

reducing sugar levels showed that within each year the slopes for the four nitrogen fertilizer application rates were the same (Fig. 8). This indicates there was no effect of nitrogen on the relationship of reducing sugars and bud cold hardiness. Furthermore, the standard errors indicate there were also no differences in bud cold hardiness. These data support the accepted relationship between soluble carbohydrates and cold hardiness. However, examination of data in Tables 1 and 2 reveals individual instances when the most hardy buds had the lowest reducing sugar levels (*i.e.*, 28 Jan. 1987, 11 Nov. 1987). Furthermore, the data in Figure 8 shows that for any given T_{50} value, the level of reducing sugar was always lowest in the 0-kg N/ha and highest in the 224-kg N/ha samples. Hence the high positive correlation between bud cold hardiness and bud reducing sugar level does not mean that a sample with high sugar concentration will always be more cold hardy. This emphasizes the need for caution in drawing "cause-effect" relationships from only correlative data. This also demonstrates the need to recognize the contribution of other factors that influence grapevine cold hardiness, such as weather and perhaps other cultural practices.

Comparison of the temperature profiles (Fig. 1) with bud cold hardiness (Fig. 3) shows a strong relationship between declining temperatures and increasing cold hardiness and is consistent with other reports (9). A similar pattern exists for air temperature and changes in carbohydrates with soluble sugar levels increasing with decreasing temperature while starch levels declined. The response of starch levels to temperature changes was slower than reducing sugars. Changes in soluble and insoluble carbohydrates occurred in both bud and cane tissues and are in agreement with previous reports for seasonal changes (10,26,31,36). The magnitude of the change associated with temperature changes is clearly greater than any differences due to nitrogen fertilization.

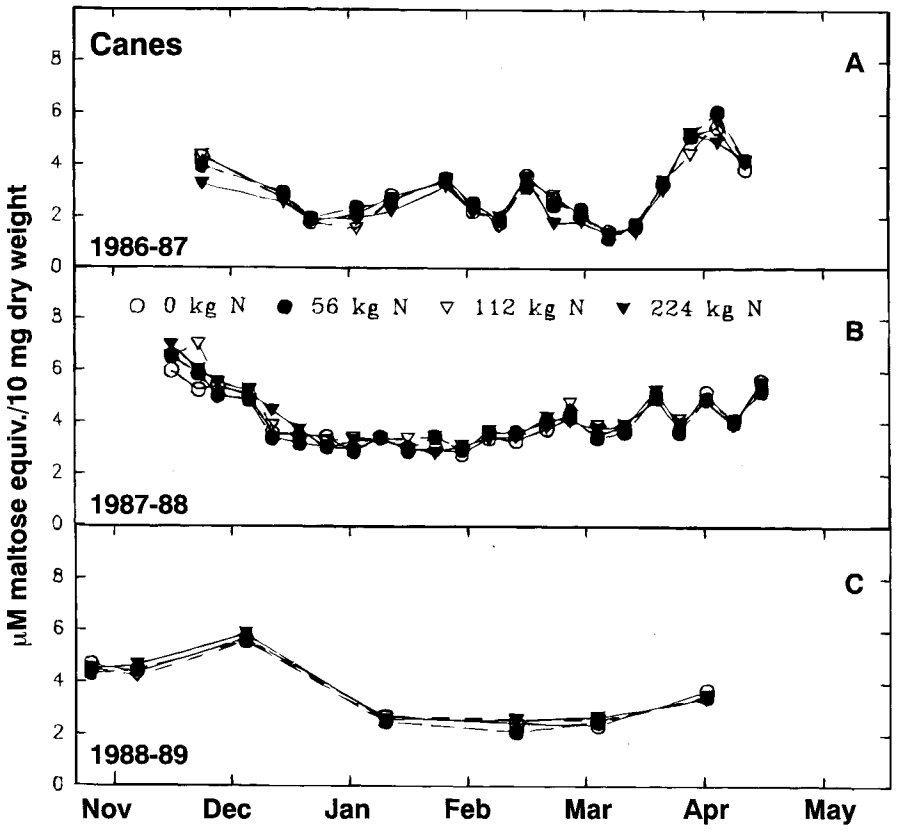

Fig. 7. Starch extracted from stems collected during the winter of 1986-87 (a), 1987-88 (b), and 1988-89 (c) from the fourth to the eighth nodes of one-year-old wood from White Riesling grapevines given four different nitrogen fertilization rates. Each point represents the mean of three or four replicates. Statistical analysis is provided in Table 5.

Conclusions

This study demonstrates that nitrogen applied in split applications of pre- and post-bloom, but prior to veraison, and at rates up to 224 kg N/ha do not consistently reduce bud cold hardiness in White Riesling. High nitrogen fertilization did not reduce soluble carbohydrates or starch reserves in either bud or cane samples and in some cases increased the levels of these substances. There was a highly significant relationship between bud cold hardiness and bud or cane soluble sugars, but not starch levels.

Overall, these data suggest that the widely held view that high nitrogen fertilization of grapevines is detrimental to bud cold hardiness may not be correct when the nitrogen is applied as described in this study and within the rates typically used in wine grape production. Furthermore, the suggestion that the reduction in cold hardiness is a consequence of lower carbohydrate reserves, caused by extended vegetative growth and/or delayed fruit maturity, is also not valid under the experimental conditions described. Since the highest level of nitrogen used in this experiment was nearly three times that typically

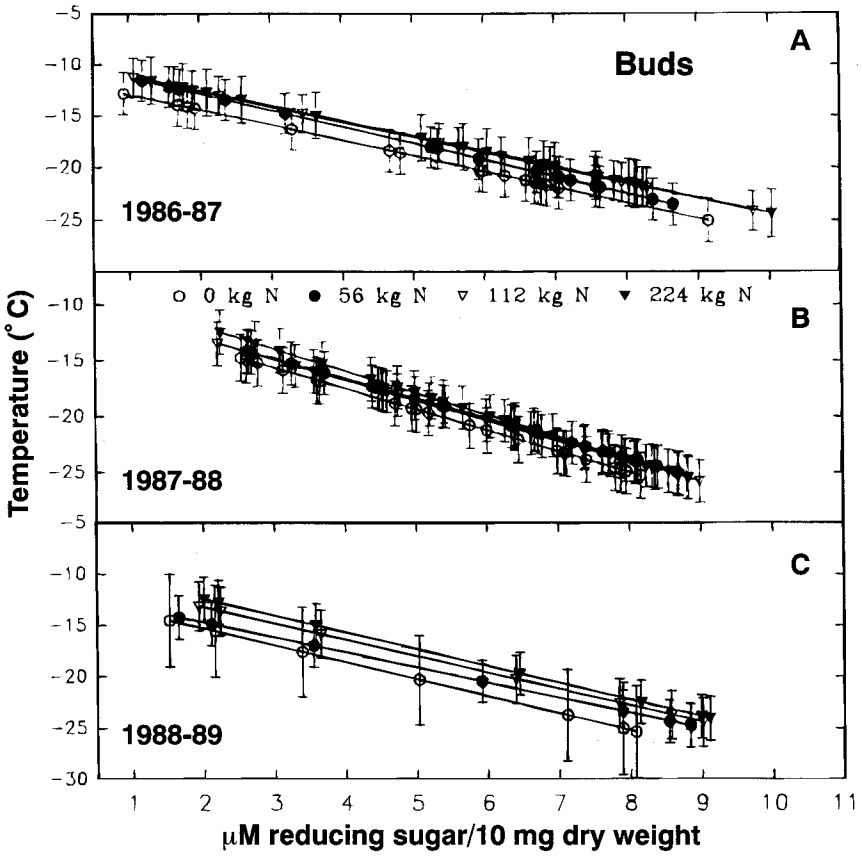

Fig. 8. Regression of bud cold hardiness and bud reducing sugars for 1986-87 (a), 1987-88 (b), and 1988-89 (c) of samples collected from the fourth to the eighth nodes of one-year-old wood from White Riesling grapevines. Error bars represent the standard error of the regression.

used, it seems unreasonable to associate grapevine winter injury with nitrogen fertilization when otherwise good management practices are followed.

Seasonal changes in hardiness and carbohydrates in bud and stem tissues are closely related to the air temperature and indicate the overriding effect of weather conditions on grapevine susceptibility to low temperature injury.

Good cultural management, including the level and timing of fertilizer applications, may contribute to cold acclimation and cold hardiness. However, the magnitude of the effects of such management appears small in comparison to the responsiveness of grapevines to changes in air temperature. Despite this, we should continue our efforts to maximize vine cold hardiness, since frequently an improvement of one to two degrees C hardiness can mean the difference between bud survival or injury.

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