Manipulating Soil Moisture and Nitrogen Availability to Improve Fermentation Behavior and Wine Quality

Part I: Vine Physiological Performance, Yield Components, Ripening Dynamics, and Fruit Composition

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Part II: Fermentable Nitrogen Content, Must and Wine Composition

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Part III: Effects on Wine Aroma, Flavor, and Color

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INTRODUCTION

This study integrates various vineyard practices that may improve nitrogen availability to the vine, particularly during ripening. Different strategies aimed at improving fermentation behavior and wine quality are being evaluated. This study aims to optimize fruit quality and maximize the juice nitrogen fraction that can be used by yeast during fermentation. This report consists of data from the third year of this study. Literature reviewed in past years' proceedings has been reprinted for pertinent information regarding the treatments used.

Fermentable Nitrogen

At harvest, low levels of yeast assimilable nitrogen in grape clusters may affect fermentation behavior. The fermentable nitrogen content of commercial Oregon juice and must samples at harvest has been shown to often be lower than minimal recommended levels and to vary with both variety and vintage (Watson, Hellman, Specht, and Chen, 2000). If assimilable nitrogen levels are too low, fermentations will be slower and may stop or 'stick' producing wine with undesirable levels of residual sugar and potential microbial instability problems. Winemakers often add supplements to juice and fermenting wines to balance perceived nutritional deficiencies (Montiero and Bisson, 1992; Bisson, 1999). It is also

thought that variations in climate, soil type, and cultivation, soil moisture, and fertilizer practices may have an impact (Bell, 1979; Butzke, 1998; Ingledew, 1985).

Irrigation

Combination of water stress with high light and temperatures has been reported to cause progressive reduction in vine growth and quality (Escalona *et al*, 1997; Kliewer, *et al*, 1983). It is suggested that optimum growth, grape yield, and grape quality can be obtained by integration of controlled irrigation during certain phenological stages of vine growth (Matthews, 1990; Van Zyl, 1984).

If vines experience drought stress during ripening, leaf photosynthetic production will decrease. The vine stomatal complex is sensitive to water deficits and will close to prevent excessive loss of water through transpiration. Stomata closure during part of the day prevents carbon dioxide from entering the leaves and inhibits photosynthesis (Salsbury *et al*, 1991; Kramer and Boyer, 1995). As a result, sugar accumulation in the fruit is hindered by lack of carbohydrate availability.

Nitrogen

Nitrogen is a primary constituent of important and common plant components such as proteins, enzymes, nucleic acid, chlorophyll and vitamins (Beevers, 1976; Wermelinger, 1991; Winkler *et al*, 1962). In grapevines, nitrogen is essential in overall vine establishment and maintenance, fruit quality, and the conversion of grape juice to wine. Nitrogen alters plant composition much more than any other mineral nutrient (Marschner, 1995; Roubelakis-Angelakis and Kliewer, 1992; Wermelinger, 1991). Typically, when nitrogen is suboptimal, the vine has poor vegetative growth, premature senescence of older leaves, limited fruit bud formation, and poor fruit production. Alternatively, an increase in nitrogen supply not only delays senescence but may change some plant morphology. It is reported that too much nitrogen in the vineyard can cause vigorous vegetative growth, little or no fruit bud formation, and poor fruit production (Araujo and Williams, 1988; Jackson and Lombard, 1993; Lohnertz, 1991; Roubelakis-Angelakis and Kliewer, 1992; Winkler *et al*, 1962). Thus, fruit quality may be affected due to abundant or insufficient available nitrogen.

Research indicates that the total amount of nitrogenous compounds in grapevine organs depends on genetic factors, environmental conditions, and cultural practices (reviewed by Roubelakis-Angelakis, 1992). During dormancy, the total amount of soluble nitrogen increases in the roots and reaches a maximum just prior to budbreak and decreases thereafter. Total nitrogen in the shoots starts to increase after budbreak and continues to be at more or less the same level until the end of the vegetative period when there is an increase due to retranslocation of nitrogen from senescing leaves. In leaves, the maximum amount of nitrogen is reached at full leaf expansion and remains constant until leaf senescence. During most of the season, nitrogen in the leaves exceeds nitrogen in the shoots. Shoots represent a nitrogen sink until the end of the main vegetative growth. After the main vegetative growth period, shoots become a source until the beginning of maturation. Shoots then terminate the year as a sink. The total amount of nitrogen in the young inflorescences starts at the same level as that of vegetative tissue and slowly decreases as the season progresses. Significant nitrogen partitioning to growing grape berries begins after bloom (Conradie, 1983, 1991;

Kubota and Kakedai, 1992; Lohnertz, 1991; Roubelakis Angelakis and Kliewer, 1992; Wermelinger, 1991; Williams, 1987).

In grape clusters, nitrogen is found primarily as ammonium cations and organic compounds such as amino acids, hexose amines, peptides, nucleic acids and proteins. There are also trace amounts of nitrate found in the berries (Winkler *et al*, 1962). As maturation occurs, organic nitrogen steadily increases while ammonia slightly decreases (Beevers, 1976; Winkler *et al*, 1962; Wermelinger, 1991). The synthesis of amino acids, peptides, and protein, occur during the last 6-8 weeks of berry ripening (Roubelakis- Angelakis and Kliewer, 1992; Wermelinger, 1991).

There are two phases of intense nitrogen incorporation in the fruit. The first takes place during the two weeks before the "pea- size" stage of the berries. The second starts one month later at véraison and lasts an additional two weeks (Lohnertz, 1988; Winkler *et al*, 1962; reviewed by Wermelinger, 1991). The amount of nitrogen in the clusters at harvest has been measured intensively. Pot studies using ^{15}N have indicated that 34% of total nitrogen at harvest is recovered in the clusters (Conradie, 1980, 1991). The results of pot studies have been fairly similar with results from field trials performed in Australia, France, and USA, which report that approximately 40-44% of total available nitrogen resided in the fruit at harvest (Alexander, 1957; Conradie, 1991; Gutierrez, 1982; Weinbaum *et al*, 1984). It is reported that of the total fruit nitrogen, only 20% is found in the juice. The remaining 80% is found in the skin and seeds. Of the 20% juice nitrogen, 50% of that (10% of total fruit nitrogen) is present in the juice as free amino acids (Peynaud, 1970; reviewed in Winkler *et al*, 1962).

Foliar N Application - Foliar application of fertilizer is a method of supplying nutrients to higher plants more rapidly than methods involving root application. It is beneficial to use foliar applications when the topsoil is dry, when there is low nutrient availability in the soil, or when there is a decrease in root activity during the reproductive stage. Decreased root activity during ripening results from sink competition for carbohydrates when nutrient uptake by the roots declines with the onset of the reproductive stage and maturity (Marschner, 1995). It has also been shown that foliar application of nutrients, specifically nitrogen, have improved the quality of some crops when applied at later stages of growth. Nitrogen supplied during maturation of wheat and other cereals is rapidly translocated from the leaves and directly transported to the developing grains, resulting in increased protein (Powleson *et al*, 1989).

Supply of nutrients by foliar application is temporary and has both limitations and problems. These include: low penetration rate, run-off from hydrophobic surfaces, washing off by rain, rapid drying of spray solution, limited rates of retranslocation, limited amounts of nutrient which can be supplied by one spray, and it may cause leaf damage (necrosis and burning) (Powleson *et al*, 1993).

Soil Cultivation

It has been shown that water availability, mineralization rate of soil nitrogen, and plant uptake of nitrogen available in the soil may override the effect of nitrogen fertilizers. Tilling can effectively be used to optimize mineralization of nitrogen and increase soil water availability (reviewed in Rupp, 1996). In clean cultivated vineyards, about 90 lbs. of

nitrogen can be mobilized per acre in one year. In vineyards with ground cover, the mobilizable nitrogen can be four times higher (Perret *et al.*, 1993).
It is important to avoid nutrient and water competition between the vine and the covercrop. To minimize or eliminate such competition, it is suggested that the cover crop be artificially reduced during times of high nitrogen and water uptake by the vine. Perret *et al* (1993) suggest mowing or tilling alternate rows of the cover crop two to three weeks before the grapevines maximum N-uptake rate at bloom.

MATERIALS AND METHODS

Experimental Design – The third year of this study was conducted on Pinot noir grapevines at Benton Lane vineyard located in Monroe, Oregon. The study is a factorial of irrigation, nitrogen, and soil cultivation (Table 1) organized in a randomized block design. Each treatment is replicated five times in groups of eleven vines. Vines were trained to double Guyot with a The soil is predominantly Bellpine and the vines are at approximately 425 ft elevation.

Irrigation –Water was applied using drip irrigation at a rate of 0.5gal/hr, 4h/day, seven days a week, from August 17 to September 14, totaling 2 in. Precipitation, irrigation, temperature and growing degree days during the 2001 season are illustrated in Fig. 1 and Fig. 2.

Nitrogen – Nitrogen treatments include an unfertilized control, 35 lbs N/acre supplied to the soil, and 2.66 lbsN/acre supplied foliarly. Foliar N fertilizer was split in two applications of 1.33 lbs N/acre. Both soil and foliar nitrogen treatments were applied manually. Soil nitrogen was applied as urea (46-0-0) on May 9. Nitrogen granules were measured per rep and broadcast by hand. Foliar nitrogen was applied in the form of wetted urea. Nitrogen granules were measured per rep and mixed with 5 gallons of water. Using a hand sprayer, the nitrogen solution was applied to leaves in the fruit zone. The first application was done at the beginning of color change on August 17 and the second on August 31 at véraison (50% color change).

Soil Cultivation – In row tilling was done in early spring to encourage nitrogen utilization and reduce nutrient and water competition. Tilling alternate rows was done on May 22.

Table 1. Main factors and treatment combinations applied to the same vines during the 1999-2001 period at Benton Lane Vineyard.

	Irrigation (I)		**No Irrigation (D)**	
	Till (T)	**No Till (NT)**	**Till (T)**	**No Till (NT)**
Zero Nitrogen (0N)	I-T-0N	I-NT-0N	D-T-0N	D-NT-0N
Foliar Nitrogen (FN)	I-T-FN	I-NT-FN	D-T-FN	D-NT-FN
Soil Nitrogen (SN)	I-T-SN	I-NT-SN	D-T-SN	D-NT-SN

Plant Material
Seven-year-old Pinot noir (clone FPMS 2A grafted on 5C) were used in this study.

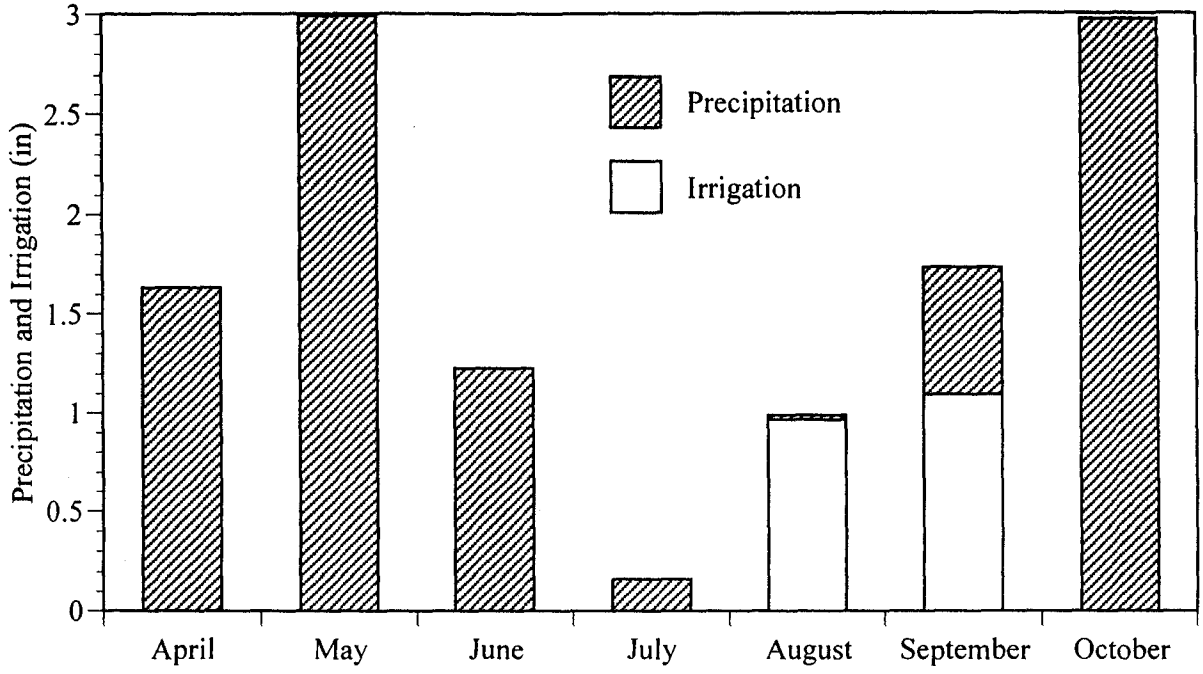

Figure 1. Seasonal precipitation and irrigation applied at Benton Lane Vineyard during 2001.

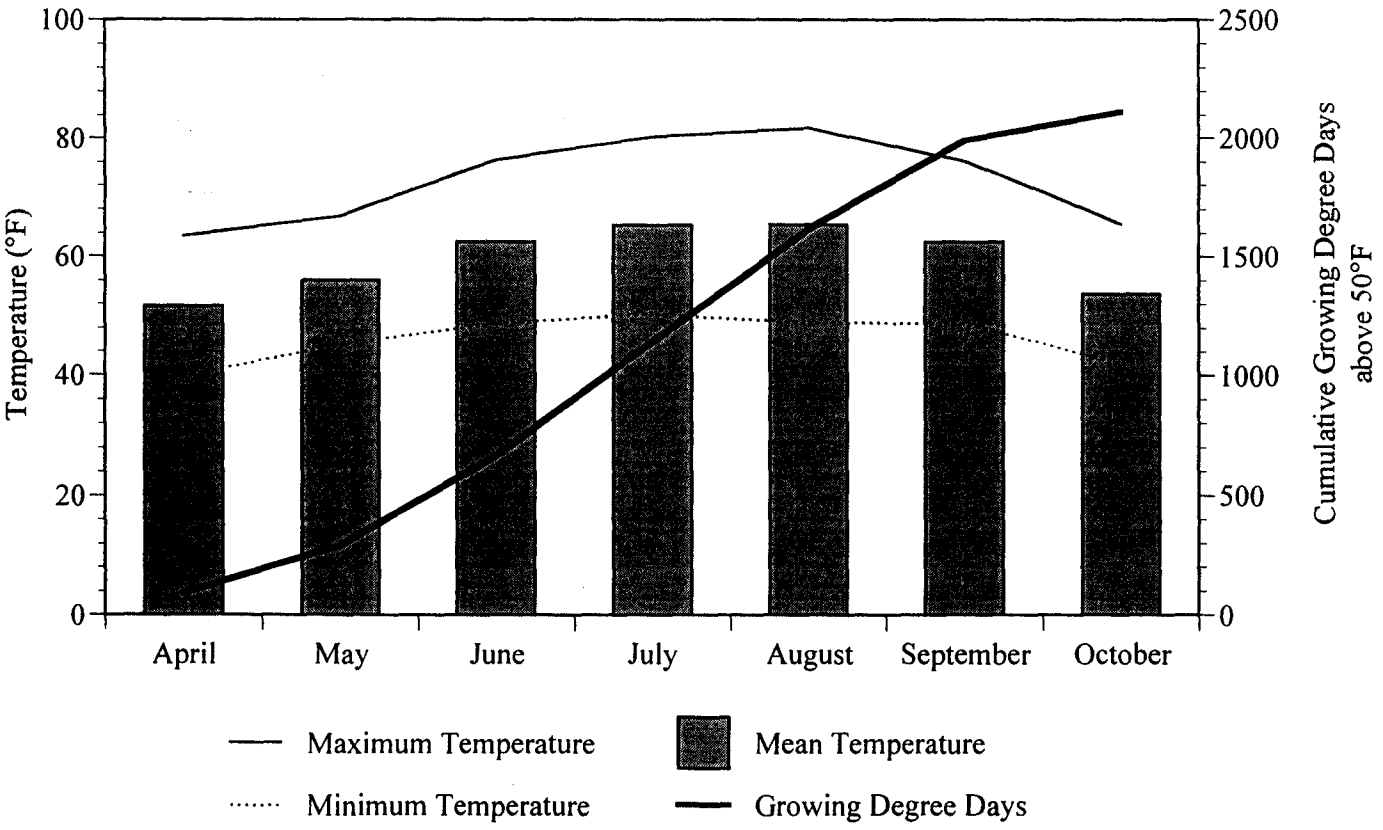

Figure 2. Mean, maximum, and minimum temperatures and accumulated growing degree days during 2001 season.

Vine Physiology

Leaf gas-exchange, chlorophyll content, chlorophyll fluorescence, vegetative growth, soil moisture, and leaf water potentials, were measured at two-week intervals during the growing season. One representative vine (data vine) per treatment replicate was selected and used throughout the season for all field measurements.

Photosynthesis, Transpiration, and Water Use Efficiency - The tenth leaf from a representative shoot on each data vine was tagged and used throughout the season to determine gas-exchange, chlorophyll fluorescence, and chlorophyll content. Leaf gas-exchange was monitored with a portable infrared gas analyzer, Ciras-1 (PP SYSTEMS, Hitchin, Herts SG5 1RT UK). Leaves were fully exposed to sunlight. Measurements were taken between 9:00 am and 1:00 p.m., at photosynthetic flux densities above 1200umol PAR $m^{-2}.s^{-1}$.

Chlorophyll Content - Leaf greenness was measured non-destructively using a SPAD-502 chlorophyll meter (Minolta). Six readings were taken per data leaf and then averaged. Chlorophyll content was calculated using the method suggested by Candolfi-Vasconcelos *et al.* (1994).

Maximum Quantum Yield of Photosynthesis - Chlorophyll fluorescence emission was measured by a pulse modulated Fluorescence Monitoring System (Hansatech Instruments LTD, King's Lynn, UK). Leaves were dark adapted during 15 minutes prior to measurements. The ratio of variable to maximum fluorescence (Fv/Fm) is a measure of the efficiency of the light dependant reactions of photosynthesis.

Leaf Area, Shoot Length and Diameter –Three shoots were collected per replicate at mid ripening. Leaf area was measured destructively using a Li-Cor leaf area meter (LI-3100, Li-cor Inc., USA). Leaf area from the main and lateral shoots was measured separately. Shoot length was measured two times during the season until hedging. Shoot diameter was measured between the second and third nodes using a digital caliper.

Soil Moisture – Soil moisture was measured 40cm from the trunk of each data vine using a Dynamax Theta Probe ML-2 (Delta-T Devices Ltd., Cambridge). Measurements were taken at 30cm and 60cm depths.

Leaf Water Potential – Predawn and midday leaf water potentials were measured using a pressure chamber (PMS Instrument Co., Corvallis, OR). Predawn measurements were taken before sunrise and midday measurements were taken between 11:00 a.m. and 1:00 p.m. Leaves were enclosed in plastic bags before being excised at the petiole from the vine. Leaves were then placed in the pressure chamber and water potential was determined.

Leaf Petiole Analysis – Petiole samples were collected from each treatment plot at bloom and véraison. Bloom petiole samples were taken from a leaf opposite a cluster from randomly selected shoots. Véraison petioles were collected from a leaf positioned in the mid-shoot region from randomly selected shoots. Samples were stored on ice until delivery (within 24

hours) to the Oregon State University Central Analytical Laboratory. Petioles were analyzed for phosphorus, potassium, calcium, magnesium, manganese, iron, copper, boron, zinc, and nitrate nitrogen.

Ripening Dynamics

The ripening survey began at the onset of véraison. Véraison was determined by 50% color change in berries. Ten cluster samples were taken from each replicate between véraison and harvest at two-week intervals. On each date, seven clusters were used for juice analysis and the remaining three clusters were frozen until further analysis. A sub-sample of 100 berries from the frozen sample was used to calculate berry weight and extract skin and seed phenols. Juice soluble solids were measured using a digital refractometer. Titratable acidity and pH were measured using an automatic titrator (Mettler Toledo, DL21 Titrator).

Yield and Fruit Composition

The vines were harvested at commercial ripening on October 7, 2001. Each replicate was harvested separately. A 25-cluster sub sample was taken from each replicate and used to determine cluster weight. The 25 clusters were then crushed and used to determine soluble solids, pH, titratable acidity, aminoacids, and organic acids. In addition, a 5-cluster sub sample was taken from each replicate and used to determine berry weight, skin and seed phenols, and skin anthocyanin content as described above.

Aminoacids and Organic Acids– Determination of amino acid and organic acid was done by HPLC. (In progress)

Phenolic compounds – Total phenols were extracted using the method described by Vasconcelos and Castagnoli (2000). Skin and seed phenols were measured using the Folin-Ciocalteau method.

Anthocyanin Analysis - Anthocyanins were measured from the skins of 100 berries using the method described by Candolfi-Vasconcelos and Koblet (1990b). Absorbance was measured at 530nm using a spectrophotometer. A malvidin calibration curve was used to calculate anthocyanin content.

Carbohydrate Content – During pruning, wood samples were collected and dried. Carbohydrates were extracted and are presently being analyzed using the method described by Candolfi-Vasconcelos and Koblet (1990b). (In progress).

RESULTS AND DISCUSSION

Part I

Soil Moisture

Irrigation – There were significant differences in soil moisture at 30cm depth and 60cm depth, after the application of irrigation (Figs. 3.1 and 3.4). Irrigated vines maintained higher soil moisture than non-irrigated vines prior to harvest.

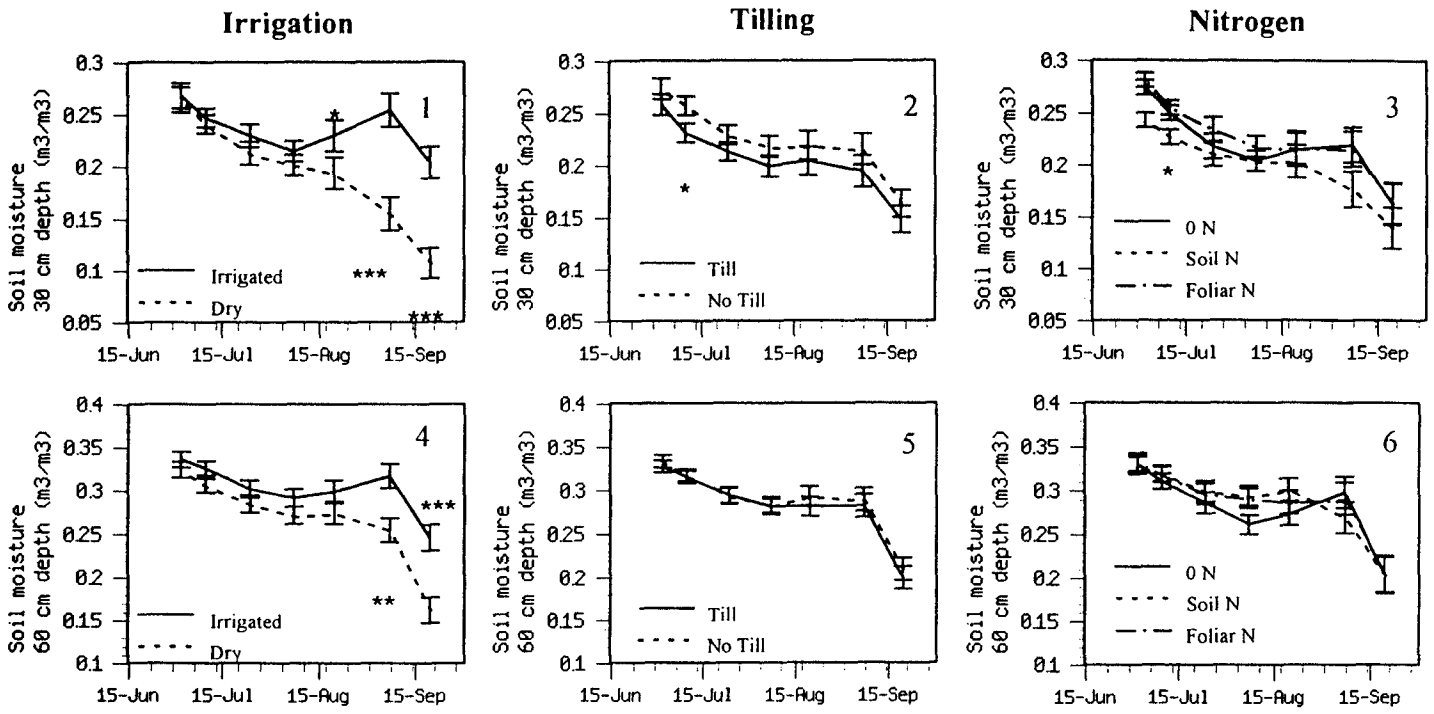

Figure 3: Effect of irrigation, tilling, and nitrogen fertilization on volumetric soil water content at 30 cm (1,2,3) and60 cm depth (4,5,6) at Benton Lane vineyard during the 2001 growing season.

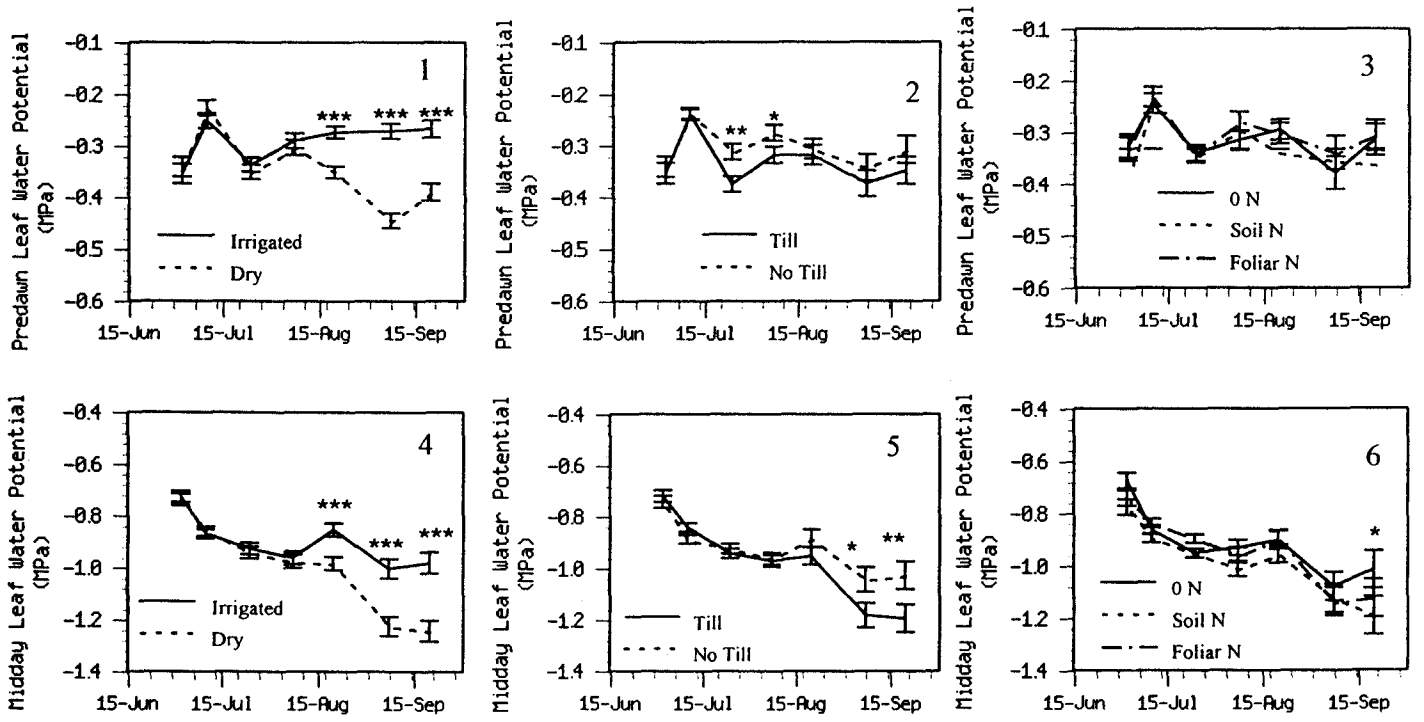

Figure 4: Effect of irrigation, tilling, and nitrogen fertilization on leaf water potential at predawn (1,2,3) and midday (4,5,6) at Benton Lane vineyard during the 2001 growing season.

Cultivation – Vines on tilled soil tended to have lower moisture content on the upper soil layers but not at deeper layers (Figs. 3.2 and 3.5). This could be a result of increased evaporation from bare soil as compared to covered soil. It could also be a consequence of increased vine vegetative growth in tilled soil, depleting soil water faster than in non-tilled soil.

Nitrogen – Early in the season, vines fertilized with soil-applied nitrogen had lower soil moisture content (Figs. 3.3 and 3.6). As hypothesized before, this could be the result of a flush of vegetative growth induced by the addition of nitrogen, requiring more moisture to sustain leaf transpiration.

Leaf Water Potential

Irrigation – From the onset of irrigation, differences in both predawn and midday leaf water potential between irrigated and non-irrigated vines were observed (Figs. 4.1 and 4.4). Non-irrigated vines were consistently more water stressed from August until October. Midday leaf water potentials of non-irrigated vines exceeded –1 MPa during the ripening period (Fig. 4.4).

Cultivation – Vines on non-tilled ground were less stressed earlier in the season and this became more evident during the ripening period (Figs. 4.2 and 4.5). As observed before, the lush vegetative growth on tilled ground may have depleted soil moisture at a faster rate. In support to this interpretation, leaf area, internode length, cane diameter and pruning weights of vines on tilled ground were a lot larger on vines on tilled soil (Tables 2 and 6).

Nitrogen – At the end of the season, vines that did not receive nitrogen fertilizer were less water stressed than vines that received soil applied nitrogen (Fig. 4.6).

Leaf Gas Exchange

Irrigation – Photosynthesis steadily declined through the growing season. Irrigated vines tended to assimilate CO2 at a higher rate than non-irrigated vines for the entire season (Fig. 5.1). During the same time, transpiration rate of irrigated vines tended to be higher for irrigated vines the entire growing season (Fig. 5.4). Differences were more pronounced after the onset of the irrigation treatment. At the end of the season, non-irrigated vines were more efficient in the use of water (Fig. 5.7).

Cultivation – There was no effect of tilling on C02 assimilation rate (Fig.5.2). Vines on tilled ground transpired at a lower rate and were more efficient in the use of water than vines on non-tilled soil (Figs. 5.5 and 5.8). This could be an adjustment to the larger leaf surface on these vines (Table 2).

Nitrogen – There were no significant differences among nitrogen treatments in C02 assimilation, transpiration, or water use efficiency (Figs. 5.3, 5.6, and 5.9).

Maximum Quantum Yield of Photosynthesis

Irrigation – Peak Fv/Fm values for all treatments occurred in early July as in the past seasons (Fig. 5.10). There was no response to irrigation on the maximum quantum yield of photosynthesis.

Cultivation – Tilling increased the efficiency of light driven photosynthetic reactions when compared to non-tilled vines (Fig. 5.11). The differences increased as the season progressed.

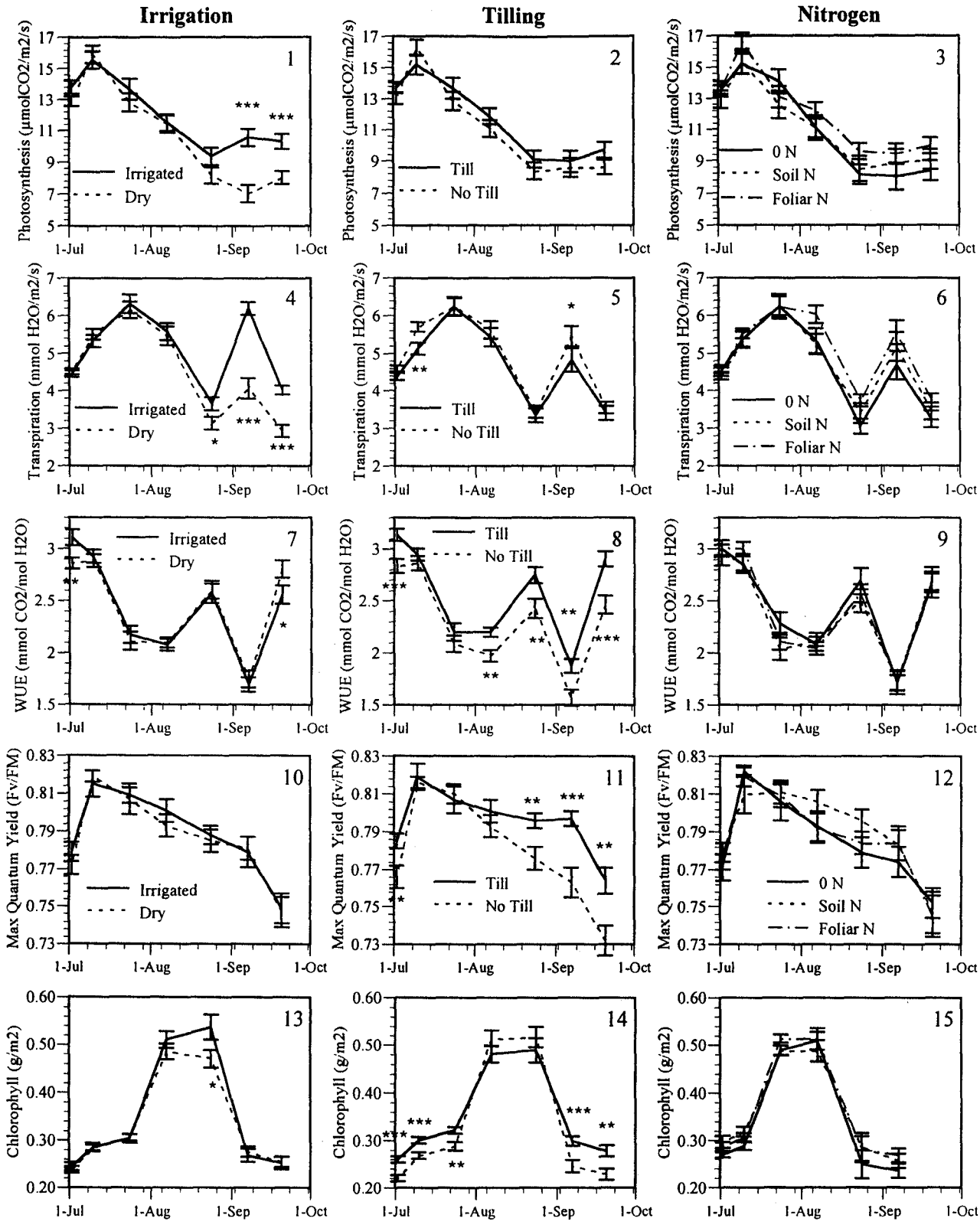

Figure 5: Effect of irrigation, tilling, and nitrogen fertilization on photosynthesis, transpiration, water use efficiency (WUE), maximum quantum yield of photosynthesis (Fv/Fm), and leaf chlorophyll content of Pinot noir grapevines at Benton Lane vineyard during the 2001 growing season. Soil nitrogen was applied on May 9; foliar nitrogen was applied Aug. 17 and Aug. 31. Alternate rows were tilled on May 22. Irrigation was applied from Aug. 17 to Sep. 14. Véraison took place on Aug. 31. Vines were harvested on Oct. 7, 2001.

Nitrogen – There was no clear response of Fv/Fm values to nitrogen treatments (Fig. 5.12).

Chlorophyll Content

Irrigation – Chlorophyll content was higher on irrigated vines during véraison. There were no differences due to irrigation prior to or after véraison (Fig. 5.13).

Cultivation – Tilled treatments had increased leaf chlorophyll content as compared to non-tilled treatments (Fig. 5.14). This could be the result of a better initial leaf differentiation in response to the elimination of the competition for water and nutrients between vines and green cover.

Nitrogen – Differences in chlorophyll content among nitrogen treatments were not observed (Fig. 5.15).

Leaf area

Irrigation – Irrigated vines had canopies with more lateral leaves of larger size compared to non-irrigated vines (Table 2). However, total leaf area and leaf area per amount of fruit was not significantly affected by irrigation.

Cultivation – Soil cultivation had a major impact on leaf area. Till treatments had larger size main and lateral leaves, more leaves per shoot (data not shown), more leaf area arising from main and lateral shoots and higher total leaf area per vine (Table 2). The proportion of lateral leaf area to total leaf area was also increased by tilling alternate rows. Leaf area per gram of fruit was 38% for the tilled treatments (Table 2).

Nitrogen – Vines receiving no nitrogen fertilizer had a higher leaf area arising from lateral shoots. Increase in lateral leaf area is a typical response to stress (Candolfi-Vasconcelos, 1990a).

Petiole Analysis

Petiole nutrient content at bloom during the 2001 season reflects treatments implemented during the previous two seasons while véraison nutrient content reflects also current year treatments.

Irrigation – Phosphorus was the only nutrient that increased in response to irrigation at both samplings (Table 3).

Cultivation – Of all the treatments, soil cultivation had the most prominent effect on petiole nutrient concentration. This effect was only seen at véraison (Table 3). Phosphorous, potassium, boron, manganese, and copper were higher on the till treatments.

Nitrogen – Vines receiving foliar nitrogen had lower petiole calcium content at bloom. Soil nitrogen fertilization increased zinc at bloom and manganese at véraison (Table 3). At the véraison sampling, unfertilized vines had lower magnesium concentration as compared to vines receiving foliar or soil applied nitrogen (Table 3).

Yield Components

Irrigated and tilled treatments had higher yields mainly as result of a better fruit set (more berries per cluster) (Table 4). Number of seeds per berry was higher for non-irrigated vines, which must be a result of previous seasons conditions, since pollination occurred before irrigation treatments were applied in 2001. Vines on tilled ground had less shoots per vine (Table 4) but they had larger diameter and longer internodes (Table 6). Bud fertility

Table 2: Leaf area of Pinot noir grapevines at Benton Lane vineyard during the 2001 season

	Main leaves size (cm^2)	Lateral leaves size (cm^2)	Main leaf area / vine (m^2)	Lateral leaf area / vine (m^2)		Total leaf area / vine (m^2)	Lateral leaf area percent of total	Leaf : fruit ratio cm^2 /g fruit
Irrigation								
Irrigated	113	35	3.50	2.69		6.18	40.5	20
Dry	109	30	3.24	2.06		5.30	35.5	21
p-value	ns	*	ns	*		ns	*	ns
Nitrogen								
Zero Nitroge	110	35	3.54	2.95	a	6.50	40.7	21
Foliar Nitrog	108	32	3.18	2.16	b	5.34	37.6	20
Soil Nitroger	115	31	3.39	2.00	b	5.38	35.7	21
p-value	ns	ns	ns	*		ns	ns	ns
Cultivation								
Till	126	38	3.99	3.29		7.28	43.6	24
No Till	96	27	2.75	1.45		4.20	32.4	17
p-value	***	***	***	***		***	***	***
Significant Interactions								
Irrigation * Nitrogen	ns	ns	ns	ns		ns	*	ns
Tilling * Nitrogen		**		**		ns	*	ns
Irrigation * Tilling * Nit	ns	ns	ns	ns		ns	ns	*

ns, *, **, and *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels of probability, respectively

[2] Values followed by the same letter do not differ significantly.

Table 3. Petiole nutrient content at bloom and véraison at Benton Lane Vineyard in 2001.

	P %		K %		Ca %		Mg %		NO3 ppm	
Macronutrients	B	V	B	V	B	V	B	V	B	V
Irrigation										
Irrigated	0.41	0.11	2.5	1.7	1.57	1.05	0.61	0.93	12.8	2.7
Dry	0.37	0.09	2.5	1.6	1.52	1.01	0.65	0.95	12.2	3.4
	*	*	ns	ns	ns	ns	ns	ns	ns	ns
Nitrogen										
Zero Nitrogen	0.41	0.09	2.4	1.7	1.58	1.02	0.63	0.90	11.7	2.8
Foliar Nitrogen	0.39	0.11	2.5	1.7	1.49	1.06	0.63	0.98	10.1	3.1
Soil Nitrogen	0.37	0.08	2.5	1.6	1.57	1.00	0.64	0.94	15.6	3.3
	ns	ns	ns	ns	*	ns	ns	*	ns	ns
Cultivation										
Till	0.39	0.11	2.5	1.8	1.56	1.06	0.64	0.93	13.4	3.0
No Till	0.39	0.08	2.5	1.5	1.53	1.00	0.62	0.96	11.8	3.1
	ns	**	ns	***	ns	ns	ns	ns	ns	ns
Significant Interactions										
Irrigation x Nitrogen	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Irrigation x Tilling	ns	ns	ns	ns	ns	ns	*	ns	ns	ns

	B ppm		Zn ppm		Mn ppm		Cu ppm	
Micronutrients	B	V	B	V	B	V	B	V
Irrigation								
Irigated	43	34	63	56	222	172	12.5	5.8
Dry	42	33	66	58	218	162	12.5	6.0
	ns	ns	ns	ns	ns	ns	ns	ns
Nitrogen								
Zero Nitrogen	42	33	60	53	236	151	12.6	6.2
Foliar Nitrogen	43	34	62	58	226	174	12.2	5.9
Soil Nitrogen	43	33	71	60	195	179	12.7	5.6
	ns	ns	*	ns	ns	**	ns	ns
Cultivation								
Till	42	33	64	58	228	158	12.7	6.3
No Till	43	35	65	56	211	175	12.3	5.5
	ns	**	ns	ns	ns	*	ns	**
Significant Treatment Interactions								
none								

ns, *, **, and *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels of probability, respectively. B and V indicate sampling at bloom and véraison, respectively

Table 4. Yield components of Pinot noir vines at Benton Lane Vineyard in 2001.

	Yield ton/acre		Yield kg/vine		Berries/ cluster		Seeds/ berry		Berry wt. (g)		Cluster wt. (g)		Clusters/ shoot		Shoots/ vine	
Irrigation																
Irrigated	3.0	a	3.1	a	115	a	1.38	a	1.22		139	a	1.4		15.7	
Dry	2.6	b[2]	2.7	b	103	b	1.51	b	1.25		128	b	1.4		15.3	
	*[1]		*		**		**		ns		**		ns		ns	
Nitrogen																
Zero Nitrogen	3.0		3.2		107		1.44		1.26	a	134		1.5		16.0	
Foliar Nitrogen	2.7		2.8		110		1.49		1.19	b	129		1.4		15.4	
Soil Nitrogen	2.6		2.7		110		1.42		1.25	a	137		1.3		15.1	
	ns		ns		ns		ns		*		ns		ns		ns	
Cultivation																
Till	3.0	a	3.2	a	119	a	1.42		1.20	b	142	a	1.4		14.9	b
No Till	2.5	b	2.6	b	99	b	1.48		1.27	a	125	b	1.4		16.1	a
	**		**		***		ns		*		***		ns		*	
Significant Interactions																
Irrigation x Tilling	ns		ns		ns		ns		*		*		ns		ns	

[1] ns, *, **, and *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels of probability, respectively.

[2] Values followed by the same letter do not differ significantly.

(clusters/shoot) was not affected by any of the treatments. Treatments that received foliar nitrogen had lower berry weights. Curiously, berries from the tilled treatments were smaller compared to no till treatments. It has been reported that during fruit ripening, water in the berries can be transferred from the clusters into shoot xylem during the morning and afternoon, in response to transpiration demand. Water is recaptured from the shoot xylem in the later afternoon and evening (Zhang and Luo, 1993). The significantly higher transpiring leaf area on the till treatments (Table 2) may have contributed to reduce the amount of water in the berries.

Fruit Composition during Ripening

Irrigation – Differences in juice soluble solids were very small during the ripening period. However, at harvest, non-irrigated vines had a higher content of soluble solids in the juice (Fig.6.1). At the onset of ripening irrigated vines had a significantly higher pH than non-irrigated vines (Fig. 6.4).

Cultivation – Tilling increased juice soluble solids during early stages of ripening (Fig. 6.2) and induced higher pH at the onset of ripening (Fig. 6.5). These differences leveled out at harvest.

Nitrogen – There was no impact of nitrogen fertilization on juice soluble solids, pH and titratable acidity (Fig. 6.3, 6.6, and 6.9).

Juice Nitrogen Compounds

Tilling treatments had a major impact on the juice amino-acid profiles and other nitrogen sources.

Irrigation – There were no measurable differences due to irrigation on aminoacid profiles, ammonia, or yeast assimilable nitrogen (Table 5).

Cultivation – Aspartic acid, methionine, glutamine, lysine, therionine, and serine, were not affected by till treatments, while all the remaining measured juice nitrogen compounds increased greatly in response to tilling alternate rows (Table 5).

Nitrogen – Juice glyclycine, phenylalanine, nitrogen from free alpha-aminoacids, and total yeast assimilable nitrogen concentrations, were considerably lower for vines receiving no nitrogen fertilizer (Table 5).

Skin and seed phenols

Irrigation – Vines receiving no irrigation tended to have higher levels of skin anthocyanins per berry and per amount of fruit (Figs. 7.1 and 7.4), even though there were no differences on berry weight in response to irrigation (Fig. 6.10). Skin and seed total phenols also tended to be higher on berries from non-irrigated vines (Figs. 7.7 and 7.10).

Cultivation – Berries from tilled treatments had generally lower levels of skin anthocyanins and phenols as well as lower seed phenolic content during the ripening period (Figs. 7.2, 7.5, 7.8, and 7.11). Most of these differences disappeared at harvest. Curiously, skin anthocyanin content per berry of tilled vines was higher during early phases of fruit ripening but after mid-September, this trend was reversed and at harvest, the no-till treatment had higher concentration of anthocyanins per berry (Fig. 7.5). This may reflect changes in berry weight that followed a similar pattern (Fig. 6.11).

Nitrogen – There was little or no impact of nitrogen fertilization on skin and seed phenolic compounds (Fig. 7.6, 7.9, and 7.12). Vines receiving soil nitrogen had higher skin

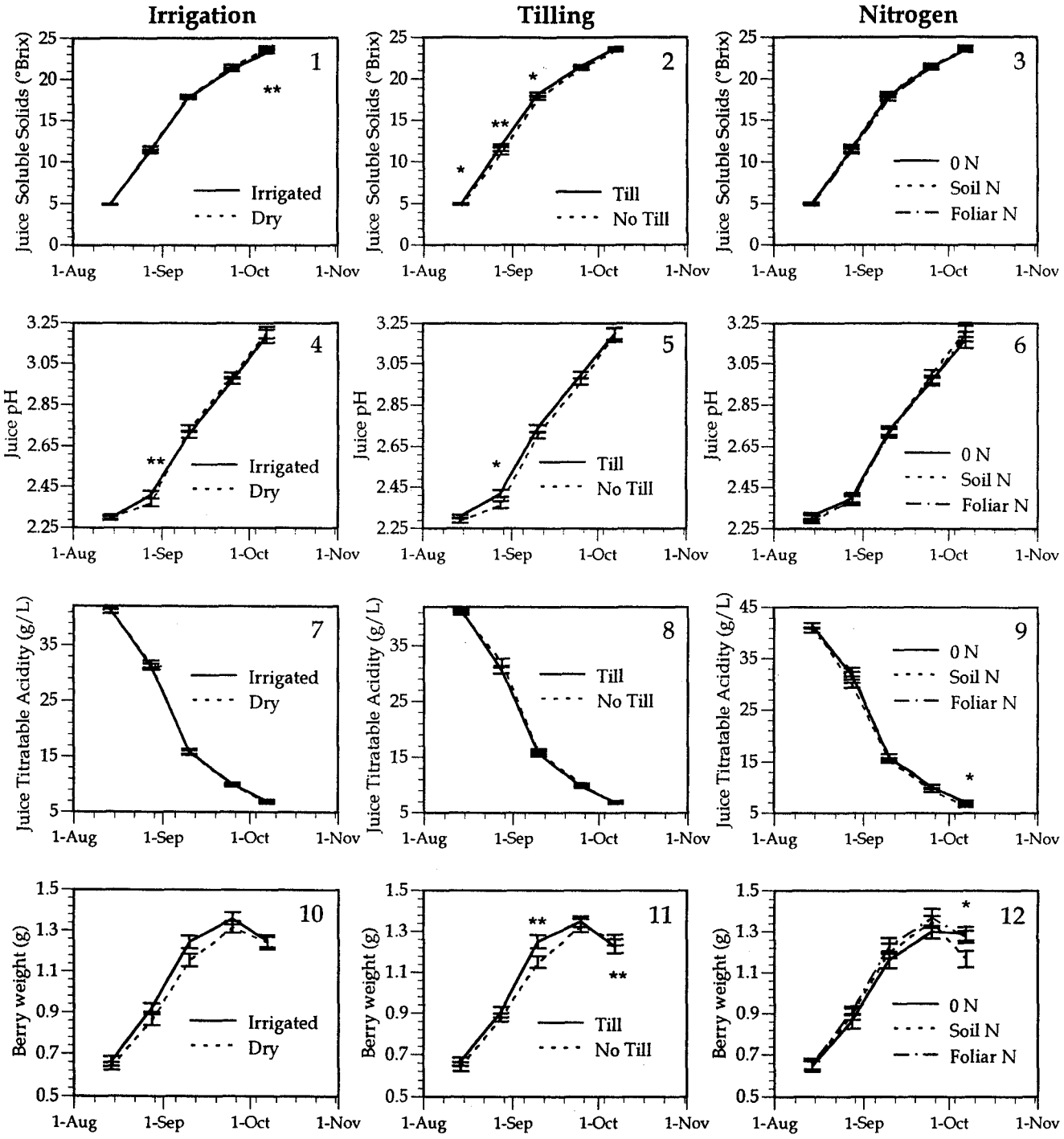

Figure 6: Effect of irrigation, tilling, and nitrogen fertilization on soluble solids (1-3), pH (4-6), titratable acidity (7-9), and berry weights (10-12) of Pinot noir grapevines at Benton Lane vineyard during the ripening period in 2001. Soil nitrogen was applied on May 9; foliar nitrogen was applied Aug. 17 and Aug. 31. Alternate rows were tilled on May 22. Irrigation was applied from Aug. 17 to Sep. 14. Véraison took place on Aug. 31. Vines were harvested on Oct. 7, 2001.

Table 5: Aminoacids, ammonia, and yeast assimilable nitrogen concentration of Pinot noir juice at fruit harvest of the 2001 season. Values are expressed in amount of nitrogen per volume of juice (mg N/L). There were no significant treatment interactions.

	Irrigated	Dry	F	0N	FN	SN	F	Till	No Till	F
Aspartic acid	7.9	8.3	ns[2]	4.1	9.1	9.6	ns	9.1	7.1	ns
Isoleucine	2.6	3.2	ns	2.3	3.0	3.3	ns	3.7	2.2	0.0493
Leucine	3.4	4.1	ns	2.9	4.3	3.8	ns	5.0	2.6	0.0118
Alanine	15.0	15.8	ns	9.2	17.3	17.5	ns	20.7	10.5	0.003
Valine	6.2	6.5	ns	4.6	6.5	7.2	ns	7.3	5.5	0.0278
Arginine	166.7	175.5	ns	116.9	182.5	193.5	ns	208.3	136.4	0.0246
Tirosine	2.1	2.5	ns	1.5	2.7	2.5	ns	3.3	1.5	0.0056
Proline	117.8	123.9	ns	79.1	128.9	138.9	ns	159.2	85.2	0.0047
Glutamic acid	13.1	12.3	ns	11.4	13.2	13.2	ns	15.2	10.5	0.0074
Methionine	1.3	1.5	ns	1.2	1.6	1.3	ns	1.6	1.2	ns
Glutamine	25.9	28.5	ns	19.8	27.5	31.5	ns	31.1	23.5	ns
Glycine	2.9	3.9	ns	1.8 b[3]	3.9 a	3.8 a	0.0341	4.6	2.2	0.004
Lysine	2.3	2.4	ns	2.1	2.7	2.2	ns	2.7	2.0	ns
Histidine	20.1	29.8	ns	15.6	28.6	26.6	ns	30.4	19.5	0.0439
Phenylalanine	2.9	3.8	ns	1.4 b	3.9 a	4.0 a	0.0116	4.6	2.1	0.0023
Therionine	6.4	6.3	ns	4.9	5.6	8.0	ns	7.9	4.9	ns
GABA[1]	4.1	5.3	ns	4.2	3.9	5.8	ns	5.9	3.5	0.033
Serine	9.0	10.9	ns	9.6	10.1	9.9	ns	10.6	9.3	ns
NH_3	32.6	35.8	ns	27.4	35.3	37.3	ns	42.5	26.4	0.0009
N from alpha-aminoacids	292.1	320.6	ns	213.4 b	326.1 a	343.8 a	0.0354	372.1	244.6	0.0076
YANC	324.7	356.5	ns	240.8 b	361.4 b	381.1 a	0.0354	414.6	271.0	0.0054

[1] Gama-Amino Butyric acid

[2] ns, *, **, and *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels of probability, respectively.

[3] Values followed by the same letter do not differ significantly.

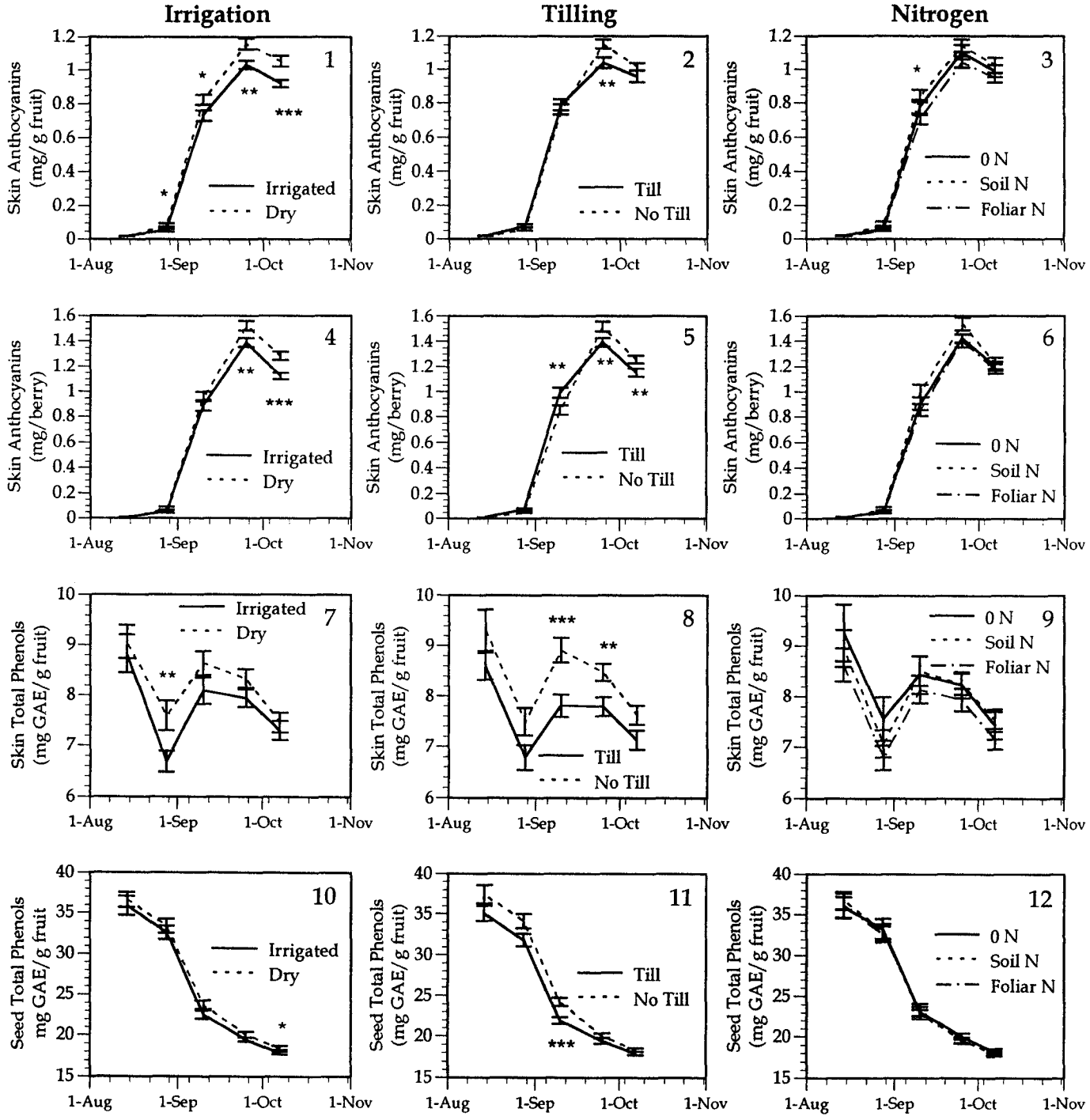

Figure 7: Effect of irrigation, tilling, and nitrogen fertilization on skin anthocyanins (1-6), skin total phenols (7-9), and seed total phenols (10-12) of Pinot noir grapevines at Benton Lane vineyard during the ripening period in 2001. Soil nitrogen was applied on May 9; foliar nitrogen was applied Aug. 17 and Aug. 31. Alternate rows were tilled on May 22. Irrigation was applied from Aug. 17 to Sep. 14. Véraison took place on Aug. 31. Vines were harvested on Oct. 7, 2001.

Table 6: Vine vigor and Ravaz Index of Pinot noir grapevines in the winter of 2001-2002.

		Internode length (mm)	Cane diameter (mm)	Cane wt (g)	Pruning wt (kg/vine)	Ravaz Index (kg fruit/kg prunings)
Irrigation						
	Irrigated	7.4	8.3	60	0.81	4.0
	Dry	6.9	8.0	57	0.75	3.7
		*	ns	ns	ns	ns
Nitrogen						
	Zero Nitrogen	7.4	8.3	56	0.79	3.8
	Foliar Nitrogen	7.2	7.8	58	0.79	4.3
	Soil Nitrogen	7.0	8.2	61	0.78	3.5
		ns	ns	ns	ns	ns
Cultivation						
	Till	7.8	8.7	65	0.91	3.5
	No Till	6.5	7.5	51	0.66	4.2
		***	***	**	***	ns
Significant Treatment Interactions						
none						

ns, **, and *** indicate not significant and statistically significant at the 0.01, and 0.001 levels of probability, respectively.

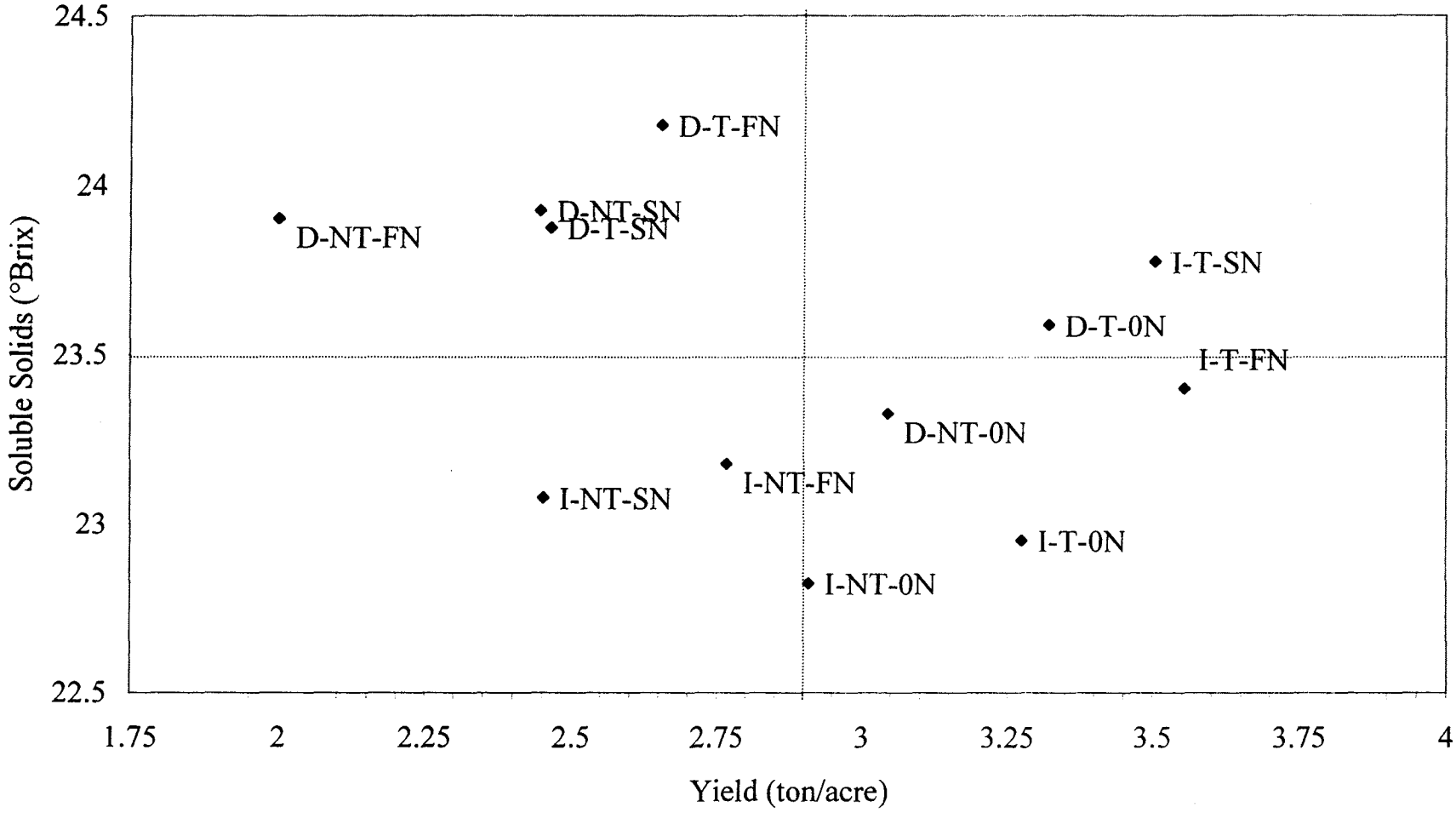

Figure 8. Juice soluble solids at harvest vs. yield of Pinot noir vines at Benton Lane Vineyard in 2001. D=dry; I=irrigated; T=till; NT=no till; 0N=zero nitrogen; FN=foliar nitrogen; SN=soil nitrogen.

anthocyanin content on a weight bases during early ripening but differences did not persist until harvest (Fig. 7.3).

Vine Vigor and Ravaz Index

Irrigation – Dormant canes had longer internodes length in response to irrigation (Table 6). Weight of prunings, cane weight and diameter, and Ravaz Index were not affected by irrigation during the growing season.

Cultivation – Vines on tilled ground were considerably more vigorous than those on no till ground. Ravaz index was not affected by cultivation.

Nitrogen – There was no impact of nitrogen fertilization on dormant cane weight, pruning weight or Ravaz index (Table 6).

Juice Soluble Solids versus Fruit Yield

Figure 8 illustrates the relationship between fruit yield and juice soluble solids for each of the treatment combinations during the 2001 season. There was no clear trend on the combined effects of irrigation, cultivation, and nitrogen fertilization. Non-irrigated vines on no till soil tended to have higher soluble solids and lower yields. The effect of nitrogen was less clear but there was a trend towards higher yields on vines receiving no nitrogen fertilizer.

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