

An Abstract of the Thesis of

Jessica Howe for the degree of Master of Science in Horticulture presented on March 5, 2002. Title: Effect of Soil Moisture Manipulation and Nitrogen Application on Leaf Gas Exchange, Fruit Composition, and Carbohydrate Storage of Pinot noir and Chardonnay Grapevines in the Willamette Valley

Abstract Approved: \_\_\_\_\_

Carmo Vasconcelos

This study integrates various vineyard practices that may improve nitrogen availability to the vine, particularly during ripening. Different strategies aimed at increasing yeast assimilable nitrogen in the fruit at harvest have been evaluated. This study seeks to improve fermentation behavior and wine quality through vineyard practices used for nitrogen management. The focus of this study is to optimize fruit quality and maximize the juice nitrogen fraction, while maintaining a physiologically healthy vine and crop system.

Treatments were applied in a factorial design to vary irrigation, cultivation, and nitrogen application to Pinot noir and Chardonnay grapevines in two commercial Oregon vineyards during the 1999 and 2000 growing seasons. Irrigated vines received supplemental irrigation after lag phase. Cultivation of alternate rows was performed in early spring to encourage nitrogen utilization and reduce nutrient and water competition. Nitrogen treatments consisted of soil-applied urea (39.2kgN/ha), foliar applied urea (2.98kgN/ha), and zero nitrogen. Soil nitrogen

was applied in early spring. Foliar nitrogen was applied once at the onset of ripening and again at véraison. The trials were established at Knudsen Vineyard located in the North Willamette Valley and Benton Lane Vineyard in the South Willamette Valley in 1999.

At Benton Lane Vineyard, photosynthesis, transpiration, water use efficiency, chlorophyll content, maximum quantum yield of photosynthesis, soil moisture, leaf petiole nutrition, pruning weights, and carbohydrate reserves were measured during the 1999 and 2000 growing seasons. Leaf water potentials were measured during the 2000 growing season. During both seasons irrigated vines assimilated CO<sub>2</sub> and transpired at a significantly higher rate than non-irrigated vines. Similarly, tilled treatments assimilated CO<sub>2</sub> at a significantly higher rate and maintained higher water use efficiency. Tilling tended to increase the efficiency of light driven photosynthetic reactions and chlorophyll content. This response became more apparent in the second year of the study, which may indicate a delayed effect of soil cultivation on maximum quantum yield of photosynthesis and chlorophyll content in grapevines. Nitrogen treatments had little impact on leaf gas exchange and chlorophyll content. Soil Cultivation had the largest impact on petiole nutrient content, with significant differences in phosphorus, potassium, manganese, copper, boron, carbon and total nitrogen. Irrigation increased total petiole nitrogen in the second year of the study. Pruning weights increased with cultivation in both years and cane weights were higher after the second year. Irrigation and nitrogen did not affect vine vigor.

Ripening dynamics, juice composition, and yield components were measured at both vineyards during the 1999 and 2000 growing seasons. During both seasons, irrigated Pinot noir vines had lower titratable acidity than non-irrigated vines and tilled treatments had higher soluble solids than non-tilled treatments. Tilled Chardonnay vines had lower soluble solids and higher titratable acidity in 2000. In 1999, from the onset of ripening until harvest, the ammonia content of Pinot noir fruit decreased from an average of 80 to 30 (mg/L) while the alpha amino acid content increased from 60 to 150 (mg/L) during ripening. The YANC of Pinot noir vines increased from 100 to 190 (mg/L), predominately due to a large increase in alpha amino acid concentration in the last two weeks of maturation. For both Pinot noir and Chardonnay, the results from 2000 indicate that tilled treatments tend to have higher YANC at harvest, predominately due to a large increase in alpha amino acids. Significant effects from tilling suggest that there may be a delayed benefit from soil cultivation. Irrigated vines tended to have a higher berry weight, however, yield components differed only slightly between treatments and year.

Effect of Soil Moisture Manipulation and Nitrogen Application on Leaf Gas  
Exchange, Fruit Composition, and Carbohydrate Storage of Pinot noir and  
Chardonnay Grapevines in the Willamette Valley

By

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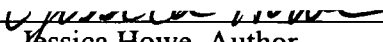
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Jessica Howe, Author

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## Table of Contents

	<u>page</u>
Chapter 1: Introduction	1
Chapter 2: Literature Review	3
Nitrogen	3
Irrigation	8
Cultivation	10
Photosynthesis	12
Transpiration	16
Water Use Efficiency	18
Photosynthetic Electron Transport	18
Leaf Water Potential	20
Vegetative Growth	22
Vine Vigor and Carbohydrate Storage	24
Ripening Dynamics and Fruit Composition	24
Yield Components	28
Chapter 3: Physiological Response to Soil Moisture Manipulation and Nitrogen Application of Pinot noir in the Willamette Valley	
Abstract	31
Introduction	32

## Table of Contents (continued)

	<u>page</u>
Materials and Methods	34
Results and Discussion	41
Chapter 4: The Effect of Soil Moisture Manipulation and Nitrogen Application on Ripening Dynamics, Juice Composition, and Yield Components of Pinot noir and Chardonnay in the Willamette Valley	
Abstract	76
Introduction	77
Materials and Methods	79
Results and Discussion	86
Chapter 5: Conclusions	126
Bibliography	129



## List of Figures

<u>Figure</u>	<u>page</u>
3.1 Seasonal precipitation and irrigation applied at Benton Lane Vineyard in 1999	37
3.2 Seasonal precipitation and irrigation applied at Benton Lane Vineyard in 2000	37
3.3 Effect of irrigation, tilling, and nitrogen fertilization on photosynthesis of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	42
3.4 Effect of irrigation, tilling, and nitrogen fertilization on photosynthesis of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	43
3.5 Effect of irrigation, tilling, and nitrogen fertilization on transpiration of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	45
3.6 Effect of irrigation, tilling, and nitrogen fertilization on transpiration of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	46
3.7 Effect of irrigation, tilling, and nitrogen fertilization on water use efficiency of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	47
3.8 Effect of irrigation, tilling, and nitrogen fertilization on water use efficiency of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	48
3.9 Effect of irrigation, tilling, and nitrogen fertilization on leaf chlorophyll content of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	51

## List of Figures (continued)

<u>Figure</u>	<u>page</u>
3.10 Effect of irrigation, tilling, and nitrogen fertilization on leaf chlorophyll content of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	52
3.11 Effect of irrigation, tilling, and nitrogen fertilization on maximum quantum yield of photosynthesis of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	54
3.12 Effect of irrigation, tilling, and nitrogen fertilization on maximum quantum yield of photosynthesis of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	55
3.13 Soil moisture content at 30cm depth of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	56
3.14 Soil moisture content at 30cm depth of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	57
3.15 Soil moisture content at 60cm depth of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	58
3.16 Soil moisture content at 60cm depth of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	59
3.17 Effect of irrigation, tilling, and nitrogen fertilization on predawn leaf water potential of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	61
3.18 Effect of irrigation, tilling, and nitrogen fertilization on midday leaf water potential of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	62
4.1 Seasonal precipitation and irrigation applied at Benton Lane Vineyard in 1999	82

## List of Figures (continued)

<u>Figure</u>	<u>page</u>
4.2 Seasonal precipitation and irrigation applied at Benton Lane Vineyard in 2000	82
4.3 Seasonal precipitation and irrigation applied at Knudsen Vineyard in 1999	83
4.4 Seasonal precipitation and irrigation applied at Knudsen Vineyard in 2000	83
4.5 Effect of irrigation, tilling, and nitrogen fertilization on juice soluble solids of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	87
4.6 Effect of irrigation, tilling, and nitrogen fertilization on juice soluble solids of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	88
4.7 Effect of irrigation, tilling, and nitrogen fertilization on berry wieght of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	89
4.8 Effect of irrigation, tilling, and nitrogen fertilization on juice pH of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	92
4.9 Effect of irrigation, tilling, and nitrogen fertilization on juice titratable acidity of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	93
4.10 Effect of irrigation, tilling, and nitrogen fertilization on juice titratable acidity of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	94

## List of Figures (continued)

<u>Figure</u>	<u>page</u>
4.11 Effect of irrigation, tilling, and nitrogen fertilization on juice pH of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	96
4.12 Effect of irrigation, tilling, and nitrogen fertilization on juice soluble solids of Chardonnay grapevines at Knudsen vineyard during the 1999 growing season	97
4.13 Effect of irrigation, tilling, and nitrogen fertilization on juice titratable acidity of Chardonnay grapevines at Knudsen vineyard during the 1999 growing season	98
4.14 Effect of irrigation, tilling, and nitrogen fertilization on juice soluble solids of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season	99
4.15 Effect of irrigation, tilling, and nitrogen fertilization on juice titratable acidity of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season	100
4.16 Effect of irrigation, tilling, and nitrogen fertilization on juice pH of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season	101
4.17 Effect of irrigation, tilling, and nitrogen fertilization on juice pH of Chardonnay grapevines at Knudsen vineyard during the 1999 growing season	103
4.18 Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from ammonia of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	104

## List of Figures (continued)

<u>Figure</u>	<u>page</u>
4.19 Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from alpha-amino acids of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	105
4.20 Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen as yeast assimilable nitrogen (YANC) of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season	106
4.21 Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from ammonia of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	107
4.22 Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from alpha-amino acids of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	108
4.23 Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen as yeast assimilable nitrogen (YANC) of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	109
4.24 Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from ammonia of Chardonnay grapevines at Knudsen vineyard during the 1999 growing season	111
4.25 Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from alpha-amino acids of Chardonnay grapevines at Knudsen vineyard during the 1999 growing season	112
4.26 Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen as yeast assimilable nitrogen (YANC) of Chardonnay grapevines at Knudsen vineyard during the 1999 growing season	113
4.27 Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from ammonia of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season	115

## List of Figures (continued)

<u>Figure</u>	<u>page</u>
4.28 Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from alpha-amino acids of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season	116
4.29 Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen as yeast assimilable nitrogen (YANC) of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season	117
4.30 Effect of irrigation, tilling, and nitrogen fertilization on berry wieght of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season	120
4.31 Effect of irrigation, tilling, and nitrogen fertilization on berry wieght of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season	125

## List of Tables

<u>Table</u>	<u>page</u>
3.1 Main factors and treatment combinations at Benton Lane Vineyard for 1999 and 2000	35
3.2 Leaf area of Pinot noir grapevines at Benton Lane Vineyard in 1999	64
3.3 Vine vigor and Ravaz Index of Pinot noir grapevines at Benton Lane Vineyard in 1999 and 2000	65
3.4a Petiole nutrient content during bloom at Benton Lane Vineyard in 1999	67
3.5a Petiole nutrient content during bloom at Benton Lane Vineyard in 2000	68
3.4b Petiole nutrient content during veraison at Benton Lane Vineyard in 1999	70
3.5b Petiole nutrient content during veraison at Benton Lane Vineyard in 2000	71
3.4c Petiole nutrient content during veraison at Benton Lane Vineyard in 1999	72
3.6 Wood carbohydrate reserves of Pinot noir vines at Benton Lane Vineyard in 1999	74
3.7 Wood carbohydrate reserves of Pinot noir vines at Benton Lane Vineyard in 1999	75
4.1 Main factors and treatment combinations at Benton Lane and Knudsen Vineyards for 1999 and 2000	81
4.2a Yield components of Pinot noir at Benton Lane Vineyard in 1999	90
4.2b Yield components of Pinot noir at Benton Lane Vineyard in 2000	121

List of Tables (continued)

<u>Table</u>	<u>page</u>
4.3a Yield components of Chardonnay at Knudsen Vineyard in 1999	122
4.3b Yield components of Chardonnay at Knudsen Vineyard in 1999	124



# **Effect of Soil Moisture Manipulation and Nitrogen Application on Leaf Gas Exchange, Fruit Composition, and Carbohydrate Storage of Pinot noir and Chardonnay Grapevines in the Willamette Valley**

## **Chapter 1**

### **Introduction**

Wine quality is essential to both winemakers and grape growers. Thus, optimization of vine health and fruit quality is among the top priorities of premier grape growing and winemaking establishments.

Commercial Oregon must samples have often been shown to contain lower than adequate levels of fermentable nitrogen at commercial ripeness (Watson *et al.*, 2000). At harvest, low levels of yeast assimilable nitrogen in grape clusters may affect fermentation behavior and be deleterious to the quality of the finished wine (Kunkee, 1991; Butzke, 1998).

In nitrogen deficient musts, sulfate and sulfite tend to be reduced to sulfide as yeast synthesize sulfur-containing amino acids (Zoecklein *et al.*, 1999).

Henschke and Jiranek (1991) suggest that in nitrogen deficient musts, sulfite reduction is the major source of H<sub>2</sub>S, an undesirable odor-active compound.

This study integrates various vineyard practices that may improve nitrogen availability to the vine, particularly during ripening. Different strategies aimed at optimizing nitrogen partitioning to the fruit have been evaluated. This study seeks to improve fermentation behavior and wine quality through vineyard practices used

for nitrogen management. The focus of this study is to optimize fruit quality and maximize the juice nitrogen fraction, while maintaining a physiologically healthy vine and crop system.

## Chapter 2

### Literature Review

#### Nitrogen

Nitrogen is a primary constituent of plant components such as proteins, enzymes, nucleic acid, chlorophyll, and vitamins (Beevers, 1976; Wermelinger, 1991; Winkler *et al.*, 1974). Nitrogen is essential in grapevine establishment and maintenance, fruit quality, and the conversion of grape juice to wine. Nitrogen alters plant composition more than any other mineral nutrient (Marschner, 1995; Roubelakis-Angelakis and Kliewer, 1992; Wermelinger, 1991). When nitrogen is suboptimal, the vine has poor vegetative growth, premature senescence of older leaves, limited fruit bud formation, and poor fruit production. Increases in nitrogen supply not only delay senescence but may change plant morphology. Excess 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; Löhnertz, 1991; Roubelakis-Angelakis and Kliewer, 1992; Winkler *et al.*, 1974). Thus, fruit quality may be affected due to abundant or insufficient available nitrogen.

### Nitrogen uptake

In grapevines, nitrogen originates either directly from available soil nitrogen, or indirectly from the mobilization of nitrogen stored as reserve material in the permanent structure of the vine (Löhnertz *et al.*, 2000). Efficient nitrogen uptake occurs during periods of active growth and depends on active photosynthesis (Huett, 1996). In higher plants, nitrogen is taken up as either ammonium or nitrate (Hall and Rao, 1994; Marshner, 1995). Nitrate is a highly mobile nutrient whereas ammonium is less mobile (Marshner, 1995). Ammonium is incorporated into organic compounds that are used by plants and may be derived from primary nitrogen sources and metabolic pathways such as photorespiration and/or deamination of amino acids and other nitrogenous compounds (Milfin and Lea, 1980; Lea *et al.*, 1990; reviewed by Loulakakis and Roubelakis-Angelakis, 1997). Nitrate must be reduced to ammonium in order to be incorporated into organic structures and fulfill its essential functions as a plant nutrient (Marshner, 1995).

### Seasonal grapevine nitrogen requirement and partitioning

During grapevine dormancy, total soluble nitrogen increases in the roots and reaches a maximum just prior to budbreak (Conradie, 1983, 1991; Wermelinger, 1991; Kubota and Kakedai, 1992; reviewed by Roubelakis-Angelakis and Kliewer, 1992). After budbreak, total nitrogen in the shoots

increases and remains stable until the end of the vegetative growth period. At the end of the main vegetative growth period there is another increase of nitrogen in the shoots. This increase is due to senescing leaves retranslocating nitrogen back to the permanent vine structure (Williams, 1987; Wermelinger, 1991; reviewed by Roubelakis- Angelakis and Kliewer, 1992). Leaves achieve the maximum amount of nitrogen at full leaf expansion and remain constant until leaf senescence and nitrogen retranslocation begin. Total leaf nitrogen exceeds total shoot nitrogen for most of the season (Löhnertz, 1991; reviewed by Roubelakis- Angelakis and Kliewer, 1992; reviewed by Keller, 1998). Growing shoots serve as a nitrogen sink until the end of the main vegetative growth. After the main vegetative growth period, shoots become a nitrogen source for leaves and young inflorescences until the beginning of maturation. Shoots once again become a sink, during retranslocation, just prior to grapevine dormancy (Löhnertz, 1988; Wermelinger, 1991; reviewed by Roubelakis-Angelakis and Kliewer, 1992). The total amount of nitrogen in a young inflorescence 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; Löhnertz, 1991; Williams and Biscay, 1991; reviewed by Roubelakis- Angelakis and Kliewer, 1992; Wermelinger, 1991; reviewed by Keller, 1998).

In grape clusters, nitrogen is found primarily as ammonium cations and organic compounds such as amino acids, hexose amines, peptides, nucleic acids

and proteins. Trace amounts of nitrate are found in grape berries (Winkler *et al.*, 1974). As maturation occurs, organic nitrogen increases and ammonia decreases (Beevers, 1976; Winkler *et al.*, 1974; Wermelinger, 1991). The synthesis of amino acids, peptides, and protein, occur during the last 6-8 weeks of berry ripening (reviewed by Roubelakis-Angelakis and Kliewer, 1992; Wermelinger, 1991; Löhnertz *et al.*, 2000).

There are two phases of intense nitrogen incorporation in the fruit (reviewed by Wermelinger, 1991). The first takes place during two weeks prior to the “pea-size” stage of berries. The second starts one month later at véraison and lasts an additional two weeks (Löhnertz, 1988; Winkler *et al.*, 1974; reviewed by Wermelinger, 1991). The amount of nitrogen in the clusters at harvest has been measured intensively. Container studies using  $^{15}\text{N}$  indicate that 34% of the total nitrogen at harvest is recovered in the clusters (Conradie, 1980 and 1991). The results of container studies have been similar with results from field trials which report that approximately 40-44% of total available nitrogen is present in the fruit at harvest (Alexander, 1957; Conradie, 1991; Gutierrez, 1985). Of the total fruit nitrogen, only 20% is found in the juice. The remaining 80% is found in the skin and seeds. Only 50% of the nitrogen present in the juice (10% of total fruit nitrogen) is in the form of free amino acids (Peynaud, 1970; Winkler *et al.*, 1974). The timing of harvest strongly influences the concentration and form of nitrogen

present in grapes. Early harvests in cool climates have resulted in decreased amino acid content in grapes (Löhnertz *et al.*, 2000).

### Nitrogen application

By altering the amount of nitrogen applied and the timing and method of application, plants can be managed for both optimum vigor and nitrogen concentration in various tissues (Khemira *et al.*, 1998).

*Soil available nitrogen* - In order to meet the nutrient demand of grapevines, nutrients in the soil must reach the root surface (Marshner, 1995). The concentration of nutrients in the soil solution is therefore important for nutrient supply to the roots. Soil solution mineral nutrient concentration depends on soil type, soil moisture, soil depth, pH, cation-exchange capacity, redox potential, quantity of soil organic matter and microbial activity, aeration, leaching, time of year, and fertilizer application (Marshner, 1995; Sanchez *et al.* 1990).

*Foliar applied nitrogen* - Foliar application of fertilizer supplies nutrients to higher plants more rapidly than soil application. It is beneficial to use foliar nutrient applications when the topsoil is dry, there is low nutrient availability in the soil, or there is a decrease in root activity during the reproductive stage (Marschner, 1995). Decreased root activity during grapevine ripening results from sink competition for carbohydrates (Conradie, 1991). This commonly occurs in plants when nutrient uptake by the roots declines with the onset of the reproductive stage

and maturity, making less nutrients available to the entire plant (Marschner, 1995). Foliar application of nutrients, specifically nitrogen, has improved the quality of some crops when applied at later stages of growth when root activity might be low. Nitrogen supplied to wheat and other cereals during maturation is rapidly translocated from the leaves and directly transported to the developing grains. This results in increased protein concentration at harvest (Powlson *et al.*, 1989).

However, supplying nutrients by foliar application has limitations and problems. Such limitations 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 possible necrosis and burning of the leaves (Powlson *et al.*, 1993).

## **Irrigation**

In Oregon, grapevines are subject to low soil water availability, accompanied by high levels of solar irradiance, temperature, and air vapor pressure deficits during the summer. The combination of water stress with high light and temperatures has been reported to cause progressive reduction in vine growth, fruit quality, and amino acid concentration in grapes (Löhnertz *et al.*, 2000; Escalona *et al.*, 1997; Kliewer *et al.*, 1983). It is suggested that optimum growth, yield, and quality can be obtained by integration of controlled irrigation during certain phenological stages of vine growth (Matthews *et al.*, 1990; Van Zyl, 1984).



In grapevines, there is low vine water demand at the beginning of shoot growth and at the end of the vegetative cycle when leaf senescence begins. There is high water demand when the canopy is fully developed (Reviewed by Gómez-del-Campo *et al.*, 1997). In spite of grapevines having a deep root system, severe grapevine water stress may occur during ripening (Chaves and Rodrigues, 1987). Low soil water content in the topsoil impairs root elongation and can inhibit actively growing root tips, resulting in a decrease in nutrient uptake (Van Zyl, 1984; Marshner, 1995).

When compared to other fruit crops, grapevine survival under non-irrigated conditions involves root spatial distribution and the ability to extract water from a large volume of soil (Winkler *et al.*, 1974). Survival also involves the grapevines ability to change leaf orientation to minimize heat load (Smart and Coombe, 1983). The grapevines ability to decrease water loss by changing stomatal conductance is also necessary for survival (Naor *et al.*, 1994; reviewed by Naor and Bravdo, 2000).

There are stomatal and non-stomatal effects in photosynthesis of grapevines in response to soil water deficit (Escalona *et al.*, 1999). Stomatal effects are due to stomatal closure, which decreases CO<sub>2</sub> availability in the mesophyll. Non-stomatal effects may occur when water stress affects mesophyll metabolism and consequently reduces photosynthetic capacity (reviewed by Escalona *et al.*, 1999).

The changes in tissue nitrogen concentration observed in water-stressed plants imply that dehydration does affect nitrogen metabolism (Kramer and Boyer, 1995). In cool climates, an increase in temperature and a decrease in soil water availability during ripening results in very low amino acid concentration in grapes at harvest (Löhnertz *et al.*, 2000). Löhnertz and coworkers (2000) suggest that the duration of limited soil water availability strongly influences the amino acid concentration in the fruit.

## **Cultivation**

Water availability, mineralization rate of soil nitrogen, and plant uptake of soil available nitrogen may override the effect of nitrogen fertilizers (reviewed by Rupp, 1996). In clean cultivated vineyards, about 100 kg of nitrogen can be mobilized per hectare in one year. In vineyards with ground cover, the mobilizable nitrogen can be four times higher (Perret *et al.*, 1992). Tilling can effectively be used to optimize mineralization of nitrogen and increase soil water availability (reviewed by Rupp, 1996).

There are many benefits to soil cultivation. Soil tillage increases microbial activity, accelerating decomposition of organic matter and mineralization of organic nitrogen (Schaller, 1991). In addition, soil cultivation has been shown to increase amino acid concentration in grapes during ripening (Löhnertz *et al.*, 2000). However, the effects of cultivation are highly variable and depend on soil texture,

seasonal rainfall, irrigation, the presence of root-limiting soil horizons, and the type of crop being grown (Holt and Smith, 1998). Soil physical, chemical, and biological properties are greatly altered by soil cultivation (reviewed by Holt and Smith, 1998).

In general, the nitrogen demand of grapevines is met in a conventionally tilled vineyard. If additional permanent grass cover is present in the vineyard, a nitrogen shortage may develop shortly after budburst (reviewed by Schaller, 1991). Schaller (1991) suggests that nitrate transport to deeper soil layers is greater in tilled soils than in non-tilled soils. Nitrate leaching is found to be less under no-till conditions (Kanwar *et al.*, 1985). Under no-till conditions, much of the water flows through macropores to the subsoil, leaving most of the remaining nitrate distributed throughout the soil surface. Under conventional tillage, no large macropores or channels leading from the soil surface to the subsoil are present. Thus, the infiltrating water moves down the soil profile as a front, carrying the nitrate with it (Schaller, 1991).

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.* (1992) suggest mowing or tilling alternate rows of the cover crop two to three weeks before bloom when the grapevines maximum N-uptake rate occurs. Schaller and co-workers (1991) found that, from the beginning of April

to the end of May in Germany, soil water is depleted in the root zone (0-40cm) until the wilting point. When this occurs, 20% of the plant-available water can be found from 0-80cm in the soil. They suggest that excessive loss of soil water is mainly due to the competing consumption of the cover crop.

In annual crop systems such as maize, soybean, sunflower, and wheat, it has been reported that soil cultivation has little or no effect on nutrient uptake (Barber and Navarro, 1994).

### **Photosynthesis**

Plant productivity depends on photosynthesis. Photosynthesis is the process by which plants synthesize organic compounds from inorganic raw materials in the presence of sunlight (Hall and Rao, 1994; Salsbury and Ross, 1991). The quality and quantity of incident light (PAR), temperature, availability and utilization of water and mineral nutrients, and photorespiration are all factors that affect plant productivity (Hall and Rao, 1994).

### **Nitrogen and photosynthesis**

The availability of fixed nitrogen is a contributing factor to plant productivity (Hall and Rao, 1994). Nitrogenous compounds, especially proteins, are required for all photochemical and biochemical processes of photosynthesis (Hall and Rao, 1994; reviewed by Cheng, 1999).

Grapevine photosynthetic capacity is dependent on total leaf nitrogen. Approximately 75-80% of the leaf nitrogen is associated with chloroplasts in C3 plants (Buchanan *et al.*, 2000). In fruit crops such as apple, peach, and grape, photosynthetic capacity and leaf nitrogen per unit area are highly correlated (reviewed by Cheng, 1999; and McDonald and Davies, 1996). The nitrogen status of the leaf directly influences its protein and enzyme content and thereby affects the rate of photosynthesis (Hall and Rao, 1994; reviewed by Cheng, 1999). Net photosynthetic rate has been shown to be lower when nitrogen application rates are reduced in a given cropping system (Gay-Eynard *et al.*, 2000; reviewed by McDonald and Davies, 1996). In addition, nitrogen deficiency reduces leaf chlorophyll content which is highly correlated to photosynthetic capacity (Huett, 1996).

Because fruit stimulates leaf photosynthetic rate through its role as a strong carbohydrate sink, the photosynthetic capacity of leaves is most enhanced by providing an adequate nitrogen supply to exposed leaves when fruit is present (Löhnertz *et al.*, 2000). Alternatively, removal of fruit can lead to carbohydrate accumulation in the leaves, which provides a negative feedback to photosynthesis (reviewed by Huett, 1996).

### Irrigation and photosynthesis

The photosynthetic metabolism of plants is robust. However, when water deficit becomes severe, the photosynthetic capacity of plants can be hindered (Kramer and Boyer, 1995). Water is a major limiting factor for photosynthesis in many environments. Most metabolic stages in the photosynthetic process can be inhibited by dehydration (Kramer and Boyer, 1995).

Reduced photosynthesis of water stressed plants can be caused by stomatal closure, and/or an altered pathway of photosynthetic processes (reviewed by Peterlunger *et al.*, 1997; and Flexas *et al.*, 1999). It has been reported that stress-induced photosynthetic reduction is due initially to stomatal closure, but that with prolonged stress there is an effect on non-stomatal components of photosynthesis, especially in the rates of key enzyme activity (reviewed by Smart and Coombe, 1983). Reports that stomatal control explain most of the observed decrease in leaf photosynthesis exist (reviewed by Peterlunger *et al.*, 1997). However, water stress involves both photochemical and biochemical changes in the photosynthetic machinery. Other reports suggest that the decay in carboxylation efficiency, measured under water stress and high light intensity, might be explained by a reduction of the maximum rate of Rubisco activity, photosynthetic electron transport, and photochemical quenching (Kaiser, 1987; reviewed by Peterlunger *et al.*, 1997).

The effects of water stress involve reactions at intracellular, cellular, and tissue levels. One of the most significant responses to water deficit is a decrease in the stomatal aperture, which enables the plant to alleviate adverse conditions of water status (Kramer and Boyer, 1995). It is reported that following depletion of soil available water, an immediate reduction in stomatal conductance is usually observed (reviewed by McDonald and Davies, 1996; Kramer and Boyer, 1995). A decrease in the stomatal aperture also reduces the uptake of CO<sub>2</sub> and hence photosynthesis (Kramer and Boyer, 1995; Smart, 1974). However, non-stomatal effects on photosynthesis have been observed also. In container grown grapevines, changes in mesophyll resistance, photoinhibition and photochemical capacity were found to be determinant of an important part of the water stress induced reduction of photosynthesis (Liu *et al.*, 1978; Correia *et al.*, 1990).

Photosynthesis is markedly reduced in water-stressed grapevines (Rodrigues *et al.*, 1993; Schultz, 1996; Naor and Bravdo, 1993). Down regulation of photosynthesis occurs when water potential begins to drop (McDonald and Davies, 1996). When studying Shiraz grown under field conditions, Kriedemann and Smart (1971) found that photosynthesis declined at leaf water potentials below -0.5 MPa and fell close to zero from -1.3 to -1.5 MPa. Non-irrigated vines were found to photosynthesize 40-50% less than irrigated vines, but never cease photosynthesizing completely (Kriedemann and Smart, 1971; Escalona *et al.*, 1999).

## **Transpiration**

Transpiration is the evaporation of water from cell surfaces into intercellular spaces and its consequent diffusion out of plant tissue (Kramer and Boyer, 1995). Transpiration occurs most commonly through the stomata and cuticle of woody plants (Kramer and Boyer, 1995; Salsbury and Ross, 1991). Transpiration can be a disadvantageous consequence of CO<sub>2</sub> assimilation, in that it results in loss of water from the plant. Alternatively, transpiration can be advantageous to a plant due to its cooling mechanism of leaf tissue (Salsbury and Ross, 1991).

## **Nitrogen and transpiration**

Nitrogen uptake is independent of transpiration (Shaner and Boyer, 1976). Shaner and Boyer (1976) found that transpiration has little effect on nitrogen uptake by roots in low external solution concentrations, but has a significant effect when the external concentrations are high. Thus, as transpiration varies, nutrient solute depletion or accumulation zones may occur around the root system.

When transpiration is rapid, the concentration of incoming nitrogen is low because water dilutes the xylem solution. Consequently, root ion uptake is rapid due to opposing concentration gradients that are small inside the root (Kramer and Boyer, 1995). When transpiration is slow, nitrogen concentrations build up to high levels in the xylem because metabolically driven ion uptake proceeds even though



water flow is slow (Kramer and Boyer, 1995). As xylem nutrient concentrations are built up, root uptake can be inhibited (Shaner and Boyer, 1976; Kramer and Boyer, 1995). High soil concentrations of mineral nutrients promote high xylem concentration and increase the tendency for transpiration to affect ion uptake (Shaner and Boyer, 1976).

### Irrigation and transpiration

When transpiration occurs, and soils dry out, a critical soil moisture deficit is reached. It is from this point on that it is thought to be very difficult for plants to extract any remaining water in the profile (Trought and Naylor, 1988). At a critical soil moisture deficit, a plant will conserve water by stomatal closure. Besides affecting photosynthesis, stomatal closure will also result in a decrease in transpiration (Reynolds and Naylor, 1994).

Transpiration plays a very important role in maintaining leaf temperature. Increased leaf temperature usually results when high stomatal resistance inhibits transpiration. In cool climates, leaf temperatures over 30°C have been shown to depress photosynthesis (Kriedemann and Smart, 1971). Millar (1972) found that leaf temperature of water stressed vines were 7°C higher than irrigated vines.

## **Water Use Efficiency**

Water use efficiency is the ratio of carbon acquired per unit of water loss (Schultz, 2000). Relative water use efficiency of a plant can be used to determine how dry matter production will be affected by water availability (Kramer and Boyer, 1995).

Stomatal closure is the dominant factor changing water use efficiency during water deficit (Naor and Bravdo, 2000). Thus, changes in water use efficiency affect the photosynthetic apparatus. Water use efficiency has been described as an integrator of other physiological mechanisms, such as osmoregulation, reduction in leaf area, and hormonal signals from the roots which control stomata and photosynthesis (Schultz, 2000).

Briggs and coworkers (1914), suggest that water use efficiency does not differ under varying availability of soil water. They suggest that water use efficiency is more determined by species, climate, season, and mesoclimate conditions. This work has been supported by more recent work (reviewed by Kramer and Boyer, 1995).

## **Photosynthetic Electron Transport**

Chlorophyll pigments are responsible for giving plants their characteristic green color and capturing light quanta. They are one of three major classes of

organic pigments in photosynthetic organisms that are capable of absorbing visible radiation which will initiate the photochemical reactions of photosynthesis (Hall and Rao, 1994). Chlorophyll fluorescence occurs when a molecule of chlorophyll becomes excited to a higher energy state with the absorption of light. Chlorophyll fluorescence is used to quantify photosynthetic efficiency (Schreiber *et al.*, 1994; Genty *et al.*, 1989).

#### Nitrogen and quantum yield

Although leaf nitrogen concentration and chlorophyll content are directly proportional, light absorption and chlorophyll content are not (reviewed by Cheng, 1999). When chlorophyll content decreases, it has a relatively small effect on light absorption at the absorption peaks of chlorophyll. A decrease in chlorophyll content has a large effect in the far-red region where the chlorophyll absorption coefficient is low (reviewed by Cheng, 1999).

An *in vivo* balance between rubisco activity and electron transport exists and is maintained when leaf nitrogen concentrations are altered. This balance can be described by the A/Ci curves of leaves with varying nitrogen content (reviewed by Cheng, 1999). However, the effect of leaf nitrogen on quantum yield and actual photosynthetic efficiency has not been closely examined.

### Irrigation and quantum yield

Evidence suggests that whole chain electron transport and related processes are very resistant to leaf water deficit. The apparent maximum quantum yield of photosynthesis does not vary much in most species over a range of 30-40% leaf water deficit (reviewed by McDonald and Davies, 1996). This may be a stomatal or non-stomal response. Flexas *et al.* (1998) report that down regulation of photochemical reactions is low and that water stress does not induce photoinhibition in field-grown grapevines, even when stomatal conductance and photosynthesis are reduced.

### **Leaf Water Potential**

Leaf water potential is a commonly used indicator of plant water stress. The water potential of any given system is the chemical potential of water, expressed in units of pressure and compared with the chemical potential of pure water at atmospheric pressure (Salsbury and Ross, 1991). Under Australian conditions, Smart (1974) demonstrated that diurnal changes of grapevine leaf water potential follow a general pattern, due primarily to the diurnal variation in solar radiation and temperature. Because of these diurnal variations, leaf water potential begins to decrease rapidly in the early morning. This decrease is associated with stomatal opening in response to increased light, and continues to fall until about midday. In late afternoon leaf water potential begins to increase (Smart, 1974).

### Irrigation and leaf water potential

Decreased soil moisture availability is known to reduce leaf water potential (reviewed by Naor and Bravdo, 2000; Escalona *et al.*, 1999). Some studies suggest that as leaf water potential drops, photosynthesis and stomatal conductance decrease (Escalona *et al.*, 1999). Other studies suggest that stomatal conductance is not always affected by leaf water potential. Naor and Bravdo (2000) observed that stomatal conductance of non-irrigated Concord vines decreased as leaf water potentials decreased. At the same time, stomatal conductance of irrigated vines did not respond to any decreases in leaf water potential. However, studies indicate that as leaf water potential drops, water use efficiency decreases (Escalona *et al.*, 1999; Naor and Bravdo, 2000).

Smart (1974) found that the ambient environment, especially solar radiation, had a dominating effect on leaf water potential. Water stress induced stomatal closure was observed at water potentials of -1.3 MPa, though shoot growth rate was inhibited before negative tensions became that large. Matthews and co-workers (1987) found that withholding irrigation after véraison decreased leaf water potential approximately -0.1 Mpa per week until just before harvest.

## **Vegetative Growth**

### Nitrogen and vegetative growth

A plants response to excessive nitrogen may involve a stimulation of vegetative growth, accompanied by low fruit yield (reviewed by Huett, 1996). The nature of deciduous crops is that they have relatively distinct growth phases for storage and mobilization of nitrogen assimilates (Sanchez *et al.*, 1992). Thus, vegetative response to nitrogen is highly dependent on the time at which nitrogen is available. To a certain extent, vegetative growth is desirable as leaves serve as major sources of amino acids (Löhnertz *et al.*, 2000) and carbohydrates (Winkler *et al.*, 1962).

### Irrigation and vegetative growth

Irrigation has been shown to affect vegetative growth of grapevines. The combination of soil water deficit with climatic constraints such as high leaf-air vapor tension, high light, and high temperatures can cause a progressive reduction of vine growth (Kliewer *et al.* 1983; Chaves and Rodrigues, 1987; Schultz, 1996).

Vines subjected to extensive water stress tend to have reduced shoot length, reduced shoot number, and smaller leaf size (Reynolds and Naylor, 1994). Shoot growth has been shown to be suppressed by water stress during bud burst until flowering (Van Zyl, 1984). The growth of vegetative organs, such as internodes, leaves, and tendrils, are inhibited initially at soil water potentials of  $-0.065$  MPa

and cease completely at  $-0.54$  MPa (Schultz and Matthews, 1988). The sensitivity of growth to water deficits have not been found to differ among shoot organs (Schultz and Matthews, 1988).

Schultz and Matthews (1988) demonstrated that the region along the shoot in which organs expand is reduced during water deficits. Similarly, the regions within organs in which growth occurs diminishes as water deficits develop. Although growth is inhibited in all tissues, inhibition is complete in older tissues while some growth is maintained in younger tissues (Schultz and Matthews, 1988). Thus, the sensitivity of growth to water deficits increases with ontogeny.

Irrigation during the later part of the season can cause continued active growth in grapevines, sometimes even from lateral shoots. Additional growth during this time is undesirable since it delays ripening due to competition with fruit for assimilates or to shading of fruit by leaves (Hepner *et al.*, 1985). The restricted vegetative growth of non-irrigated vines reduces shade in the canopy, leaving the fruit more exposed to direct solar radiation (Millar, 1972).

Regulated Deficit Irrigation (RDI) is a strategy based on the concept that vegetative growth can be limited by low plant water potentials during particular periods of ripening (Mitchell *et al.*, 1984). The RDI strategy has received much attention because of its potential for limiting excessive vegetative growth while increasing water use efficiency (Girona *et al.*, 1993). Another related concept is that shoot growth is integrally linked with root growth. Thus, restricting root

growth, through water deficit, will result in restricted shoot growth (Chalmers *et al.*, 1983).

### **Vine Vigor and Carbohydrate Storage**

Pruning weight, the weight of wood removed at dormant pruning, is a common viticultural measurement used to determine vine vigor and fruit/shoot ratio (reviewed by Smart and Coombe, 1983).

Carbohydrate reserves have been found in several parts of the vine, especially the permanent wood of the trunk and arms (Winkler *et al.*, 1974). It is generally thought that these reserves may be available for rapid movement to the fruit at the beginning of ripening. Candolfi-Vasconcelos and coworkers (1996) reported that grapevines do not use these reserves during ripening unless they undergo stress. Candolfi-Vasconcelos and Koblet (1990) report a positive correlation between sugar concentration of must and starch concentration of the vines permanent structure.

### **Ripening Dynamics and Fruit Composition**

The ripening stage in grapes extends from the beginning of ripening (the turning point in the development of the berries) until the grapes are ripe for their given purpose (Winkler *et al.*, 1974). Variety, rootstock, seasonal conditions, and



vineyard management influence the rate at which ripening will occur (Winkler *et al.*, 1974).

The chemical composition of the fruit is made up of sugars, acids, pH, color pigments, tannins, pectins, aroma and flavor constituents, enzymes, vitamins and minerals, and nitrogenous compounds (Winkler *et al.*, 1974). Sugars, titratable acid, pH, and nitrogenous compounds all play a very important role in fermentation, yeast nutrition, and overall wine quality (Zoecklein *et al.*, 1999)

#### Effect of nitrogen on ripening dynamics and fruit composition

Nitrogen partitioning to the expanding fruit begins after bloom (Wermelinger, 1991). Nitrogenous compounds, especially amino acids, increase with fruit maturity (Kliewer, 1969; Kliewer, 1968; Winkler *et al.*, 1974). The specific amino acids present in the fruit at harvest, and their relative concentrations, influence the rate of fermentation by yeast and the formation of higher alcohols in wines (reviewed by Kliewer, 1970).

#### Effect of irrigation on ripening dynamics and fruit composition

It is unclear exactly how irrigation affects ripening dynamics and fruit quality. In general, research supports that the major effects of irrigation on yield and quality are indirect via modifications of vegetative growth and crop load (Noar *et al.*, 1993; Noar and Bravdo, 2000). There are contradictory results as to whether

irrigation increases or decreases total soluble solids in grapes at harvest. In many studies both positive and negative effects on fruit quality are observed with irrigation. Intensive irrigation may increase soluble solids per berry but dilute total brix with excessive water or competition by vegetative sinks (Noar *et al.*, 1993).

Irrigation may have specific effects on wine quality via its effect on berry hydration. Examples of such effects are low skin to flesh ratio due to increased berry size and dilution of color and flavor constituents (reviewed by Hepner *et al.*, 1985; Spiegel-Roy and Bravdo, 1964). Anthocyanin and phenolic concentrations in fruit were found to be greater in water stressed vines, even when expressed on the basis of berry surface area (Matthews and Anderson, 1988). Van Zyl (1984) reports that water stress during ripening can have a deleterious effect on berry mass. However, berry mass is not as sensitive to moisture stress in the ripening period as in the cell division phase. Severe water stress during ripening may result in wilted berries which fail to mature, dull fruit color, and sunburn (Winkler *et al.*, 1974). Hepner and co-workers (1985) report that Cabernet Sauvignon vines that were irrigated during ripening with a total of 260mm irrigation had repeatedly higher wine quality ratings than vines irrigated during other physiological stages or not irrigated at all.

Numerous studies have found that the solute composition of grapes at harvest was dependent upon the water status of the vines (Williams and Matthews, 1990; reviewed by Matthews *et al.*, 1990). Some results indicate that there is a

negative effect of excessive water stress on fruit soluble solids (Noar *et al.*, 1993). This contradicts the common belief that irrigation may be deleterious to fruit and wine quality. Reynolds and Naylor (1994) found that soluble solid concentration during maturation and pH at harvest increased with increasing water stress duration, but titratable acidity was not affected. Alternatively, Noar *et al.* (1993) found that intensive irrigation may increase titratable acidity at harvest.

The effect of timing of irrigation on ripening dynamics and fruit quality is important and has been researched extensively. Mixed results are reported as to whether pre or post véraison water stress results in soluble solid reduction (Matthews and Anderson, 1989; Hardie and Considine, 1976). Trought and Naylor (1988) found that an increase in soluble solids is observed at harvest only when irrigation is applied early in the growing season before véraison.

It is important to note that reproductive processes of plants are highly sensitive to water deficits (Bradford and Hsiao, 1983; Matthews and Anderson, 1989). Results indicate that fertility of grapevine buds can be depressed by water stress. Thus, irrigation during bud formation can be important in influencing potential crop. (Buttrose, 1974). When water was supplied to six-year-old Cabernet franc on Ganzin AxR1 rootstock, at a rate double the standard practice (90L/vine/week), fruit growth, cluster initiation, and differentiation of buds were increased (Matthews and Anderson, 1989). In the same study, water deficits imposed before or after véraison inhibited fruit expansion, and bud development.

Water deficits imposed before véraison were found to be the most inhibitory to overall vine health (Matthews and Anderson, 1989).

### **Yield Components**

Yield is an economically important production consideration. In general, the majority of vineyards producing quality wines tend to be those having low to moderate yields (Zoecklein *et al.*, 1999).

#### Nitrogen and yield components

Excessive nitrogen application may increase yield but has been shown to delay ripening and enhance some disease pressures (Gay-Eynard *et al.*, 2000). In contrast to normal findings from field crop experiments, in viticulture there is only a slight to negligible correlation between nitrogen fertilization and yield. The influence of yearly weather conditions is much more important than nitrogen fertilization (Schaller, 1991).

#### Irrigation and yield components

Irrigation has been shown to increase the marketable yield of many fruit and vegetable crops (Clarke *et al.*, 1992). For grapevines, it has been reported that yield

increases of 30-40% can be obtained by increasing irrigation above standard practice (Matthews and Anderson, 1989; Hepner *et al.* 1985).

Soil water deficit and climatic constraints can cause reduction of grape yield (Kliewer *et al.* 1983; Chaves and Rodrigues, 1987; Schultz, 1996). Yield and quality loss has been reported as results of water deficit (Trought and Naylor, 1988). Results from California indicate that water deficits imposed before or after véraison inhibit yield of six-year-old Cabernet franc vines, with deficits imposed before véraison being the most inhibitory (Matthews and Anderson, 1989; Matthews *et al.*, 1990).

Most studies indicate that the greatest amount of variation in yield is explained by variation in berries per cluster (Matthews and Anderson, 1989). It has been reported that generally, pre-véraison water stress tends to have greater effects on berry size reduction as compared to post-véraison water stress (Smart, 1974; Hardie and Considine, 1976; Matthews and Anderson, 1988). Poni and co-workers (1993) found this to be true when looking at the effects of pre-véraison and post-véraison water stress on yield components of container grown Pinot noir vines. Reynolds and Naylor (1994) found that berry weights of Pinot noir and Riesling were less in treatments of vines exposed to a duration of water stress. Hepner *et al.* (1985) report that wine quality is best correlated with yield to pruning ratio (more specifically Ravaz Index) as opposed to yield.

### Cultivation and yield components

In many crops soil cultivation is said to increase crop productivity. Holt and Smith (1998) suggest that the effect of cultivation on crop yield is more pronounced during dry years. However, the authors also state that deep tillage cannot overcome excessively low soil moisture. Yield increases in annual crop systems, due to cultivation during dry seasons, of 22-63% in beans (Stone, 1982), 8-15% in cotton (Smith, 1995), 37% in wheat (Ouwerkerk and Raats, 1986), and 56% soybeans (Barber and Diaz, 1992) have been reported.

## **Chapter 3**

### **Physiological Response to Soil Moisture Manipulation and Nitrogen Application of Pinot noir in the Willamette Valley**

#### **Abstract**

The goal of this study was to observe vine physiological response to various vineyard practices aimed at increasing nitrogen availability to the vine. Treatments were applied in a factorial design to vary irrigation, cultivation, and nitrogen application to Pinot noir grapevines during two seasons. Irrigated vines received supplemental irrigation after lag phase (82mm in 1999, 90mm in 2000). Cultivation of alternate rows was performed in early spring to encourage nitrogen utilization and reduce nutrient and water competition. Nitrogen treatments consisted of soil-applied urea (39.2kgN/ha), foliar applied urea (2.98kgN/ha), and zero nitrogen. Soil nitrogen was applied in early spring. Foliar nitrogen was applied once at the onset of ripening and again at véraison. The trial was established in a commercial vineyard located in the South Willamette Valley in 1999. Photosynthesis, transpiration, water use efficiency, chlorophyll content, maximum quantum yield of photosynthesis, soil moisture, leaf petiole nutrition, pruning weights, and carbohydrate reserves were measured in the 1999 and 2000 growing seasons. Leaf water potentials were measured during the 2000 growing

season. During both seasons irrigated vines assimilated CO<sub>2</sub> and transpired at a significantly higher rate than non-irrigated vines. Similarly, tilled treatments assimilated CO<sub>2</sub> at a significantly higher rate and maintained higher water use efficiency. Tilling tended to increase the efficiency of light driven photosynthetic reactions and chlorophyll content. This response became more apparent in the second year of the study, which may indicate a delayed effect of soil cultivation on maximum quantum yield of photosynthesis and chlorophyll content in grapevines. Nitrogen treatments had little impact on leaf gas exchange and chlorophyll content. Soil Cultivation had the largest impact on petiole nutrient content, with significant differences in phosphorus, potassium, manganese, copper, boron, carbon and total nitrogen. Irrigation increased total petiole nitrogen in the second year of the study. Pruning weights increased with cultivation in both years and cane weights were higher after the second year. Irrigation and nitrogen did not affect vine vigor.

## **Introduction**

In Oregon, grapevines are subject to low soil water availability, accompanied by high levels of solar irradiance, temperature, and air vapor pressure deficits during the summer. Under these conditions photosynthesis is greatly reduced, particularly toward the end of the growing season. Amino acid formation requires photoassimilated carbon (Buchanan *et al.*, 2000). The inability of vines to photosynthesize prior to harvest results in a shortage of carbohydrates. This



shortage is thought to be responsible for a reduction of nitrogenous compounds in grapes at harvest (Löhnertz *et al.*, 2000). Commercial Oregon must samples have often been shown to contain lower than minimal levels of fermentable nitrogen at harvest (Watson *et al.*, 2000). The goal of this study was to observe vine physiological response to various vineyard practices aimed at increasing nitrogen availability to the vine.

Nitrogen is essential in grapevine establishment and maintenance, fruit quality, and the conversion of grape juice to wine (Marschner, 1995; Roubelakis-Angelakis and Kliewer, 1992; Wermelinger, 1991). When nitrogen is suboptimal, the vine has poor vegetative growth, premature senescence of older leaves, limited fruit bud formation, and poor fruit production. Increases in nitrogen supply not only delay senescence but may change plant morphology. 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; Löhnertz, 1991; Roubelakis-Angelakis and Kliewer, 1992; Winkler *et al.*, 1974).

The changes in nitrogen concentration observed in tissue of water-stressed grapevines imply that dehydration does affect nitrogen metabolism (Kramer and Boyer, 1995). In cool climates, an increase in temperature during ripening and a decrease in soil water availability results in very low amino acid concentration in grapes (Löhnertz *et al.*, 2000). In addition, combination of water stress with high light and temperatures has been reported to cause progressive reduction in vine

growth and quality (Löhnertz *et al.*, 2000; Escalona *et al.*, 1997; Kliewer *et al.*, 1983). It is suggested that optimum growth, yield, and quality can be obtained by implementation of controlled irrigation during certain phenological stages of vine growth (Matthews *et al.*, 1990; Van Zyl, 1984).

Soil cultivation is another tool that can be used in the vineyard to manipulate the availability of soil water and mineralized nitrogen. Soil cultivation has been shown to increase microbial activity, accelerating decomposition of organic matter and mineralization of organic nitrogen (Schaller, 1991). Soil cultivation has also been shown to increase amino acid concentration in the fruit at harvest (Löhnertz *et al.*, 2000).

Typically, vineyards tend not to be nitrogen deficient systems. It is common practice in Oregon for grape growers to apply nitrogen to the soil in early spring if soil tests call for it. Foliar application of nitrogen is not a commonly used practice in Oregon. Most Oregon grape growers will only apply as much nitrogen as was removed the previous harvest in the fruit to avoid over-application of nitrogen which can lead to vigor problems in the vineyard.

## **Materials and Methods**

### **Experimental design**

This study was conducted at Benton Lane Vineyard, a commercial Oregon vineyard, during the 1999 and 2000 growing seasons. It was a factorial of

irrigation, nitrogen, and soil cultivation (Table 3.1) organized in a randomized block design. Each treatment was replicated five times in groups of eleven vines. There were guard rows between each data row, and two guard vines between each replicate per row. Benton Lane vineyard is located in Monroe of the south Willamette Valley. Site elevation is approximately 130m. The vines used were Pinot noir clone FPMS 2A grafted on Teleki 5C rootstock. Vine rows were oriented north to south. The vines were planted in 1992, trained to a double Guyot, and are spaced 1.5m x 3m apart on predominately Bellpine soil. Vineyard floor cover consisted of resident plant species. Alternate rows were mowed after resident species were allowed to bloom. Powdery mildew control was performed by the grower.

Table 3.1: Main factors and treatment combinations at Benton Lane Vineyard for 1999 and 2000

	Irrigation (I)		No Irrigation (D)	
	Till (T)	No Till (NT)	Till (T)	No Till (NT)
<b>Zero Nitrogen (0N)</b>	I-T-0N	I-NT-0N	D-T-0N	D-NT-0N
<b>Foliar Nitrogen (FN)</b>	I-T-FN	I-NT-FN	D-T-FN	D-NT-FN
<b>Soil Nitrogen (SN)</b>	I-T-SN	I-NT-SN	D-T-SN	D-NT-SN

### Irrigation

Water was applied using drip irrigation during lag phase. A total of 82mm (1999) and 90mm (2000) irrigation was applied per season at a rate of 1.9 L H<sub>2</sub>O/h. Annual precipitation for the vineyard site during both 1999 and 2000 is illustrated in Fig 3.1 and Fig 3.2.

### Nitrogen

Nitrogen treatments include an unfertilized control, 39.2 kg N/ha supplied to the soil, and 2.98 kg N/ha supplied foliarly. Foliar N fertilizer was split in two applications of 1.49 kg N/ha. Both soil and foliar nitrogen treatments were applied manually. Soil nitrogen was applied as urea (46-0-0). The amount of N applied to each replicate was measured and broadcast by hand. Foliar nitrogen was applied in the form of wetted urea at a .3% concentration. Using a hand sprayer, the nitrogen solution was applied to leaves in the fruit zone. Soil nitrogen was applied on May 4, 1999 and May 8, 2000. The first foliar nitrogen application was at the beginning of color change, and the second application was done at véraison (approximately 14° Brix) for both years. Berries started changing color on August 13, 1999 and August 30, 2000. Véraison occurred on September 8, 1999 and September 6, 2000.

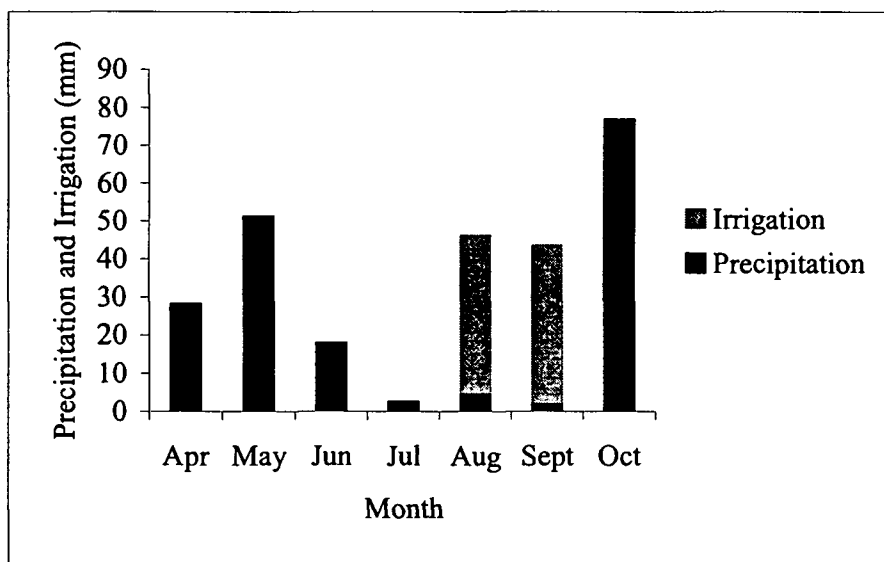


Figure 3.1: Seasonal precipitation and irrigation applied at Benton Lane vineyard during 1999. Total annual precipitation = 184 mm. Total irrigation applied = 82 mm

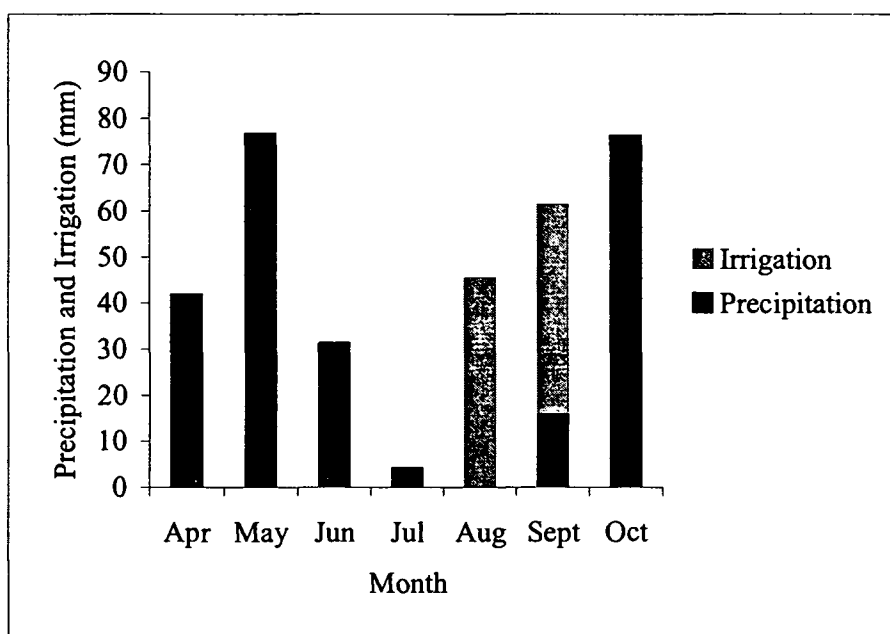


Figure 3.2: Seasonal precipitation and irrigation applied at Benton Lane vineyard during 2000. Total annual precipitation = 247 mm. Total irrigation applied = 90 mm

### Soil Cultivation

In row tilling was done in early spring to encourage nitrogen utilization and reduce nutrient and water competition. Tilling of alternate rows was done on May 24, 1999 and May 22, 2000. Tilling depth was 15cm.

### Photosynthesis, transpiration, and water use efficiency

One representative vine (data vine) per treatment replicate was selected and used throughout the two seasons for all field measurements. The tenth leaf from a representative shoot on each data vine was tagged and used throughout each season to determine gas-exchange, chlorophyll fluorescence, and chlorophyll content (Candolfi-Vasconcelos *et al.*, 1994b). Leaf gas-exchange was monitored with a portable infrared gas analyzer, Ciras-1 (PP SYSTEMS, Hitchin, Herts SG5 1RT UK). Data leaves were fully exposed to sunlight prior to measurement. Measurements were taken between 9:00 am and 1:00 p.m., at photosynthetic flux densities above  $1200 \mu\text{mol PAR m}^{-2} \cdot \text{s}^{-1}$ .

### Chlorophyll content

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

### 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 ( $F_v/F_m$ ) was used as a measure of the efficiency of the light dependent reactions of photosynthesis.

### Leaf area and vine vigor

In 1999, 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.

During vine winter dormancy, vines were balanced pruned to 28 buds per kilogram of one-year old wood. From this weight, cane weight and Ravaz Index were calculated.

### 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. PVC guide pipes were permanently installed at a 60° angle in the soil for the probe. This was to insure measurements were taken in the same soil profile on all dates.

#### Leaf water potential

In 2000, 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 a plastic bag before being excised at the petiole from the vine. Leaves were then immediately 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, nitrate nitrogen, total nitrogen and carbon.



### Carbohydrate content

During vine winter dormancy (2000 and 2001) two-year-old wood samples, one internode in length, and proximal to the trunk, were collected and dried. Soluble solids and starch were extracted from the dried material and analyzed using the method described by Candolfi-Vasconcelos and Koblet (1990).

### Data analysis

All data was submitted to MANOVA using the general linear model. The SAS statistical package (SAS Institute, Cary, NC), with mean separation at  $p < 0.05$  was used.

## **Results and Discussion**

### Photosynthesis, transpiration, and water use efficiency

*Irrigation* – In 1999 and 2000, there was a general decline in carbon fixation capacity throughout the growing season in both irrigated and non-irrigated vines (Fig 3.3a and Fig 3.4a). Photosynthesis was highest at bloom and then declined steadily throughout the season as the sampled leaf aged. However, irrigated vines assimilated  $\text{CO}_2$  at a significantly higher rate than non-irrigated vines after the implementation of irrigation treatments in both 1999 and 2000. The

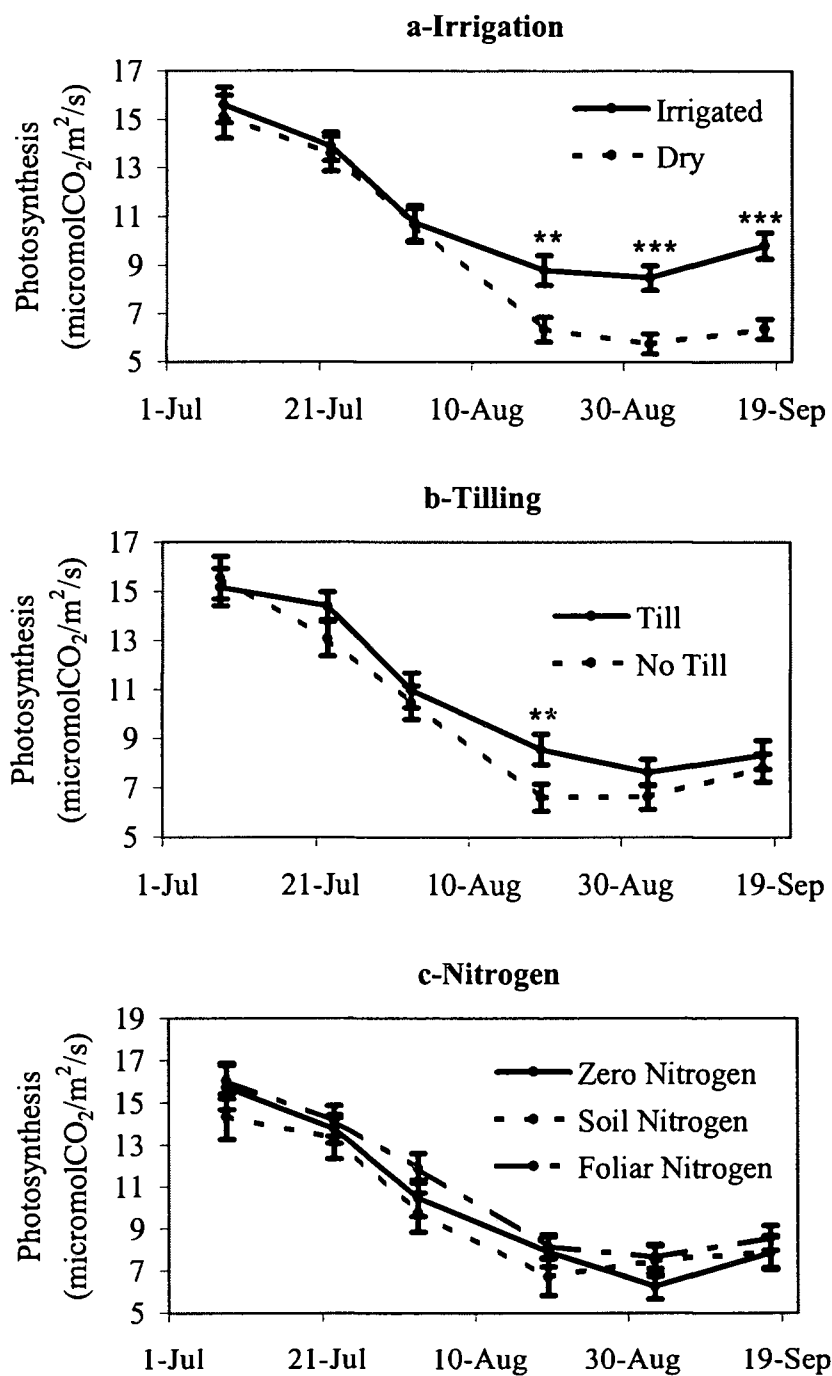


Figure 3.3: Effect of irrigation, tilling, and nitrogen fertilization on photosynthesis of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

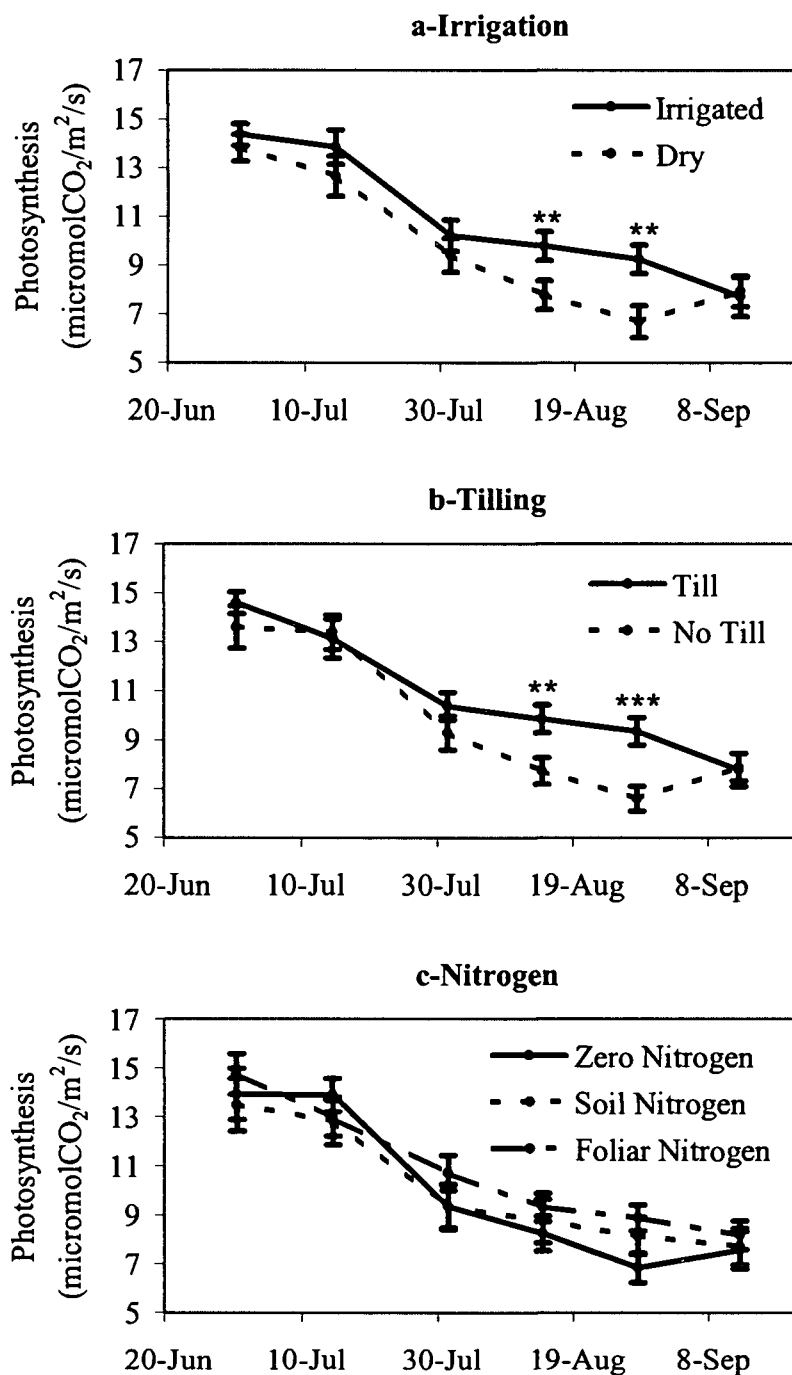


Figure 3.4: Effect of irrigation, tilling, and nitrogen fertilization on photosynthesis of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

beneficial effect of irrigation on photosynthesis agrees with previously published work (Rodrigues *et al.*, 1993; Escalona *et al.*, 1997; and Flexas *et al.*, 1998).

At the same time, the transpiration rate of irrigated vines was significantly higher than non-irrigated vines in 1999 and 2000 (Fig 3.5a and Fig 3.6a). In 1999 and 2000, there was no significant difference between irrigation treatments in water use efficiency (Fig 3.7a and Fig 3.8a). However, in 1999, the non-irrigated vines tended to compensate for having less water (Fig 3.7a). Similar studies on Temprnillo grapevines have shown that water use efficiency is usually higher in non-irrigated vines (Flexas *et al.*, 1998). Flexas and co-workers (1998) also demonstrated that water use efficiency tends to increase through the growing season whether vines are irrigated or not. In 1999, regardless of treatment, vines tended to increase their water use efficiency from mid August until harvest (Fig 3.7). In 2000, however, the opposite was observed (Fig 3.8). All vines tended to decrease their water use efficiency from mid August until harvest. This is most likely due to increased precipitation during the latter half of the growing season in 2000 (Fig 3.2).

*Cultivation* –In 1999 and 2000, CO<sub>2</sub> assimilation rate and water use efficiency were higher for vines in tilled soil as compared to non-tilled soil (Fig 3.3b, Fig 3.4b, Fig 3.7b, and Fig 3.8b). The effect of tilling on photosynthesis was less evident than the effect on water use efficiency in 1999 (Fig 3.3b and Fig 3.7b). These responses reflect the lower level of competition for water and nutrients

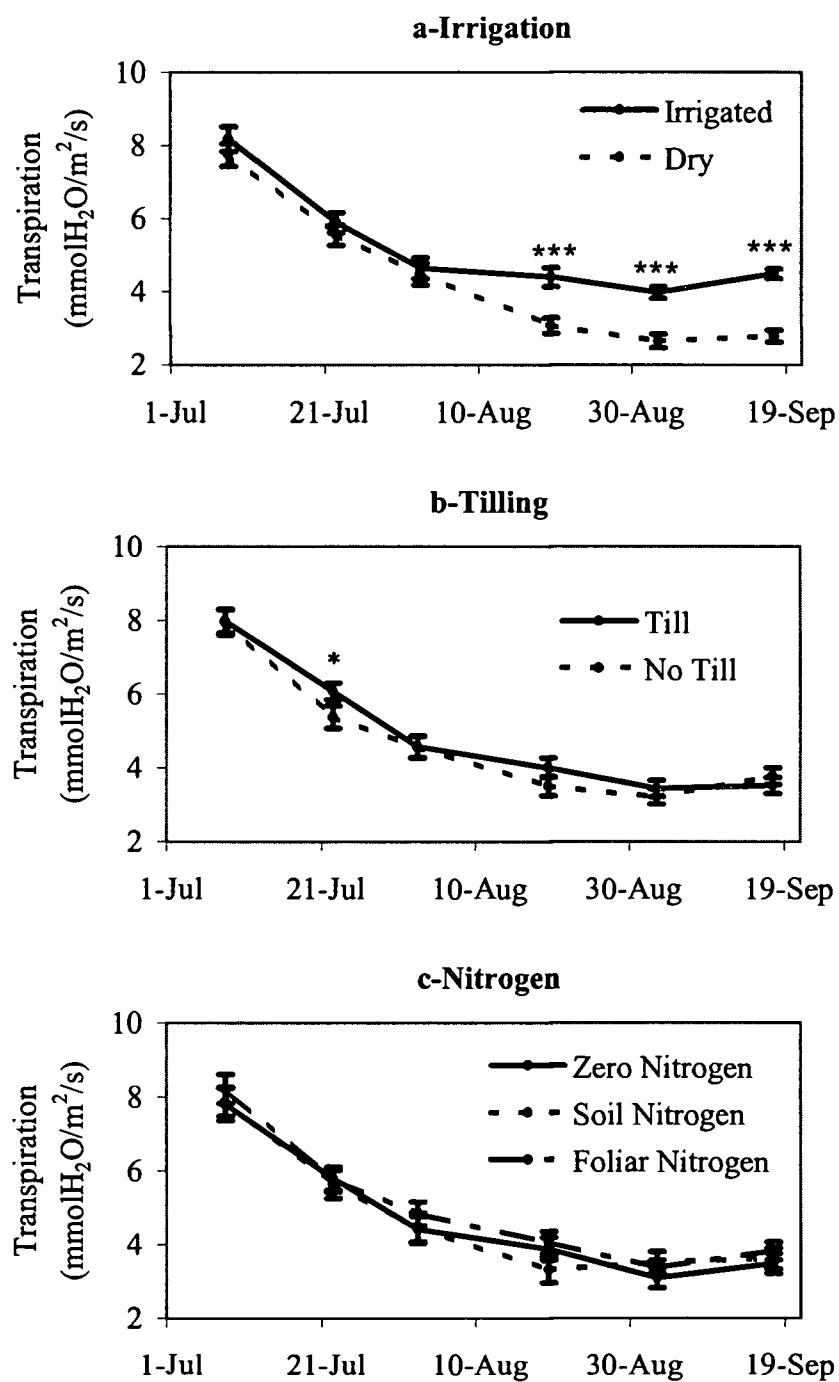


Figure 3.5: Effect of irrigation, tilling, and nitrogen fertilization on transpiration of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

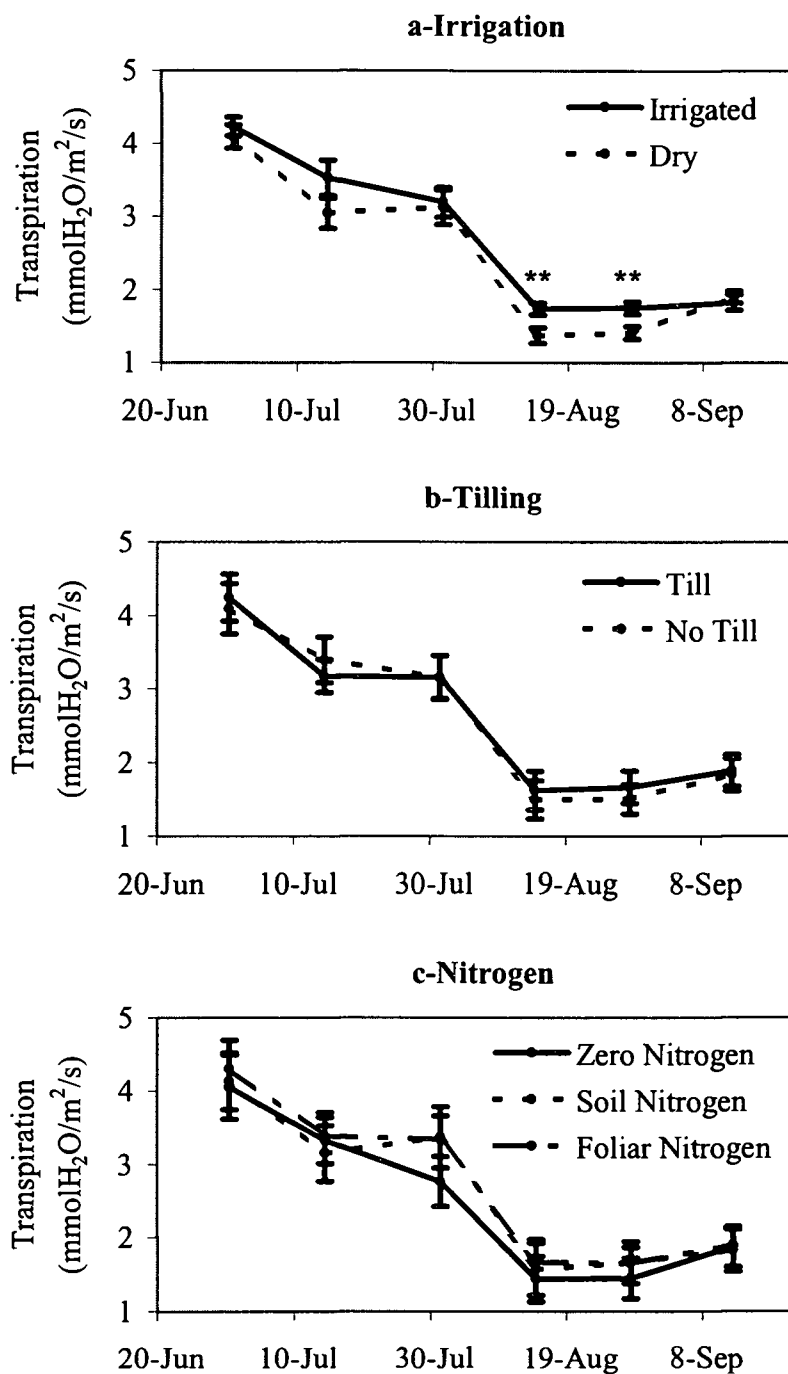


Figure 3.6: Effect of irrigation, tilling, and nitrogen fertilization on transpiration of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

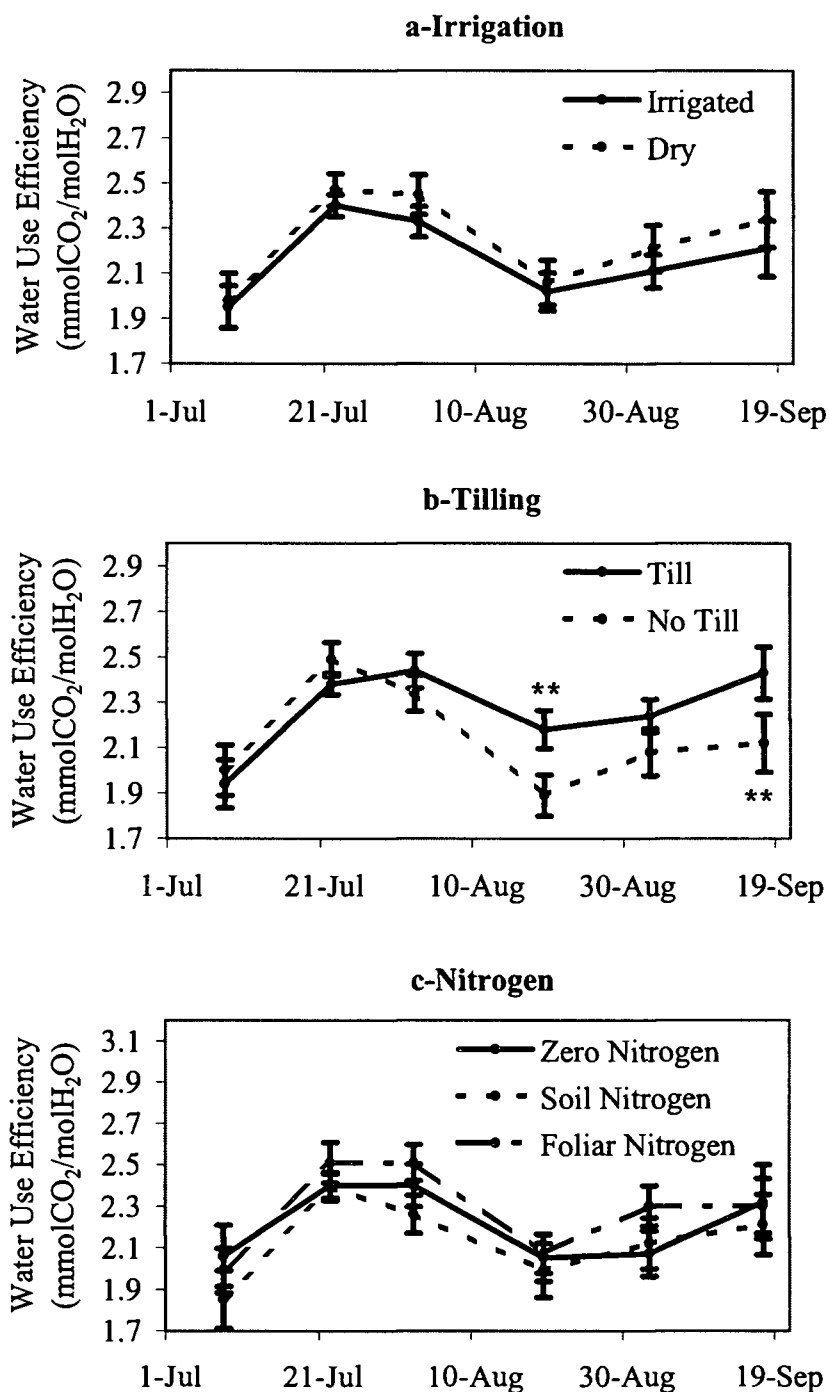


Figure 3.7: Effect of irrigation, tilling, and nitrogen fertilization on water use efficiency of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

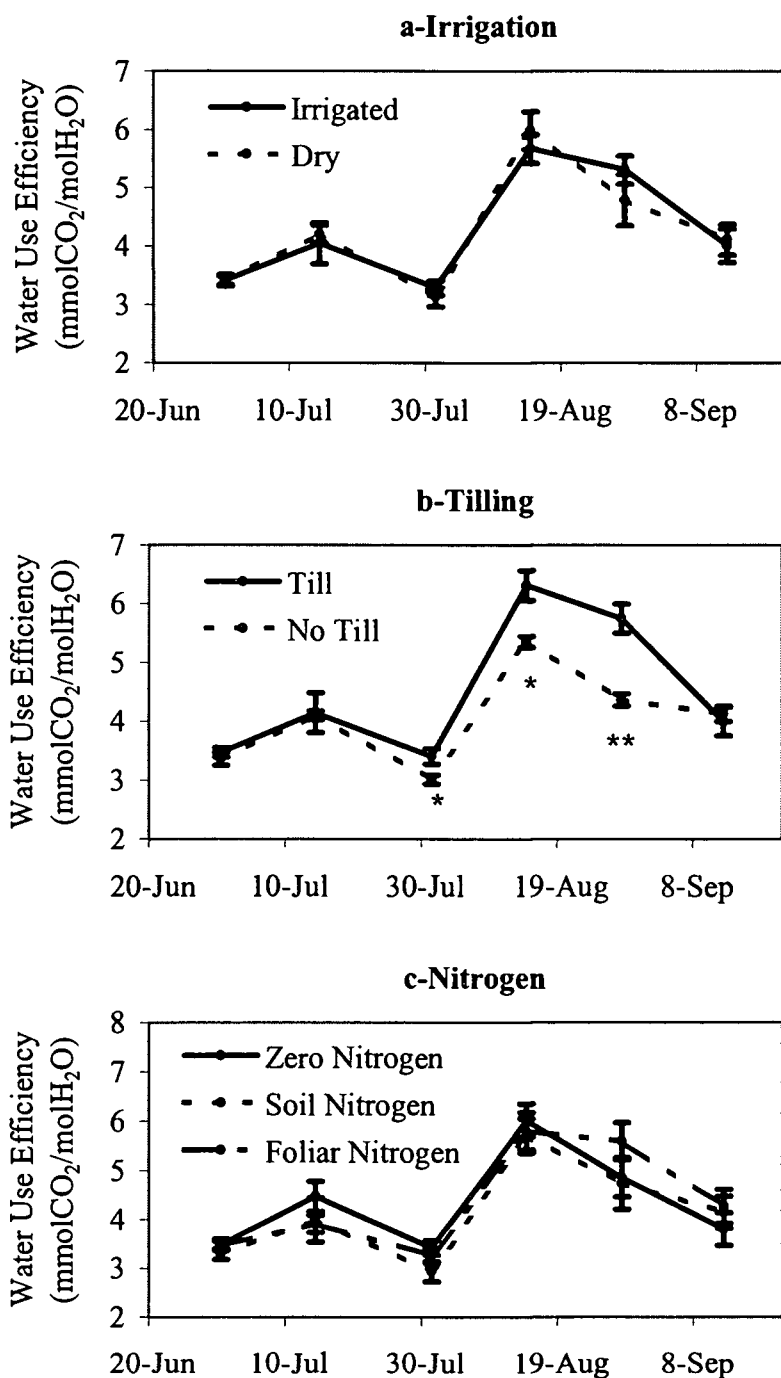


Figure 3.8: Effect of irrigation, tilling, and nitrogen fertilization on water use efficiency of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.



experienced by the vines on tilled ground. It is interesting to note that the effect of tilling on gas-exchange performance became more pronounced after irrigation treatments were applied. This suggests that part of the water applied to the non-tilled treatment was used by the cover crop. In 1999 and 2000, no significant differences in transpiration rate occurred, although tilled vines tended to transpire slightly more than non-tilled vines (Fig 3.5b and Fig 3.6b).

*Nitrogen* – In 1999 and 2000, there were no significant differences among nitrogen treatments in  $\text{CO}_2$  assimilation, transpiration, or water use efficiency (Fig 3.3c, Fig 3.4c, Fig 3.5c, Fig 3.6c, Fig 3.7c, and Fig 3.8c). A decrease in  $\text{CO}_2$  assimilation (Fig 3.3c and Fig 3.4c) and transpiration (Fig 3.5c and Fig 3.6c) occurred from the beginning of the season to the end of ripening in both 1999 and 2000 for all nitrogen treatments. This decrease, which was observed regardless of treatment, was probably due to the aging of leaves. In 1999, water use efficiency was highest during late July for all nitrogen treatments (Fig 3.7c). In 2000, water use efficiency was highest during mid August for all nitrogen treatments (Fig 3.8c). During both seasons, an increase in water use efficiency occurred before véraison. This suggests a sink driven increase on the water use efficiency of the vines. These results suggest that leaf nitrogen content was not limiting photosynthesis, even on the vines that did not receive nitrogen fertilizer.

### Chlorophyll content

*Irrigation* – Leaf chlorophyll content did not differ significantly between irrigated and non-irrigated vines in 1999 or 2000 (Fig 3.9a and Fig 3.10a).

However, on all dates in 2000, except July 31, leaves from irrigated vines tended to be higher in chlorophyll (Fig 3.10a). This is most likely due to irrigation increasing nitrogen availability to the vines.

*Cultivation* – In 1999, tilling tended to increase chlorophyll content when compared to non-tilled vines (Fig 3.9b). In 2000, obvious differences were observed between tilled and non-tilled treatments with respect to overall chlorophyll content. On all dates in 2000, tilled vines had significantly higher chlorophyll content than non-tilled vines (Fig 3.10b). This suggests that tilling reduced nutrient competition between vines and cover crop, making nitrogen more available in the tilled treatments. This effect was not as obvious in 1999 and could possibly be due to a delayed effect of cultivation on vine physiological response. Extensive literature exists regarding the effects of cultivation on annual crops. However the effects of cultivation on perennial crop systems has not been closely examined.

*Nitrogen* – In 1999 and 2000, differences in chlorophyll content between nitrogen treatments were not observed (Fig 3.9c and Fig 3.10c).

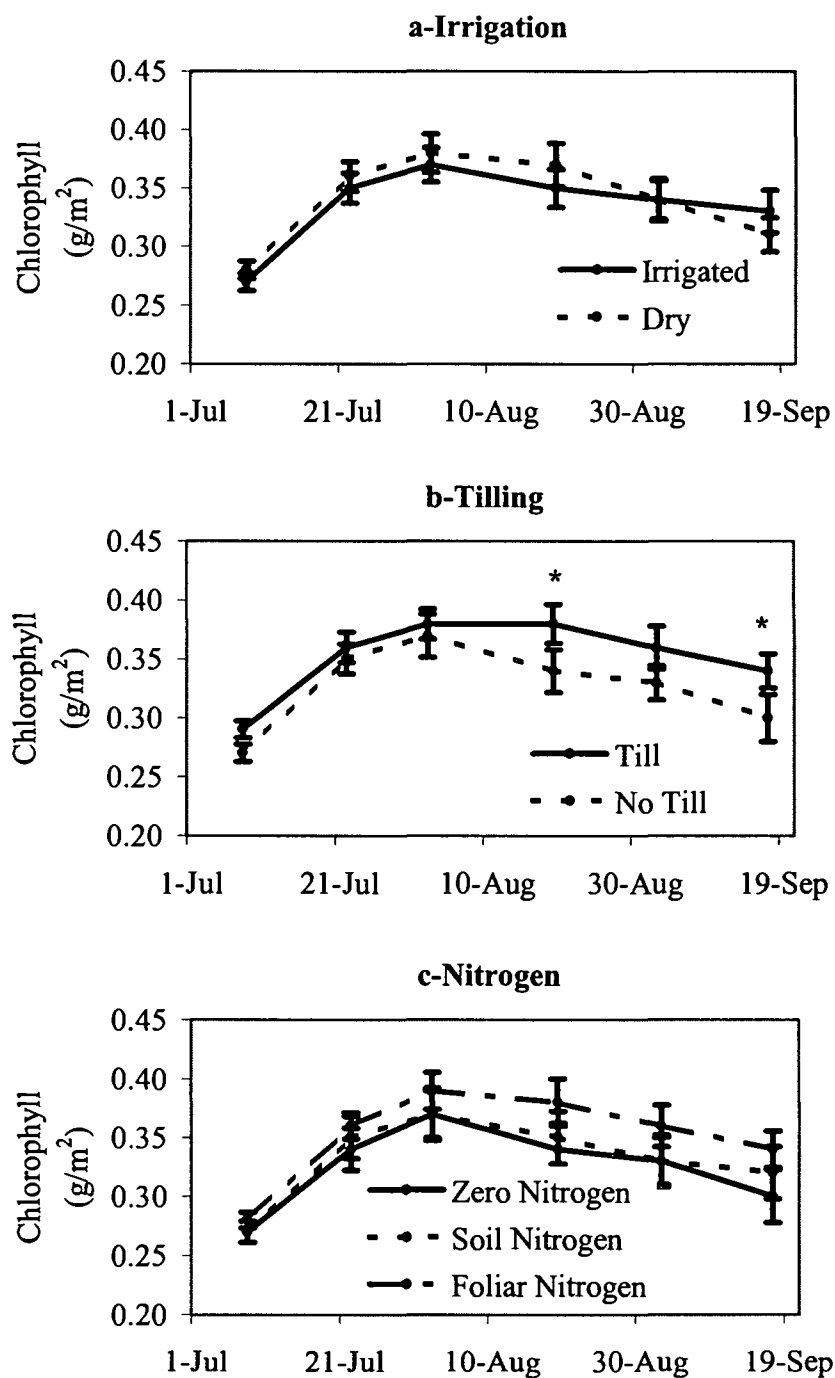


Figure 3.9: Effect of irrigation, tilling, and nitrogen fertilization on leaf chlorophyll content of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

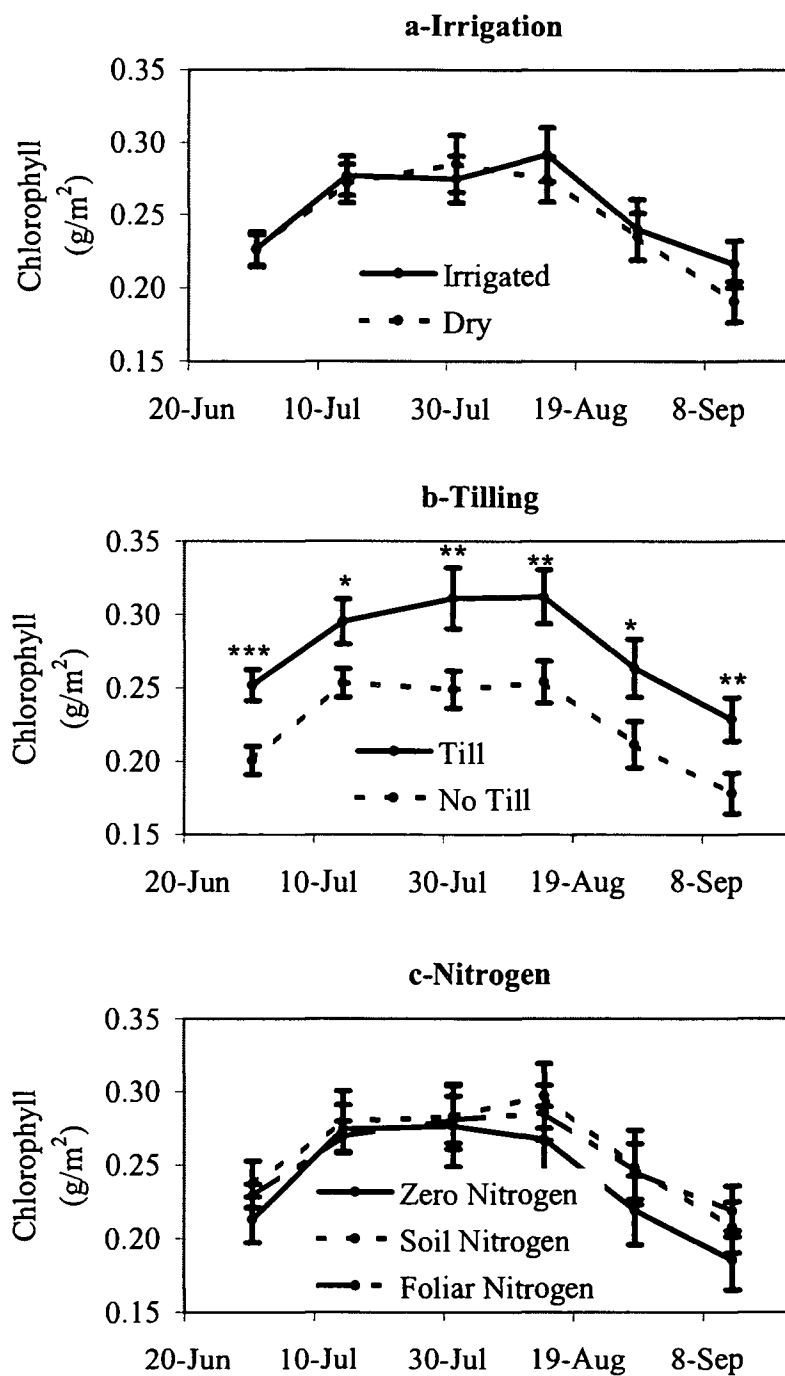


Figure 3.10: Effect of irrigation, tilling, and nitrogen fertilization on leaf chlorophyll content of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

### Maximum quantum yield of photosynthesis

*Irrigation* – In 1999, there was no significant difference in the maximum quantum yield of photosynthesis ( $F_v/F_m$ ) between irrigated and non-irrigated vines (Fig 3.11a). In 2000, irrigated vines tended to have a higher  $F_v/F_m$  after the onset of irrigation and had significantly higher efficiency at harvest (Fig 3.12a).

*Cultivation* – In 1999, tilling tended to increase the efficiency of light driven photosynthetic reactions (Fig 3.11b). In 2000, similar differences were observed and the effect was more pronounced, suggesting that cultivation has a delayed effect on vine physiological response (Fig 3.12b). This is most likely a result of reduced water and nutrient competition. Flexas *et al.* (1998) found that water competition does not induce photoinhibition in field grown grapevines, even when stomatal conductance and photosynthesis are reduced to very low values.

*Nitrogen* – There was no clear response of  $F_v/F_m$  to nitrogen treatments in 1999 or 2000 (Fig 3.11c and Fig 3.12c).

### Soil moisture

Benton Lane vineyard has been dry land farmed prior to the implementation of irrigation treatments in 1999. In 1999 and 2000, there were significant differences in soil moisture at 30cm depth and 60cm depth, after the application of irrigation (Fig 3.13a, Fig 3.14a, Fig 3.15a, Fig 3.16a). Irrigated vines tended to

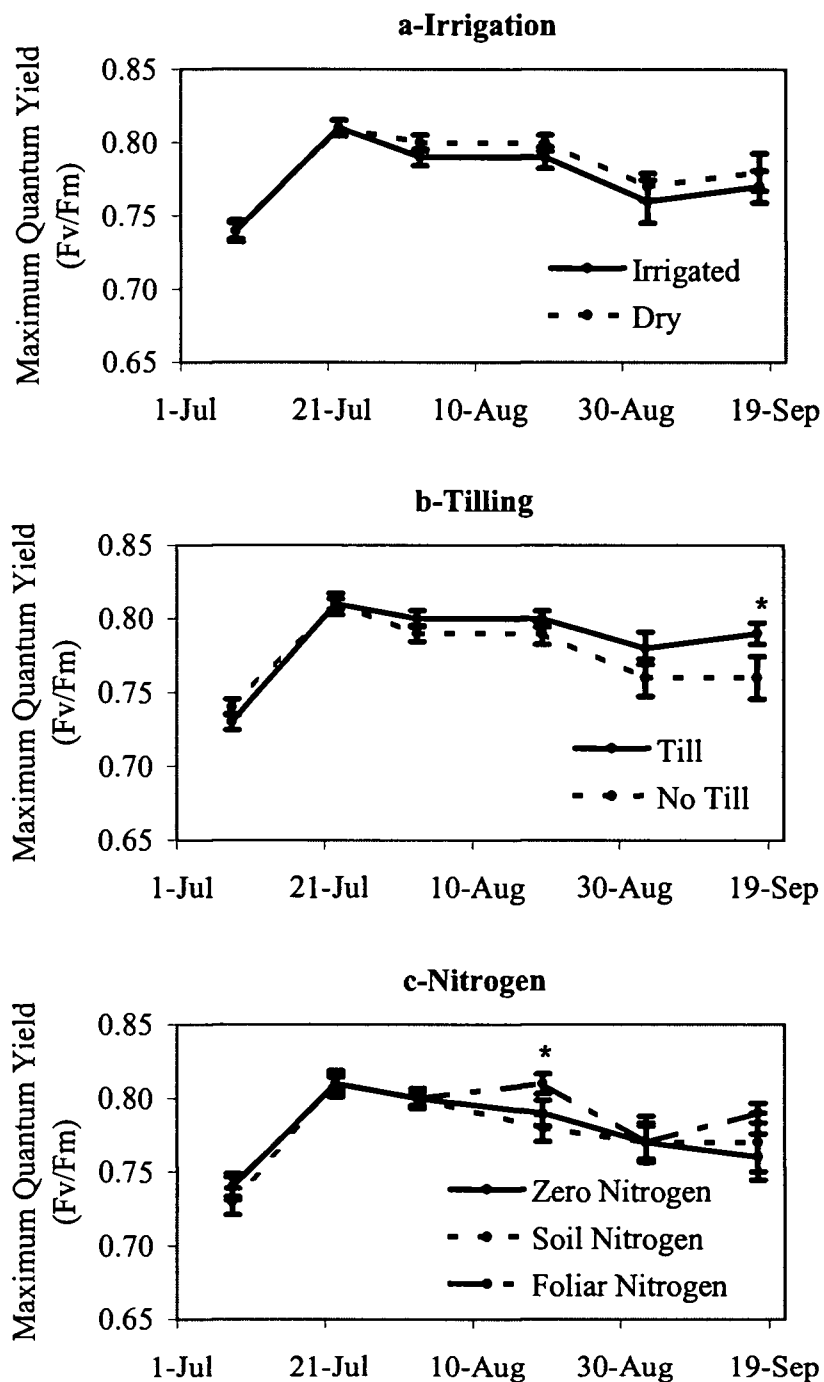


Figure 3.11: Effect of irrigation, tilling, and nitrogen fertilization on maximum quantum yield of photosynthesis of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

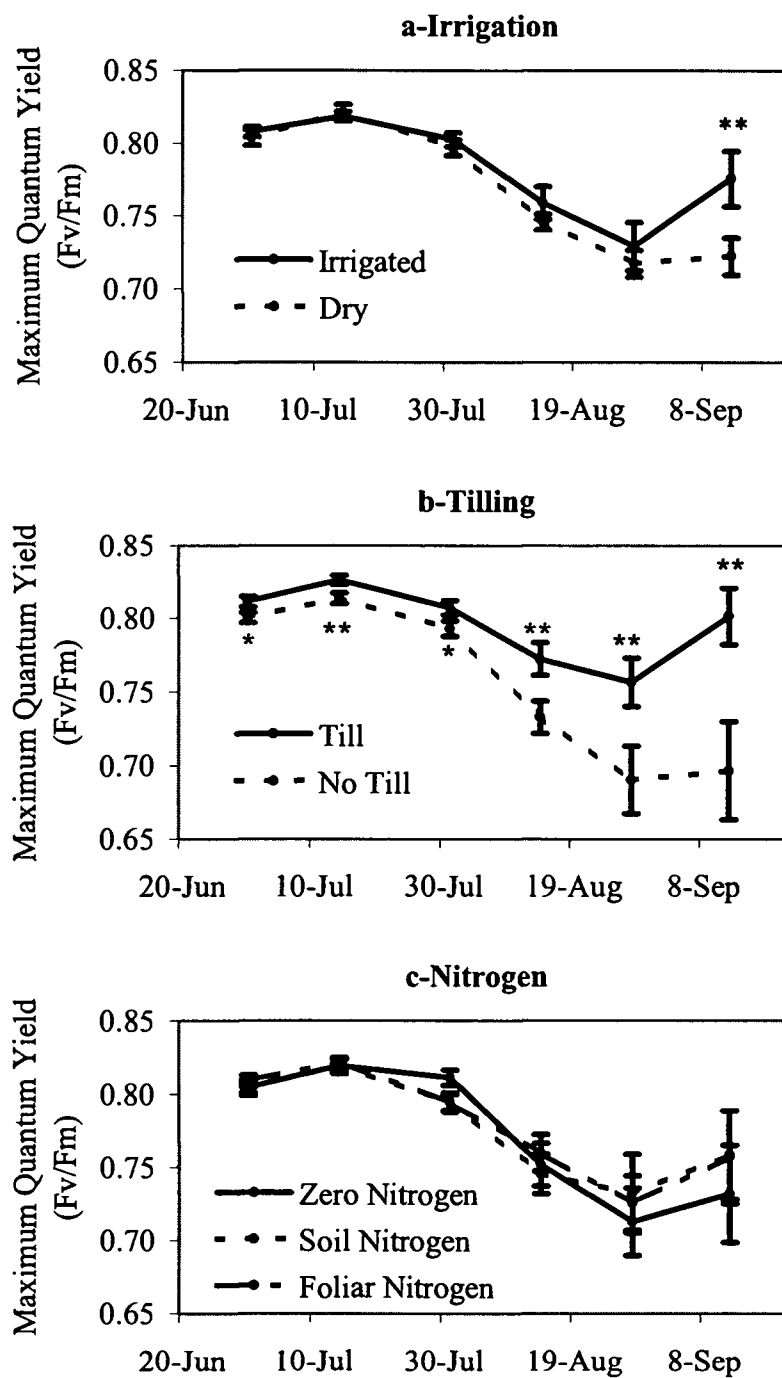


Figure 3.12: Effect of irrigation, tilling, and nitrogen fertilization on maximum quantum yield of photosynthesis of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

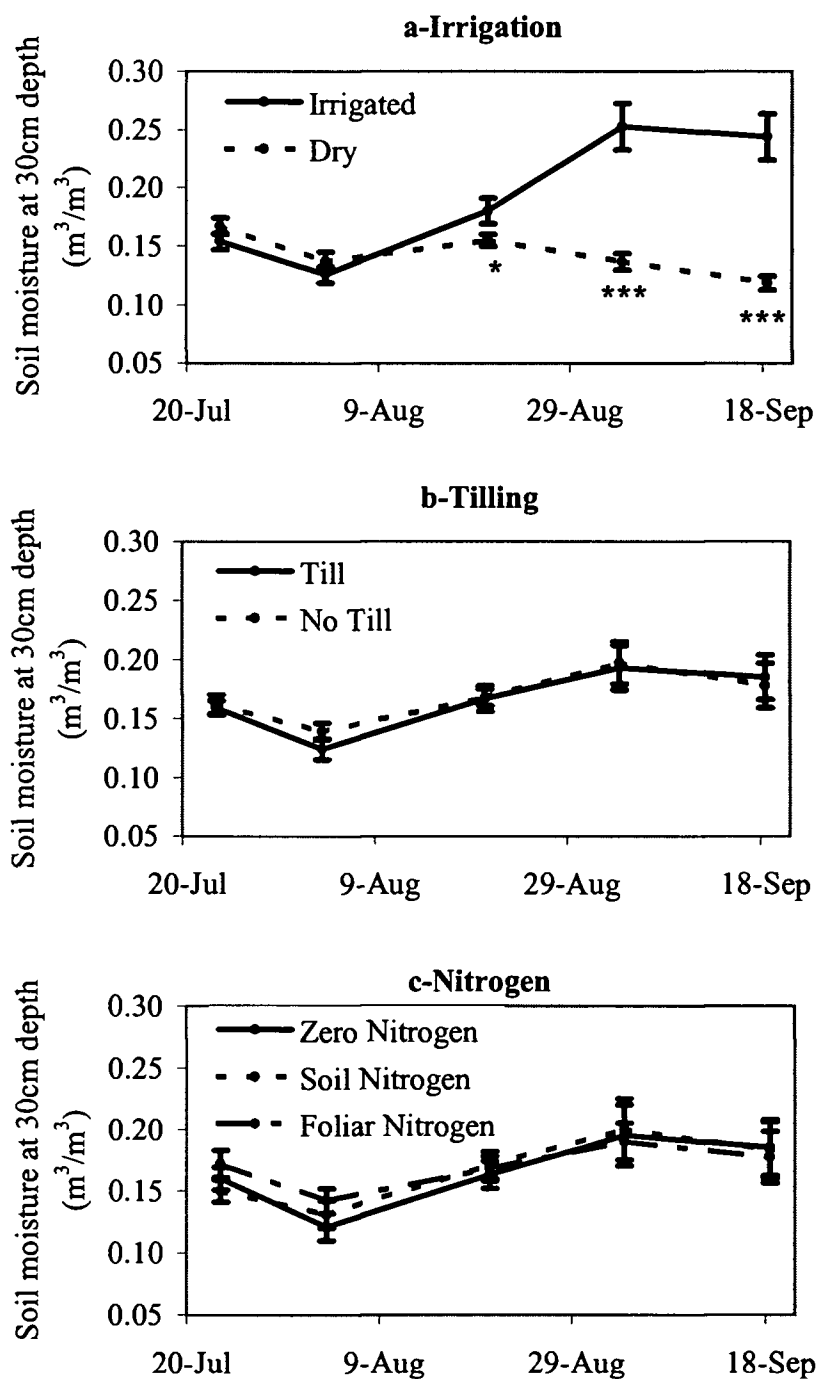


Figure 3.13: Soil moisture content at 30cm depth of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.



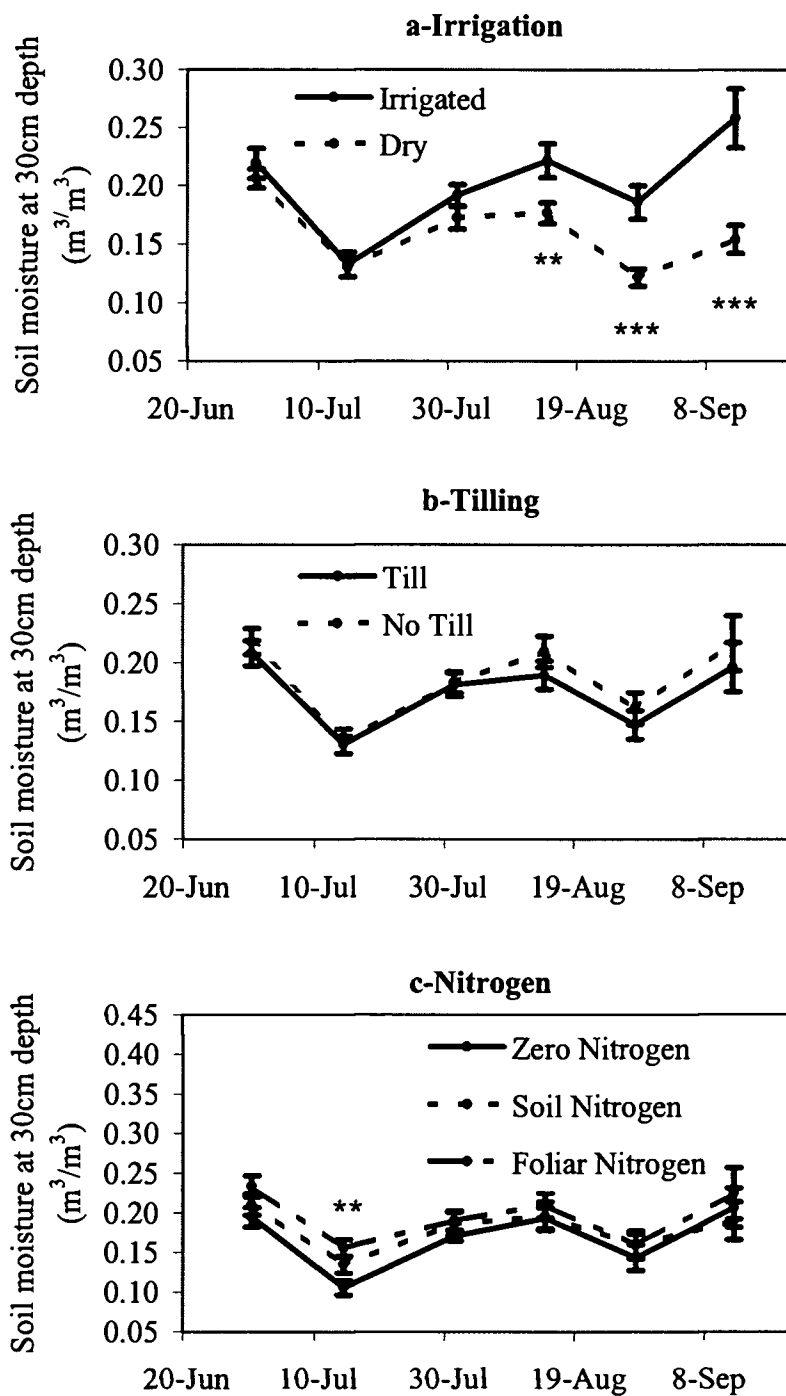


Figure 3.14: Soil moisture content at 30cm depth of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

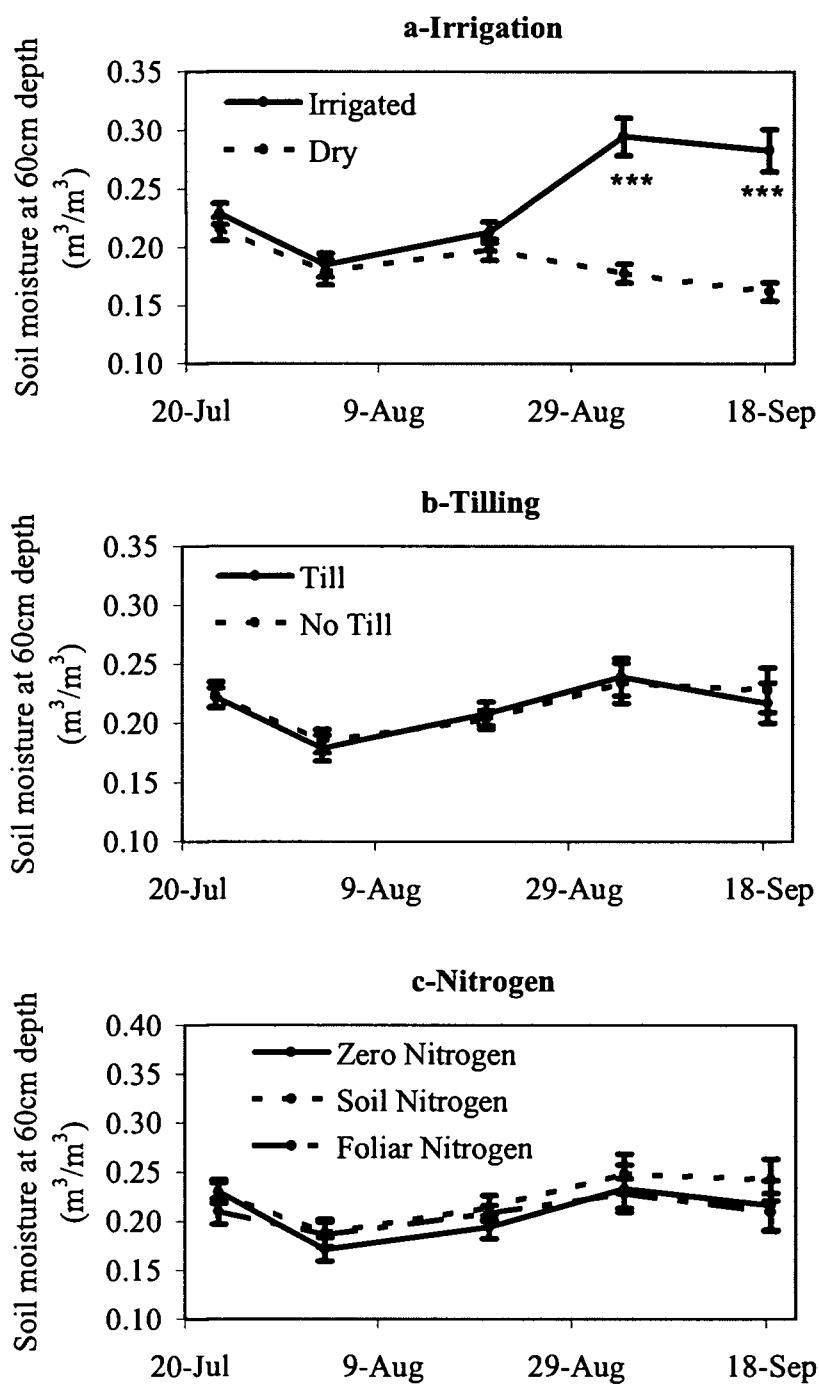


Figure 3.15: Soil moisture content at 60cm depth of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

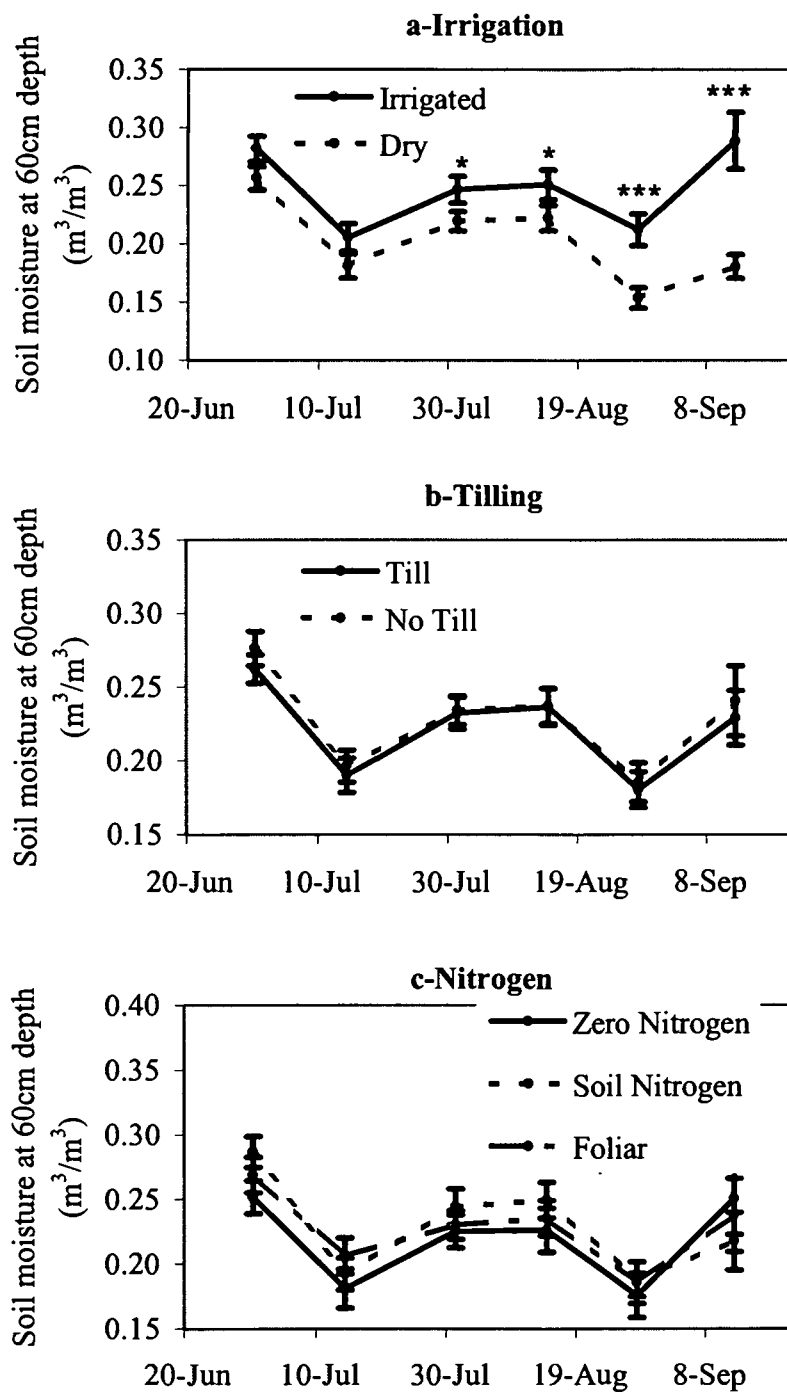


Figure 3.16: Soil moisture content at 60cm depth of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

maintain higher soil moisture until harvest during both seasons. There were no significant differences in soil moisture with respect to tilling (Fig 3.13b, Fig 3.14b, Fig 3.15b, and Fig 3.16b) or nitrogen treatments (Fig 3.13c, Fig 3.14c, Fig 3.15c, and Fig 3.16c) during both 1999 and 2000.

### Leaf water potential

*Irrigation* – Leaf water potential was only monitored during the 2000 growing season. Visually, however, it was observed in both 1999 and 2000, that non-irrigated vines showed changes in leaf angle during the day, which has been reported to be indicative of water stress (Smart, 1974).

From the onset of irrigation, differences in both predawn and midday leaf water potential between irrigated and non-irrigated vines were observed (Fig 3.17a and 3.18a). Irrigated vines had consistently higher predawn and midday leaf water potential than non-irrigated vines. Hardie and Considine (1976), Smart (1974), Kliewer *et al.* (1983), and Matthews *et al.* (1987) all found similar results in grapevine irrigation studies. However, leaf water potential values obtained during this study were consistently higher than the aforementioned studies. Similar to Matthews and co-workers (1987) midday leaf water potentials of non-irrigated vines decreased more than -0.1 Mpa per week until just before harvest (Fig 3.18a).

Changes in leaf water potential followed similar patterns as changes in photosynthesis. This is in agreement with the findings of Kriedemann and Smart

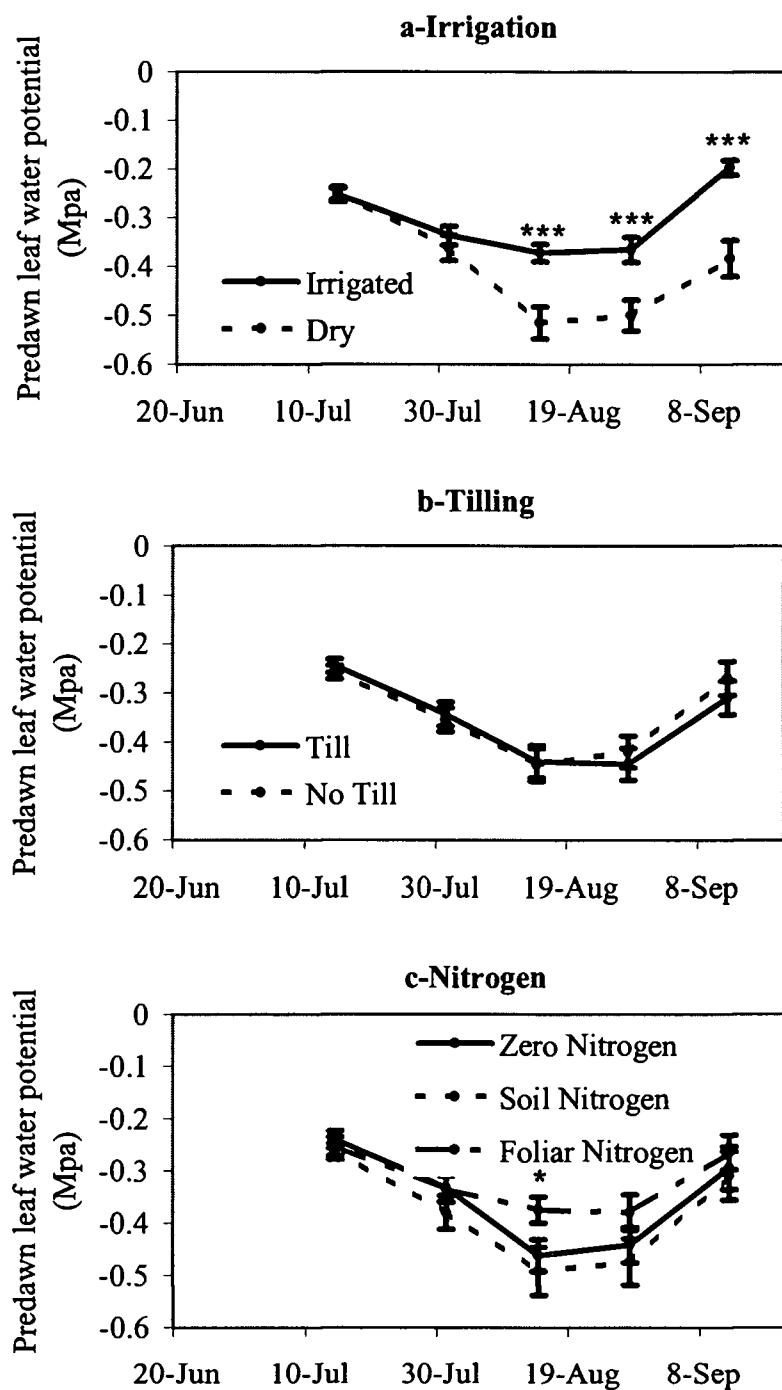


Figure 3.17: Effect of irrigation, tilling, and nitrogen fertilization on predawn leaf water potential of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

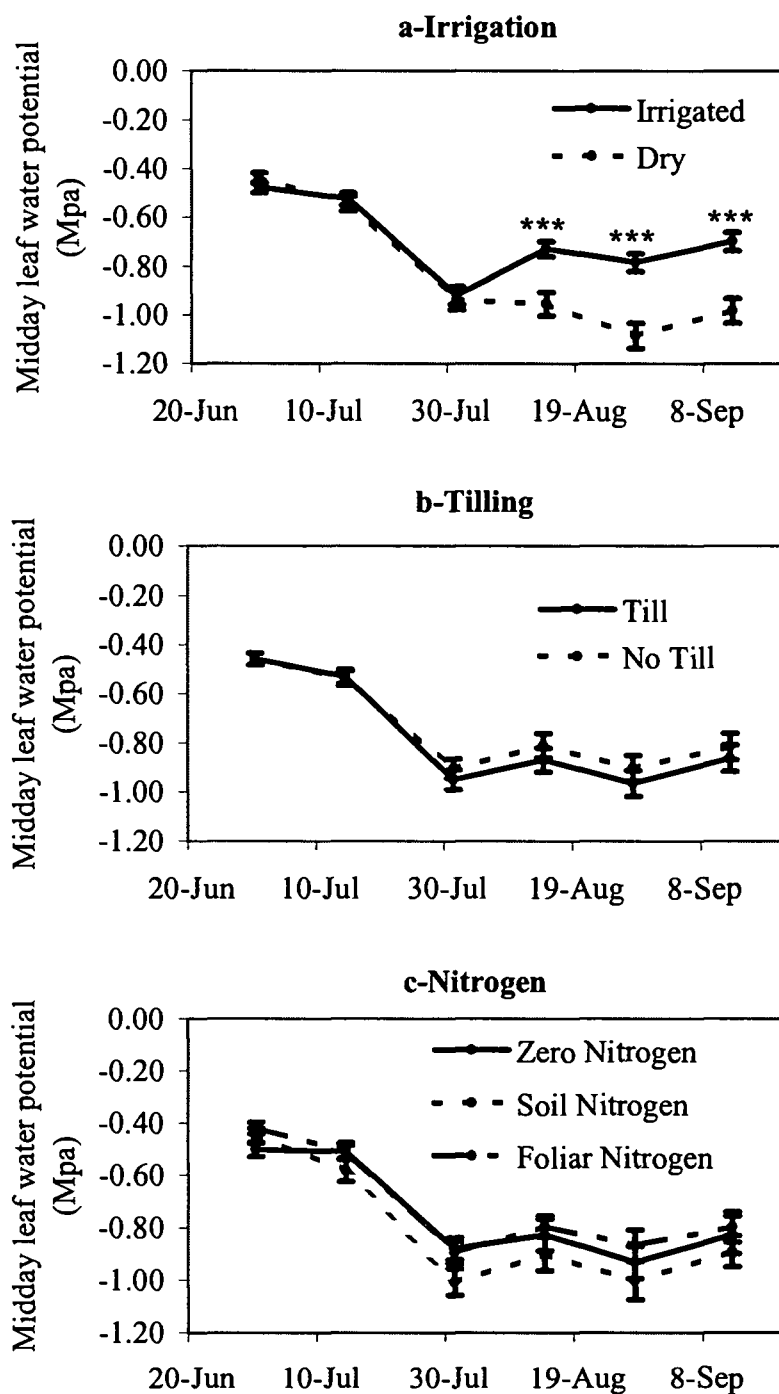


Figure 3.18: Effect of irrigation, tilling, and nitrogen fertilization on midday leaf water potential of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

(1971). They reported that when photosynthesis was reduced by 50%, non-irrigated Shiraz vines reached midday leaf water potentials of  $-1.2$  MPa when compared to irrigated vines. In the present study, midday leaf water potentials of non-irrigated vines ranged from  $-1.0$  MPa to  $-1.5$  Mpa just prior to harvest (Fig 3.18a). The corresponding photosynthetic rate of non-irrigated vines was approximately 30% less than that of irrigated vines (Fig. 3.4a).

*Cultivation* – Tilling had no effect on predawn or midday leaf water potentials (Fig 3.17b and Fig 3.18b).

*Nitrogen* – There were no differences in predawn or midday leaf water potentials with respect to nitrogen application (Fig 3.17c and Fig 3.18c).

#### Leaf area and vine vigor

Leaf area was measured only during the 1999 season. There was no response to irrigation, tilling, or nitrogen application on leaf area or leaf/fruit ratio (Table 3.2).

During both seasons tilled vines tended to be more vigorous than non-tilled vines. In 1999 and 2000, tilled vines had higher cane weights (Table 3.3). Tilled vines had a smaller Ravaz Index than non-tilled vines in both 1999 and 2000 (Table 3.3). Overall pruning weights of tilled vines were higher than non-tilled vines in 2000 (Table 3.3). This shows that tilling, by reducing water and nutrient

Table 3.2: Leaf area of Pinot noir grapevines at Benton Lane Vineyard in 1999.

	Main Leaf Size (cm <sup>2</sup> )	Lateral Leaf Size (cm <sup>2</sup> )	Main Leaf Area/Vine (m <sup>2</sup> )	Lateral Leaf Area/Vine (m <sup>2</sup> )	Total Leaf Area/Vine (m <sup>2</sup> )	Leaf:Fruit ratio (cm <sup>2</sup> /g)
Irrigation						
Dry	110.1	31.3	3.4	1.6	4.8	26.9
Irrigated	103.9	30.7	3.7	1.6	5.3	26.3
	ns	ns	ns	ns	ns	ns
Nitrogen						
Zero Nitrogen	112.7	32.0	3.6	1.4	5.0	24.0
Foliar Nitrogen	104.9	29.6	3.8	1.9	5.7	28.2
Soil Nitrogen	103.3	31.3	3.2	1.5	4.6	27.7
	ns	ns	ns	ns	ns	ns
Cultivation						
No Till	104.2	30.9	3.5	1.5	5.0	25.3
Till	109.7	31.1	3.6	1.7	5.1	27.9
	ns	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.



Table 3.3: Vine vigor and Ravaz Index of Pinot noir grapevines at Benton Lane Vineyard in 1999 and 2000

	Cane wt (g)	Pruning wt (kg/vine)	Ravaz Index (kg fruit/kg prunings)
<b>1999</b>			
Irrigation			
Irrigated	35.4	0.67	2.69
Dry	38.8	0.69	2.31
	<b>ns</b>	<b>ns</b>	<b>**</b>
Nitrogen			
Zero Nitrogen	39.7	0.75	2.49
Foliar Nitrogen	37.0	0.68	2.55
Soil Nitrogen	34.7	0.61	2.45
	<b>ns</b>	<b>ns</b>	<b>ns</b>
Cultivation			
Till	39.7	0.72	2.32
No Till	34.5	0.64	2.68
	<b>**</b>	<b>ns</b>	<b>**</b>
Significant Treatment Interactions			
none			
<b>2000</b>			
Irrigation			
Irrigated	27.1	0.52	8.79
Dry	26.1	0.50	8.47
	<b>ns</b>	<b>ns</b>	<b>ns</b>
Nitrogen			
Zero Nitrogen	27.7	0.56	8.48
Foliar Nitrogen	26.3	0.49	9.14
Soil Nitrogen	25.9	0.48	8.26
	<b>ns</b>	<b>ns</b>	<b>ns</b>
Cultivation			
Till	29.4	0.58	7.79
No Till	23.8	0.44	9.47
	<b>**</b>	<b>**</b>	<b>***</b>
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.

competition, shifts the balance between reproductive and vegetative growth, increasing vine vigor.

In both 1999 and 2000, irrigation and nitrogen treatments had no significant effect on vine vigor. In 1999, irrigated vines tended to have a higher Ravaz Index than non-irrigated vines (Table 3.3).

#### Leaf petiole analysis

The data presented for the 1999 petiole elemental analysis was extracted from Hellman (2000).

*Bloom* – Irrigation treatments were implemented after the bloom sampling in 1999 (Table 3.4a). Tilling had a small effect on petiole potassium, magnesium, copper, and manganese concentration during bloom (Table 3.4a). Vines that received foliar nitrogen had slightly less zinc present in the petioles than vines that received soil or zero nitrogen (Table 3.4a).

In 2000, petiole nutrient analysis at bloom indicates that phosphorus, calcium, and boron were higher for vines that had been irrigated during the previous season (Table 3.5a). Phosphorus content was lowest for vines that received soil nitrogen fertilization. This agrees with studies which show that increased nitrogen application in the spring tends to reduce phosphorus in the

Table 3.4a: Petiole nutrient content during bloom at Benton Lane Vineyard in 1999

	P %	K %	Ca %	Mg %	C %	N %	NO <sub>3</sub> ppm
<b>Macronutrients</b>							
<b>Irrigation</b>							
Irrigated	0.2	2.6	1.5	0.8	41.4	0.8	201.0
Dry	0.2	2.6	1.5	0.8	41.3	0.8	263.7
	ns	ns	ns	ns	ns	ns	ns
<b>Nitrogen</b>							
Zero Nitrogen	0.2	2.6	1.5	0.8	41.4	0.8	235.6
Foliar Nitrogen	0.2	2.6	1.6	0.8	41.3	0.8	221.1
Soil Nitrogen	0.2	2.6	1.5	0.8	41.4	0.8	240.3
	ns	ns	ns	ns	ns	ns	ns
<b>Cultivation</b>							
Till	0.2	2.7	1.6	0.9	41.1	0.8	238.9
No Till	0.2	2.6	1.5	0.8	41.5	0.8	225.8
	ns	*	ns	*	**	ns	ns
<b>Significant Treatment Interactions</b>							
none							
	B ppm	Zn ppm	Mn ppm	Cu ppm			
<b>Micronutrients</b>							
<b>Irrigation</b>							
Irrigated	37.1	60.0	297.0	13.8			
Dry	38.0	66.1	315.6	14.5			
	ns	ns	ns	ns			
<b>Nitrogen</b>							
Zero Nitrogen	37.9	65.4a	310.7	14.4			
Foliar Nitrogen	37.7	56.8b	328.4	14.1			
Soil Nitrogen	37.0	67.0a	279.7	14.0			
	ns	*	ns	ns			
<b>Cultivation</b>							
Till	37.2	65.0	330.8	14.6			
No Till	38.0	61.1	281.8	13.7			
	ns	ns	**	*			
<b>Significant Treatment Interactions</b>							
none							
ns, *, **, and *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levelsof probability, respectively. Means followed by different letters are significantly different.							

Table 3.5a: Petiole nutrient content during bloom at Benton Lane Vineyard in 2000

	P %	K %	Ca %	Mg %	C %	N %	NO <sub>3</sub> ppm
<b>Macronutrients</b>							
<b>Irrigation</b>							
Irrigated	0.19	2.42	1.34	0.53	42.4	0.53	50.6
Dry	0.14	2.43	1.24	0.54	42.5	0.53	59.5
	***	ns	***	ns	ns	ns	ns
<b>Nitrogen</b>							
Zero Nitrogen	0.17a	2.38	1.32	0.54	42.5	0.53	51.0
Foliar Nitrogen	0.19a	2.47	1.30	0.55	42.4	0.53	49.3
Soil Nitrogen	0.14b	2.42	1.25	0.52	42.5	0.53	64.9
	**	ns	ns	ns	ns	ns	ns
<b>Cultivation</b>							
Till	0.15	2.43	1.29	0.55	42.4	0.54	63.5
No Till	0.18	2.42	1.29	0.52	42.5	0.52	46.6
	ns	ns	ns	ns	ns	ns	ns
<b>Significant Treatment Interactions</b>							
none							
	B ppm	Zn ppm	Mn ppm	Cu ppm			
<b>Micronutrients</b>							
<b>Irrigation</b>							
Irrigated	22.7	53.0	258	9			
Dry	22.1	50.3	248	8.93			
	*	ns	ns	ns			
<b>Nitrogen</b>							
Zero Nitrogen	22.3	53.6	251	9.15			
Foliar Nitrogen	22.8	51.8	266	9.05			
Soil Nitrogen	22.2	49.6	242	8.7			
	ns	ns	ns	ns			
<b>Cultivation</b>							
Till	22.2	52.3	264	9.17			
No Till	22.6	51.0	242	8.77			
	ns	ns	ns	ns			
<b>Significant Treatment Interactions</b>							
none							

ns, \*, \*\*, and \*\*\* indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levelsof probability, respectively. Means followed by different letters are significantly different.

leaves (Bell, 1991; Spayd *et al.*, 1993; Larchevêque *et al.*, 1998). In 2000, cultivation did not affect petiole nutrient content at bloom (Table 3.5a).

*Véraison* – Irrigation had no effect on petiole nutrient content during *véraison* in 1999 (Table 3.4b). Tilling had a small effect on petiole manganese concentration (Table 3.4b). Nitrogen treatments in 1999 produced small differences in phosphorus, manganese, total nitrogen and carbon (Table 3.4b). However, these differences were found to be small and may not be of biological significance.

In 2000, cultivation had the biggest impact on petiole nutrient analysis at *véraison* (Table 3.5b). Tilled vines had significantly higher phosphorus, potassium, manganese, copper, and nitrogen than non-tilled vines. Irrigated vines had significantly higher phosphorus, calcium, magnesium, and nitrogen at *véraison* than non-irrigated vines (Table 3.5b). Non-irrigated vines tended to have higher nitrate concentration in the petioles than irrigated vines. Vines that were not given any nitrogen had higher copper than vines which received foliar or soil applied nitrogen (Table 3.5b).

Significant treatment interactions between irrigation and cultivation were observed during *véraison* in 1999 (Table 3.4c). Irrigated and tilled vines had significantly higher petiole nitrate concentration and non-irrigated and tilled vines had significantly higher petiole zinc concentration.

Table 3.4b: Petiole nutrient content during veraison at Benton Lane Vineyard in 1999

	P %	K %	Ca %	Mg %	C %	N %	NO <sub>3</sub> ppm
Macronutrients							
Irrigation							
Irrigated	0.04	1.6	1.1	1.0	43.5	0.3	16.2
Dry	0.04	1.7	1.1	1.0	43.4	0.3	14.4
	ns	ns	ns	ns	ns	ns	ns
Nitrogen							
Zero Nitrogen	0.04	1.7	1.1	1.0	43.3b	0.3b	17.6
Foliar Nitrogen	0.04	1.6	1.1	1.0	44.0a	0.4a	13.1
Soil Nitrogen	0.04	1.6	1.1	1.0	43.5b	0.3b	15.2
	ns	ns	ns	ns	*	*	ns
Cultivation							
Till	0.04	1.7	1.1	1.0	43.3	0.3	17.9
No Till	0.04	1.5	1.1	1.0	43.4	0.3	12.7
	ns	ns	ns	ns	**	ns	ns
Significant Treatment Interactions See Table 3.4c							
	B ppm	Zn ppm	Mn ppm	Cu ppm			
Micronutrients							
Irrigation							
Irrigated	22.6	51.9	228.1	4.7			
Dry	22.9	58.3	222.2	6.0			
	ns	ns	ns	ns			
Nitrogen							
Zero Nitrogen	23.0	60.3	252.3a	5.2			
Foliar Nitrogen	23.0	53.4	220.2ab	5.0			
Soil Nitrogen	23.0	51.6	203.9b	6.3			
	ns	ns	*	ns			
Cultivation							
Till	23.0	57.0	240.0	6.2			
No Till	23.0	53.0	211.3	4.5			
	ns	ns	*	ns			
Significant Treatment Interactions See Table 3.4c							

ns, \*, \*\*, and \*\*\* indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 level of probability, respectively. Means followed by different letters are significantly different.

Table 3.5b: Petiole nutrient content during veraison at Benton Lane Vineyard in 2000

	P %	K %	Ca %	Mg %	C %	N %	NO <sub>3</sub> ppm
<b>Macronutrients</b>							
<b>Irrigation</b>							
Irrigated	0.04	0.89	1.17	1.23	43.4	0.35	8.45
Dry	0.03	0.88	1.10	1.21	43.2	0.34	10.31
	<b>**</b>	<b>ns</b>	<b>*</b>	<b>ns</b>	<b>ns</b>	<b>**</b>	<b>ns</b>
<b>Nitrogen</b>							
Zero Nitrogen	0.04	0.91	1.16	1.19	43.2	0.34	7.84
Foliar Nitrogen	0.04	0.85	1.15	1.26	43.2	0.34	10.77
Soil Nitrogen	0.04	0.90	1.09	1.21	43.5	0.34	9.54
	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>
<b>Cultivation</b>							
Till	0.04	0.98	1.14	1.23	43.1	0.35	9.5
No Till	0.03	0.79	1.12	1.21	43.6	0.34	9.26
	<b>*</b>	<b>**</b>	<b>ns</b>	<b>ns</b>	<b>**</b>	<b>*</b>	<b>ns</b>
<b>Significant Treatment Interactions</b>							
none							
	B ppm	Zn ppm	Mn ppm	Cu ppm			
<b>Micronutrients</b>							
<b>Irrigation</b>							
Irrigated	21.5	60.3	279	4.9			
Dry	21.2	59.5	270	4.8			
	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>			
<b>Nitrogen</b>							
Zero Nitrogen	21.9	60.7	273	5.1a			
Foliar Nitrogen	21.1	59.5	283	4.8ab			
Soil Nitrogen	21.1	59.6	268	4.6b			
	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>**</b>			
<b>Cultivation</b>							
Till	21.0	61.0	291	5.0			
No Till	21.7	58.9	258	4.7			
	<b>*</b>	<b>ns</b>	<b>***</b>	<b>**</b>			
<b>Significant Treatment Interactions</b>							
none							

ns, \*, \*\*, and \*\*\* indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels of probability, respectively. Means followed by different letters are significantly different.

Table 3.4c: Petiole nutrient content during veraison at Benton Lane Vineyard in 1999

Significant Treatment Interactions

	P %	K %	Ca %	Mg %	C %	N %	NO <sub>3</sub> ppm
Macronutrients							
Irrigation x Cultivation							
Irrigated x Till	0.04	1.7	1.1	1.0	43.3	0.3	23.6a
Irrigated x No Till	0.04	1.5	1.1	1.0	43.7	0.3	8.7c
Dry x Till	0.04	1.7	1.1	1.0	43.4	0.3	12.3b
Dry x No Till	0.04	1.6	1.1	1.0	43.5	0.4	16.6b
	ns	ns	ns	ns	ns	ns	**
	B ppm	Zn ppm	Mn ppm	Cu ppm			
Micronutrients							
Irrigation x Cultivation							
Irrigated x Till	23.0	50.2c	243.1	5.1			
Irrigated x No Till	22.2	54.0b	213.2	4.2			
Dry x Till	23.0	65.0a	236.2	7.3			
Dry x No Till	22.8	52.0bc	209.3	4.7			
	ns	*	ns	ns			

ns, \*, \*\*, and \*\*\* indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levelsof probability, respectively. Means followed by different letters are significantly different.



### Wood carbohydrate reserves

There were no measurable treatment differences in the level of carbohydrate reserves in the permanent vine structure during the winter following the first year of this study (Table 3.6).

In 2000, irrigation and nitrogen application did not affect carbohydrate concentration (Table 3.7). However, soil cultivation did impact the amount of starch, sugar, and total non-structural carbohydrates (TNSC) found in the permanent structure of the vine (Table 3.7). Tilled vines had significantly higher starch, sugar, and TNSC than non-tilled vines. This could be related to the increased rates of photosynthesis and vine vigor that were observed in tilled treatments in 1999 and which became even more apparent in 2000 (Fig 3.3b, Fig 3.4b, and Table 3.3).

Candolfi-Vasconcelos and co-workers (1994a) found that under non-stressing conditions, there is no retranslocation of carbon reserves to supplement fruit ripening. If there is a shortage of photoassimilates due to imbalances between sinks (fruit) and source tissues (leaves), vines are able to retranslocate carbon from reserves during the ripening period. In 1999, fruit yields were lower (2kg/vine) than in 2000 (4kg/vine). The smaller crop load in 1999 allowed vines to fully replenish the reserves. In 2000, the carbohydrate reserves were about half the levels observed in 1999, probably as a result of the heavier crop.

Table 3.6: Wood carbohydrate reserves of Pinot noir vines at Benton Lane Vineyard in 1999.

	trunk volume (cm <sup>3</sup> )	starch (%)	sugar (%)	TNSC (%)	starch (g/trunk)	sugar (g/trunk)	TNSC (g/trunk)
Irrigation							
Irrigated	504.5	10.1	11.3	21.4	24.8	27.6	52.4
Dry	498.9	9.3	10.3	19.6	23.8	26.4	50.2
	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>
Nitrogen							
Zero Nitrogen	493.8	10.9	12.1	23.0	27.1	30.1	57.1
Foliar Nitrogen	506.8	9.6	10.7	20.3	24.2	26.9	51.0
Soil Nitrogen	504.5	8.6	9.6	18.2	21.6	24.0	45.7
	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>
Cultivation							
Till	493.9	9.5	10.6	20.2	22.5	25.0	47.6
No Till	509.5	9.9	11.0	20.8	26.0	28.9	55.0
	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>

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.

Means followed by different letters are significantly different

Table 3.7: Wood carbohydrate reserves of Pinot noir vines at Benton Lane Vineyard in 2000.

	trunk volume (cm <sup>3</sup> )	starch (%)	sugar (%)	TNSC (%)	starch (g/trunk)	sugar (g/trunk)	TNSC (g/trunk)
<b>Irrigation</b>							
Irrigated	568.2	4.5	5.0	9.5	14.2	15.8	30.1
Dry	562.0	4.5	5.1	9.6	14.7	16.3	31.1
	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>
<b>Nitrogen</b>							
Zero Nitrogen	566.7	4.2	4.7	8.9	13.4	14.9	28.3
Foliar Nitrogen	584.1	4.5	5.0	9.6	15.5	17.2	32.7
Soil Nitrogen	544.7	4.8	5.4	10.2	14.6	16.2	30.7
	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>
<b>Cultivation</b>							
Till	579.2	4.9	5.5	10.4	16.4	18.2	34.5
No Till	555.1	4.1	4.6	8.7	12.6	14	26.6
	<b>ns</b>	<b>***</b>	<b>***</b>	<b>***</b>	<b>*</b>	<b>*</b>	<b>*</b>
<b>Significant Treatment Interactions</b>							
<b>Irrigation x Cultivation</b>							
Irrigated x Till	584.0	4.6b	5.1ab	9.6b	14.9	16.6	31.6
Irrigated x No Till	552.5	4.5b	5.0b	9.4b	13.5	15.0	28.6
Dry x Till	574.4	5.3a	5.8a	11.1a	17.8	19.7	37.5
Dry x No Till	549.7	3.8c	4.2c	8.1c	11.7	6.1	24.6
	<b>ns</b>	<b>**</b>	<b>**</b>	<b>**</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>

ns, \*, \*\*, and \*\*\* indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels of probability, respectively. Means followed by different letters are significantly different

## **Chapter 4**

### **The Effect of Soil Moisture Manipulation and Nitrogen Application on Ripening Dynamics, Juice Composition, and Yield Components of Pinot noir and Chardonnay in the Willamette Valley**

#### **Abstract**

The aim of this study was to optimize fruit quality and maximize the juice nitrogen fraction that can be used by yeast during fermentation. In 1999, various vineyard practices that may improve nitrogen availability to the vine were integrated into two replicated trials located in two commercial vineyards, Knudsen Vineyard in the North Willamette Valley and Benton Lane in the South Willamette Valley. Treatments were applied in a factorial design to vary irrigation, cultivation, and nitrogen application to Pinot noir (Benton Lane) and Chardonnay (Knudsen) grapevines during two seasons. Irrigated vines received supplemental irrigation after lag phase. Cultivation of alternate rows was performed in early spring to encourage nitrogen utilization and reduce nutrient and water competition. Nitrogen treatments consisted of soil-applied urea (39.2kgN/ha), foliar applied urea (2.98kgN/ha), and zero nitrogen. Soil nitrogen was applied in early spring. Foliar nitrogen was applied once at the onset of ripening and again at véraison. Ripening dynamics, juice composition, and yield components were measured in the 1999 and

2000 growing seasons. During both seasons, irrigated Pinot noir vines had lower titratable acidity than non-irrigated vines and tilled treatments had higher soluble solids than non-tilled treatments. Tilled Chardonnay vines had lower soluble solids and higher titratable acidity in 2000. In 1999, the ammonia content of Pinot noir fruit decreased from an average of 80 to 30 (mg/L) while the alpha amino acid content increased from 60 to 150 (mg/L) during ripening. The YANC of Pinot noir vines increased from 100 to 190 (mg/L), predominately due to a large increase in alpha amino acid concentration in the last two weeks of maturation. For both Pinot noir and Chardonnay, the results from 2000 indicate that tilled treatments tend to have higher YANC at harvest, predominately due to a large increase in alpha amino acids. Significant effects from tilling suggest that there may be a delayed benefit from soil cultivation. Irrigated vines tended to have a higher berry weight, however, yield components differed only slightly between treatments and year.

## **Introduction**

Commercial Oregon must samples have often been shown to contain lower than minimal levels of fermentable nitrogen at harvest (Watson *et al.*, 2000). At harvest, low levels of yeast assimilable nitrogen in grape clusters may affect fermentation behavior and be deleterious to the quality of the finished wine (Kunkee, 1991; Butzke, 1998). Differences in vine water status have also been

shown to result in wines with significantly different composition, appearance, and flavor (Matthews *et al.*, 1990).

The specific amino acids present in the fruit at harvest, and their relative concentrations, influence the rate of fermentation by yeast and the formation of higher alcohols in wine (reviewed by Kliewer, 1969). It has been shown that nitrogenous compounds, especially amino acids, increase with fruit maturity (Kliewer, 1969; Kliewer, 1968; Winkler *et al.*, 1974).

Numerous studies have found that the solute composition of grapes at harvest is highly dependent upon the water status of the vine (Williams and Matthews, 1990; reviewed by Matthews *et al.*, 1990). Thus, in a given growing season, soil moisture management is important during specific physiological stages of the vine. There are two phases of intense nitrogen incorporation into the fruit (reviewed by Weimelinger, 1991). The first takes place during two weeks prior to the “pea- size” stage of berries. The second starts one month later at véraison and lasts an additional two weeks (Löhnertz, 1988; Winkler *et al.*, 1974; reviewed by Wermelinger, 1991).

Water availability, mineralization rate of soil nitrogen, and plant uptake of soil available nitrogen may override the effect of nitrogen fertilizers (reviewed by Rupp, 1996). Irrigation is one cultural practice that may increase nitrogen concentration in the fruit at harvest. It is suggested that optimum vine growth, grape yield, and grape quality can be obtained by integration of controlled

irrigation during certain phenological stages of vine growth (Matthews *et al.*, 1990; Van Zyl, 1984).

In addition, there are many benefits from soil cultivation. In clean cultivated vineyards, about 100 kg of nitrogen can be mobilized per hectare in one year. In vineyards with ground cover, the mobilizable nitrogen can be four times higher (Perret *et al.*, 1992). Soil cultivation can effectively be used to optimize mineralization of nitrogen and increase soil water availability (reviewed by Rupp, 1996).

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 have been evaluated. The focus of this study is to optimize fruit quality and maximize the juice nitrogen fraction, while maintaining a physiologically healthy vine and crop system.

## **Materials and Methods**

### **Experimental design**

This study was conducted in two commercial Oregon vineyards during the 1999 and 2000 growing seasons. It was a factorial of irrigation, nitrogen, and soil cultivation (Table 4.1) organized in a randomized block design. Each treatment was replicated five times in groups of eleven vines. There were guard rows between

each data row, and guard vines between each replicate per row (2 guard vines at Benton Lane Vineyard, 4 guard vines at Knudsen Vineyard).

*Site #1* - Knudsen vineyard is located in Dundee of the north Willamette Valley. Site elevation is approximately 229m. The vines used were Chardonnay clone FPMS 4 (108) and are own rooted. Vine rows were oriented north to south. The vines were planted in 1989 and are spaced 1.5m x 2m apart on predominantly Jory soil.

*Site #2* - Benton Lane vineyard is located in Monroe of the south Willamette Valley. Site elevation is approximately 130m. The vines used were Pinot noir clone FPMS 2A grafted on Teleki 5C rootstock. Vine rows were oriented north to south. The vines were planted in 1992 and are spaced 1.5m x 3m apart on predominately Bellpine soil.

At both sites, vineyard floor cover consisted of resident plant species. Alternate rows were mowed after resident species were allowed to bloom. Powdery mildew control was performed by the grower.



Table 4.1: Main factors and treatment combinations at Benton Lane and Knudsen Vineyards for 1999 and 2000.

	Irrigation (I)		No Irrigation (D)	
	Till (T)	No Till (NT)	Till (T)	No Till (NT)
<b>Zero Nitrogen (0N)</b>	I-T-0N	I-NT-0N	D-T-0N	D-NT-0N
<b>Foliar Nitrogen (FN)</b>	I-T-FN	I-NT-FN	D-T-FN	D-NT-FN
<b>Soil Nitrogen (SN)</b>	I-T-SN	I-NT-SN	D-T-SN	D-NT-SN

### Irrigation

At both vineyards, water was applied using drip irrigation during lag phase. A total of 82mm irrigation and 90mm irrigation was applied, in 1999 and 2000 respectively, at Benton Lane Vineyard. At Knudsen Vineyard a total of 51mm irrigation was applied per season. Both vineyards irrigated at a rate of 1.9-L H<sub>2</sub>O/hour. Annual precipitation for both sites during both 1999 and 2000 are illustrated in Fig 4.1, Fig 4.2, Fig 4.3, and Fig 4.4.

### Nitrogen

Nitrogen treatments include an unfertilized control, 39.2 kg N/ha supplied to the soil, and 2.98 kg N/ha supplied foliarly. Foliar N fertilizer was split in two applications of 1.49 kg N/ha. Both soil and foliar nitrogen treatments were applied manually. Soil nitrogen was applied as urea (46-0-0). The amount of N to be

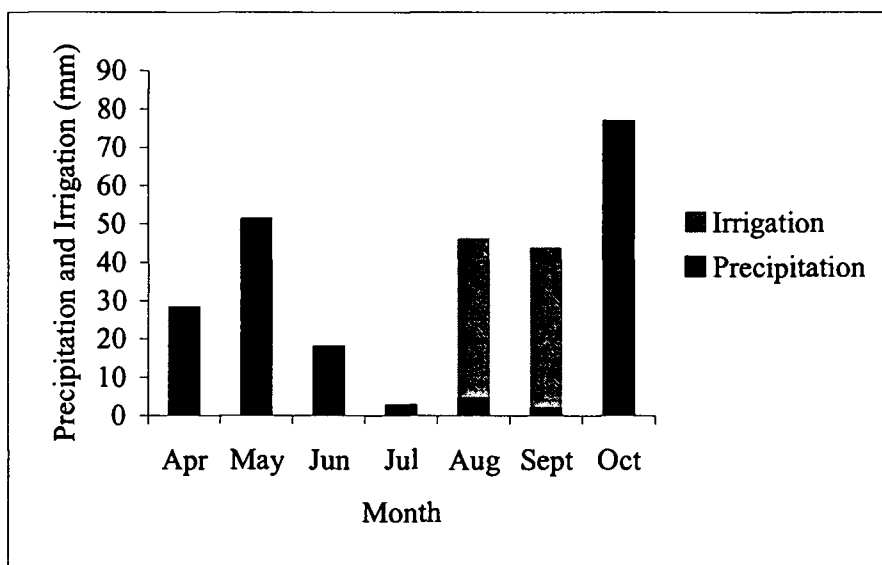


Figure 4.1: Seasonal precipitation and irrigation applied at Benton Lane vineyard during 1999. Total annual precipitation = 184 mm. Total irrigation applied = 82 mm

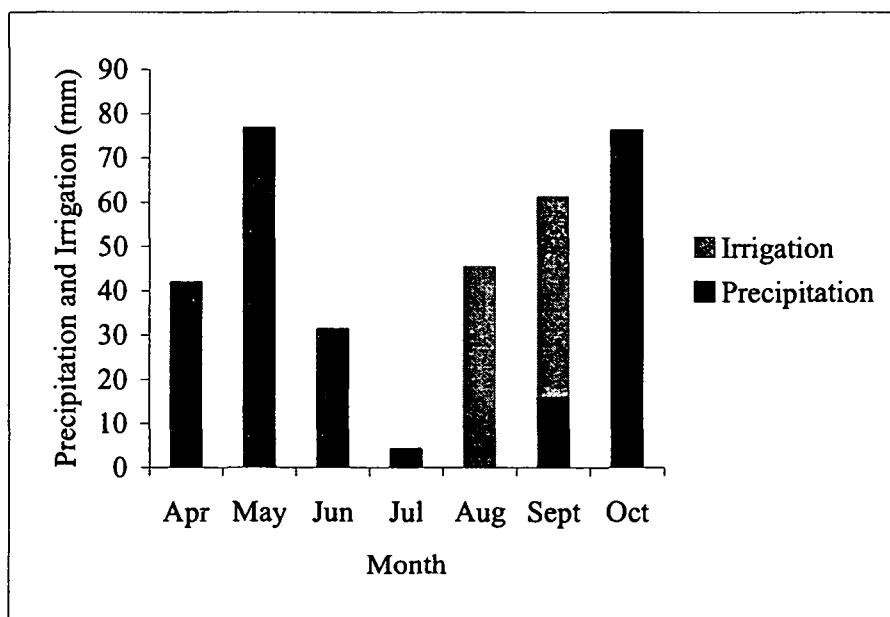


Figure 4.2: Seasonal precipitation and irrigation applied at Benton Lane vineyard during 2000. Total annual precipitation = 247 mm. Total irrigation applied = 90 mm

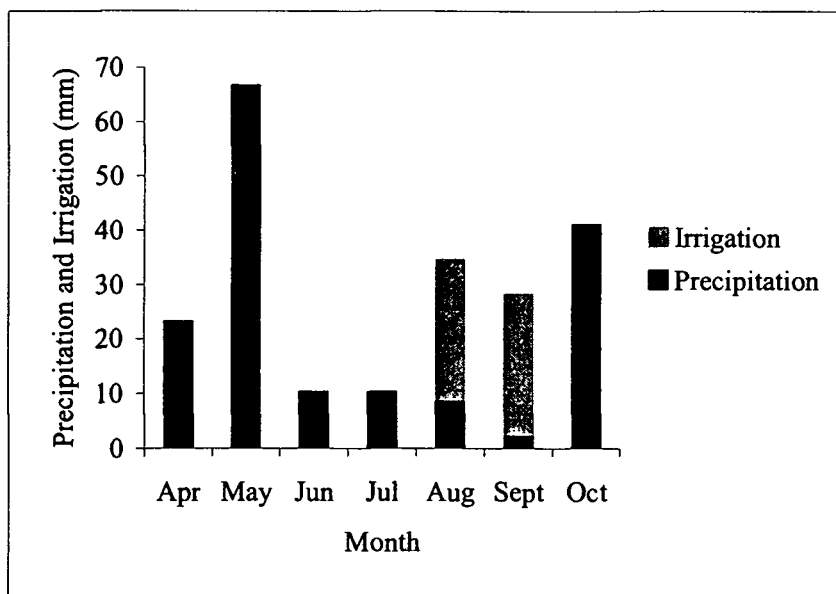


Figure 4.3: Seasonal precipitation and irrigation applied at Knudsen vineyard during 1999. Total annual precipitation = 210 mm. Total irrigation applied = 51 mm

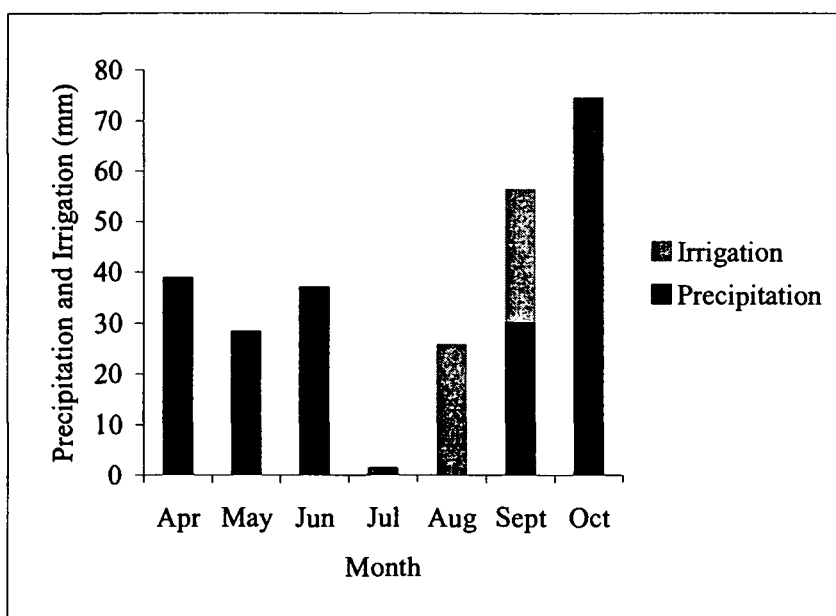


Figure 4.4: Seasonal precipitation and irrigation applied at Knudsen vineyard during 2000. Total annual precipitation = 210 mm. Total irrigation applied = 51 mm

applied to each replicate was measured and broadcast by hand. Foliar nitrogen was applied in the form of wetted urea at a .3% concentration. Using a hand sprayer, the nitrogen solution was applied to leaves in the fruit zone. Soil nitrogen was applied on May 4, 1999 and May 8 2000 at Benton Lane Vineyard. Soil nitrogen was applied on May 5, 1999 and May 10, 2000 at Knudsen Vineyard. At both vineyards, 50% foliar nitrogen was applied at the beginning of color change and 50% at véraison (approximately 14° Brix) for both years. Berries started changing color on August 13, 1999 and August 30, 2000 at Benton Lane Vineyard. Véraison occurred on September 8, 1999 and September 6, 2000 at Benton Lane. Berries started changing color on August 30, 1999 and September 6 2000 at Knudsen Vineyard. Véraison occurred on September 22, 1999 and September 13, 2000 at Knudsen.

#### Soil cultivation

In row tilling was done in early spring to encourage nitrogen utilization and reduce nutrient and water competition. Tilling of alternate rows was done on May 12, 1999 and May 15, 2000 at Knudsen. Tilling of alternate rows was done on May 24, 1999 and May 22, 2000 at Benton Lane. Tilling depth was 15cm.

Results from each vineyard are presented separately. One representative vine (data vine) per treatment replicate was selected and used throughout the two seasons for all field measurements.

### Ripening dynamics

Ripening surveys began at the onset of ripening. Véraison was determined by 50% color change in berries. Eight cluster samples were taken from each replicate between véraison and harvest at approximately one-week intervals. On each date, five 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 determine skin anthocyanin content. Soluble solids of juice were measured using a digital refractometer (Atago Co., LTD, Pelette 100, Honcho, Tokyo). Titratable acidity and pH were measured using an automatic titrator (Mettler Toledo, DL21 Titrator, Hightstown, NJ).

### Yield and fruit composition

Each replicate was harvested separately. Benton Lane vineyard was harvested on October 22, 1999 and October 12, 2000. Knudsen Vineyard was harvested on October 25, 1999 and October 19, 2000. A 25-cluster 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, and titratable acidity as described above. In addition, a 5-cluster sample was taken from each replicate and used to determine berry weight and skin anthocyanin concentration.

### Yeast assimilable nitrogen content

Cluster samples taken at two-week intervals from véraison to harvest were crushed and pressed. The juice was then analyzed for yeast fermentable nitrogen content. Ammonia content was determined using a Sigma enzymatic diagnostic kit. Alpha amino acid content was determined using the NOPA spectrophotometric assay (Butzke, 1998). Yeast assimilable nitrogen content (YANC) is expressed as nitrogen mg/L and is determined as the sum of the assimilable nitrogen from ammonia and the assimilable nitrogen from alpha amino acids (Butzke, 1998).

### Data analysis

All data was submitted to MANOVA using the general linear model. The SAS statistical package (SAS Institute, Cary, NC), with mean separation at  $p < 0.05$  was used.

## **Results and Discussion**

### Ripening dynamics

*Benton Lane Vineyard* - Juice soluble solids were significantly higher for irrigated vines on two dates during ripening in 2000 (Fig 4.5a). A similar trend was observed in 1999, although differences were not as marked (Fig 4.6a). This could not be explained by berry size since irrigated vines had larger berries in 1999 (Fig 4.7a and Table 4.2a). However, it is probably a result of higher photosynthetic rates

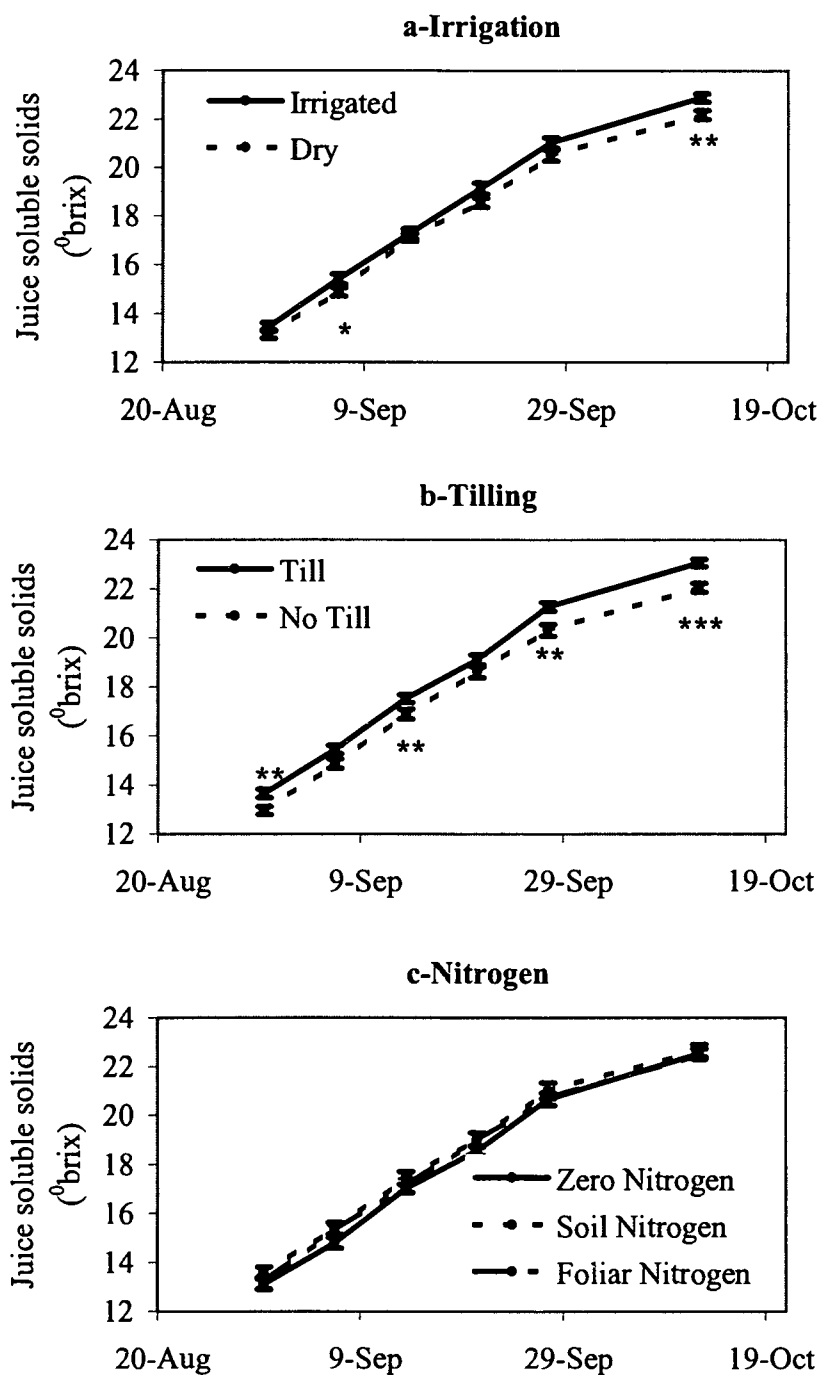


Figure 4.5: Effect of irrigation, tilling, and nitrogen fertilization on juice soluble solids of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

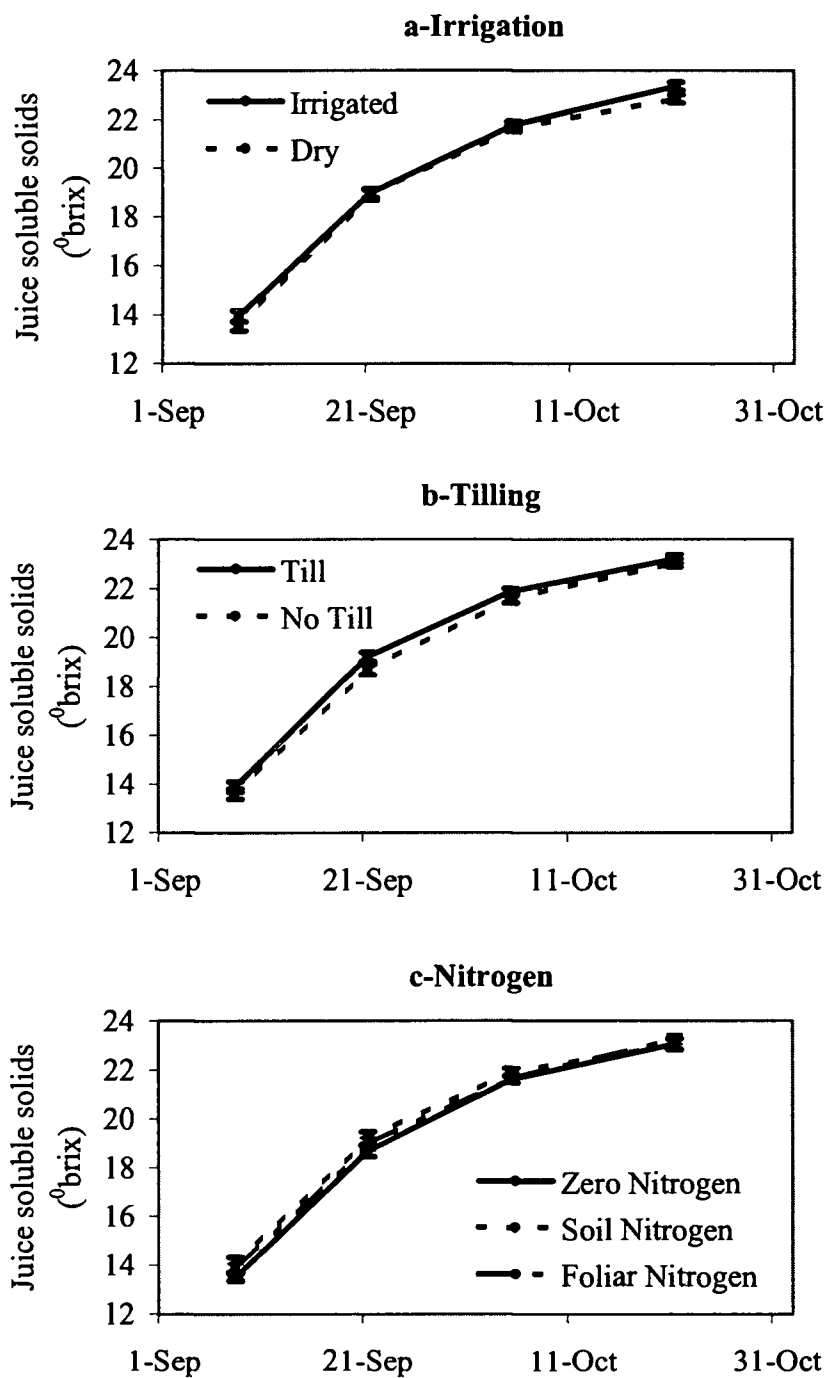


Figure 4.6: Effect of irrigation, tilling, and nitrogen fertilization on juice soluble solids of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.



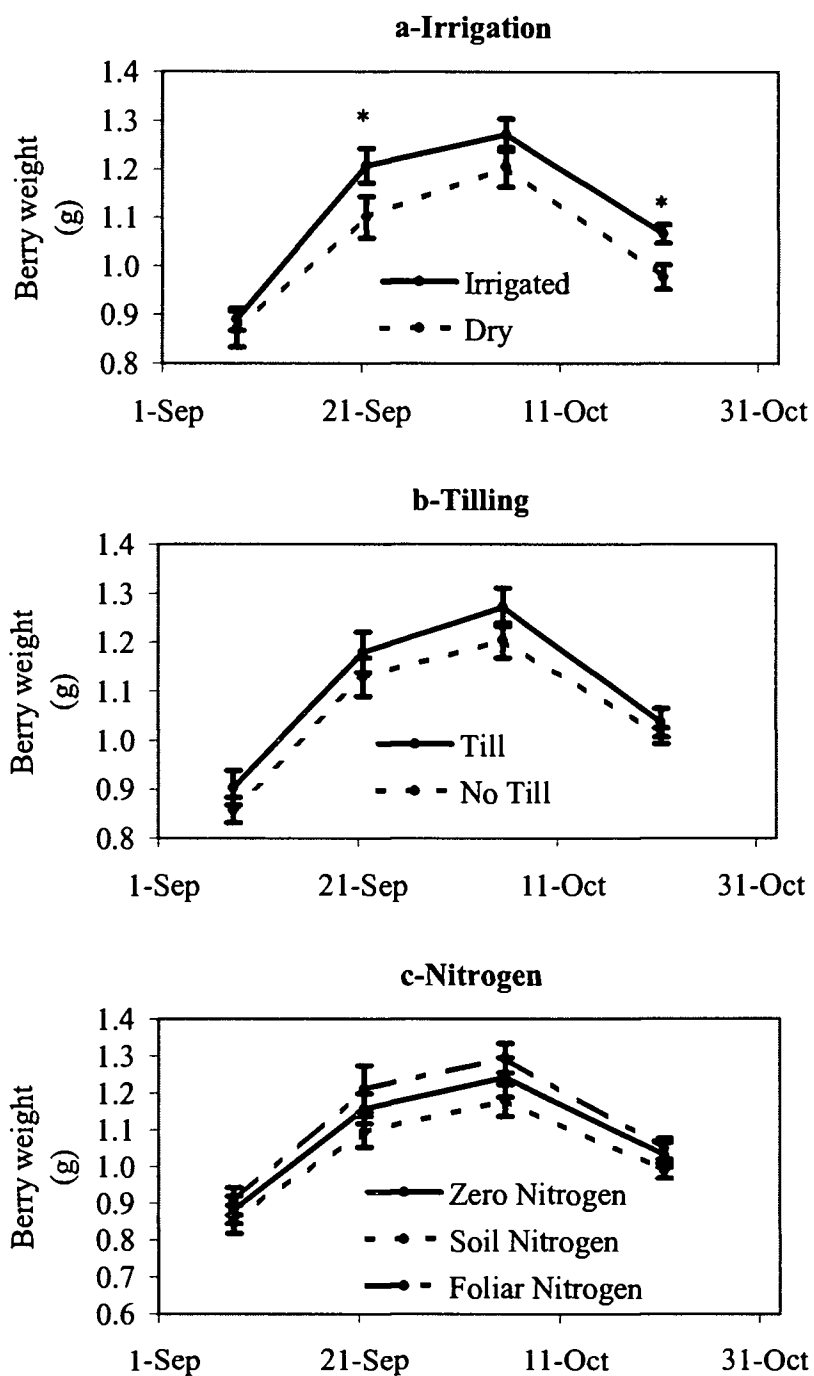


Figure 4.7: Effect of irrigation, tilling, and nitrogen fertilization on berry weight of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

Table 4.2a: Yield components of Pinot noir vines at Benton Lane Vineyard in 1999.

		Yield (kg/vine)	Berries/ cluster	Berry wt. (g)	Cluster wt. (g)
<b>Irrigation</b>					
	Irrigated	2.2	83.1	1.1	88.7
	Dry	2.0	89.0	1.0	86.9
		ns	*	*	ns
<b>Nitrogen</b>					
	Zero Nitrogen	2.3	87.7	1.0	90.2
	Foliar Nitrogen	2.2	86.4	1.1	90.2
	Soil Nitrogen	1.9	84.1	1.0	83.0
		ns	ns	ns	ns
<b>Cultivation</b>					
	Till	2.1	86.5	1.0	89.4
	No Till	2.1	85.6	1.0	86.3
		ns	ns	ns	ns
<b>Significant Treatment Interactions</b>					
	none				

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

(Fig 3.3a) of vines receiving supplemental irrigation. The increase in both soluble solid concentration and berry size suggests that non-irrigated vines were operating under drought stress. The concentration of sugar in berries is often decreased as vine water stress is alleviated, in part, due to larger berry size (reviewed by Smart and Coombe, 1983). In 2000, on all but one date, juice from tilled vines had higher soluble solids than non-tilled vines (Fig 4.5b). A similar trend was observed in 1999, although differences were not significant (Fig 4.6b). This may also be attributed to the higher photosynthetic rates of these vines during both seasons (Fig 3.3b and Fig 3.4b).

At the onset of ripening in 2000, juice from irrigated vines had significantly higher pH than non-irrigated vines (Fig 4.8a). Prior to harvest in 2000, juice from tilled vines had higher pH than non-tilled vines (Fig 4.8b). In Australia, Freeman *et al.* (1980) found that decreased water stress increased juice and wine pH in Shiraz. In late September of 2000, juice from vines that received no nitrogen had lower pH than other nitrogen treatments (Fig 4.8c).

In 1999 and 2000, juice from non-irrigated vines had significantly higher titratable acidity than irrigated vines at the onset of ripening (Fig 4.9a and Fig 4.10a). This effect is contradictory to much of the reported research. Spiegel-Roy and Bravdo (1964), Van Zyl and Weber (1977), and Coombe and Monk (1979) all report that higher water availability causes higher acidity concentration of berries. In 2000, juice from vines that received zero nitrogen had higher titratable acidity on

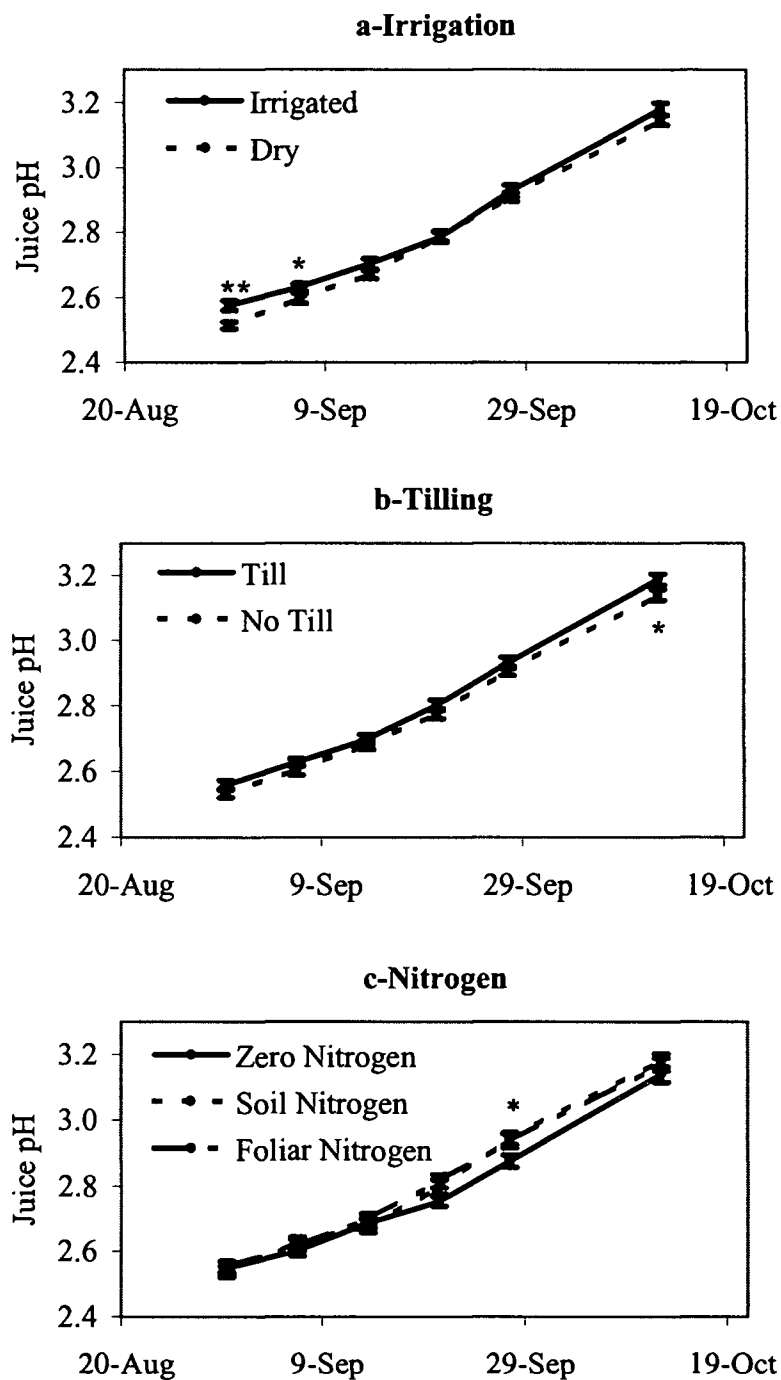


Figure 4.8: Effect of irrigation, tilling, and nitrogen fertilization on juice pH of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

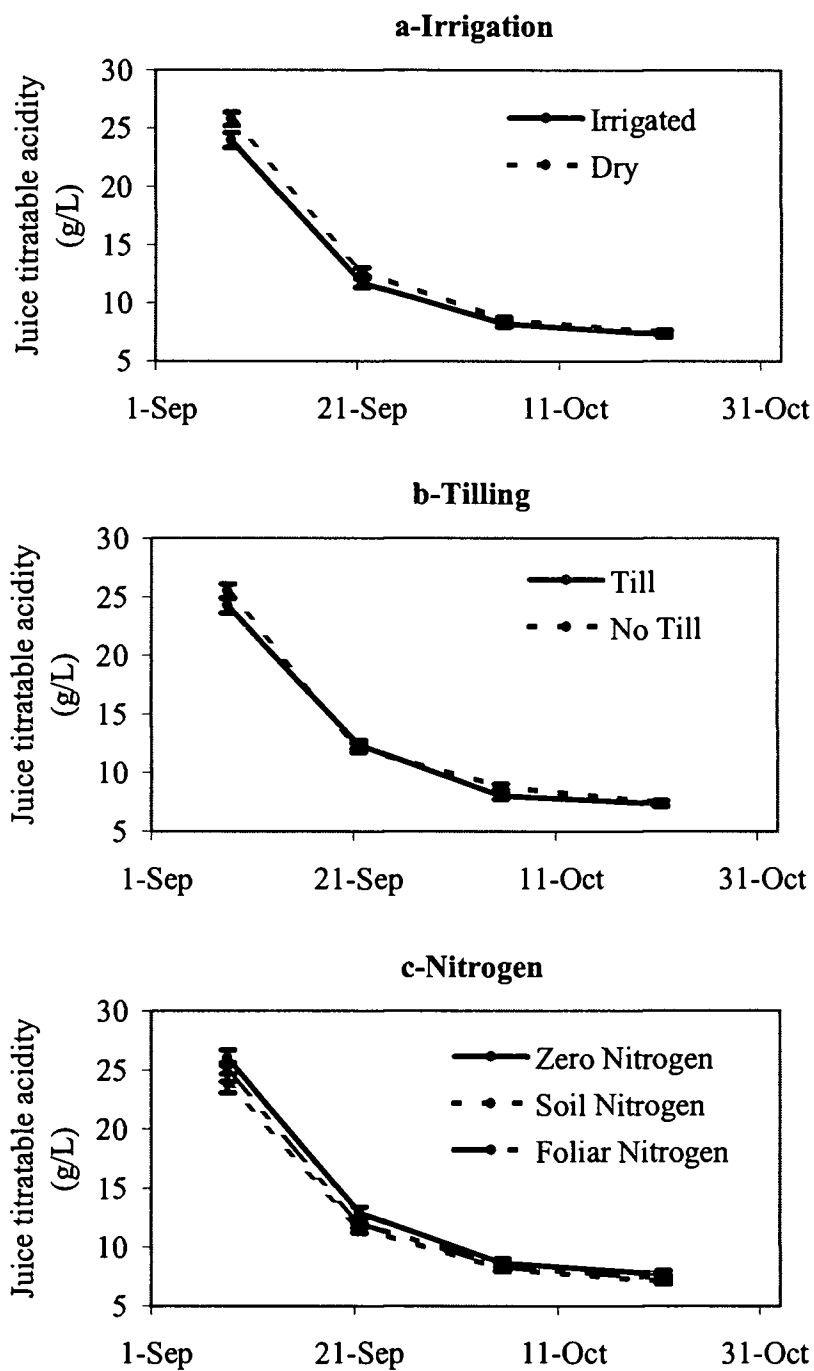


Figure 4.9: Effect of irrigation, tilling, and nitrogen fertilization on juice titratable acidity of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

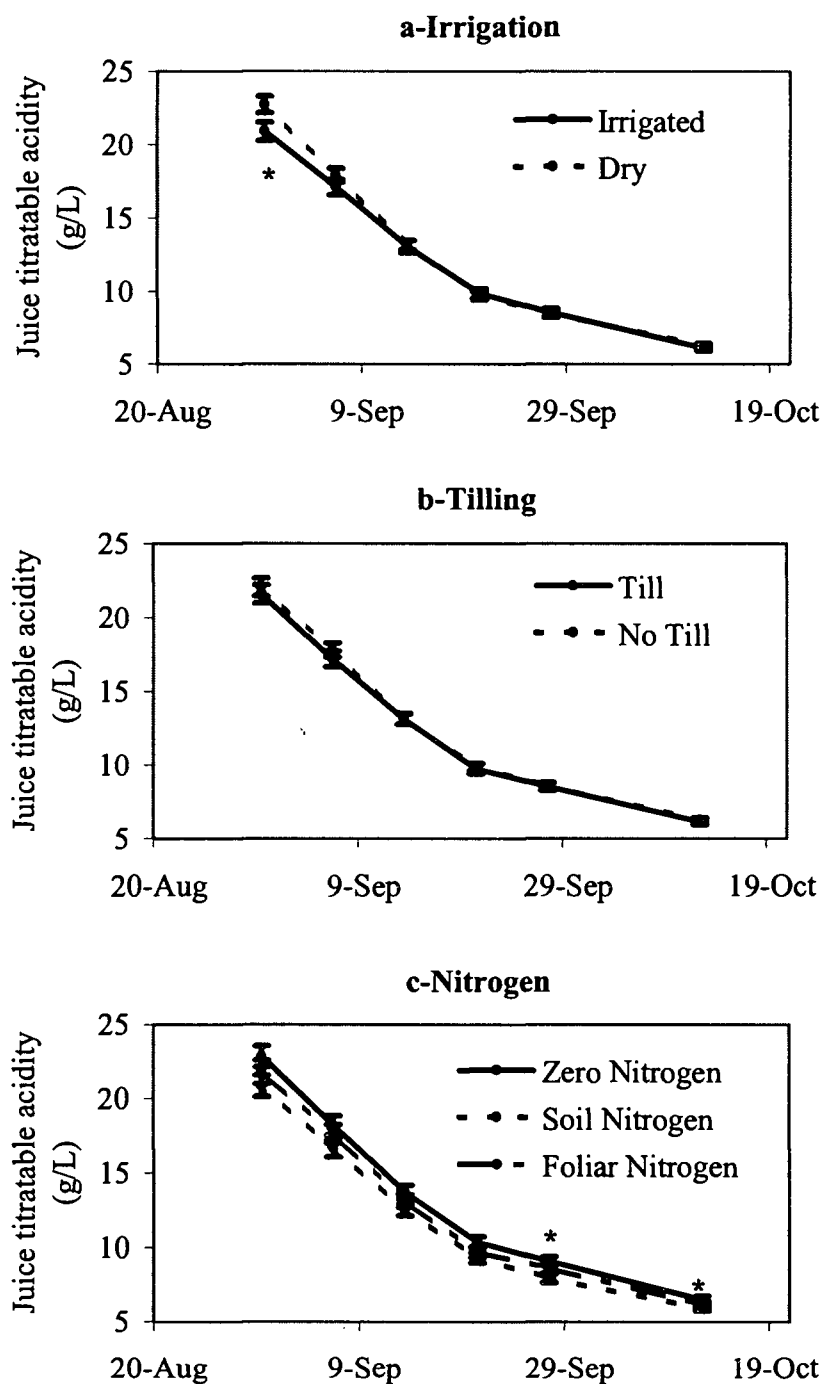


Figure 4.10: Effect of irrigation, tilling, and nitrogen fertilization on juice titratable acidity of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

two dates prior to harvest (Fig 4.10c). There were no significant differences in juice soluble solids, pH, or titratable acidity among nitrogen treatments in 1999 (Fig 4.6c, Fig 4.11c, and Fig 4.9c).

*Knudsen Vineyard* – In 1999 and 2000, there were no significant differences between irrigated and non-irrigated vines with respect to juice soluble solids or titratable acidity (Fig 4.12a, Fig 4.13a, Fig 4.14a and Fig 4.15a). Two weeks prior to harvest in 2000, juice pH of non-irrigated vines was significantly higher than irrigated vines (Fig 4.16a). Juice from Chardonnay vines grown in deep soils in the cool climate of Salinas Valley, California showed a slight decrease in pH when irrigated (Wildman *et al.*, 1976). Neja *et al.* (1977) also showed that Cabernet Sauvignon, grown in a cool climate, resulted in lower juice pH with increasing amounts of irrigation.

Vines at this site have been irrigated since establishment and have not shown signs of drought stress in the past. It is likely that non-irrigated vines were unaffected by lack of water during two growing seasons. Deep soils and northern exposure may also be mitigating factors.

In 2000, on all dates except that prior to harvest, non-tilled vines had higher juice soluble solids than tilled vines (Fig 4.14b). Juice from tilled vines had higher titratable acidity than non-tilled vines on three dates prior to harvest in 2000 (Fig 4.15b). Differences in ripening dynamics between tilling treatments were not

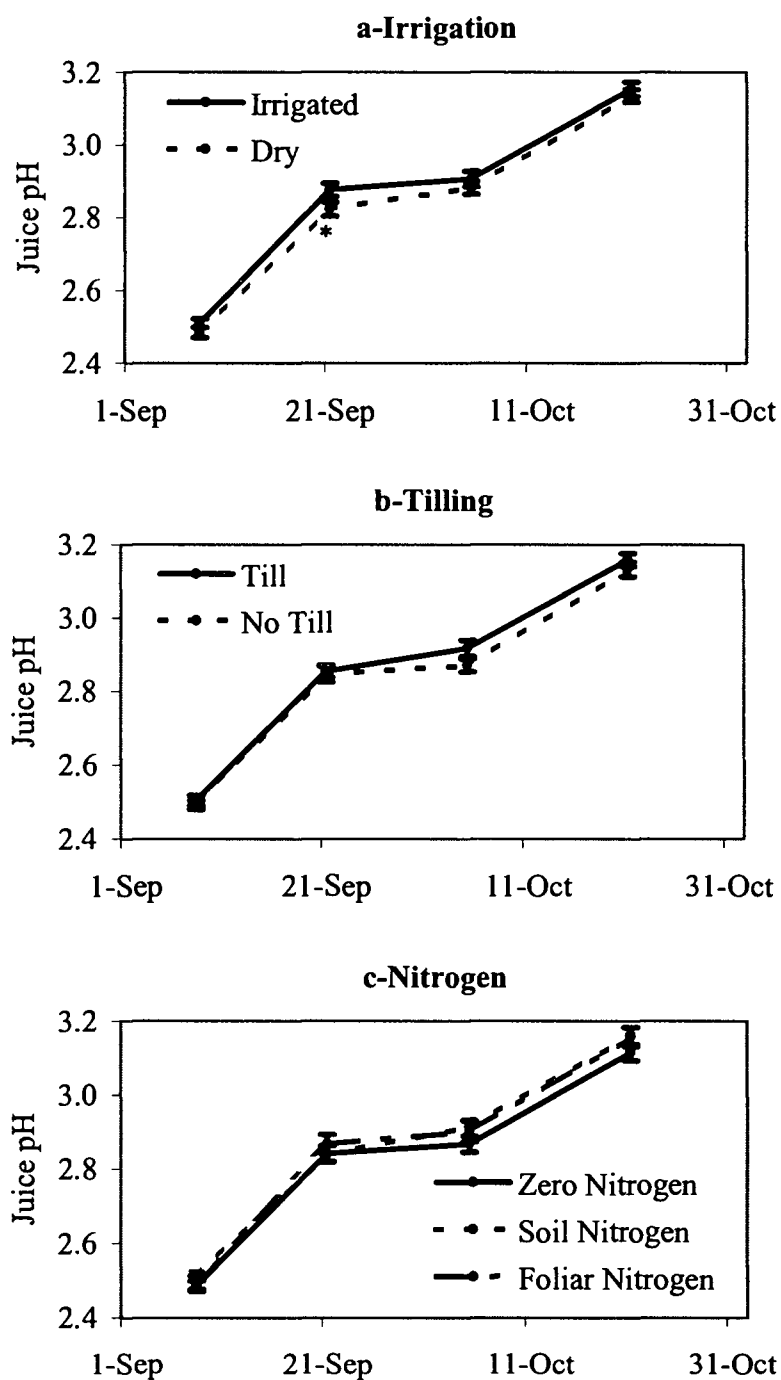


Figure 4.11: Effect of irrigation, tilling, and nitrogen fertilization on juice pH of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.



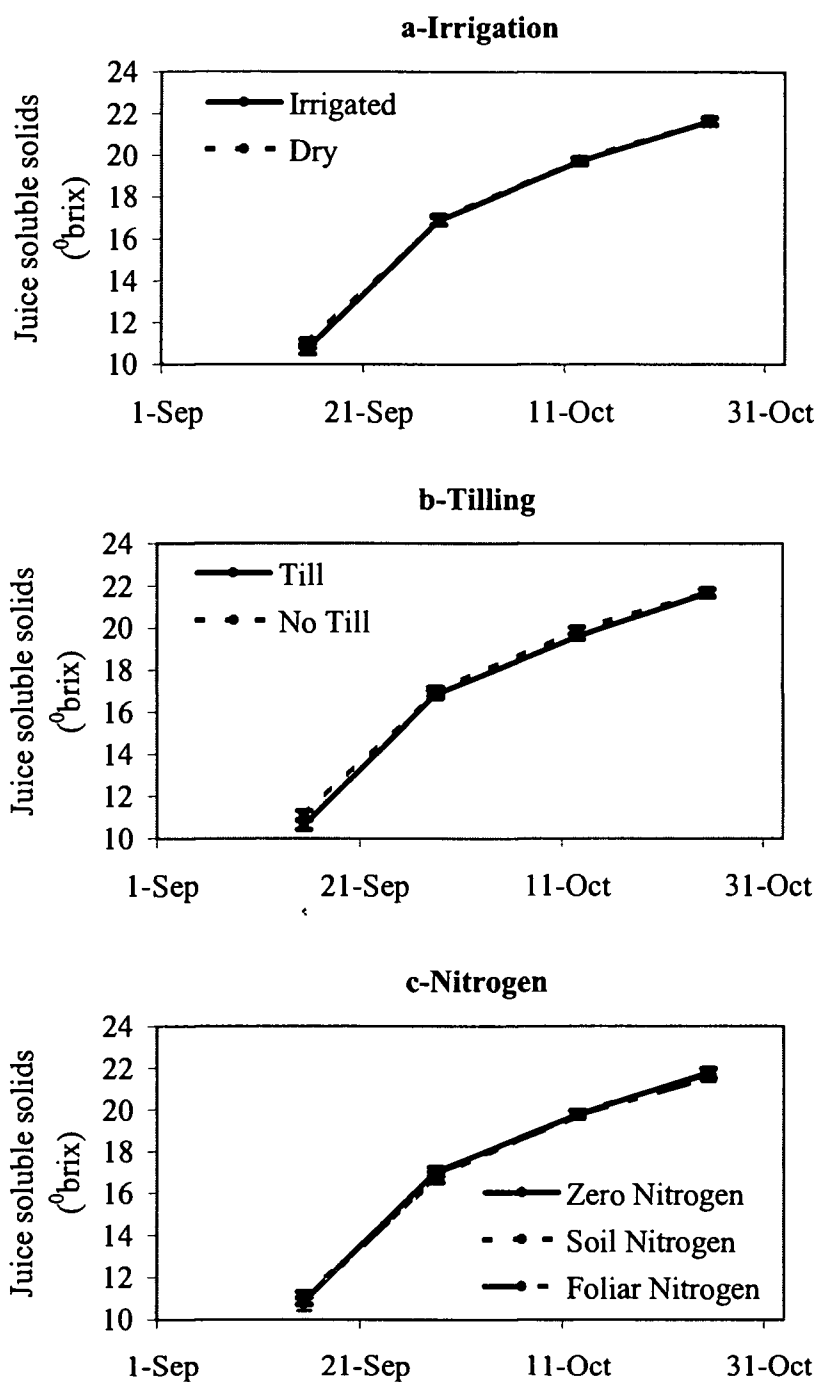


Figure 4.12: Effect of irrigation, tilling, and nitrogen fertilization on juice soluble solids of Chardonnay grapevines at Knudsen vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

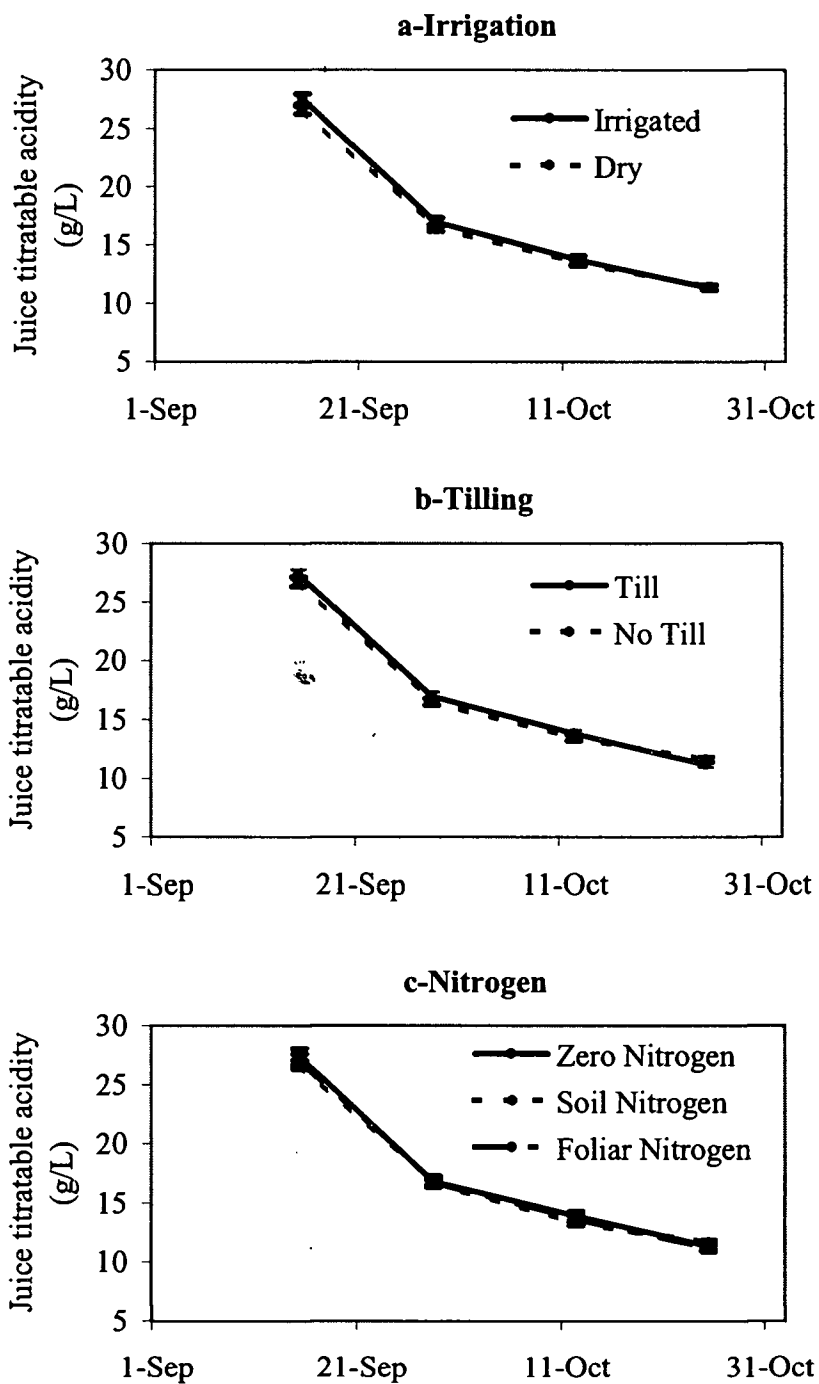


Figure 4.13: Effect of irrigation, tilling, and nitrogen fertilization on juice titratable acidity of Chardonnay grapevines at Knudsen vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

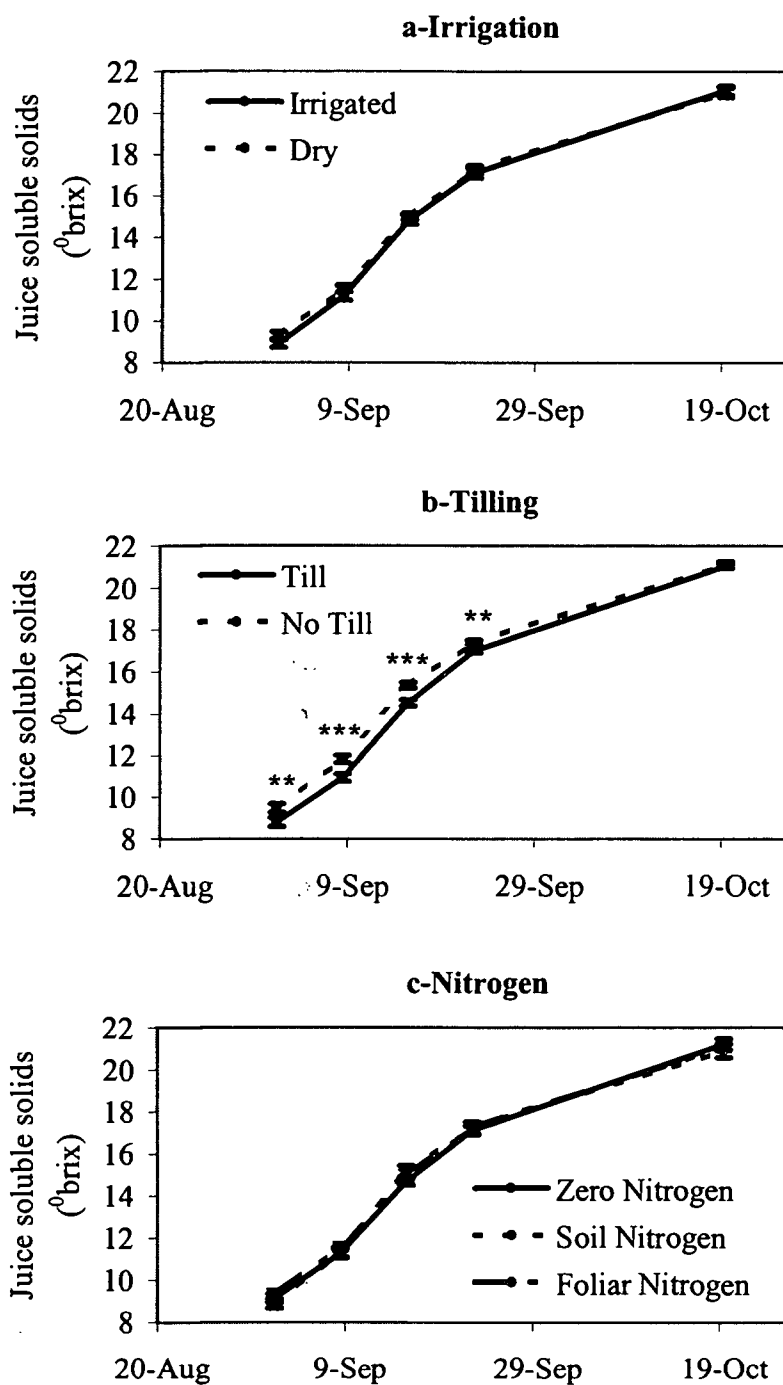


Figure 4.14: Effect of irrigation, tilling, and nitrogen fertilization on juice soluble solids of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

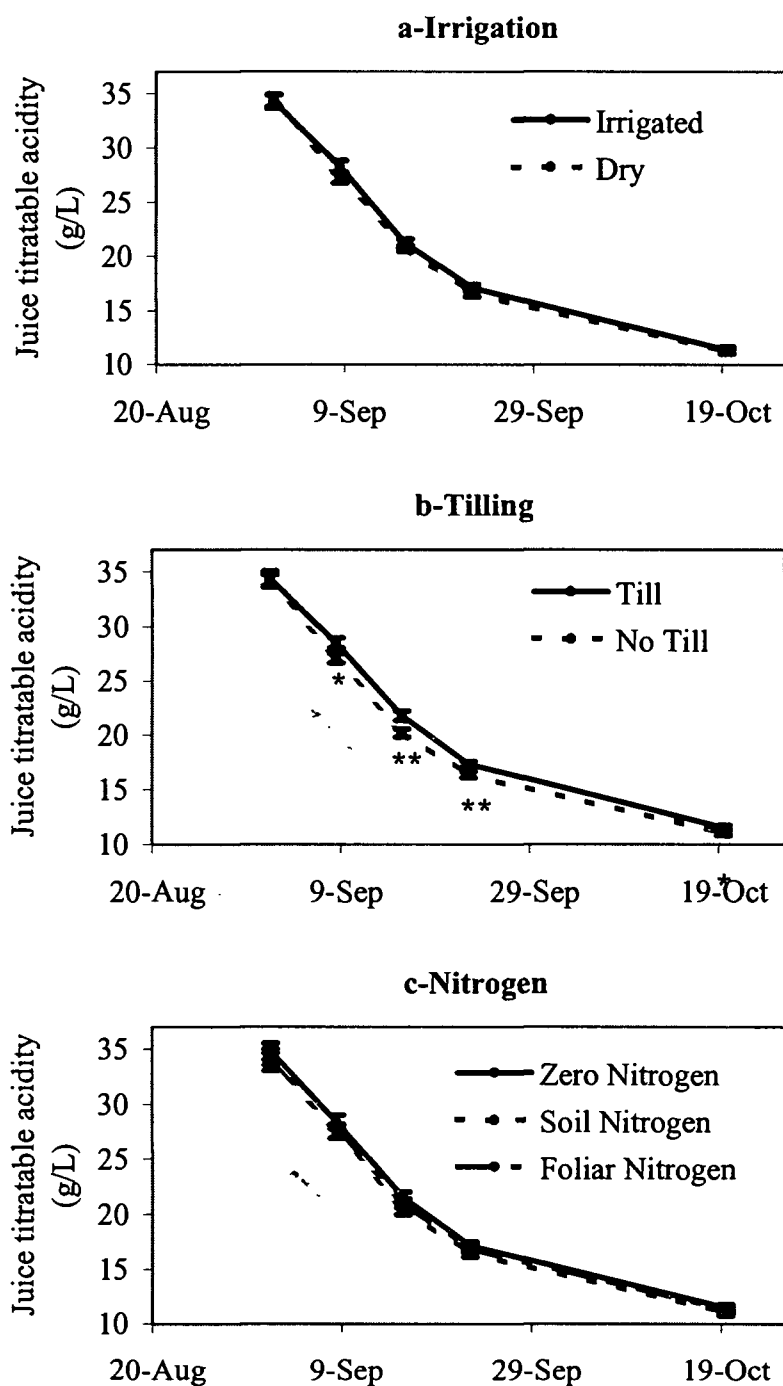


Figure 4.15: Effect of irrigation, tilling, and nitrogen fertilization on juice titratable acidity of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

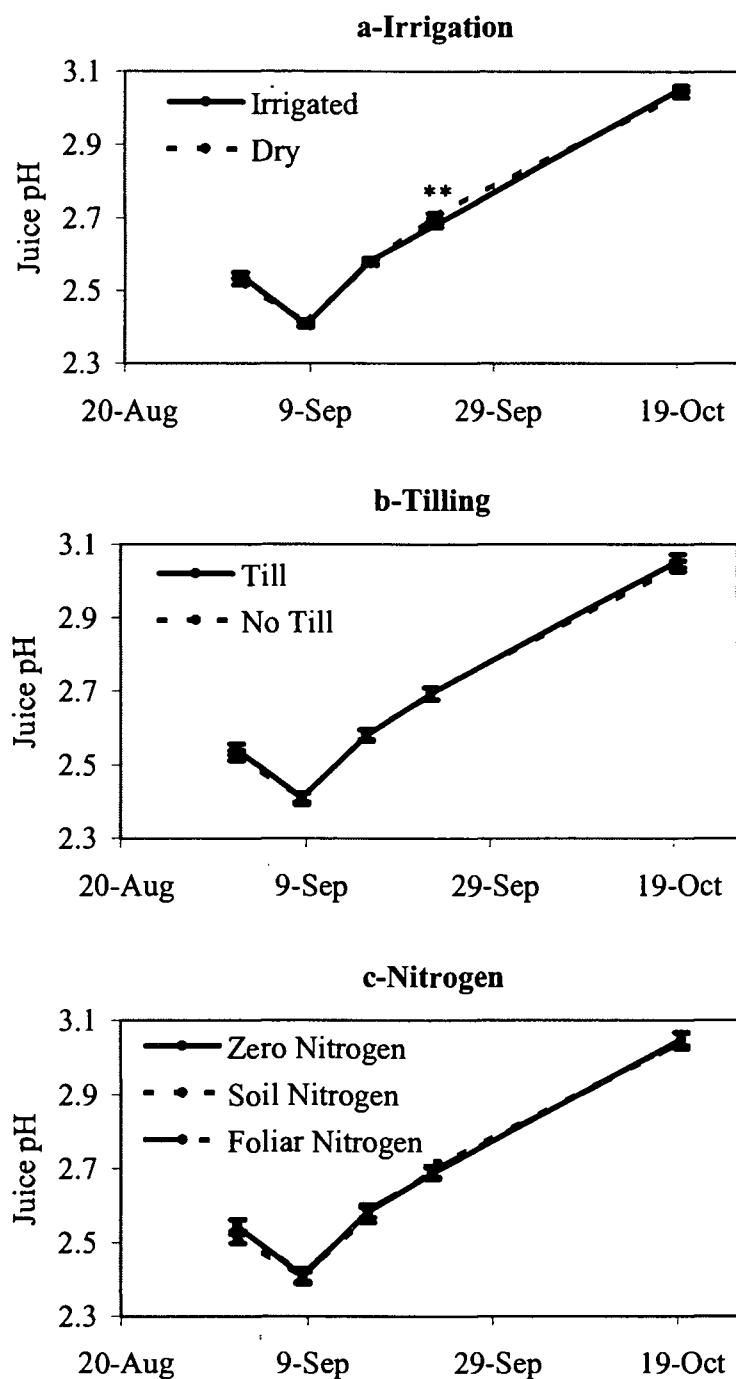


Figure 4.16: Effect of irrigation, tilling, and nitrogen fertilization on juice pH of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

observed in 1999 (Fig 4.12b, Fig 4.17b, and Fig 4.13b). No significant differences in ripening dynamics between nitrogen treatments were observed in 1999 or 2000 (Fig 4.12c, Fig 4.17c, Fig 4.13c, Fig 4.14c, Fig 4.16c, and Fig 4.15c).

### Nitrogenous compounds

During ripening fruit ammonia content decreased while total alpha-amino acid content increased, agreeing with previously reported studies (Roubelakis-Angelakis and Kliewer 1992). The extent and at what rate total alpha-amino acid content in the fruit increases is dependent on many factors (Roubelakis-Angelakis and Kliewer, 1992).

*Benton Lane Vineyard* – During the 1999 ripening period (Fig 4.18, Fig 4.19, and Fig 4.20), juice ammonia content of Pinot noir vines decreased from approximately 80 mg/L to 30 mg/L. At the same time, alpha-amino acid content increased from approximately 60 mg/L to 150 mg/L. Yeast assimilable nitrogen (YANC) increased from approximately 100 mg/L to 190 mg/L. The largest percent of YANC increase occurred during the last two weeks of fruit maturation. This is thought to be due to the large increases in alpha-amino acid content during this period.

Overall, juice ammonia content, alpha-amino acid content, and YANC were lower during the 2000 ripening period (Fig 4.21, Fig 4.22, and Fig 4.23). Juice

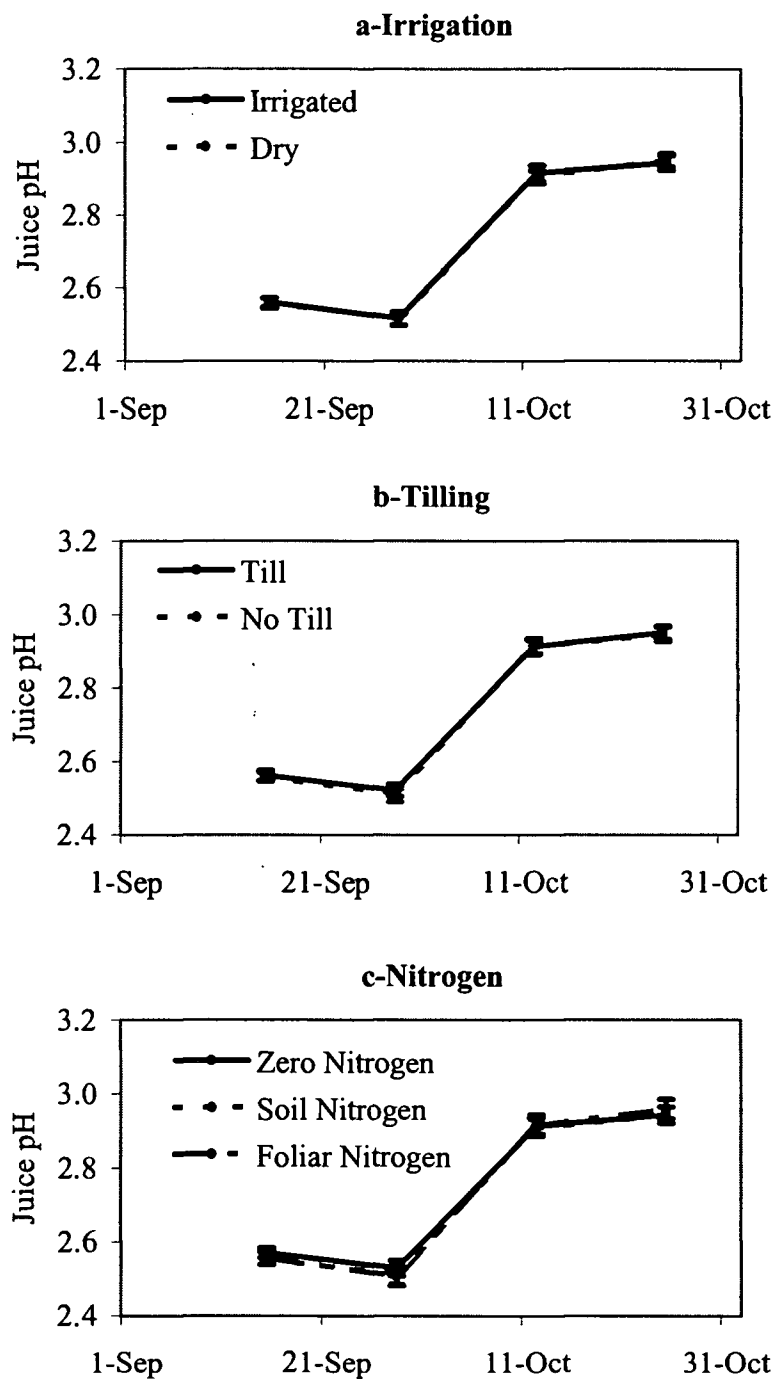


Figure 4.17: Effect of irrigation, tilling, and nitrogen fertilization on juice pH of Chardonnay grapevines at Knudsen vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

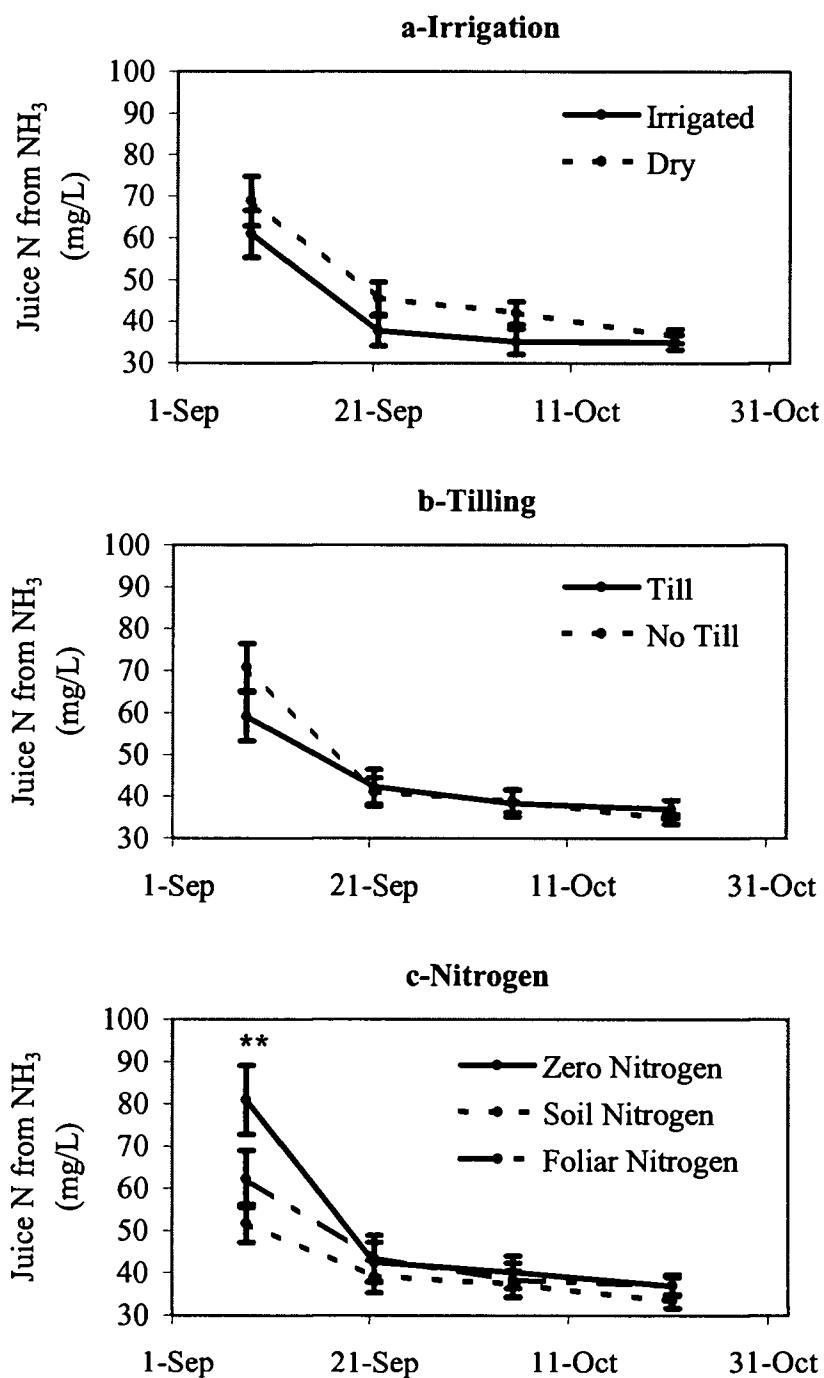


Figure 4.18: Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from ammonia of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.



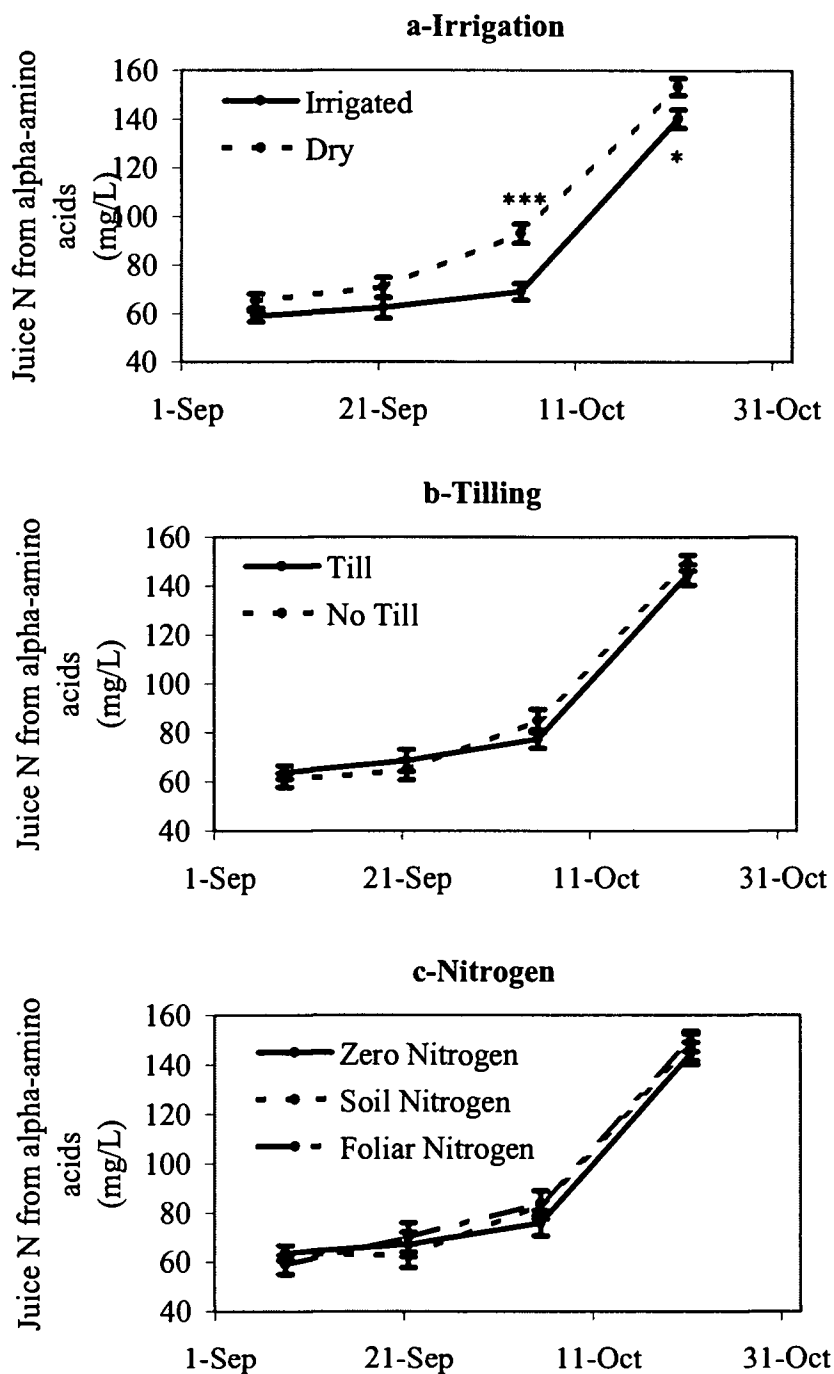


Figure 4.19: Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from alpha-amino acids of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

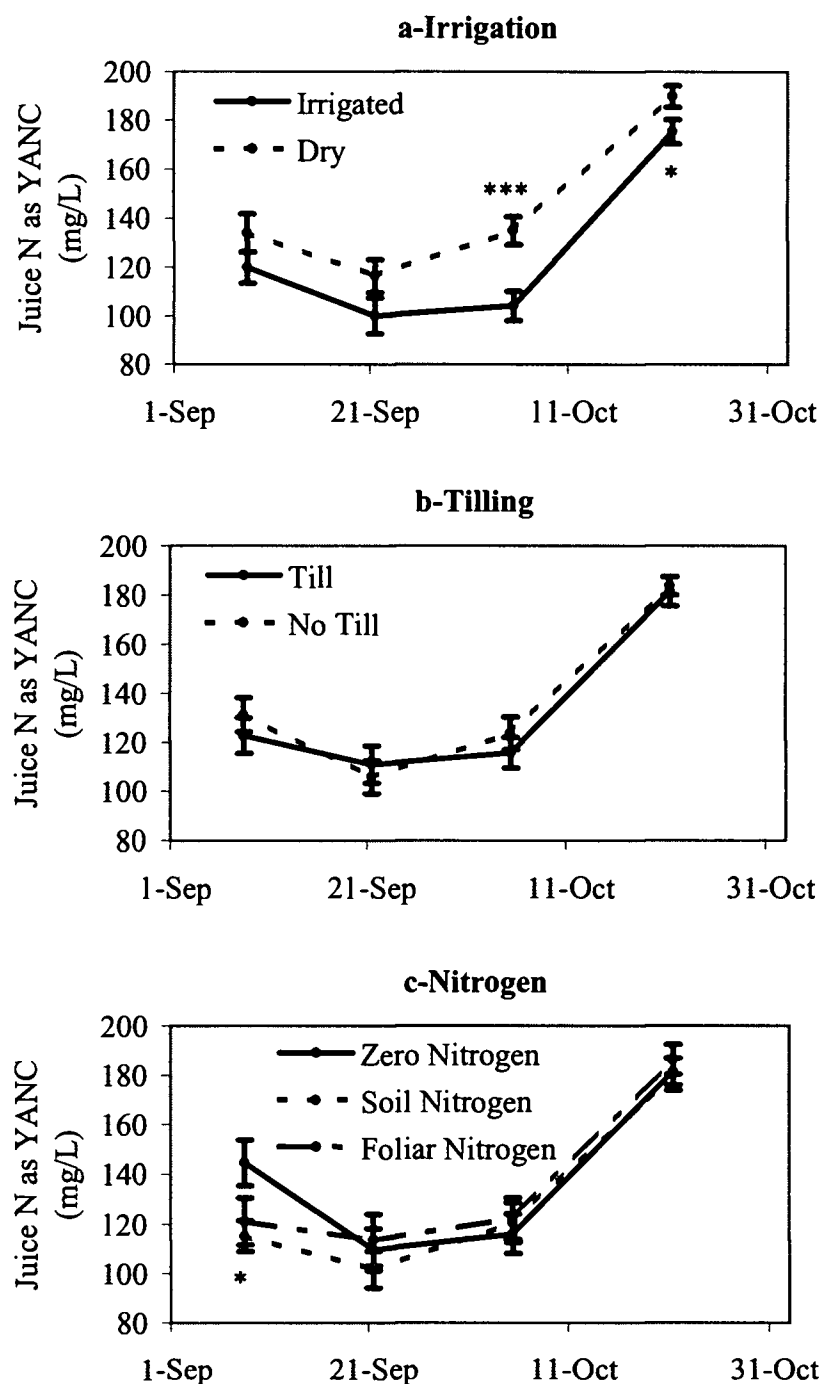


Figure 4.20: Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen as yeast assimilable nitrogen (YANC) of Pinot noir grapevines at Benton Lane vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

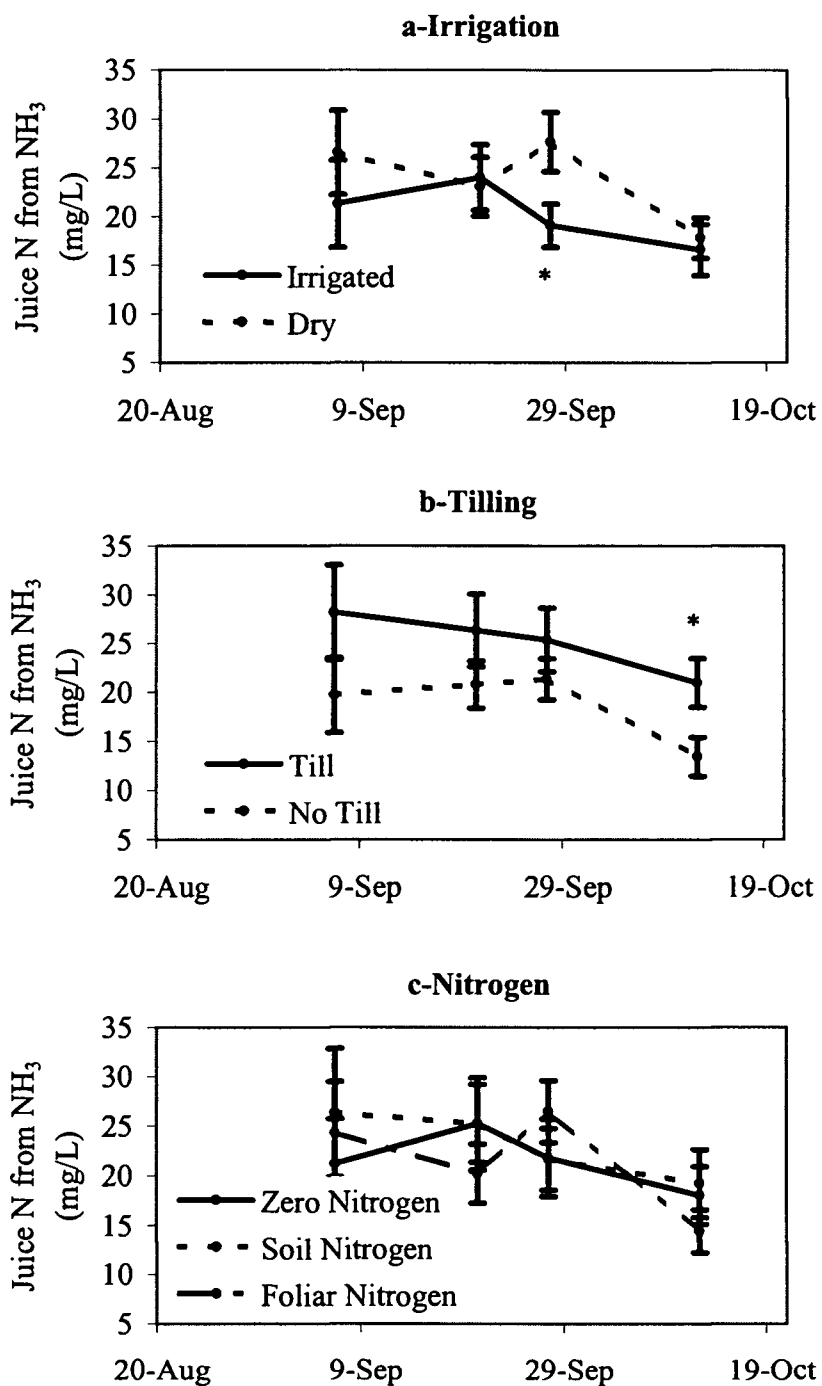


Figure 4.21: Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from ammonia of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

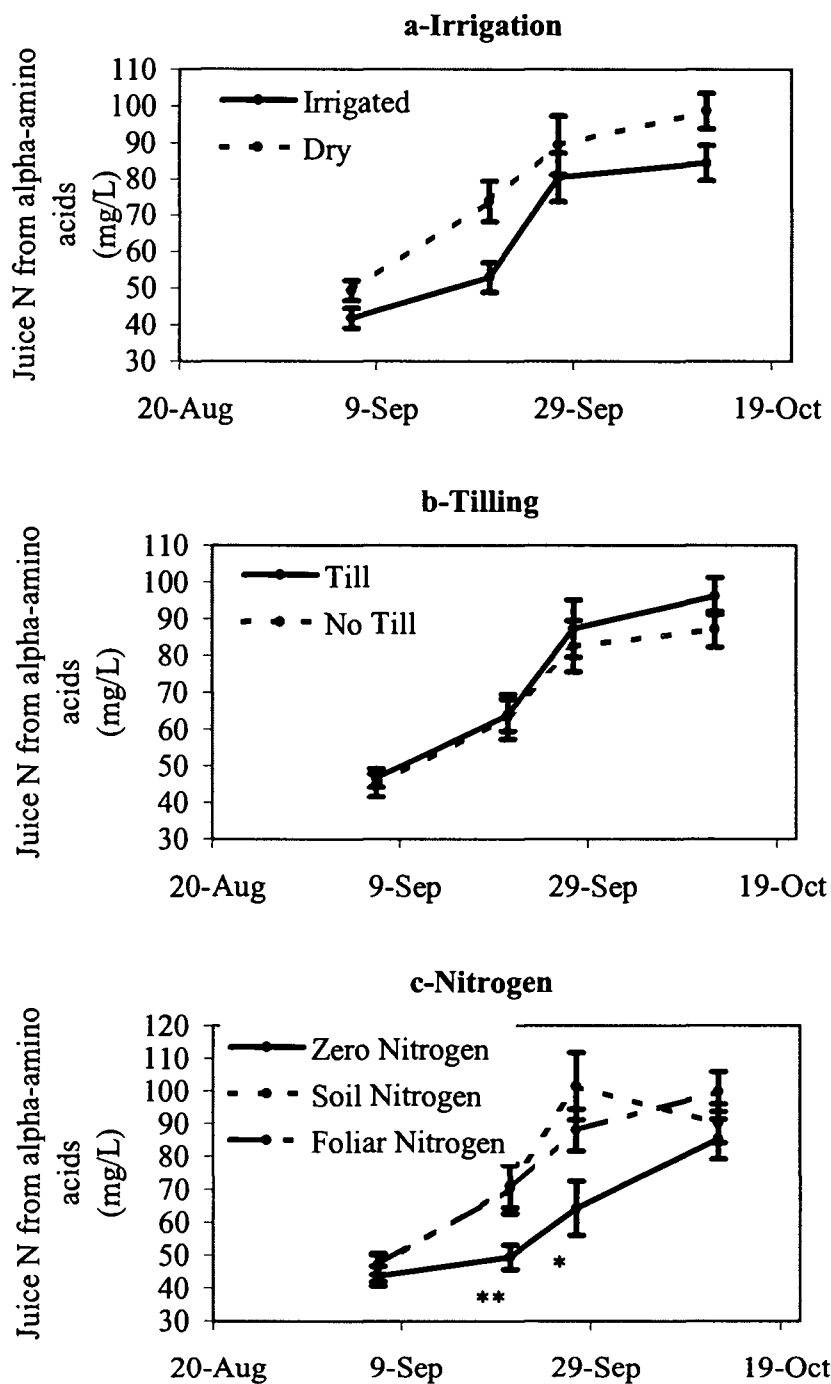


Figure 4.22: Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from alpha-amino acids of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

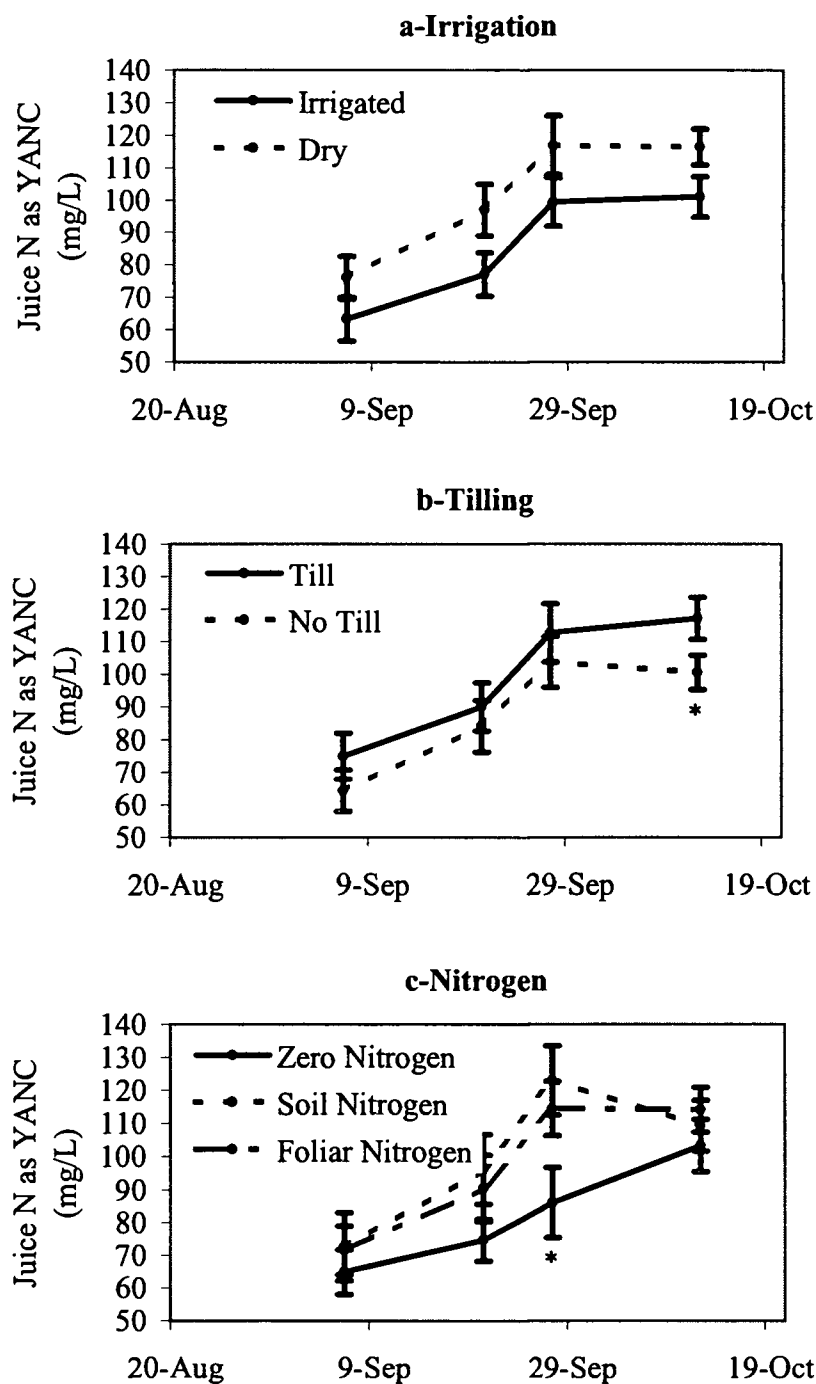


Figure 4.23: Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen as yeast assimilable nitrogen (YANC) of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

ammonia content decreased from approximately 30 mg/L to 10 mg/L. Alpha-amino acid content increased from approximately 40 mg/L to 100 mg/L. YANC increased from approximately 60 mg/L to 120 mg/L.

In 1999, juice from non-irrigated vines had higher alpha-amino acid concentration (Fig 4.19a) and YANC (Fig 4.20a) than irrigated vines, two weeks prior to harvest and at harvest. At the onset of ripening, juice from vines that did not receive nitrogen fertilization had higher YANC than foliar nitrogen or soil nitrogen treatments (Fig 4.20c). However, this difference was not apparent at harvest.

In 2000, juice from non-irrigated vines had significantly higher ammonia content than irrigated vines on one date prior to harvest (Fig 4.21a). Juice from non-irrigated vines had higher alpha-amino acid concentration at harvest when compared to irrigated vines (Fig 4.22a). Juice from tilled vines had higher ammonia content and YANC at harvest than non-tilled vines (Fig 4.21b and Fig 4.23b). Juice from vines that did not receive nitrogen fertilization had significantly less alpha-amino acid content on two dates prior to harvest (Fig 4.22c) and less YANC two weeks prior to harvest (Fig 4.23c), when compared to soil nitrogen and foliar nitrogen treatments.

*Knudsen Vineyard* – In 1999 (Fig 4.24, Fig 4.25, and Fig 4.26), the juice ammonia content decreased from approximately 120 mg/L to 80 mg/L in 1999. From véraison to mid October, juice alpha-amino acid content increased from

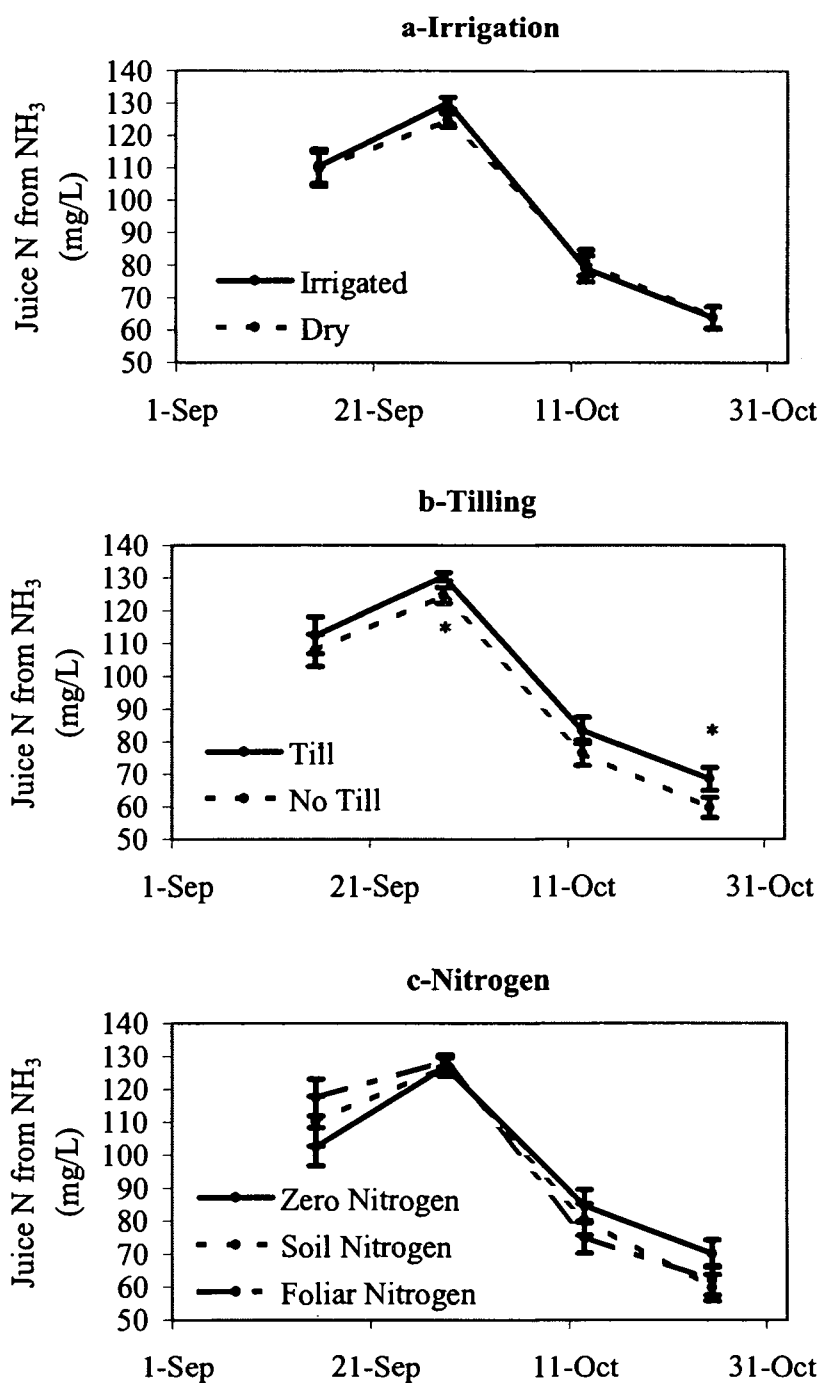


Figure 4.24: Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from ammonia of Chardonnay grapevines at Knudsen vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

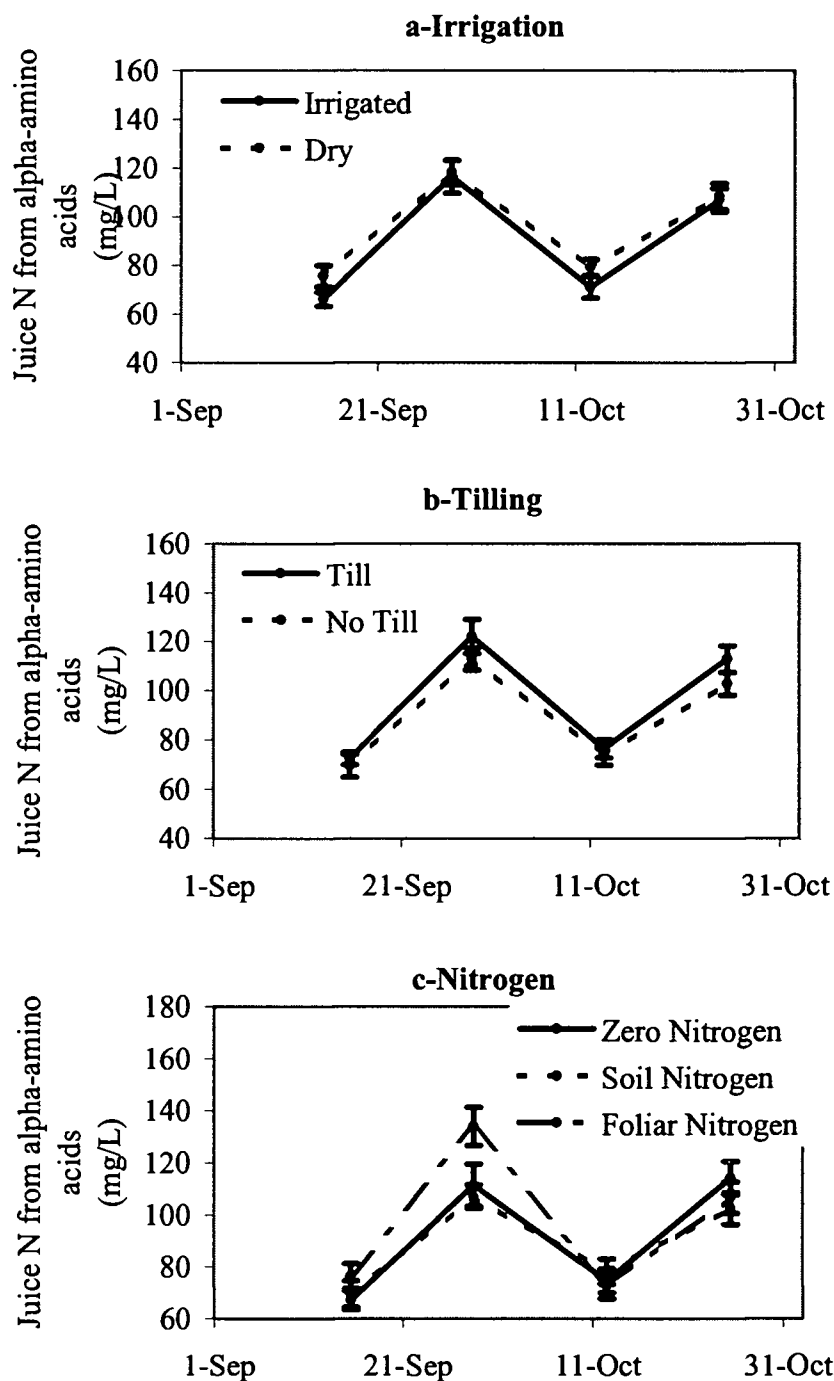


Figure 4.25: Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from alpha-amino acids of Chardonnay grapevines at Knudsen vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.



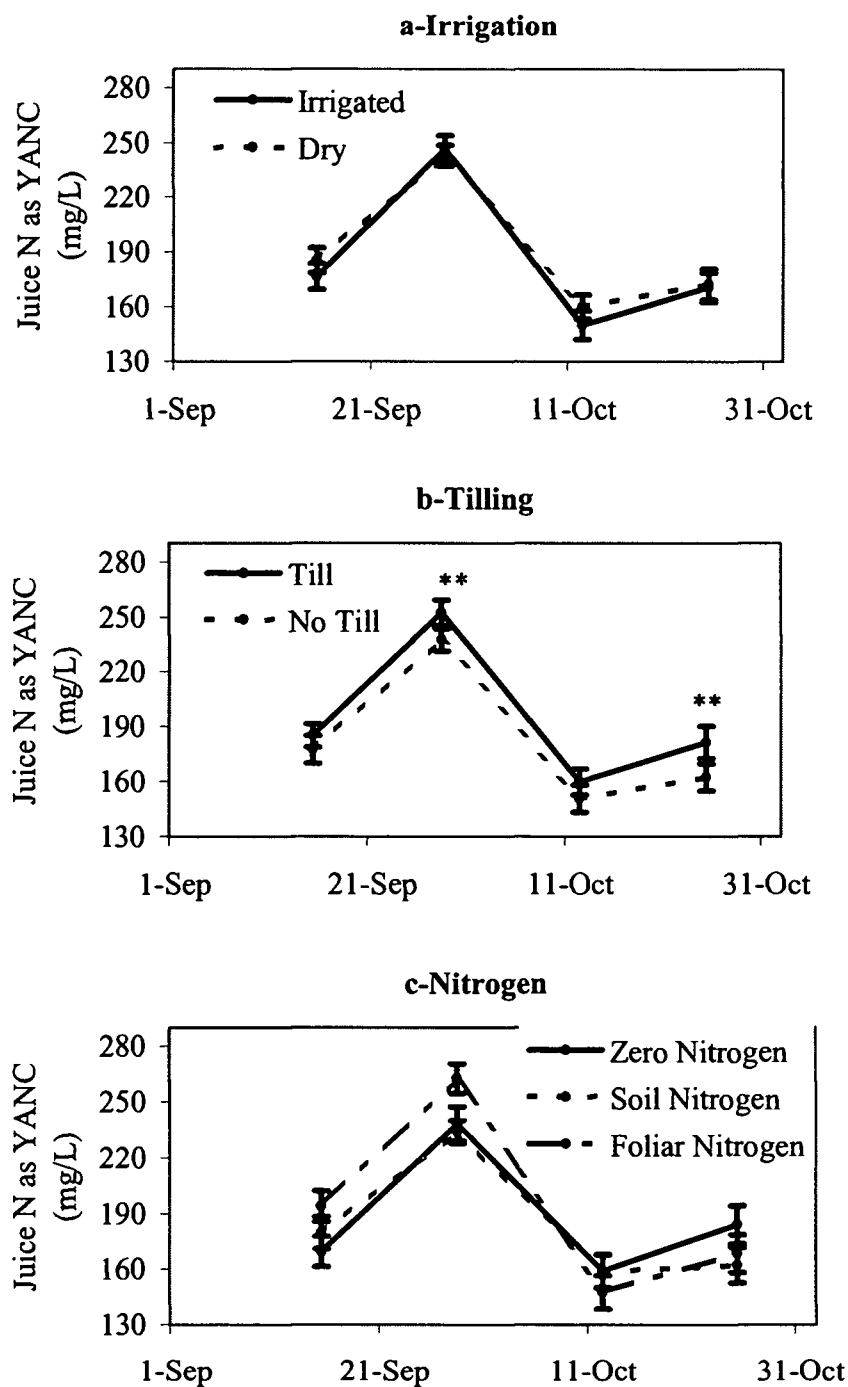


Figure 4.26: Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen as yeast assimilable nitrogen (YANC) of Chardonnay grapevines at Knudsen vineyard during the 1999 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

approximately 80 mg/L to 130 mg/L. YANC increased from approximately 190 mg/L, reaching 230 mg/L two weeks prior to harvest. YANC then decreased to approximately 200 mg/L at harvest. The decrease in YANC just prior to harvest appeared to be due to the decrease in ammonia content during the same period.

In 2000 (Fig 4.27, Fig 4.28, and Fig 4.29), juice ammonia content increased slightly from approximately 100 mg/L to 130 mg/L at the onset of ripening. A decrease from approximately 130 mg/L to 50 mg/L in juice ammonia content was observed from early September until harvest. At the onset of ripening, alpha-amino acid content was approximately 60mg/L. Alpha-amino acid content values were approximately 110mg/L at harvest. YANC increased from approximately 170 mg/L to 260 mg/L at the beginning of ripening, then decreased to approximately 175 mg/L at harvest.

Juice from tilled vines had significantly higher ammonia (Fig 4.24b) and YANC (Fig 4.26b) at harvest in 1999. In 2000, juice from irrigated vines had higher ammonia content than non-irrigated vines early in the season (Fig 4.27a). However, this difference was not apparent at harvest. Juice from tilled vines had higher ammonia content than non-tilled vines in early September as well as at harvest in 2000 (Fig 4.27b). Juice from treatments that received foliar nitrogen had higher alpha-amino acid content (Fig 4.28c) and YANC (Fig 4.29c) early in the season. This difference was not apparent at harvest.

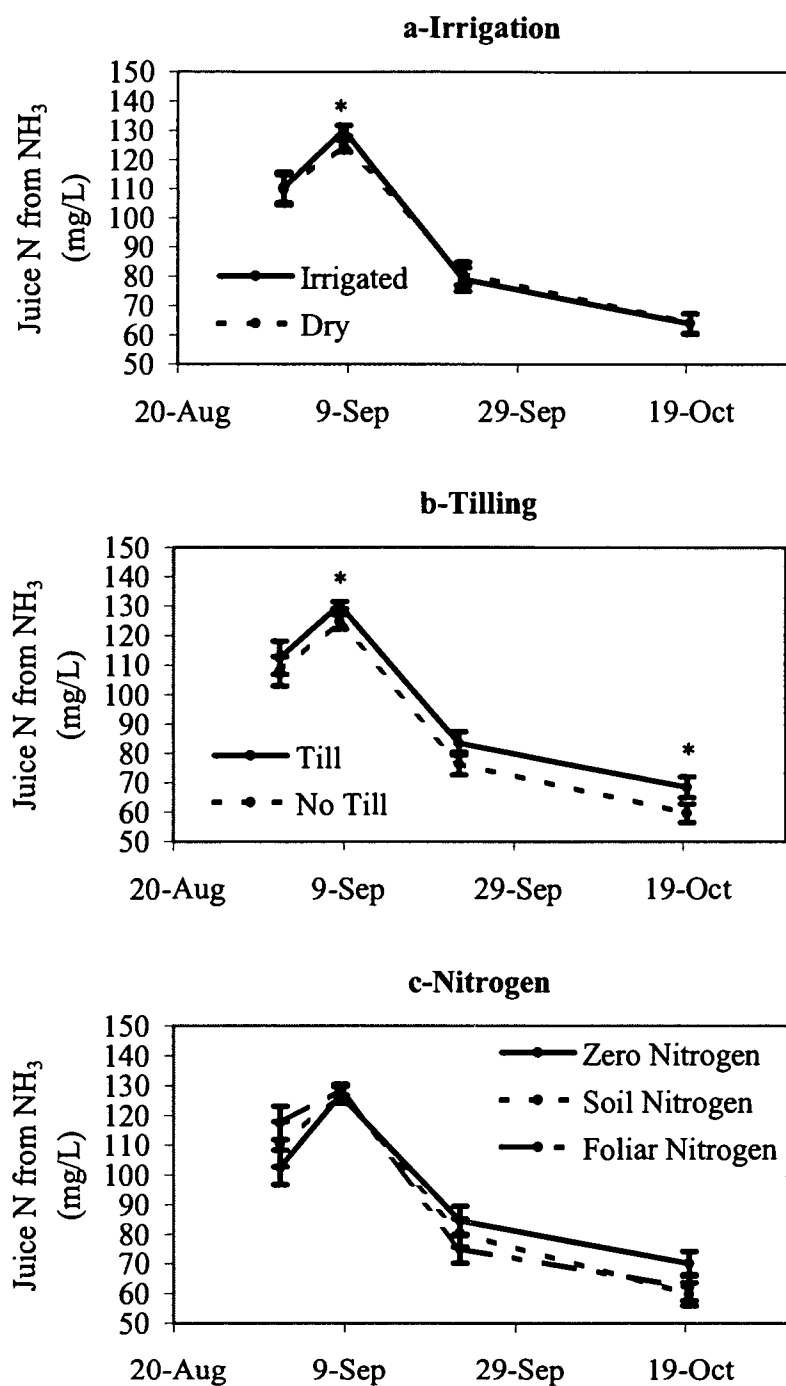


Figure 4.27: Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from ammonia of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

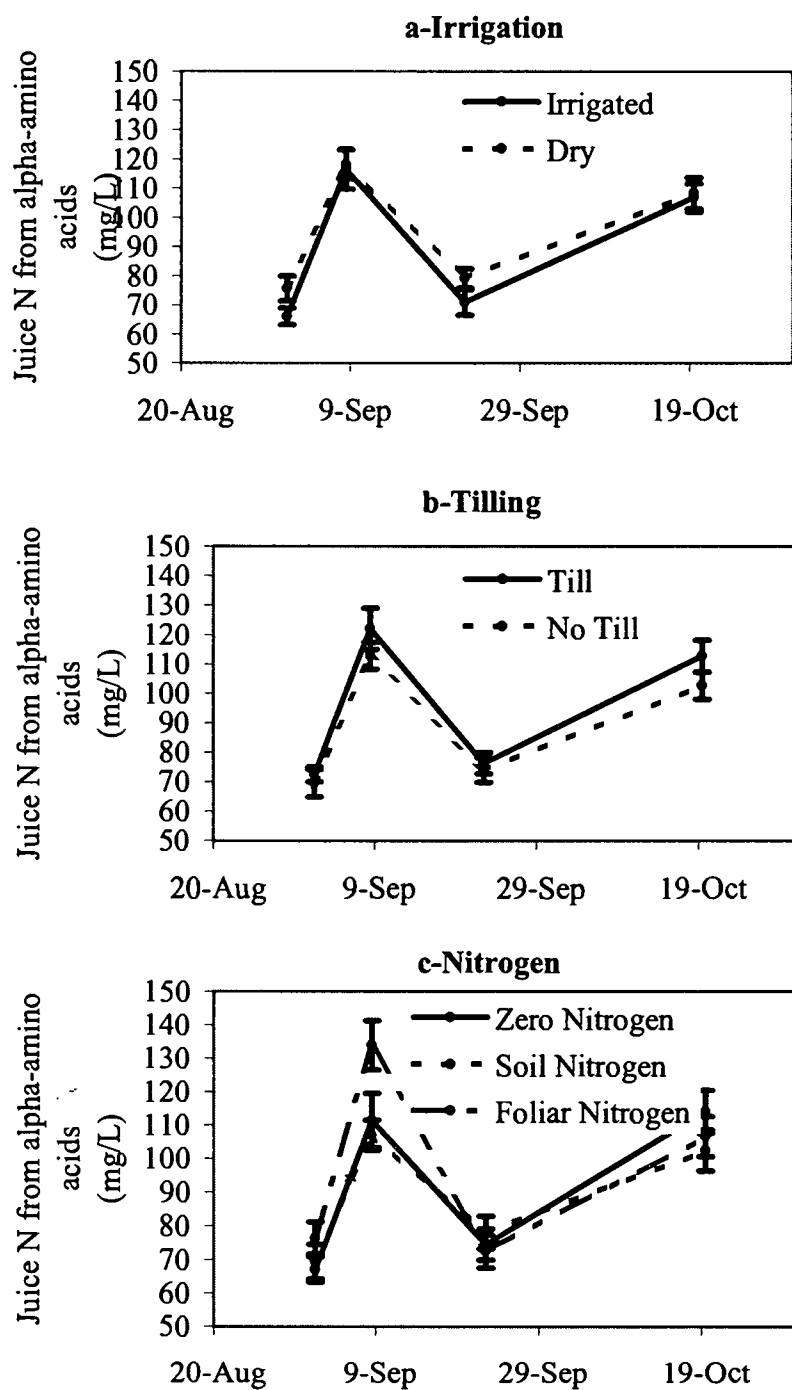


Figure 4.28: Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen from alpha-amino acids of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

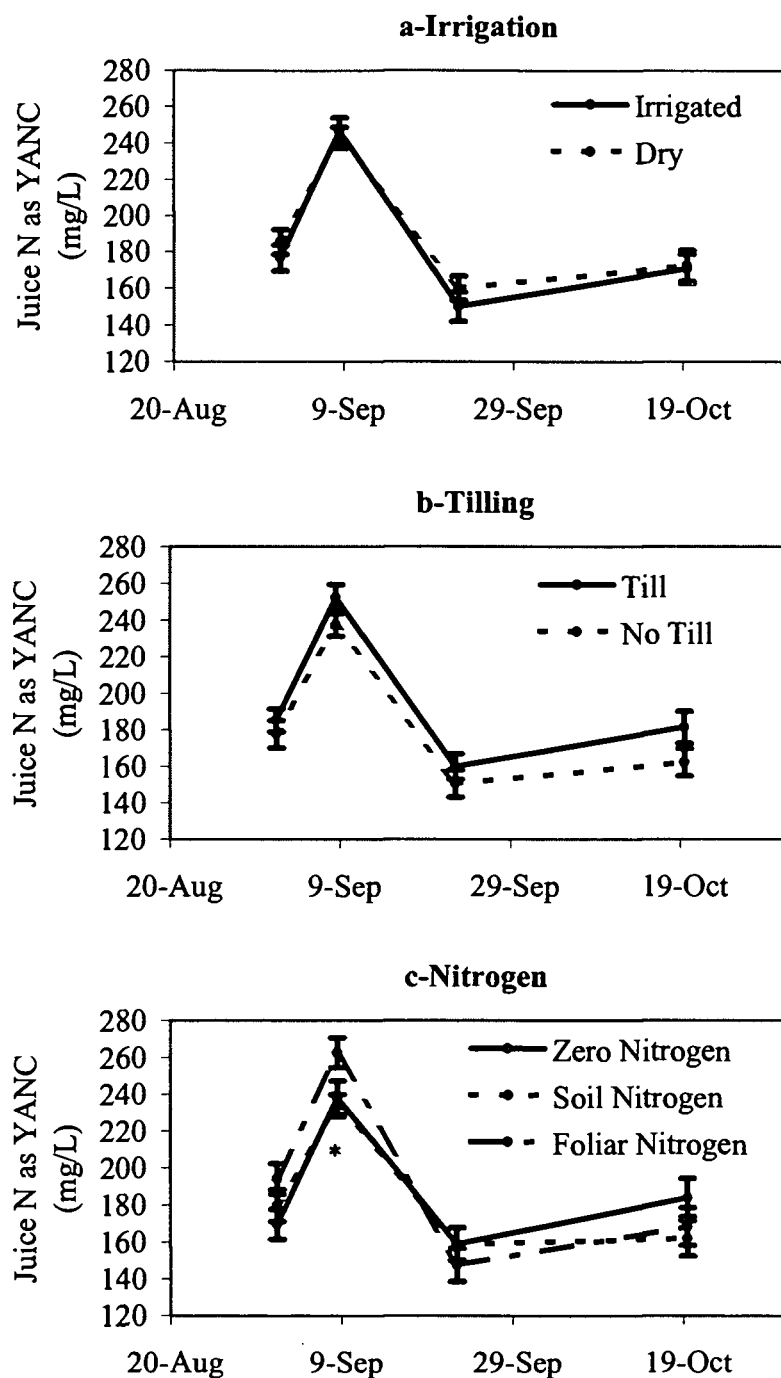


Figure 4.29: Effect of irrigation, tilling, and nitrogen fertilization on juice nitrogen as yeast assimilable nitrogen (YANC) of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

Research indicates that there is a great degree of variation between low and high juice alpha-amino acid contents. When compared to research done in Germany (Sponholz, 1991) and California (Kliewer, 1970), total alpha-amino acid values observed in these two vineyards would be considered low. Total alpha-amino acid content of Pinot noir grown in Washington has been reported to be around 300 mg/L (Spayd and Andersen-Bagge, 1996). The same study reported total alpha-amino acid content of Chardonnay grown in Washington to be on average 250 mg/L.

Agenbach (1977) reported that 140 mg/L of YANC was required to complete fermentation of juices having 25.8° Brix. It was demonstrated that YANC up to 500 mg/L increased yeast mass and fermentation rate. YANC above 500 mg/L increased fermentation rate but no longer increased yeast mass (reviewed by Ingledew and Kunkee, 1995). In 1999, both Pinot noir and Chardonnay juices analyzed, had more than the minimal required YANC (140 mg/L) at harvest (Fig 4.20 and Fig 4.26). In 2000, YANC in Pinot noir was well below the minimal requirement (Fig 4.23). YANC in Chardonnay was above the minimal requirement in 2000, but was less than in 1999 (Fig 4.29).

#### Yield components

*Benton Lane Vineyard* – In 1999, non-irrigated vines had significantly more berries per cluster than irrigated vines (Table 4.2a). This result is not considered to

be a treatment effect because irrigation was not applied until after fruit set. It is unlikely that this effect is a result of water stress because fruit set most often occurs under mild spring conditions when soil water status is normally adequate. In 1999, berry weight was significantly higher at harvest in vines that had been irrigated (Fig 4.7a). This same difference was observed in 2000 on all dates prior to harvest (Fig 4.30a). However, at harvest, berry weights of irrigated and non-irrigated vines were not significantly different (Table 4.2b). It is reported that water stress may increase the risk of berry shrivel, thus reducing berry weight (reviewed by Smart and Coombe, 1983). Smart (1974) and Van Zyl (1984) report that in Shiraz and Colombard grapevines, water stress induced after véraison reduced final berry weight less than stress induced prior to véraison which may affect cell division. In 2000, there were no yield component differences between any of the treatments (Table 4.2b). However, in 2000, there was a clear trend towards higher yields in irrigated and tilled treatments.

It has been reported that vine yield is mostly increased by irrigation (reviewed by Smart and Coombe, 1983). With the exception of Chasselas, 13 of 14 varieties studied resulted in yield increase up to 130%, with the largest response being for climates characterized by low summer rainfall (Smart and Coombe, 1983).

*Knudsen Vineyard* – In 1999, there were no significant differences in yield components (Table 4.3a). In 2000, non-tilled vines had more berries per cluster and

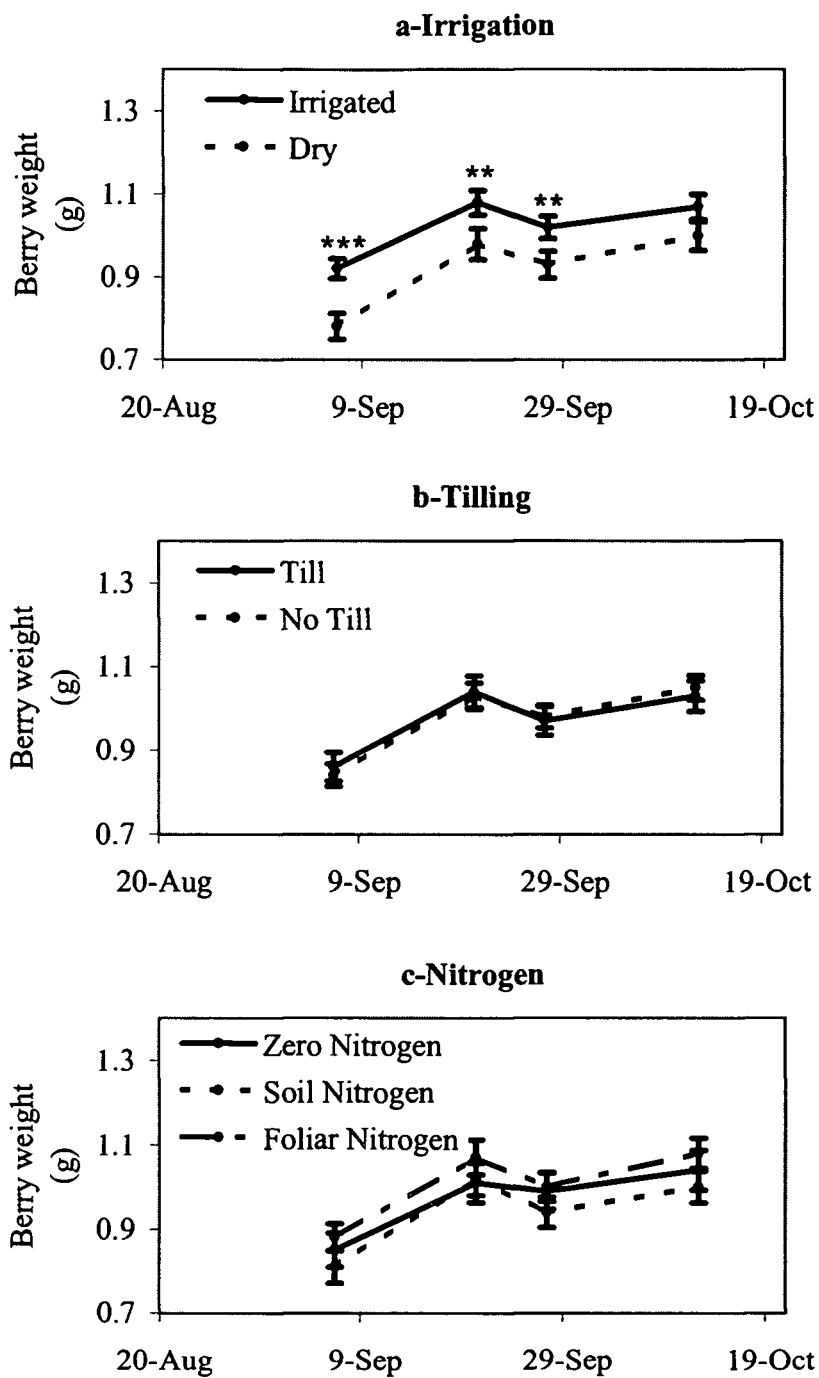


Figure 4.30: Effect of irrigation, tilling, and nitrogen fertilization on berry weight of Pinot noir grapevines at Benton Lane vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.



Table 4.2b: Yield components of Pinot noir vines at Benton Lane Vineyard in 2000.

		Yield (kg/vine)	Berries/ cluster	Berry wt. (g)	Cluster wt. (g)
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Irrigation					
	Irrigated	4.4	113.2	1.1	121.2
	Dry	4.1	111.6	1.0	111.6
		<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>
Nitrogen					
	Zero Nitrogen	4.6	117.3	1.0	122.4
	Foliar Nitrogen	4.3	108.8	1.1	117.3
	Soil Nitrogen	3.9	111.0	0.1	109.7
		<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>
Cultivation					
	Till	4.4	114.1	1.0	116.8
	No Till	4.1	110.7	1.1	116.0
		<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>
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.

Table 4.3a: Yield components of Chardonnay vines at Knudsen Vineyard in 1999.

		Yield (kg/vine)	Berries/ cluster	Berry wt. (g)	Cluster wt. (g)
<hr/>					
Irrigation					
	Irrigated	3.7	115.1	1.4	161.8
	Dry	3.6	111.3	1.4	157.2
		ns	ns	ns	ns
Nitrogen					
	Zero Nitrogen	3.5	114.8	1.4	161.3
	Foliar Nitrogen	3.8	112.7	1.4	159.8
	Soil Nitrogen	3.6	112.1	1.4	157.5
		ns	ns	ns	ns
Cultivation					
	Till	3.7	114.5	1.4	163.4
	No Till	3.6	111.9	1.4	155.6
		ns	ns	ns	ns
Significant Treatment Interactions					
	none				
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ns, \*, \*\*, and \*\*\* indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels of probability, respectively.

smaller berry weight than tilled vines (Table 4.3b and Fig 4.31b). The release of nitrogen following cultivation may have shifted soil nitrogen content to values higher than desirable, promoting vegetative growth. Competition for assimilates between growing shoot tips and inflorescences may have occurred in response to tilling, resulting in decreased fruit set.

Table 4.3b: Yield components of Chardonnay vines at Knudsen Vineyard in 2000.

		Yield (kg/vine)	Berries/ cluster	Berry wt. (g)	Cluster wt. (g)
<hr/>					
Irrigation					
	Irrigated	2.7	104.9	1.5	151.3
	Dry	2.8	105.6	1.5	151.7
		<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>
Nitrogen					
	Zero Nitrogen	2.8	102.8	1.5	147.6
	Foliar Nitrogen	2.8	104.9	1.5	153.2
	Soil Nitrogen	2.8	108.0	1.4	153.8
		<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>
Cultivation					
	Till	2.9	101.3	1.5	149.0
	No Till	2.7	109.2	1.4	154.1
		<b>ns</b>	<b>**</b>	<b>*</b>	<b>ns</b>
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.

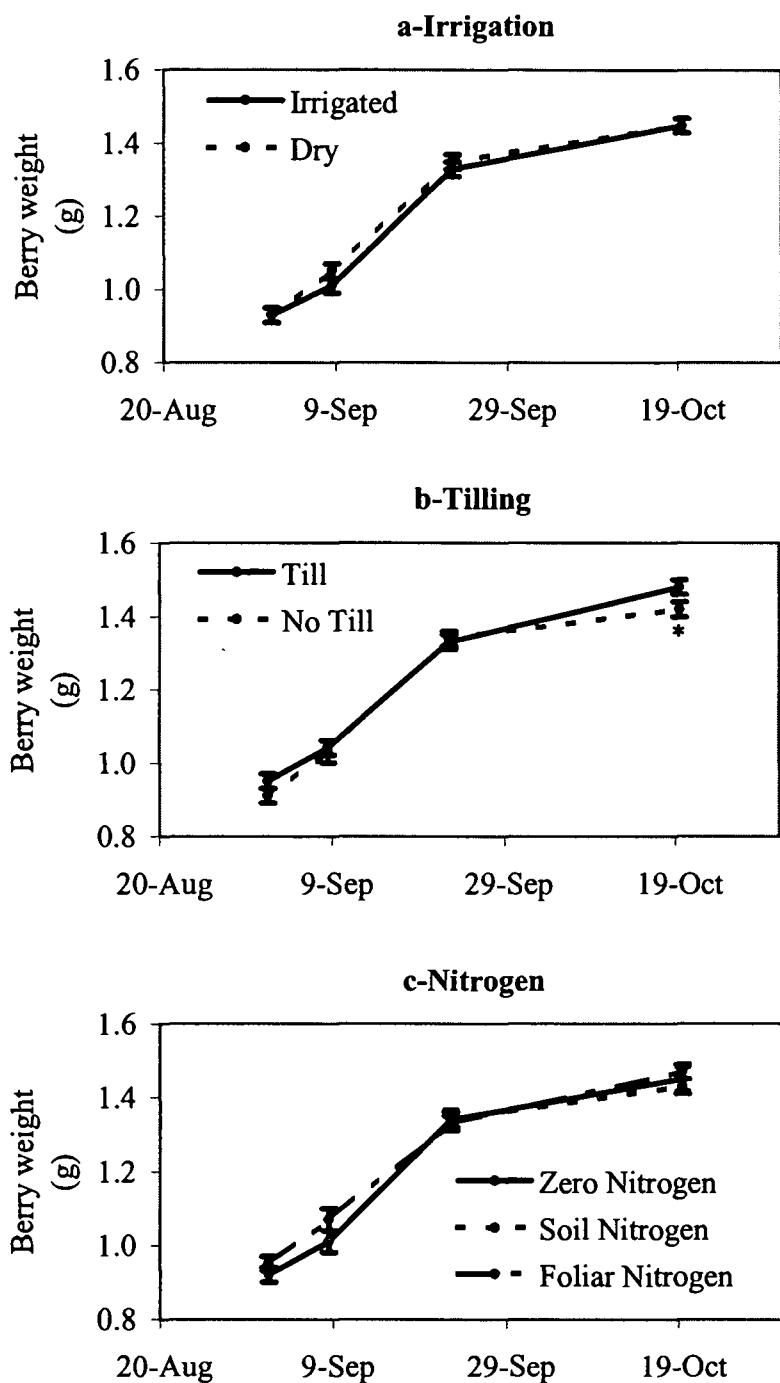


Figure 4.31: Effect of irrigation, tilling, and nitrogen fertilization on berry weight of Chardonnay grapevines at Knudsen vineyard during the 2000 growing season. \*, \*\*, and \*\*\* indicate statistical significance at the 0.05, 0.01, and 0.001 levels of probability, respectively.

## **Chapter 5**

### **Conclusions**

The vineyard is a dynamic system in-which environmental factors interact with the vast physiological mechanisms of the vine. To fully understand any system, one must consider all of its parts.

The two vineyards studied responded differently to the treatments applied. Although the results from the two vineyards were in no way statistically compared to one another, it is both interesting and important to consider the microclimatic differences between the sites. At the southern Willamette Valley site, the temperatures are slightly warmer than the northern Willamette Valley site. During both years of this study, ripening occurred earlier at the southern site. The soils at the southern site are shallower and contain less clay than the soils at the northern site. Consequently, the vines in the southern Willamette Valley site suffer more severe summer drought than do the vines in the northern Willamette Valley site.

Irrigation and tilling treatments successfully decreased competition for water and nutrients between the vines and cover crop at the southern site. These treatments had a positive effect on both fruit composition and yield components of Pinot noir. These treatments also had a positive effect on the photosynthetic capacity of vines at the southern site. All vines at the southern site are grown on 5C rootstock, which has been shown to be sensitive to water stress. Non-irrigated

treatments at the southern site may have been more photosynthetically sensitive to water stress because of the shallow soil and/or rootstock.

The removal of 50% cover crop by tilling reduced nutrient competition enough that by the second year of the study chlorophyll content in the leaves was much higher than non-tilled vines. Tilling also increased ammonia concentration and YANC of juice during ripening and at harvest. This indicates that more nitrogen was available for the vine to manufacture additional chlorophyll and allocate more nitrogen to the fruit because a portion of cover crop competition had been removed.

At the northern Willamette Valley site there was little response to the irrigation and tilling treatments. It is very likely that this is because the vines had not been subject to drought or sub-optimal nutrient availability since planting. Availability of water during ripening achieved by supplemental irrigation or elimination of 50% cover crop was not beneficial for non-stressed vines.

At both sites, responses to irrigation and tilling suggested a shift to “luxury consumption mode” resulting in either no effect or a potential negative effect on vine vigor, yield components, and/or fruit composition. At the southern site this was illustrated by a delayed response in chlorophyll content and vine vigor to the tilling treatments. This may indicate that excess nitrogen was taken up and stored as reserves during the first year of the study.

At both the southern and northern site, vines responded very little to nitrogen fertilization treatments. Nitrogen treatments did not have an impact on leaf gas exchange, yield components, carbohydrate accumulation, and very little impact on fruit composition. This may be because Willamette Valley vineyards typically have high levels of soil organic matter and nitrogen is usually not limiting. However, the timing of nitrogen availability and uptake throughout the season is critical with respect to the fate of this nutrient.

With respect to the objectives of this study, Pinot noir grown at the southern Willamette Valley site benefited from supplemental irrigation and the removal of 50% of the cover crop. However, Chardonnay grown at the northern Willamette Valley site did not benefit from these treatments. There was no treatment response to nitrogen fertilization at either site.



## Bibliography

- Alexander, D. Seasonal changes in the nitrogen content of the Sultana vine. *Aust. J. Agric. Res.* 8:162-178 (1957).
- Andersen, P.C. and M.B. Odneal. Effect of soil profile modification and irrigation on senescence and bud hardiness of young grapes. *Hortscience.* 20:749-751 (1985).
- Araujo, F.J. and L.E. Williams. Dry matter and nitrogen partitioning and root growth of young field-grown 'Thomson Seedless' grapevines. *Vitis.* 27:21-23 (1988).
- Barber, R.G. and O. Diaz. Effects of deep tillage and fertilization on soya yields in a compacted Ustchrept during seven cropping seasons, Santa Cruz, Bolivia. *Soil Till. Res.* 22:371-381 (1992).
- Barber, R.G. and F. Navarro. The rehabilitation of degraded soils in Eastern Bolivia by subsoiling and the incorporation of cover crops. *Land Deg. Rehab.* 5:247-259 (1994).
- Beevers, L. Nitrogen Metabolism in Plants, 276-289. Edward Arnold, London (1976).
- Bell, A.A., C.S. Ough and W.M. Kliever. Effects on must and wine composition, rates of fermentation, and wine quality of nitrogen fertilization of *Vitis vinifera* var. Thompson Seedless grapevines. *Am. J. Enol. Vitic.* 30:124-129 (1979).

- Bell, S. The effect of nitrogen fertilization on growth, yield, and juice composition of *Vitis vinifera* cv Cabernet Sauvignon grapevines. *In* Proceedings of the International Symposium of Nitrogen in Grapes and Wine, Seattle, WA. J. M. Rantz (Ed.), 206-210. Am. J. Enol. Vitic. (1991).
- Bisson, L. Stuck and sluggish fermentations. Am. J. Enol. Vitic. 50:107-119 (1999).
- Bradford, K.J. and T.C. Hsiao. Physiological responses to moderate water deficits. *In* Encyclopedia of Plant Physiology. Springer-Verlag (Ed.), Springer-Verlag, Berlin (1983).
- Briggs, L.J. and H.L. Shantz. Relative water requirement of plants. J. Agric. Res. 3:1-63 (1914).
- Buchanan, B.B., W. Gruissem and R.L. Jones. Biochemistry and Molecular Biology of Plants, American Society of Plant Physiologists, Rockville, Maryland (2000).
- Buttrose, M.S. Fruitfulness in grapevines: Effects of water stress. Vitis. 12:299-305 (1974).
- Butzke, C.E. Survey of yeast assimilable nitrogen status in musts from California, Oregon, and Washington. Am. J. Enol. Vitic. 49:220-224 (1998).
- Candolfi-Vasconcelos, M.C. and W. Koblet. Yield, fruit quality, bud fertility and starch reserves of the wood as a function of leaf removal in *Vitis vinifera*. Evidence of compensation and stress recovering. Vitis. 29:199-221 (1990).

- Candolfi-Vasconcelos, M.C., M.P. Candolfi, and W. Koblet. Retranslocation of carbon reserves from the woody storage tissues into the fruit as a response to defoliation stress during the ripening period in *Vitis vinifera* L. *Planta*. 192(4): 567-573 (1994a).
- Candolfi-Vasconcelos, M.C., W. Koblet, G.S. Howell and W. Zweifel. Influence of defoliation, rootstock, training system and leaf position on gas exchange of Pinot noir grapevines. *Am. J. Enol. Vitic.* 45:173-180 (1994b).
- Chalmers, D.J., P.D. Mitchell and L. van Heek. Water relations of peach trees and orchards, 197-232. Academic, New York (1983).
- Chaves, M.M. and M.L. Rodrigues. Photosynthesis and water relation in grapevines - response to environmental factors, 279-290. Springer-Verlag, Berlin (1987).
- Cheng, L. Photosynthesis in relation to nitrogen. Thesis, Oregon State University (1999).
- Clarke, N.D., C.S. Tan and J.A. Stone. Expert system for scheduling supplemental irrigation for fruit and vegetable crops in Ontario. *Can. Agric. Engin.* 34:27-31 (1992).
- Conradie, W.J. Seasonal uptake of nutrients by Chenin blanc in sand culture. I. Nitrogen. *S. Afr. J. Enol. Vitic.* 1:59-65 (1980).

- Conradie, W.J. The uptake and distribution of  $^{15}\text{N}$  enriched nitrate by three rootstock cultivars grafted to Chenin blanc. *S. Afr. J. Enol. Vitic.* 4:45-47 (1983).
- Conradie, W.J. Distribution and translocation of nitrogen absorbed during early summer by two-year-old grapevines grown in sand culture. *Am. J. Enol. Vitic.* 42:180-190 (1991).
- Conradie, W.J. Translocation and storage of nitrogen by grapevines as affected by time of application. *In International Symposium on Nitrogen in Grapes and Wine, Seattle, WA. (Ed.),* 32-42. *Am. J. Enol. Vitic.* (1991).
- Coombe, B.G. and P.R. Monk. Proline and abscisic acid content of the juice of ripe Riesling grape berries: effect of irrigation during harvest. *Am. J. Enol. Vitic.* 30:64-67 (1979).
- Correia, M.J., M.M. Chaves and J.S. Pereira. Afternoon depression in photosynthesis in grapevine leaves: evidence for a high light stress effect. *J. Exp. Bot.* 41:417-426 (1990).
- Escalona, J., E. Delgado and H. Medrano. Irrigation effects on grapevine photosynthesis. *In Proceedings of the 2nd International Symposium on Irrigation of Horticultural Crops, K. S. Chartzonlakis (Ed.),* 449-455. *Acta Horticulture*, (1997).
- Escalona, J.M., J. Flexas and H. Medrano. Stomatal and non-stomatal limitations of photosynthesis under water stress in field-grown grapevines. *Aust. J. Plant Physiol.* 26:421-433 (1999).

- Flexas, J., M. Badger, W.S. Chow, H. Medrano and C.S. Osmond. Analysis of the relative increase in photosynthetic O<sub>2</sub> uptake when photosynthesis in grapevine leaves is inhibited following low night temperatures and/or water stress. *Plant Physiol.* 121:675-684 (1999).
- Flexas, J., J.M. Escalona and H. Medrano. Down-regulation of photosynthesis by drought under field conditions in grapevines leaves. *Aust. J. Plant Physiol.* 25:893-900 (1998).
- Freeman, B.M., T.H. Lee and C.R. Turkington. Interaction of irrigation and pruning level on growth and yield of Shiraz vines. *Am. J. Enol. Vitic.* 31:124-135 (1980).
- Gay-Eynard, G., A. Morando, C. Lovisolo and M. Bovio. Nitrogen effects on yield and canopy of 'White Muscat' grapevine. *In* Proceeding of the XXV International Horticultural Congress. Part 2: Mineral Nutrition and Grape and Wine Quality, Nutrition Management to Optimize Fruit Quality, Brussels, Belgium. J. V. Possingham and G. H. Neilson (Ed.), 47-54. *Acta Horticulture* 512, (2000).
- Genty, B., J.M. Briantais and N.R. Baker. The relationship between the quantum yield of photosynthetic electron transport and quenching of chlorophyll fluorescence. *Biochim. Biophys. Acta.* 87-92 (1989).
- Girona, J., M. Mata, D.A. Goldhamer, R.S. Johnson and T.M. Dejong. Patterns of soil and tree water status and leaf functioning during regulated deficit irrigation scheduling in peach. *J. Amer. Soc. Hort. Sci.* 118:580-586 (1993).

- Gomez-del-Campo, M., C. Ruiz, V. Sotes and J.R. Lissarrague. Water consumption, leaf area development, and production in four grapevine varieties. *In* Proceedings of the Fifth International Symposium on Grapevine Physiology, Jerusalem. B. A. Bravdo (Ed.), 193-2000. Acta Horticulture, (1997).
- Gutierrez, A.P., D.W. Williams and H. Kido. A model of grape growth and development: The mathematical structure and biological considerations. *Crop Sci.* 25:721-728 (1985).
- Hall, D.O. and K.K. Rao. Photosynthesis, 5. Cambridge University Press, Cambridge (1994).
- Hardie, W.J. and J.A. Considine. Response of grapes to water-deficit stress in particular stages of development. *Amer. J. Enol. Vitic.* 27:55-61 (1976).
- Hellman, E. Manipulating soil moisture and nitrogen availability to improve fermentation behavior and wine quality Part III: effect of irrigation and soil managment strategy on grapevine petiole nutrient content. *In* Proceedings of OSU Winegrape Research Day, Corvallis, Oregon. 59-60. (2000).
- Henschke, P.A. and V. Jiranek. Hydrogen sulfide formation during fermentation: effect of nitrogen composition in model grape musts. *In* International Symposium on Nitrogen in Grapes and Wine, Seattle, Wa. J. Rantz (Ed.), 172-184. *Am. J. Enol. Vitic.* (1991).
- Hepner, Y., B. Bravdo, C. Loinger, S. Cohen and H. Tabacman. Effect of drip irrigation schedules on growth, yield, must composition, and wine quality of Cabernet Sauvignon. *Am. J. Enol. Vitic.* 36:77-85 (1985).

- Holt, B.F. and I.K. Smith. Small-scale intensive cultivation methods: The effects of deep hand tillage on the productivity of bush beans and red beets. *Am. J. Altn. Agric.* 13:28-39 (1998).
- Huett, D.O. Prospects for manipulating the vegetative-reproductive balance in horticultural crops through nitrogen nutrition: a review. *Aust. J. Agric. Res.* 47:47-66 (1996).
- Ingledeu, W.M. and R.E. Kunkee. Factors influencing sluggish fermentations of grape juice. *Am. J. Enol. Vitic.* 36:65-76 (1985).
- Jackson, D.I. and P.B. Lombard. Environmental and management practices affecting grape composition and wine quality - a review. *Am. J. Enol. Vitic.* 44:409-430 (1993).
- Kanwar, R.S., J.L. Baker and J.M. Laflen. Nitrate movement through the soil profile in relation to tillage systems and fertilizer application methods. *Trans. ASAE.* 28:1802-1807 (1985).
- Keller, M., K.J. Arnink and G. Hrazdina. Interaction of nitrogen availability during bloom and light intensity during véraison. I. Effects of grapevine growth, fruit development, and ripening. *Am. J. Enol. Vitic.* 49:333-340 (1998).
- Khemira, H., T.L. Righetti and A.N. Azarenko. Nitrogen partitioning in apple as affected by timing and tree growth habit. *J. Hort. Sci. Biotech.* 73:217-223 (1998).

Kliewer, W.M. Free amino acids and other nitrogenous substances of table grape varieties. *J. Food Sci.* 34:274-278 (1969).

Kliewer, W.M. Free amino acids and other nitrogenous fractions in wine grapes. *J. Food Sci.* 35:17-21 (1970).

Kliewer, W.M., B.M. Freeman and C. Hossom. Effect of irrigation crop level and potassium fertilizer on Carignane vines. I. Degree of water stress and effect on growth and yield. *Am. J. Enol. Vitic.* 34:186-196 (1983).

Kliewer, W.M., B.M. Freeman and C. Hossom. Effect of irrigation, crop level and potassium fertilization on Carignane vines. I. Degree of water stress and effect on growth and yield. *Am. J. Enol. Vitic.* 34:186-196 (1983).

Kliewer, W.M. and L.A. Lider. Influence of cluster exposure to the sun on the composition of Thompson Seedless fruit. *Am. J. Enol. Vitic.* 19:175-184 (1968).

Koblet, W., M.C. Candolfi-Vasconcelos, W. Zweifel and G.S. Howell. Influence of leaf removal, rootstock, and training system on yield and fruit composition of Pinot noir grapevines. *Am. J. Enol. Vitic.* 45:181-187 (1994).

Kovessi, M.F. Recherches biologiques sur l'aoutement des sarments de la vigne. Cited in Matthews *et al.*, 1987. (1901).

Kramer, P.J. and J.S. Boyer. *Water Relations of Plants and Soils*, Academic Press, San Diego (1995).



- Kriedemann, P.E. Observations on gas exchange in the developing Sultana berry. Aust. J. Biol. Sci. 21:907-916 (1968).
- Kriedemann, P.E. and R.E. Smart. Effects of irradiance, temperature, and leaf water potential on photosynthesis of vine leaves. Photosynthetica. 5:6-15 (1971).
- Kubota, N. and Y. Kakedai. Effects of root temperature and time of application of  $^{15}\text{N}$  on its absorption and translocation in 'Muscat of Alexandria' vines grown under forced conditions. J. Japan. Soc. Hort. Sci. 61:257-264 (1992).
- Larchevêque, C., A. Casanova, V. Dupuch and R. Renard. Influence de la fumure azotée sur la vigne de *Vitis vinifera* L. var. Merlot avec enherbement permanent. Int. Sci. Vigne Vin. 32:27-43 (1998).
- Lea, P.J., R.D. Blackwell, F.L. Chen and U. Hecht. Enzymes of ammonia assimilation. In Methods in Plant Biochemistry. P. J. Lea (Ed.), 257-276. Academic Press, London (1990).
- Liu, W.T., R. Pool, W. Wenkert and P.E. Kriedemann. Changes in photosynthesis, stomatal resistance and abscisic acid of *Vitis labruscana* through drought and irrigation cycles. Am. J. Enol. Vitic. 29:239-246 (1978).
- Löhnertz, O. Soil nitrogen and the uptake of nitrogen in grapevines. In International Symposium on Nitrogen in Grapes and Wine, Seattle, WA. J. M. Rantz (Ed.), 1-11. Am. J. Enol. Vitic. (1991).

Löhnertz, O., B. Prior, M. Blesser and A. Linsenmeier. Influence of N-supply and soil management on the nitrogen composition of grapes. *In* Proceeding of the XXV International Horticultural Congress. Part 2: Mineral Nutrition and Grape and Wine Quality, Nutrition Management to Optimize Fruit Quality, Brussels, Belgium. J. V. Possingham and G. H. Neilson (Ed.), 55-64. Acta Horticulture 512, (2000).

Loulakakis, K.A. and K.A. Roubelakis-Angelakis. Enzymes of ammonia assimilation in *Vitis vinifera* L. *In* Proceedings of the Fifth International Symposium on Grapevine Physiology, Jerusalem. B. A. Bravdo (Ed.), 209-223. Acta Horticulture 526, (1997).

Marschner, H. Mineral Nutrition of Higher Plants, Academic Press Inc., San Diego (1995).

Matthews, M.A. and M.M. Anderson. Fruit ripening in *Vitis vinifera* L.: Responses to seasonal water deficits. Amer. J. Enol. Vitic. 39:313-320 (1988).

Matthews, M.A. and M.M. Anderson. Reproductive development in grape (*Vitis vinifera* L.): responses to seasonal water deficits. Am. J. Enol. Vitic. 40:52-60 (1989).

Matthews, M.A., M.M. Anderson and H.R. Schultz. Phenological and growth responses to early and late season water deficits in Cabernet franc. Vitis. 26:147-160 (1987).

Matthews, M.A., R. Ishii, M.M. Anderson and M. O'Mahony. Dependence of wine sensory attributes on vine water status. J. Sci. Food Agric. 51:321-335 (1990).

- McDonald, A.J.S. and W.J. Davies. Keeping in touch: Responses of the whole plant to deficits in water and nitrogen supply. *Adv. Bot. Res.* 22:229-300 (1996).
- Miflin, B.J. and P.J. Lea. Ammonia assimilation. *In* The Biochemistry of Plants. B. J. Milfin (Ed.), 169-202. Academic Press, New York (1980).
- Mitchell, P.D., P.H. Jerie and D.J. Chalmers. The effects of regulated water deficits on pear tree growth, flowering, fruit growth, and yield. *J. Amer. Soc. Hort. Sci.* 109:604-606 (1984).
- Millar, A.A. Thermal regime of grapevines. *Am. J. Enol. Vitic.* 4:176-176 (1972).
- Naor, A., B. Bravdo and Y. Hepner. Effect of post-véraison irrigation level on Sauvignon blanc yield, juice quality, and water relations. *S. Afr. J. Enol. Vitic.* 14:19-25 (1993).
- Naor, A. and B.A. Bravdo. Irrigation and water relations interactions in grapevines. *In* Proceeding of the Fifth International Symposium on Grapevine Physiology, Jerusalem. B. A. Bravdo (Ed.), 109-113. *Acta Horticulture* 526, (2000).
- Neja, R.A., W.E. Wildman, R.S. Ayers and A.N. Kasimatis. Grapevine response to irrigation and trellis treatments in the Salinas Valley. *Am. J. Enol. Vitic.* 28:16-26 (1977).
- Noar, A., B. Bravdo and J. Gelobter. Gas exchange and water relations in field-grown Sauvignon blanc grapevines. *Am. J. Enol. Vitic.* 45:423-428 (1994).

- Ouwerkerk, C.V. and P.A.C. Raats. Experiences with deep tillage in the Netherlands. *Soil Till. Res.* 7:273-283 (1986).
- Perold, A.I. A Treatise on Viticulture. Macmillan and co., ltd., London (1927).
- Perret, P., P. Weissenbach, H. Schwager, W.E. Heller and W. Koblet. "Adaptive nitrogen management" a tool for optimization of N-fertilization in vineyards. *In* Proceedings of the Third International Symposium of Cool Climate Viticulture and Enology, Geisenheim-Mainz University. (Ed.), 124-126. *Vitic. Enol. Sci.*, (1992).
- Peterlunger, E., A. Buccella and F. Iacono. Physiological changes in grapevine during adjustment to water stress: ABA, leaf gas exchanges, and root hydraulic conductivity. *In* Proceedings of the Fifth International Symposium on Grapevine Physiology, Jerusalem. B. A. Bravdo (Ed.), 201-206. *Acta Horticulture* 526, (1997).
- Peynaud, E. and P. Ribereau-Gayon. The grape. *In* The Biochemistry of Fruits and Their Products. A. C. Hulme (Ed.), Academic Press, London (1970).
- Poni, S., A.N. Lakso, J.R. Turner and R.E. Melious. The effects of pre-and post-véraison water stress on growth and physiology of potted Pinot noir grapevines at varying crop levels. *Vitis*. 32:207-214 (1993).
- Powlson, D.S. and D. Barraclough. Mineralization and assimilation in soil-plant systems. *In* Nitrogen Isotope Techniques. R. Knowles and T. H. Blackburn (Ed.), 209-242. Academic Press, San Diego (1993).

- Powlson, D.S., P.R. Poulton, N.E. Moller, M.V. Hewitt, A. Penny and D.S. Jenkinson. Uptake of foliar applied urea by winter wheat (*Triticum aestivum*). The influence of applicaiton time and the use of a new  $^{15}\text{N}$  technique. J. Sci. Food Agric. 48:429-440 (1989).
- Reynolds, A.G. and A.P. Naylor. 'Pinot noir' and 'Riesling' grapevines respond to water stress duration and soil water-holding capacity. HortScience. 29:1505-1510 (1994).
- Rodrigues, M.L., M.M. Chaves, R. Wendler, M.M. David, W.P. Quick, R.C. Leegood, M. Stitt and J.S. Pereira. Osmotic adjustment in water stressed grapevine leaves in relation to carbon assimilation. Aust. J. Plant Physiol. 20:309-321 (1993).
- Roubelakis-Angelakis, K.A. and W.M. Kliewer. Nitrogen metabolism in grapevine. In Horticultural Reviews. E. G. W. J.N. Cummins, N. Zieslin (Ed.), 407-452. J. Wiley and Sons Inc., New York (1992).
- Rupp, D. Green cover management to optimize the nitrogen supply of grapevines. In Proceedings of the First ISHS Workshop on Strategies to Optimize Wine Grape Quality, Conegliano, Italy. S. Poni, E. Peterlunger, F. Iacono and C. Intrieri (Ed.), 57-62. Acta Horticulture 427, (1996).
- Salsbury, F.B. and C.W. Ross. Plant Physiology, 4. Wadsworth, (1991).
- Sanchez, E.E., T.L. Righetti, D. Sugar, and P.B. Lombard. Response of 'Comice' pear trees to postharvest urea spray. J. Hort. Sci. 65:541-546 (1990).

- Sanchez, E.E., T.L. Righetti, D. Sugar and P.B. Lombard. Effects of timing of nitrogen application on nitrogen partitioning between vegetative, reproductive, and structural components of mature 'Comice' pears. *J. Hort. Sci.* 67:51-58 (1992).
- Schaller, K. Ground water pollution by nitrate in viticultural areas. *In* International Symposium on Nitrogen in Grapes and Wine, Seattle, WA. J. M. Rantz (Ed.), 12-22. *Am. J. Enol. Vitic.* (1991).
- Schreiber, U., W. Bilger and C. Neubauer. Chlorophyll fluorescence as a noninvasive indicator for rapid assessment of *In Vivo* Photosynthesis. *In* Ecophysiology of Photosynthesis. E. D. Schulze and M. M. Caldwell (Ed.), 49-70. Springer-Verlag, Berlin (1994).
- Schultz, H.R. Water relations and photosynthetic responses of two grapevine cultivars of different geographical origin during water stress. *In* Proceedings of the First ISHS Workshop on Strategies to Optimize Wine Grape Quality, Conegliano, Italy. S. Poni, E. Peterlunger, F. Iacono and C. Intrieri (Ed.), 251-266. *Acta Horticulture* 427, (1996).
- Schultz, H.R. Physiological mechanisms of water use efficiency in grapevines under drought conditions. *In* Proceedings of the Fifth International Symposium on Grapevine Physiology, Jerusalem. B. A. Bravdo (Ed.), 115-136. *Acta Horticulture* 526, (2000).
- Schultz, H.R. and M.A. Matthews. Vegetative growth distribution during water deficits in *Vitis vinifera* L. *Aust. J. Plant Physiol.* 15:641-656 (1988).
- Shaner, D.L. and J.S. Boyer. Nitrate reductase activity in maize (Sea mays L.) leaves. I. Regulation by nitrate flux. *Plant Physiol.* 58:449-504 (1976).

- Smart, R.E. and B.G. Coombe. Water relations of grapevines. *In* Water Deficit and Plant Growth. T. T. Kozlowski (Ed.), 138-196. Academic Press, New York (1983).
- Smart, R. Aspects of water relations of the grapevine (*Vitis vinifera*). *Am. J. Enol. Vitic.* 25:84-91 (1974).
- Smith, L.A. Cotton response to deep tillage with controlled traffic on clay. *Trans. Amer. Soc. Agric. Engin.* 38:45-50 (1995).
- Spayd, S.E. and J. Andersen-Bagge. Free amino acid composition of grape juice from 12 *Vitis vinifera* cultivars in Washington. *Am. J. Enol. Vitic.* 47:389-402 (1996).
- Spayd, S.E., R.L. Wample, R.G. Stevens, R.G. Evans and A.K. Kawakami. Nitrogen fertilization of White Riesling in Washington: Effects on petiole nutrient concentration, yield, yield components, and vegetative growth. *Am. J. Enol. Vitic.* 44:378-386 (1993).
- Spiegel-Roy, P. and B.A. Bravdo. Le regime hydrique de la vigne. *Bull. OIV.* 37:232-248 (1964).
- Sponholz, W.R. Nitrogen compounds in grapes, must, and wine. *In* International Symposium on Nitrogen in Grapes and Wine, Seattle, WA. J. M. Rantz (Ed.), 67-77. *Am. J. Enol. Vitic.* (1991).
- Stone, D.A. The effects of subsoil loosening and deep incorporation of nutrients on yield of broad beans, cabbage, leek, potatoes, and red beet. *J. Agric. Sci.* 98:297-306 (1982).

- Trought, M. and A.P. Naylor. Irrigation responses in a cool climate. *In* Proceedings of the Second International Cool Climate Viticulture and Oenology Symposium, Auckland, New Zealand. 156-160. (1988).
- Van Zyl, J.L. and H. Weber. Irrigation of Chenin Blanc in the Stellenbosch area within the framework of the climate-soil-water-plant continuum. *In* Proc. Symp. Qual. Vintage, Stellenbosch, South Africa. 331-350. (1977).
- VanZyl, J.L. Response of Colombar grapevines to irrigation as regards quality aspects and growth. *S. Afr. J. Enol. Vitic.* 5:19-28 (1984).
- Watson, B.T., E. Hellman, A. Specht and H.P. Chen. Evaluation of nitrogen deficiencies in Oregon grapevines and musts. *In* Proceedings of OSU Winegrape Research Day, Corvallis, Oregon. 3-8. (2000).
- Weinbaum, S.A., I. Klein, F.E. Broadent, W.C. Micke and T.T. Muraoka. Effects of time of nitrogen application and soil texture on the availability of isotopically labeled fertilizer nitrogen to reproductive and vegetative tissue of mature almond trees. *J. Am. Soc. Hortic. Sci.* 109:339-343 (1984).
- Wermelinger, B. Nitrogen dynamics in grapevine: physiology and modeling. *In* International Symposium on Nitrogen in Grapes and Wine., Seattle, WA. J. M. Rantz (Ed.), 23-31. *Am. J. Enol. Vitic.* (1991).
- Wildman, W.E., R.A. Neja and A.N. Kasimatis. Improving grape yield quality with depth-controlled irrigation. *Am. J. Enol. Vitic.* 27:168-175 (1976).



- Williams, L.E. Growth of 'Thompson Seedless' grapevines. II. Nitrogen distribution. *J. Amer. Soc. Hort Sci.* 112:330-333 (1987).
- Williams, L.E. and P.J. Biscay. Partitioning of dry weight, nitrogen, and potassium in Cabernet sauvignon grapevines from anthesis until harvest. *Am. J. Enol. Vitic.* 42:113-117 (1991).
- Williams, L.E. and M.A. Matthews. Grapevines. *In* Irrigation of Agricultural Crops. B. A. Stewart and D. R. Nielsen (Ed.), Am. Soc. Agron., Madison (1990).
- Winkler, A.J., J.A. Cook, W.M. Kliewer and L.A. Lider. General Viticulture, University of California Press, Berkeley (1974).
- Yang, Y.S. and Y. Hori. Studies on retranslocation of accumulated assimilates in "Delaware" grapevines. III. Early growth of new shoots as dependent on accumulated and current year assimilates. *Tohoku J. Agric. Res.* 31:120-129 (1980).
- Zoecklein, B.W., K.C. Fugelsang, B.H. Gump and F.S. Nury. Wine Analysis and Production, Aspen, Gaithersburg (1999).