AN ABSTRACT OF THE THESIS OF

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Abstract approved

Mina R. McDaniel

Two vintages of *Vitis vinifera cv.* Pinot noir wine from a viticulture trial evaluating nitrogen fertilization, tilling and irrigation underwent descriptive analysis using a modified version of free-choice profiling. Wines were made from three field blocks of the twelve factorial combinations of Irrigation (Dry or Irrigated), Tillage (Tilled or not Tilled) and Fertilization (None, Foliar nitrogen supplementation or soil applied nitrogen). Irrigation was associated with lower anthocyanins and total phenols as well as lower color intensity and purple hue in both vintages. Irrigation increased vegetative and spicy character in the 1999 vintage while non-irrigated treatments were characterized by fruit, cherry and berry characteristics. Tilling significantly increased fruity flavor and body in the 1999 vintage and was associated with increased vegetative character in the 2000 vintage. In the 2000 vintage, non-fertilized treatments were significantly higher in floral aroma than the soil or foliar fertilized treatments.

Descriptive Analysis of Two Consecutive Vintages of Oregon Pinot noir Wines as Effected by Irrigation, Tillage and Nitrogen Supplementation in the Vineyard

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Heather Byrne Hjorth

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CONTRIBUTION OF AUTHORS

Carmo Vasconcelos and Jessica Howe designed and executed the fieldwork for this experiment. Statistical consultation for the 1999 vintage was provided by Jan-Shiang Taur and Siwei Jia of the Department of Statistics at Oregon State University. Alix Gitelman assisted with the statistics in both vintages. Kelly Helms collected the color data for the 1999 vintage new wines. Dr. Michael Qian was involved in the flavor chemistry extraction, analysis and interpretation. Patrick Taylor collected the data for the 2000 vintage color panel and assisted with the analysis. All wines from both the 1999 and 2000 vintages were produced under the direction of Barney Watson in the OSU experimental winery. Barney Watson also helped with the interpretation of the data for both vintages.

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Descriptive Analysis of Two Consecutive Vintages of Oregon Pinot noir Wines as Effected by Irrigation, Tillage and Nitrogen Supplementation in the Vineyard

I. INTRODUCTION:

The Oregon wine industry continues to grow with 8,800 vineyard acres harvested in the 2001 vintage, yielding 22,800 tons of harvested wine grapes worth over 33 million dollars (2002). Pinot noir is the leading winegrape in Oregon. Pinot noir accounts for roughly 40% of the harvested weight and 53% of the total value. The average wine grape price across all varieties was $1,480 per ton, with Pinot noir averaging $1,990 per ton in 2001. Wineries reported a total of 427,848 cases of Pinot noir were sold in 2001, accounting for 39.6% of the total number of cases sold. This is up from 35.5% of the total cases sold in the 2000 vintage. There are five appellations in the state of Oregon that are recognized by the Bureau of Alcohol, Tobacco and Firearms. These include Applegate Valley, Columbia River Valley, North Willamette Valley, South Willamette Valley, Rogue Valley and Umpqua Valley. The North Willamette Valley is the most productive of these, accounting for 59% of the states' wine grape production.

Nitrogen deficiencies can limit yeast growth, lead to stuck or sluggish fermentations and result in the release of hydrogen sulfide (Hallinan et al., 1999; Kunkee, 1991; Spayd and Andersen-Bagge, 1996). A survey of the amino acid

composition of wine grapes grown in the Pacific Northwest found that most were deficient in nutritionally available nitrogen (Spayd and Andersen-Bagge, 1996). A yeast assimilable nitrogen content of 140 mg/L has been cited as required for musts with low solids content and normal sugar concentrations (Butzke, 1998; Kunkee, 1991) (Watson et al., 2000a). This project sought to determine optimal vineyard management strategies to ensure adequate nitrogen in the must.

The aim of this segment of the project was to perform descriptive analysis on wines from a project evaluating the effects of manipulating soil moisture and nitrogen availability in a Pinot noir vineyard by using tilling, irrigation and nitrogen supplementation. The goal was to see if the main viticultural effects, or combinations thereof, led to significant differences in aroma, flavor, mouthfeel and color for the descriptors. Overall trends caused by the main effects were observed through multivariate mapping techniques including principal components analysis and generalized Procrustes analysis. Wines for this project were produced from grapes grown at a mature vineyard site in the southern Willamette Valley, Oregon.

Pinot noir has a reputation for being a difficult grape to grow well. Nutritional deficits were noted among wine samples from the Pacific Northwest (Spayd and Andersen-Bagge, 1996; Watson et al., 2000b). Low levels of nutritionally available nitrogen sources to the yeasts were noted, although these levels were higher than for other varieties grown in Oregon. Pinot noir also has had historical

problems with color stability, producing wines with low color intensity and little potential for ageing (Price et al., 1995).

Sensory evaluation involved slightly different types of descriptive panels in the 1999 and 2000 vintages respectively. Aroma, flavor, mouthfeel and color were evaluated in both years. Through both vintages, data was collected using a modified version of free-choice profiling that had panelists rate wines for a set of pre-determined descriptors while allowing them to generate and use their own descriptive vocabulary. A winemaker panel of 16 experienced winemakers from the Pacific Northwest who make Pinot noir was used to evaluate the 1999 vintage. A semi-trained panel was convened to evaluate the 2000 vintage wines. Color evaluations were collected using both a sensory panel and a spectrophotometer in both vintages.

II. LITERATURE REVIEW

SENSORY EVALUATION OF WINE

Wine has been part of Western Civilization since the advent of recorded history. Wine is referred to in The Iliad of Homer, written around 700BC and Herodotus mentions wine on numerous occasions in The History, written in BC 440(Herodotus; Homer). Wine is discussed multiple times in the Old Testament . "My people of Israel…shall plant vineyards and drink the wine from them" (Amos 9:14). Chronicles 32:27 describes the division of labor: "And Shimei the Ramathite was over the vineyards, and Zabdi the Shipmite was over the produce of the vineyards for the supply of wine." References are made to wine produced and transported in animal skins (Samuel 16:20, 25:18; Job 32:19).

By the time of the New Testament, wine was an integral part of important celebrations. John 2:1-11 describes the wedding in Cana of Galilee, where Jesus is credited with turning water into wine. After tasting the wine thus created, the master of the feast called the bridegroom over and said "Every man at the beginning doth set forth good wine; and when men have well drunk, then that which is worse: but thou has kept the good wine until now."

DESCRIPTIVE ANALYSIS TECHNIQUES:

Descriptive analysis is a form of sensory evaluation where trained panelists rate specified attributes of a product on scales of perceived intensity (Lawless and Heymann, 1999). These techniques were developed in response to a need to quantify objective differences between products. The difference between descriptive analysis and hedonic based approaches lies in the specific, objective descriptors used in descriptive analysis, versus the subjective nature of 'quality' assessments, which vary widely from person to person.

Most organized wine tasting sessions involve proceedings where wines are scored for their 'quality'. This generally involves each wine being evaluated for a set of descriptors based on how much each judge likes a particular character or how 'appropriate' he or she thinks it is. In general, quality is related to visual, aroma or taste characters which are perceived to be above average for a given type of wine (Jackson and Lombard, 1993). Unfortunately 'quality' is inherently subjective and may best be described: "Quality is an intellectual phenomenon that occurs between the wine and the taster; it is independently related to neither" Richard Nelson, PhD, Canada (Young, 1986). In a study looking at beer quality ratings by experts, Guinard and others found a lack of defects may be the most important aspect of beer sensory quality. A highly significant judge by beer interaction was found in

the analysis of variance of six different qualities, suggesting a difference in the determination of quality by beer experts (Guinard et al., 2000).

Some common descriptive analysis techniques include The Flavor Profile Method, The Texture Profile Method, Quantitative Descriptive Analysis and Spectrum Analysis. The differences between these formalized descriptive analysis techniques lie in panel composition (experts vs. novices), training (length, composition), scaling (type of scale & training), data collection, and the role of the panel leader. Many researchers use variations and/or combinations of the many formal types of descriptive analysis (Martin et al., 2000).

The Flavor Profile Method

The first formal descriptive analysis technique, The Flavor Profile Method, was developed at the Arthur D. Little Company in the 1940s (Caul, 1957) (Meilgaard et al., 1999). Many panelists are screened and 4-6 are selected on the basis of taste discrimination, taste intensity discrimination, olfactory discrimination & descriptive ability. Training is intensive and lasts for several months during which time panelists are exposed to a wide range of products in the product category they will be working with. The panel leader plays a large, active role in sample preparation, language development, product evaluation and consensus generation. The scale used began as a 4-point scale and was later expanded. Panelists are

trained to evaluate specific descriptors with a variety of standards and are trained to use a flavor intensity scale. Samples are evaluated monadicaly, and comparison among samples is not allowed. A consensus-derived profile is created for each sample evaluated by the group. This is considered a qualitative descriptive analysis technique because statistical analysis of the data is not performed.

The Texture Profile Method

The Texture Profile method was developed in the 1960s to describe the textural attributes of food, following the same basic principles as the Flavor Profile Method. The profile was meant to capture *'the texture complex of a food in terms of its mechanical, geometrical, fat and moisture characteristics, the degree of each present, and the order in which they appear from first bite through complete mastication'* (Brandt et al., 1963). Training for this method is rigorous, with an initial training orientation with 2-3 hour meetings daily for two weeks followed by six months of hourly practice sessions 4-5 times each week. A panel can be fully trained to evaluate a range of products or an abbreviated training can be used to train a group to evaluate a specific product (Civille and Szczeniak, 1973).

The Quantitative Descriptive Analysis (QDA) Method

QDA was developed by Herb Stone and Joel Sidel in 1974 to make descriptive analysis quantitative by applying statistics (Stone and Sidel, 1998). Panelists are trained for a minimum of three weeks. The role of panel leader is as facilitator only. Panelists are instructed to develop a vocabulary based on a consensus. The specific vocabulary used is not stressed as important as long as there is agreement among the panel as to what they mean (Stone and Sidel, 1998). Data is collected using line scales.

The Spectrum Descriptive Analysis Method

The Spectrum method of descriptive analysis was created by Gail Civille in the 1970s (Sensory Spectrum, Chatham, NJ) as a technique for companies interested in obtaining reproducible sensory descriptive analysis of their products (Meilgaard et al., 1999). This technique encompasses many of the principals of the Texture Profile method. One unique aspect is that panelists do not use a panel specific vocabulary, rather they use a standardized lexicon of terms which can be duplicated anywhere. This technique gives the panel leader tools to design a 'custom' descriptive analysis procedure appropriate for a specific product. Panelist training is intensive. The role of the panel leader is more involved and assertive than in QDA. Scales are absolute and standardized, most commonly a 16-point scale, and

have standards to anchor them. The scales are created to have equi-intenisty, so a 5 of sweetness is equal in intensity to a 5 of sourness (Lawless and Heymann, 1999). In contrast to QDA, scores are considered to have absolute meaning because panelists are trained to use the descriptor scales in the same way. Because the scale is absolute, the same reference standards can be used in multiple panels. This allows companies to develop and maintain panels that can be used over extended periods of time to evaluate multiple product types with relatively minimal additional training.

Free-choice Profiling & Generalized Procrustes Analysis

Free choice profiling is a descriptive analysis technique that allows panelists to generate their own descriptors. The analysis is performed using Generalized Procrustes analysis. Procrustes statistics provide an alternative to the traditional presentation of sensory data as the panel mean. The Procrustes approach does not require that panelists share the same interpretation of the vocabulary (Williams and Langron, 1984).

Generalized Procrustes analysis was developed in 1975 by J. C. Gower as a method to analyze multivariate data (Gower, 1975). The algorithm has been improved throughout the years but involves the basic steps of translating, rotating, reflecting and scaling of mn points in p-dimensional space. This technique was pioneered in

the field of sensory evaluation by Williams and Langron who used it to describe commercial port wines (Williams and Langron, 1984). This showed that while the 10 assessors used their own descriptive vocabulary to evaluate the interrelationships between the ports, the plots generated by individual panelists showed the same general relationships between the samples despite using different words to describe them (Williams and Langron, 1984).

Williams and Arnold compared free-choice profiling to a conventional profile analysis and similarity scaling in evaluating coffee aroma in 1985 (Williams and Arnold, 1985). They found that all methods provide similar information about the inter-relationship of samples. Work comparing Free-choice profiling to a procedure based on Kelly's repertory grid method was done investigating the sensory characteristics of chocolate (McEwan and Colwill, 1989). It was found that configurations and interpretations for both techniques were very similar. However, because the repertory grid technique is more labor intensive and time consuming, free-choice profiling was suggested as the preferred approach (McEwan and Colwill, 1989).

Rubico and McDaniel (1992) used free-choice profiling to describe the sensory properties of common organic and inorganic acids (Rubico and McDaniel, 1992). Heymann compared free-choice profiling to multidimensional scaling in the comparison of vanilla samples (Heymann, 1994). She found that sensory-naive

panelists failed to generate a consensus space while a sensory savvy group did using generalized Procrustes analysis. It was suggested that this may be a good technique for a group of panelists trained for one product who suddenly had to evaluate a different type of product (Heymann, 1994). Stucky and McDaniel (1997) successfully used free-choice profiling to describe the aromas of hop varieties (Stucky and McDaniel, 1997).

LEXICON

The Wine Aroma Wheel was created in response to the need for a common aroma and flavor language and is similar in format to the Beer Aroma Wheel (Noble, 1984) and the Whiskey Aroma Wheel (Noble et al., 1987). Descriptors are broken into tiers, with general first tier terms such as 'fruity' in addition to more specific second-tier terms such as 'berry' and third tier terms such as 'raspberry' that are even more specific. Gawel found that untrained panelists tended to use concrete descriptors when evaluating wines while trained panelists relied on more vague and abstract terms (Gawel, 1997). McDaniel and others published a lexicon and training standards used in a descriptive analysis panel evaluating the aroma of Oregon Pinot noir wines fermented with different strains of malolactic bacteria (McDaniel et al., 1987).

A Mouth-feel Wheel has recently been developed to describe the in-mouth sensory properties of red wines (Gawel et al., 2000). The characterization of these mouth-feel sensations difficult because most people do not share a common vocabulary for describing in-mouth texture. In contrast to the Beer and Whiskey wheels, which have sections devoted to mouthfeel and texture terms, the wine aroma wheel had no descriptors to describe mouthfeel effects. This 'Mouth-feel Wheel' has met with some resistance in the sensory community because of its combination of objective and hedonic descriptors.

Wine drinkers have their own lexicon for describing aroma, flavor and texture of wines, with vocabulary spread through popular magazines such as The Wine Spectator and Food & Wine. For example: *"Rich and juicy, with tangy berry accenting the rich cherry and white pepper flavors. It all hangs on a supple frame that integrates the soft tannins beautifully and lets the flavors linger enticingly"* (Wine Spectator, 2001). This type of language differs from the formal language of descriptive analysis because it combines objective descriptors with hedonic attributes and abstract terms such as 'balance'.

PANELIST PERFORMANCE

The field of sensory evaluation uses human beings as instruments to measure quantifiable aspects of food and consumer products. As with any instrument used to

make measurements, precision and accuracy need to be measured. Unlike laboratory equipment, human beings introduce physiological, psychological and cultural variables to product evaluations (Merritt, 1997).

Most methods of assessing panelist performance are based on what psychological literature calls the 'test-retest' method (Brien et al., 1987). The purpose is to evaluate an individual's ability to reproduce their evaluations on replicated evaluations of a product. Brien and others looked at the use of correlation coefficients, F-statistics and least significant difference for measuring panelist performance in terms of agreement, reproducibility, discrimination, stability, and variability. Multivariate methods such as Principal Components Analysis (PCA), Generalized Procrustes analysis (GPA), partial least squares regression (PLS) are being explored as tools to evaluate the ability of panels to perceive attributes in products (Sinesio and Rodbotten, 1990) (Cliff and King, 1999). A control chart technique for measuring panelist performance in product profile development was developed as an alternative to ANOVA for comparing panelist performance in terms of congruence with themselves and each other in identifying the intensity or presence of a given attribute (Gatchalian et al., 1991). Analysis of variance and the control chart technique were shown to give similar significant sample groupings.

In some European nations, wines must be tasted by a panels of experts and be deemed to meet certain standards before they can be sold with a given quality

designation. Examples of this are the appellation system in France and the Regulatory Council of Certified Origin in Spain. Vaamonde and others used discriminate analysis to compare the consistency of the qualification of wines by such panels with chemical and physical measurements (Vaamonde et al., 1997). It was determined that tasters were consistent with the analytical data, but that tasters were more conservative in granting certified origin than the analytical measures alone.

In sensory data, there are often one or several panelists who give response patterns that differ from the remainder of the panel. Panelist by treatment interaction variation can be used to investigate panel inconsistency (Lundahl and McDaniel, 1990). Non-perceivers, non-discriminators and magnitude interaction effects have little effect on sensory test outcomes but crossover interactions increase the chances of type 2 error, that is, missing a difference that exists (Lundahl and McDaniel, 1991). The use of contrasts for the evaluation of panel inconsistency was found to be useful when only one panelist outlier is present.

Lundahl and McDaniel argue that the panelist effect should in most cases be considered random effect in Analysis of Variance. Because panelists are viewed as random selections from a population, results can be related to a larger population of prospective panelists (Lundahl and McDaniel, 1988).

WINE CHEMISTRY

Instrumental Approaches

The separation and detection of aroma and flavor components of a complex mixture such as wine often begins with analysis of concentrated extracts by gas chromatography (GC). This can provide a general idea of the complexity of a mixture, the relative magnitude and distribution of components. The limitation of GC is that it cannot identify peaks except by comparison with known standards, and no idea of aroma activity for a given peak is given. GC also does not analyze for nonvolatile components (unless derivitized which may contribute to mouthfeel and texture of wines. For this reason, GC analysis is often done in conjunction with Mass Spectroscopy to help identify the peaks.

One instrumental approach used to evaluate the sensory properties of wine involves Gas Chromatography-Olfactometry (Miranda-Lopez et al., 1992a; Miranda-Lopez et al., 1992b; Noble, 1978). This technique involves splitting the GC effluent so that it simultaneously elutes to the detector as well as to a separate port where a human subject evaluates it. A variety of approaches to gas chromatography olfactometry exist including dilution-based approaches such as Charm Analysis ™. The Charm technique was developed by Terry Acre in 1984 as a formalized approact to GC olfactometry that uses a serial dilution approach to generate a

'charm chromatogram' which provides information about odor activity (Acree et al., 1984).

Osme, developed at Oregon State University, is another approach to this technique that creates a time-intensity response, which is similar in appearance to output from standard GC detectors (Miranda-Lopez et al., 1992b). The Osme approach is not based on thresholds but at intensity at a single stimulus level. Consensus Osme grams are made from the results of at least four panelists with time-intensity output similar in appearance to GC output. Verbal descriptions are also collected and used to label the consensus Osme-grams (Miranda-Lopez, 1990).

Aroma and Flavor Chemistry:

Pinot noir wines are known for their fruity aromas, particularly the aroma of small stone fruits such as cherry and plum as well as strawberry, blackberry and black currant. The volatile components of wine are primarily composed of alcohols, aldehydes, ketones(sweet solventy character), esters(fruity or sweet character), and acids (Gomez et al., 1994). The volatile constituents of Pinot noir have been studied by a variety of researchers (Schreier et al., 1976) (Miranda-Lopez et al., 1992b; Moio and Etievant, 1995) (Girard et al., 1997). Moio and others found that ethyl anthranilate, ethyl cinnamate, ethyl 2,3-dihydrocinnamate and methyl anthranilate were important odorants in Pinot noir wines from Burgundy, France

(Moio and Etievant, 1995). Different chemical species are responsible for the complex "varietal character" of Pinot noir including acids, terpenes, lactones (fruity, candy, floral character) and phenols. A variety of other odor-active compounds have been identified including ethyl vanillate (spicy, herbal character), methyl vanillate (caramel, butterscotch, fruity character), acetovanillone and methionol(earthy, baked potato character). Fatty acids including isovaleric (rancid, cheese, sweaty, putrid aroma), hexanoic (fatty, rancid aroma), octanoic(sour, vinegar, sweaty, pungent aroma), decanoic, and tridecanoic acid were also identified (Miranda-Lopez et al., 1992a). Although found in low quantities in wine, fatty acids have low thresholds and pungent qualities that contribute to the complexity of wine.

'Varietal character' refers to typical aroma and flavors associated with wines made from specific grapes. This is due in part to terpene alcohols (floral and fruity character), which are important aroma constituents in wine and are present in grapes in varietal specific quantities that are not altered by fermentation (Reynolds and Wardle, 1997; Schreier, 1979). Monoterpenes are compounds which exist as either free volatile terpenes, which are highly aroma active and characterized by floral, fruity descriptors; or as potentially volatile terpenes which are not aroma active and are bound up as glycosides or polyols (Reynolds and Wardle, 1997). The formation of terpenes by *saccharomyces cerevisiae* has not yet been observed (Rapp and Versini, 1991). Some of these compounds have been found to be

suitable for analytical separation and differentiation of wine varieties. The characteristic aroma and flavor of grapes and wines made from *Vitis labrusca* and *Vitis rotundafolia* is attributable to certain esters such as methyl anthranilate (concord grape character) (Schreier, 1979).

The conversion of grape must to wine by yeast fermentation is accompanied by large changes in the flavor and aroma profile. Ethyl alcohol, carbon dioxide, and glycerol are produced in significant quantities (Schreier, 1979). Ethyl alcohol accounts for about 12-13% by volume alcohol in table wine and contributes a burning, hot, sweet taste and aroma. Carbon dioxide is a gas that is soluble in wine and is not present in detectable sensory levels at bottling for a still table wine. Effervescence indicates the presence of carbon dioxide, which is not typical of Pinot noir table wine. Glycerol contributes to the viscosity and mouthfeel of wine and may contribute sweetness in high quantities. The 'fermentation bouquet' also includes other products of yeast metabolism including acids, esters (fruity, floral character), aldehydes, ketones and sulfur compounds (Rapp and Versini, 1991). The volatile sulfur compounds formed during fermentation are especially important because of their low sensory thresholds (Hallinan et al., 1999) (Rauhut and Kurbel, 1994).

Wine is a complex stimulus that elicits a variety of gustatory responses and in-mouth sensations (Thorngate, 1997). Glucose and fructose are the major sugars that

contribute to the sweetness of wine. Acidity in wine is due primarily to tartaric acid (tart apple character), with malic and lactic acids also being important, with lactic acid being particularly important in wines in which malolactic fermentation has occurred. A variety of compounds contribute to bitterness, including tyrosol, a non-flavanoid compound, and flavan-3-ols (+)-catechin, (-)-epicatechin and their polymers (Brossaud et al., 2001; Peleg et al., 1999). Work on the sensory characteristics of different tannic fractions is ongoing (Kennedy et al., 2002).

Tannins, Phenolic Compounds in Pinot noir

The phenolic species present and their relative concentration are important in determining flavor and mouthfeel of wines (Jackson and Lombard, 1993; Kennedy et al., 2002). The phenolic compounds in wines are known to elicit both bitter and astringent sensations (Noble, 1978) (Noble, 1984) (Young, 1986). Bitterness is defined as "the taste produced by substances such as quinine or caffeine when in solution (ASTM, 1999). Astringency has been defined as "the complex of sensations due to shrinking, drawing or puckering of the epithelium as a result of exposure to substances such as alum or tannins" (ASTM, 1999). In a study of selected phenolics in wine, Robichaud and Noble found the perceived intensity of astringency increases as the molecular weight of the tannin increases (Peleg et al., 1999; Robichaud and Nobel, 1990).

Phenolic compounds in wine include anthocyanins, flavonols and condensed combinations thereof. Flavan 3-ol monomers are subunits, which polymerize to form tannins. Flavan 3-ol monomers include catechin, epicatechin and epigallocatechin, among others. Monomers of anthocyanin and flavanols can occur as oligomers and polymers called proanthocyanins. These proanthocyanins are building blocks which form tannins when condensed (Brossaud et al., 2001). The compostion of the monomeric subunits as well as the specific linkage patterns between the units impacts the perception of astringency (Peleg et al., 1999). Anthocyanin pigments are found in the skin of grapes and in the juice of a few varieties. The molecular size of polyphenols affects their relative bitterness and astringency: monomers are more bitter than astringent while larger molecular weight derivatives are more astringent than bitter (Brossaud et al., 2001; Kennedy et al., 2001). Wine astringency is attributable to the presence of flavan 3-ol polymers, occasionally referred to as condensed tannins or proanthocyanins (Thorngate, 1997). In a time intensity study of astringency in wine, Guinard and others found that the total duration of astringency increased significantly with repeated ingestion but the maximum perceived intensity and the time to maximum intensity did not change (Guinard et al., 1986).

Wine Color

Anthocyanins are the principal chemical components responsible for red wine color. These compounds are extracted from the skins of grapes during processing and fermentation (Kennedy et al., 2001; Mazza et al., 1999). Pinot noir has consistently been shown to have only delphinidin, cyanidin, petunidin, peonidin and malvidin 3-monoglucosides. Pinot noir has no acylated anthocyanins. Other *V. vinifera* cultivated varieties such as Cabernet Sauvignon, Merlot and Syrah contain anthocyanin compounds acylated by acetic, coumaric and caffeic acids in addition to non-acylated compounds (Gao et al., 1997) (Mazza et al., 1999). More of the total anthocyanins in Pinot noir is flavan 3-ol monomer than in Shiraz or Cabernet sauvignon (Kennedy et al., 2002). The relative proportion, size and degree of polymerization of these species are important to color as well as to flavor and mouthfeel of wine (Brossaud et al., 2001; Peleg et al., 1999).

Spectrophotometers are often employed as an instrumental means to measure wine color. Absorbance at 520 nm corresponds to the dark purple/red part of the spectrum and absorbance at 420 corresponds to the yellow/brown part of the spectrum. Color intensity of wine is calculated as the sum of absorbance at 420nm and 520nm. During maturation of a young red wine in the presence of oxygen, absorbance of light at 520nm decreases while absorbance at 420nm increases. This reflects a shift from monomeric anthocyanins to condensed species, which are

ultimately more stable (Gao et al., 1997). A variety of chemical reactions drive these pigment condensation reactions.

Color in Pinot noir is influenced by viticultural practice. Price and others compared the anthocyanin and flavonol content in sun-exposed and non sun-exposed berries from the same clusters and found that wines from moderate to highly exposed cluster positions had higher total anthocyanin levels than wines made from shaded clusters. Wines made from highly exposed clusters were found to have more polymeric anthocyanins than wines made from low and moderately exposed fruit (Price et al., 1995). An investigation on the effects of nitrogen supply and shoot trimming on mature Pinot noir vines found that high nitrogen supply decreased anthocyanins in juice and wine, increased pH and increased the percentage of malvidin-3-glucoside (Keller et al., 1999). These differences may be associated with increased vine vigor and vegetative growth. Vinification and maturation practices also impact wine color. Malolactic fermentation is associated with a decrease in individual anthocyanins and an increase in polymeric pigments. The polymerization of anthocyanins is associated with the ageing of wine and it is not known if malolactic bacteria can absorb anthocyanins (Gao et al., 1997; Keller et al., 1999).

VITICULTURAL PRACTICES & WINE QUALITY

It has long been understood that a relationship exists between grape producing region and wine quality. The exact influence that site has on fruit and wine quality is difficult to objectively define because site based differences encompass differences in soil type, phenology, canopy density and cultural practices. The concept of 'terroir' is roughly defined as the combination of the effects of the soil, the climate, the topography and viticultural practices on the production from the vine (Young, 1986). The French first recognized this with their wine laws based on geography, with the creation of the Institut National des Appellations d'Origin in the 1930s (Johnson, 1994). Many efforts have been made to use climactic indices for predicting areas suitable for wine grape production (Chone et al., 2001) (Jackson and Lombard, 1993) (Reynolds and Wardle, 1997).

Canopy Management

Differences in sun exposure created by variations in canopy microclimate have been shown to have an impact on anthocyanins and flavonol content in Pinot noir grapes (Price et al., 1995). In a study on monoterpene development in the vineyard, Reynolds and others concluded that fruit sun exposure might enhance monoterpene concentrations in grape berries, leading to associated increases in aroma intensity and varietal character coming from free volatile terpenes (Reynolds and Wardle,

1997). Increases in apparent wine varietal character were noted in wines receiving vertical canopy division and/or reduction in shoot density, activities that open the vine canopy. These changes may be related to improvements in wine composition including lower TA and pH, higher anthocyanins and ethanol (Reynolds et al., 1996). High shoot densities, defined as 15-20 shoots/m row in Pinot noir, have been found to result in wines with more vegetative character and less fruit aroma and flavor as well as reduced color and finish when compared to lower shoot densities (Reynolds et al., 1996).

Irrigation

Most of the quality areas of wine production worldwide have rainfall below 80mm (Jackson and Lombard, 1993). Water availability influences wine quality with both insufficiency and excess not leading to fruit with a desirable balance of sugars, acids and other components. Insufficient water availability can harm vines and destroy vintages. Using a novel difference testing protocol, (Matthews et al., 1990) showed that irrigation can alter the sensory properties of wines. The timing of the onset of water stress and irrigation is also important. The magnitude of changes caused by water stress in vegetative growth and yield are larger than the changes in berry composition (Jackson and Lombard, 1993). Reynolds and Naylor looked at the effect of water stress on Pinot noir and Riesling grapevines. They found that soluble solids concentration and pH at harvest increased with the duration of water

stress, but found no effect on titratable acidity. Vines subjected to increasing water stress had lower shoot count and lateral shoot length, smaller leaf size and berry weight than vines not stressed (Reynolds and Naylor, 1994). Esteban and others found that the soluble solids of irrigated Tempranillo vines were significantly higher in soluble solids than non-irrigated grapes, ranging from 2.8% to 14.9% higher (Esteban et al., 1999).

In a study on grape seed development, it was found that reduction in water supply imposed after flowering did not alter seed number but reduced seed weight (Hardie and Aggenbach, 1996). Grape seeds are an important source of tannins extracted into red wine during fermentation. The phenolic composition of grape seeds has been shown to change significantly during grape ripening (Kennedy et al., 2000). Changes in seed weight create different seed surface area, which might impact extraction of seed tannin.

Nitrogen

Nitrogenous compounds are nutritionally important to *Saccharomyces* yeasts. Nitrogen components are required for the formation of cellular material and cell growth and are also important for alcohol tolerance (Kunkee, 1991). Nitrogen deficiencies can limit yeast growth, lead to stuck or sluggish fermentations and result in release of hydrogen sulfide (Spayd and Andersen-Bagge, 1996) (Hallinan

et al., 1999) (Kunkee, 1991). Hydrogen sulfide has a low sensory threshold and has the odor of rotting eggs. In sub-threshold quantities, hydrogen sulfide has been shown to reduce fruit character in wines (Rauhut and Kurbel, 1994).

Ammonia and free alpha amino acids are the major nitrogen sources used and assimilated by wine yeast (Spayd and Andersen-Bagge, 1996). Spayd and others conducted a survey of the amino acid compositions of twelve *Vitis vinifera* cultivars in Washington State between 1986 and 1990. They found that 90% of the samples surveyed had less than 400 mg free α–amino N/L of juice and 39% had less than 150 mg free α–amino N/L of juice. Yeast assimilable nitrogen content (YANC) refers to the total amount of nitrogenous compounds available to wine yeast: the sum of ammonia and free α–amino acids expressed in mg/L. A YANC of approximately140 mg/L has been cited as required to complete fermentation for musts with low solids contents and normal sugar concentrations for wine production (Butzke, 1998; Kunkee, 1991; Watson et al., 2000a). Hallinan and others found that a mean concentration of 395 mg of N/L was necessary for yeast to complete fermentation in a model system (Hallinan et al., 1999) (Spayd and Andersen-Bagge, 1996).

High nitrogen availability is associated with increased vigor in grapevines (Chone et al., 2001; Keller et al., 1999) (Bell and Robson, 1999; Reynolds et al., 1996). Increased vigor can lead to changes in canopy microclimate, with increased

vegetative growth causing shading of fruit clusters by leaves. These changes in vigor must be met with appropriate canopy management strategies to avoid the lowered intensity of the aroma and flavor profile and reduced color intensity which may be associated with shaded fruit (Price et al., 1995) (van Huyssteen, 1989). Keller and others looked at the effect of shoot trimming and soil ammonium nitrate application in the vineyard on Pinot noir grapes and wine. They found that high rates of nitrogen increased malic acid (unripe apple character) while reducing skin phenols, flavonols and anthocyanins. Malic acid is the byproduct of malolactic fermentation. High nitrogen supply decreased anthocyanins in the juice and wine and increased the pH (Keller et al., 1999). It should be noted, however, that this study used grapes that only reached 16.5 degrees brix and were adjusted to 22 degrees brix with sucrose.

Conflicting reports exist in the literature regarding the effect of nitrogen supplementation on non-nitrogenous compounds (Spayd et al., 1994). A variety of researchers have reported no effect or no consistent effect of nitrogen supplementation on soluble solids. The effect on pH, titratible acidity and acid profile is similarly mixed. The effect on nitrogenous compounds is a little more consistent. Spayd and others found that juice total nitrogen, ammonia, free amino nitrogen, arginine and proline concentrations increased linearly with increasing nitrogen fertilizer rate (Spayd et al., 1994). However, differences in yeast

assimilable nitrogen are not necessarily correlated with the formation of hydrogen sulfide at the end of fermentation (Butzke, 1998).

The relationship between nitrogen fertilization and the concentration of biogenic amines in wines is not fully understood. There are health concerns with these compounds with some subjects reporting symptoms including intense headache, rashes, nausea, facial flushing, thirst, sore throat, itching, swelling, diarrhea and vomiting. Biogenic amines are fermentation by-products created by microbial decarboxylation of precursor amino acids. Their origin is not fully understood, but increases in amine concentration have been found to be associated with increases in microbial growth, particularly bacteria (Gloria et al., 1998). Pinot has putrescine (putrid aroma), histamine, spermidine, tyramine, serotonin, cadaverine (sweet, decaying flesh aroma) and spermine in notable quantities (Gloria et al., 1998). A survey of Oregon wines produced in the 1991 and 1992 vintages showed that 100% of all wines sampled contained putrescine. 97% of the Pinot noir wines tested also contained histamine (Gloria et al., 1998). The impact of these compounds on wine complexity in small quantities has not been explored. At supra-threshold concentrations, these compounds have descriptors such as 'putrid' and 'decaying flesh' that may decrease the impact of other more desirable characters.

Another concern regarding nitrogen supplementation in the vineyard is the impact on ethyl carbamate formation. Ethyl carbamate is a carcinogen formed from a

reaction of urea with ethanol. Ethyl carbamate, also known as urethane (solvent or plastic aroma), is the monomer building block of polyurethane, which is commonly used as a plastic film. Although generally low, wine urea concentrations have been found to increase linearly with increasing rate of nitrogen fertilization (Spayd et al., 1994). Voluntary limits of less than 15ppb have been established in the United States. Ough and others found that wines grown from highly fertilized vines have more ethyl carbamate than those not fertilized (Ough et al., 1989).

Soil Cultivation (Tilling)

Tilling involves breaking up of the top layer of the soil and incorporates any cover crop back into the ground. Cover crops can be competitive for nutrients and water with grapevines and result in musts lacking in sufficient nutrients to support a normal fermentation (van Huyssteen, 1989). Van Huyssteen and others reported problems with stuck fermentations in three consecutive years in the un-tilled lots of a South African viticulture trial investigating the impact of soil management and fertilization on grape composition and wine quality (van Huyssteen, 1989). Tilling eliminates competition and the incorporation of any nitrogenous material from the cover crop as it decomposes can benefit the vine nutritionally. Cultivating also increases water availability by permitting easier passage of moisture through the soil. This also impacts the availability of supplemental nitrogen, which is only

available to the plant in the presence of water. It is thought that soil management affects wine quality through its effects on vegetative growth.

The impact of tilling is difficult to separate from the effects of other concurrent cultural practices such as irrigation and fertilization. The literature has conflicting information regarding the impact of soil management practices in the vineyard (Farnham et al., 1989) (Howe and Vasconcelos, 2000) (van Huyssteen, 1989). Soil type and cover crop species also impact the effect tilling by affecting the rate and extent of mineralization of available nutrients (van Huyssteen, 1989). When tilled under, the various species of cover crops contain different levels of nutrients that interact with microorganisms in the soil and soil conditions to mineralize and become available to the plants at different rates.

Vinification Effects

The winemaking parameters of fermenter size and cellar management have a large impact on the final quality of wines (Ewart and Sitters, 1991) (Gomez et al., 1994) (Gao et al., 1997) (Clark, 1998). Fermenter dimensions impact wine style: lower ratios of height to surface area allow more skin contact with liquid and enhance uniform redistribution of the skins following pumpovers (Clark, 1998). Research winemaking is often done on a much smaller scale than commercial wine making efforts (Bertuccioli and Rosi, 1990) (Ewart and Sitters, 1991). Ewart and Sitters

found no significant difference in 'wine quality' as determined by wine scoring and preference tests for wines made in 20L fermentations to those done in large scale, 4500L, for red wine (Ewart and Sitters, 1991). Girard and others evaluated the impact that vinification practices, such as heat treatment of the must, have an impact on aroma, flavor and color characteristics of Pinot noir (Girard et al., 1997). High levels of bisulfite additions and the fermentation of unclarified musts were found to increase levels of sulfur compounds found in wines. Fermentation temperature (18° C) was found to be important, with lower temperatures limiting the formation of some volatile sulfur compounds (Karagiannis and Lanaridis, 1999).

OFF FLAVORS IN WINE

Cork Taint

Corks have been used for centuries as closures on wine storage vessels. Made from the tree *Quercus suber,* cork stoppers have unique physical properties including enduring flexibility, hydrophobicity and gas impermeability. Problems involving corks are responsible for the spoilage of large quantities of wine worldwide. 2,4,6-trichloroanisole (earthy/musty aroma), in addition to several other compounds, have been reported to be the primary compounds responsible for the characteristic cork taint of wines (Fischer and Fischer, 1997). This compound is formed when

hydrocarbon precursors in the cork tree react with the chlorine used to sterilize corks before use. Wines with sub threshold levels of 2,4,6-trichloroanisole are reported to have low fruit intensity (Fischer and Fischer, 1997). In Australia, estimates range that 2-5.5% of Australian wines exhibit cork taint.

Sulfur Compounds

Elemental sulfur is often used as a fungicide in the vineyard. *Saccharomyces cervisiae* wine yeast liberate hydrogen sulfide and other reduced sulfur compounds from a variety of inorganic precursors (Hallinan et al., 1999). Elemental sulfur residues of 3 to 5 mg/L have been found sufficient to release a sulfurous off-odor (Rauhut and Kurbel, 1994). In young wines with a sulfurous off flavor, Rauhut and others found sulfur compounds such as hydrogen sulfide, methyl mercaptan, ethyl mercaptan, dimethyl disulfide, methylethyl disulfide and diethyl sulfide (Rauhut and Kurbel, 1994). These compounds are characterized by extremely low sensory thresholds and aroma descriptors ranging from burnt match to cabbage, sewer gas, etc.

The formation of sulfur compounds is dependent on yeast strain and fermentation conditions. This variability in production of hydrogen sulfide of different strains of *Saccharomyces cerevisae* is greatest when the fermentation medium has marginal assimilable nitrogen contents (Spiropoulos et al., 2000). Starvation for nitrogen

under model winemaking conditions has been shown to cause wine yeast to liberate hydrogen sulfide (Jiranek et al., 1995). Both sulfate and sulfite can be reduced to form hydrogen sulfide (Giudici and Kunkee, 1994). There was no simple correlation between the amount of hydrogen sulfide formed and total nitrogen content, fermentation rate, or time of formation during fermentation (Spiropoulos et al., 2000).

III: DESCRIPTIVE ANALYSIS OF 1999 VINTAGE PINOT NOIR WINES AS EFFECTED BY IRRIGATION, TILLAGE AND NITROGEN SUPPLEMENTATION IN THE VINEYARD BY AN OREGON WINEMAKER DESCRIPTIVE ANALYSIS PANEL

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CONTRIBUTION OF AUTHORS

Carmo Vasconcelos and Jessica Howe designed and executed the fieldwork for this experiment. Statistical consultation for this project was provided by Alix Gitelman, Jan-Shiang Taur and Siwei Jia of the Department of Statistics at Oregon State University. Thanks to Kelly Helms for collecting the color data on the new wines. Dr. Michael Qian was involved in the flavor chemistry extraction, analysis and interpretation. All wines were produced under the direction of Barney Watson in the OSU experimental winery. Barney Watson also helped with the interpretation of the data.

ABSTRACT:

A panel of 16 winemakers performed descriptive analysis on thirty-five wine samples from a viticulture research trial evaluating the effects of nitrogen fertilization, tilling and irrigation on Pinot noir grapes grown in the Southern Willamette Valley appellation, Oregon. Wines were processed at the pilot winery at Oregon State University. Data were collected using a modified version of the descriptive analysis technique free-choice profiling. Wines were evaluated for 15 pre-determined aroma, flavor and mouthfeel descriptors plus additional descriptors generated by individual panelists. Analysis of Variance and multivariate mapping techniques including Principal Components Analysis and Generalized Procrustes analysis were used to analyze the data. Tilling was the only main effect to significantly impact descriptors outside of interactions. Tilled treatments were found to have significantly higher fruity flavor and body scores than non-tilled treatments. Significant irrigation*tillage*fertilization interactions were seen for the descriptors spicy flavor, vegetative flavor and acidity. Irrigation reduced wine color intensity, with irrigated treatments having lower color intensity and purple hue than dry treatments.

INTRODUCTION:

A survey of the amino acid composition of wine grapes grown in the Pacific Northwest found that 90% of the samples surveyed had a yeast assimilable nitrogen content (YANC) less than 400 mg/l and 39% had less than 150 mg/l (Spayd and Andersen-Bagge, 1996). YANC is the sum of all the nitrogen sources which yeast can utilize – ammonia and α-amino acids. YANC of 140 mg/L has been cited as required for musts with low solids content and normal sugar concentrations (Kunkee, 1991) (Butzke, 1998) (Watson et al., 2000a). Nitrogen deficiencies can limit yeast growth, lead to stuck or sluggish fermentations and result in the release of hydrogen sulfide (Spayd and Andersen-Bagge, 1996) (Hallinan et al., 1999) (Kunkee, 1991).

This is the final component of a collaborative study investigating how the cultural practices of irrigation, tilling, and nitrogen fertilization impact fruit quality, fermentation behavior and wine quality of Pinot noir. There were three main viticultural effects of interest: irrigation, tilling and fertilization. Irrigation had 2 levels: irrigated or not irrigated (referred to as Dry here). Tilling had 2 levels: tilled in alternate rows or not tilled. Fertilization had 3 levels: no fertilization, foliar fertilization and soil applied fertilization. The study was a 3x2x2 factorial design of Nitrogen (none, foliar applied, soil applied), Irrigation (dry or irrigated) and Tilling

(alternate in-row tilling, not tilled). This design yields 12 treatment combinations (3.1). Appendix 1 is a cross reference with treatment codes and field lot numbers. These twelve treatment combinations were laid out in five field blocks in a complete randomized block design. See (Howe and Vasconcelos, 2000) (Howe and Vasconcelos, 2001) for a discussion of the horticultural aspects of this study. The enological aspects of this study are discussed in (Watson et al., 2000b) (Watson, 2001).

Winemaker panels have historically been used with success at Oregon State University for the descriptive evaluation of wines produced in experimental trials (Goldberg, 1998). Subjects were recruited who produce Pinot noir wines in the Pacific Northwest, so they were familiar with the range of aromas and flavors typical of the product. Free-choice profiling as a data collection technique coupled with Generalized Procrustes analysis does not require panelists to have a common understanding of descriptors, and panelists are welcome to use their own vocabulary to describe product differences. These features expedite data collection by eliminating the need for lengthy training and consensus building.

MATERIALS & METHODS:

Samples

Grapes were grown at Benton Lane vineyard in the Southern Willamette Valley appellation in Oregon. Pinot noir clone FPMS 2A vines grafted on Teleki 5C rootstocks that were 7-years-old at the start of this project were used (Howe and Vasconcelos, 2000). The irrigated treatment involved water applied at the rate of 0.5gal/hour for four hours daily for a total of 200 hours during veraison only. In row tilling occurred May 24, 1999 and involved cultivating alternate rows. Fertilizer was applied either to the soil or foliarly: soil applied nitrogen was applied manually on May 4 at the rate of 39 Kg urea/ha. Foliar N was split into two applications of 1.5 kg/ha applied by spraying on the leaves. Grapes were harvested October 22, 1999.

Wines for this project were produced in the pilot winery at Oregon State University in Corvallis, Oregon. Wines were made from 3 field replications of the 12 treatment combinations (Table 3.1). 36 lots of wine were produced. One of the lots was lost during processing; this was field lot # 25, an I NT FN sample. Appendix 1 lists the treatments and field lot numbers used for tracking in the viticulture and winemaking trials. The D NT 0N wines were considered the control because this is

Table 3.1: 12 Treatment combinations from the 3x2x2 factorial design of irrigation, tilling and nitrogen main effects for 1999 vintage Pinot noir wines.

	Irrigated		Dry (Not Irrigated)	
	Tilled	**Not Tilled**	**Tilled**	**Not tilled**
Zero Nitrogen	**I T 0N**	**I NT ON**	**D T 0N**	**D NT 0N**
Foliar Nitrogen	**I T FN**	**I NT FN**	**D T FN**	**D NT FN**
Soil Nitrogen	**I T SN**	**I NT SN**	**D T SN**	**D NT SN**

how the vineyard block was managed prior to the start of this viticultural trial. Wines were approximately 15 months old at the time of the descriptive panels.

Subjects

Letters were sent to wineries in the Pacific Northwest inviting winemakers to participate in the panel. Sixteen winemakers with experience producing Pinot noir participated in the descriptive analysis of the wines. Three panelists were female and 13 were male. All subjects had prior experience with the formal evaluation of wines. Many had been involved in similar tastings to evaluate experimental wines from other Oregon State University wine trials.

Training

Training occurred on the morning of the first day of testing. Subjects were presented with three wines specifically selected for differences in sensory properties. Wines used during training were chosen based on preliminary instrumental data and informal bench testing. The training session included wines from the treatments D T SN, I T SN and D NT 0N, from field lots 47, 29 and 24 respectively (appendix 1). The choice of which field block to use was based on availability. Training focused on scale use and determination of additional descriptors for use on the panelist ballots.

Panelists were introduced to the 16-point intensity scale, which is anchored by 0 (no perceived intensity) to 15 (as intense as can be perceived). Intensity standards were provided as references including:

(3) Safflower oil (2 Tablespoons, Saffola Quality Foods, Los Angeles, CA)
(7) Hi-C Orange drink (1Tablespoon + 1 teaspoon, Coca Cola Co., Houston, TX)
(11) Welches' grape juice (1Tablespoon + 1 teaspoon, Welches Foods Inc., MA)
(15) Big Red Cinnamon gum (1 stick unwrapped, Wm. Wrigley Jr. Co., Chicago, IL)

The ballot used for this evaluation can be found in Appendix 2. During training, panelists were encouraged to develop individual descriptors to supplement the 15 pre-determined descriptors. In general, these terms were more specific (i.e. cherry or black currant) than the very broad pre-determined descriptors (e.g. overall fruity aroma). The number of additional descriptors ranged from 1 to 11. Table 3.2 contains a list of additional descriptors used by each panelist. Following the training session, ballots were customized for each panelist to include their individual descriptors.

Testing

Wines were evaluated seven months after bottling, approximately 15 months after crush. Panelists were seated at tables and provided with purified drinking water and receptacles for expectorating samples. Subjects received and evaluated wines in sets of six. Each panelist received the wines in a different serving order which was

Table 3.2: Additional descriptors by panelist used in addition to the 15 pre-determined descriptors for winemaker panel evaluations of 1999 vintage Pinot noir wines.

Panelist 1	Panelist 2	Panelist 3	Panelist 4	Panelist 5	Panelist 6	Panelist 7	Panelist 8
cherry	cherry	berry	cherry	cherry	cherry	cherry	vanilla
blackberry	blackberry	cherry	blackberry	plum	white pepper	raspberry	sweaty
blackpepper	cooked	citrus (fruity)	geranium	clove	cinnamon		dusty
		anise	anise	anise	dried herb		tannins
		hay	black pepper	dust	mulch		
		dust	dried fruit	cherry			
		berry	cherry	plum currant			
		cherry	blackberry	stemmy			
			anise	tannin			
			black pepper	sour			
			alcohol hot	finish linger			

Panelist 9	Panelist 10	Panelist 11	Panelist 12	Panelist 13	Panelist 14	Panelist 15	Panelist 16
black fruit	black fruit	red	black fruit	cherry	red fruit	black fl	black fruit
red fruit	red fruit	black		berry	black fruit	red fl	red fruit
sweet spice	green bean	exotic		pepper	red fruit fl		citrus
stem	mulchy	vanilla		pie	black fruit fl		rose petal
rubbery	finish	stemy		stem	hot alcoholic		pepper
stem fl		hot alcoholic		herbal	length		straw
		length		finish			alcohol
							length

reflected on their ballots. Panelists received a new ballot with each set of six wines. On the first day of testing, panelists evaluated three sets of six wines each. On the second day, panelists evaluated three sets of six and one set of four wines.

Serving Design

Each panelist evaluated the complete set of wines (n=35) plus an additional 5 samples, which were included in duplicate to facilitate evaluation of panelist performance. A balanced incomplete block serving design which would permit panelist replication was not an option because Procrustes analysis requires that all panelists see the same sample set (Gower, 1975). A limited quantity of product and logistical constraints prevented use of a completely randomized serving design. All panelists were required to evaluate samples for 15 pre-determined descriptors plus the additional individual descriptors selected during training. If an additional descriptor were chosen, it had to be used to evaluate all of the samples. Likewise, no descriptors could be added after the beginning of testing.

Wines were served in clear, 8oz tulip shaped wine glasses. Samples were served at room temperature, 21-23°C (70-73° F). 30 mL of each sample was poured into each glass using 30mL automatic pourers. Samples were identified by 3-digit random numberical codes printed on small labels which were placed on the foot of the wine glass.

A dishwashing protocol was followed to ensure that no residual detergent would interfere with analysis of the wines. Labels were removed and glasses were rinsed with water before being loaded into a standard dishwashing machine (Maytag brand). Glasses were washed for a complete standard cycle using 1 teaspoon of a low odor powdered dish soap (Alconox brand). Following this, glasses were then run through an additional cycle without detergent. No rinsing agent was used. All empty wineglasses were smelled before use to ensure they were aroma free.

Color Evaluations:

Panelists evaluated wine color in a separate session on the second day of testing. Panelists rated wines for intensity of overall color, purple hue and garnet hue. Wines were approximately 15 months old at the time of this evaluation and had been in the bottle for about 7 months. Wines were also evaluated spectrometricly for overall color intensity (absorbance at 420+520 nm) and hue (absorbance at 420/520 nm).

Another color panel was run on the wines near the time of bottling by Kelly Helms (Helms, 2000). 10 untrained panelists from the department of Food Science participated. Wines were rated for overall color, purple hue and garnet hue using

the 16-point intensity scale. Testing occurred with natural sunlight as the illuminant.

Panelist Performance:

Time constraints prevented the duplicate evaluation of each wine by each panelist. Thus, panelist performance was evaluated based on a selection of five wines that were replicated during testing. The following treatments were used: D NT 0N, I T SN, D NT FN, I NT SN, I T FN. The I T SN treatment was included because it represented the extreme of receiving all experimental treatments. These samples were used to explore panelist reliability. This was done using multivariate techniques as well as a simpler method looking at the average of the absolute mean error per attribute across all attributes for each panelist.

Lighting:

During aroma and flavor evaluations, lighting in the testing room was controlled to mask color differences, which have been shown to bias experienced wine judges (Gawel, 1997). Lighting was limited to natural outdoor lighting, which was regulated in the room by selectively closing parts of the drapery. Lighting was adjusted to be sufficient for filling out the ballots but was dim enough to disguise any visual cues from differences in wine color, around 8 lux. Lighting conditions in

the room were monitored using a handheld light meter. The light meter used was a VWR model # 62344-944.

During color evaluation, the incandescent overhead lights in the room were turned on and the curtains were opened to allow a maximum of natural light into the room. Light levels were monitored for balance using the handheld light meter at different points in the room. Curtains were selectively opened and closed to adjust lighting. Light intensity was measured at different positions in the testing room during the color evaluation session. The mean light intensity was found to be 39.5 lux (SD=6.9 lux) with a range from 32.4 lux to 47.0 lux during the color evaluation session.

Statistical Analysis

Project Experimental Design

The design for this experiment was a 3x2x2 factorial of the main effects Nitrogen, Tilling and Fertilization (Table 3.1). It was set out in the field as a randomized complete block design with five field blocks (Howe and Vasconcelos, 2000). For logistical reasons, wines were only made from 3 of these field blocks. 36 field lots of grapes were harvested, representing 3 field blocks of the 12 factorial combinations of the 3 main effects. Each field lot consisted of eleven vines.

Data were entered into Excel® (Microsoft Corporation, Redmond, WA) spreadsheets for sorting purposes. Data from the 15 pre-determined descriptors were pulled aside as a subset to perform Analysis of Variance. Data were coded with indicator variables so they could be explored as 35 unique wine lots or as combinations of the main effects of irrigation, tilling and nitrogen application.

A subset of the dataset was extracted containing the five samples that were presented twice to each panelist. This was used to examine panelist performance by calculating the mean error per descriptor, averaged across all descriptors, for each panelist. This data was also used to produce a generalized Procrustes analysis plot to evaluate the panel's ability as a whole to replicate its judgments.

MANOVA:

A multivariate analysis of variance (MANOVA) was run first because of the inherently multivariate nature of sensory data. MANOVA was run using SAS software (Cary, NC). Panelist was considered a random effect. Backward selection was used to arrive at the model used. Two MANOVA models were used. The first model (table 3.3) was used for the ANOVA tables presented in appendix 3.1 – 3.15. Another MANOVA model, including session as an effect is included in table 3.4.

Table 3.3: 1999 Vintage Pinot noir wines: MANOVA of Winemaker panel data using same model used for Univariate ANOVA

Effect	p-value	sig
Intercept	0.000	c
Field Rep	0.079	
Irrigation	0.243	
Tillage	0.042	a
Fertilization	0.352	
Panelist	0.000	c
Field rep*Irrigation	0.335	
Field rep*Tillage	0.688	
Field rep*Fertilization	0.069	
Field rep*Panelist	0.238	
Irrigation*Tillage	0.094	
Irrigation*Fertilization	0.003	b
Irrigation*Panelist	0.129	
Tillage*Fertilization	0.432	
Tillage*Panelist	0.981	
Fertilization*Panelist	0.219	
Irrigation*Tillage*Fertilization	0.001	c
Irrigation*Tillage*Panelist	0.771	
Irrigation*Fertilization*Panelist	0.615	
Tillage*Fertilization*Panelist	0.804	
Irrigation*Tillage*Fertilization*Panelist	0.013	a

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Table 3.4 MANOVA with Session for 1999 Vintage Pinot noir wines evaluated by winemaker panel

Source	p-value	sig.
Intercept	0.000	c
Field Rep	0.112	
Irr	0.190	
Till	0.126	
Fert	0.628	
Pan	0.000	c
Session	0.016	a
Field Rep * Irr	0.019	a
Field Rep * Till	0.762	
Field Rep * Fert	0.041	b
Pan * Field Rep	0.364	
Irr * Till	0.370	
Irr * Fert	0.137	
Pan * Irr	0.116	
Till * Fert	0.269	
Pan * Till	0.960	
Pan * Fert	0.056	
Irr * Till * Fert	0.155	
Session * Irr * Till * Fert	0.096	
Pan * Irr * Till	0.530	
Pan * Irr * Fert	0.525	
Pan * Till * Fert	0.670	
Pan * Irr * Till * Fert	0.012	a

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

ANOVA

The fifteen pre-determined descriptors were analyzed by ANOVA with panelist treated as a random effect using SPSS v10.0 (SPSS, Inc., Chicago, IL). Significant differences among treatments were discerned using a Tukey HSD post-hoc test ($p < 0.05$). Panelists were treated as random effects (Lundahl and McDaniel, 1988). A separate univariate ANOVA was run for each descriptor. A full model was fit including all 2 and 3 way interactions. The ANOVA tables for the 15 first tier descriptors are found in appendix 3.1 – 3.15.

Multivariate Methods:

Analysis of this data set involved data reduction techniques including Principal Components Analysis and Generalized Procrustes analysis. Principal Components Analysis (PCA) was performed on SPSS software (SPSS, Inc., Chicago, IL) Generalized Procrustes analysis (GPA) was carried out using Sensetool® software created by (Compusense Inc., Guelph, Canada). This analysis makes use of the individual descriptors generated by panelists, which may or may not be used by other panelists. These spatial mapping techniques reveal the important underlying structure of a data set by reducing the amount of information.

Flavor Chemistry:

The I T SN treatment was selected for further evaluation using flavor chemistry techniques. This sample was chosen because represented the extreme of all treatment levels. Extractions were made for field lot #42 and #46, both I T SN treatments. Following extraction, GC-olfactometry was coupled with mass spectroscopy to identify key aroma active compounds in the wine extracts.

Flavor Chemistry Extraction Procedure:

An extract was prepared using solvent assisted flavor extraction. A liquid-liquid solvent extraction was performed using a 1 L separator funnel and 500 ml of wine. The solution was saturated with sodium chloride by the addition of 50g NaCl. An organic solvent composed of 50:50 pentane/diethyl ether mixture was used. The initial wash used 200 ml and 2 additional washes of 100 ml were performed. The collected organic layers were combined and saved and the wine layer was discarded. The organic layers had a distinct grape nose beyond an obvious solvent aroma.

Distillation was performed using custom glassware from BAENG (Germany). A vacuum distillation set up was prepared using a vacuum set at greater than 30 in Hg and two traps. The traps were cooled with liquid nitrogen. The organic fraction was distilled to remove impurities. The distilled fraction was removed from the apparatus and allowed to evaporate until reduced, then transferred to a sample vial and evaporation was continued until a volume of approximately 2 mL remained.

Fractionation: Neutral fraction

The distilled fractions were reduced to approximately 2ml each in the hood. Approximately 0.5 ml of 1M $NaH(CO_3)$ was added to make the acids more soluble in the aqueous layer. The pH was approximately 10. A 2:1 ratio of the pentane/diethyl ether mixture was added to each vial. Vials were well shaken to extract compounds to the organic phase. The fractions were separated using a Pasteur pipette. The acid fraction was washed 1x with the pentane/ether blend. The neutral fraction was removed and placed in a separate sample vial.

Fractionation: The acid fraction

Approximately 0.5ml of a 1M HCL solution was added to each of the remaining aqueous solutions containing the acid fractions. Approximately 2ml of the pentane/ether blend was added to each vial. Each vial was saturated with NaCl. The

vials were well mixed, and the organic layer containing the acid fraction was removed and retained in sample vials.

Gas Chromatography-Olfactometry

The wine extracts were analyzed using gas chromatography olfactometry. A Hewlitt Packard 5890 gas chromatagraph was programmed with an initial temperature of 40° C, a rate of 5°C/minute, and a final temperature of 230°C. The effluent was split and was evaluated by a subject for aroma character, intensity and the time of elution was noted. Four students and faculty from the Department of Food Science & Technology participated as subjects. The wine extracts were also run in conjunction with mass spectroscopy using an Agilent 5970 Network Mass Selective detector. This allowed identification of compounds.

RESULTS & DISCUSSION:

Other presentations of this data can be found in (Hjorth et al., 2001; Watson, 2001).

Panelist Performance:

The subset of data from the 5 samples that were replicated was extracted from the data set and several techniques were used to evaluate panelists' ability to replicate their evaluations. It was determined not to remove any panelist from the data set.

The first technique used to look at panel performance was to calculate the absolute mean error per descriptor for each panelist across the 5 replicated samples. The absolute value of the difference between scores for each descriptor was calculated for each panelist. For each panelist, this was summed up and divided by the number of descriptors used by that panelist to calculate the absolute mean error per descriptor per panelist. This is the absolute mean error (in terms of the 16-point scale) calculated across the five replicated samples. The mean error ranged from 1.16 to 2.60 points on the 16-point intensity scale. Table 3.5 shows the mean error per descriptor for the panelists. It was decided a priori that subjects with errors of more than three points on replicated scorings of the same attribute for replicated samples would be rejected from the panel. Because all panelists had at least one instance of a deviation greater than three, it was decided to look at the absolute mean error.

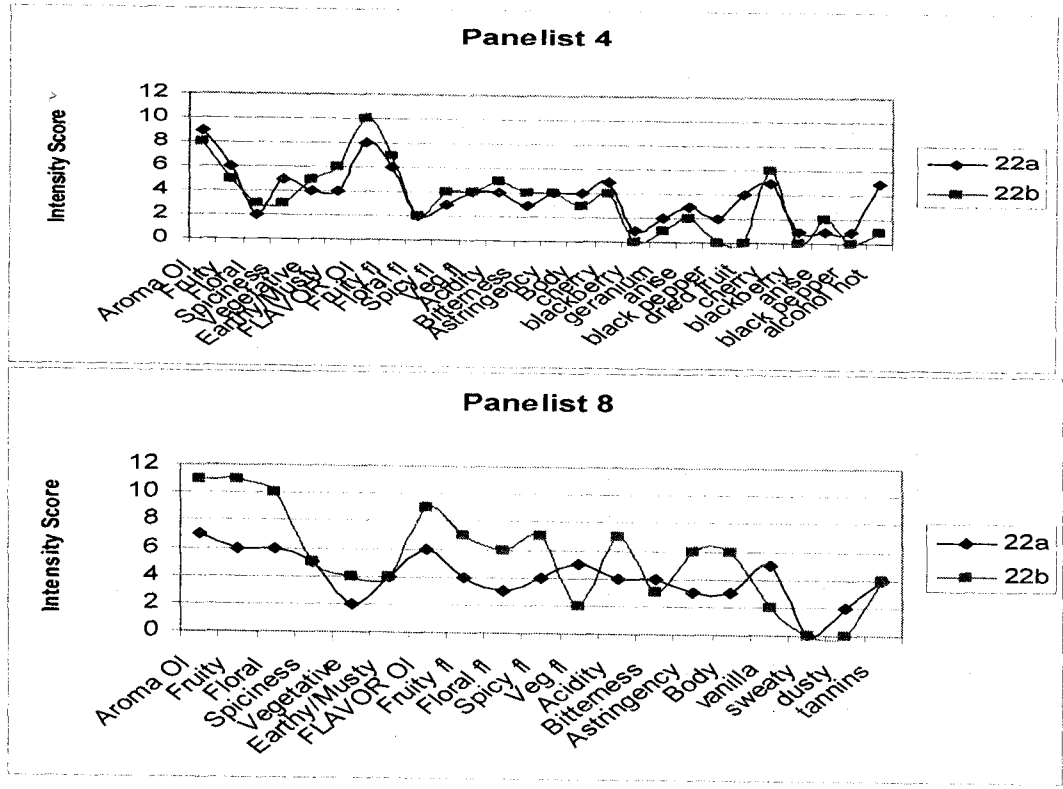
Panelist performance was also assessed graphically, using line graphs. These were prepared for individual panelists comparing their scores on replicate evaluations of the same wines. An example of this technique is in figure 3.1, which compares the performance of two panelists replicating their evaluations of Field Lot # 22, an I T FN sample. These provide a visual reflection of the mean error per descriptor measure described above. The data is interpreted in a manner similar to the absolute mean error per panelist, per descriptor. The larger the deviations in scoring in

Table 3.5: Mean Error* per panelist per descriptor from 5 replication subset of data from Winemaker Panel evaluation of 1999 vintage Pinot noir wines

Panelist	Mean Error per descriptor:
12	1.16
6	1.31
4	1.38
3	1.39
9	1.53
14	1.61
15	1.62
16	1.76
13	1.76
8	1.85
10	1.90
11	1.91
7	1.99
1	2.03
2	2.14
5	2.60

*Units of mean error are the 16-point intensity scale units used to rate descriptors.
Mean error = 1.74
Variance = 0.130785

Figure 3.1: Panelist performance by line graph: comparison of panelist 4 and panelist 8 on replicated evaluation* of field lot 22, an I T FN sample



*16-point intensity scale used where 0 = (none) and 15 = (extreme).

replicated judgments, the worse the panelist performance is deemed to be. This technique is used in conjunction with multivariate methods such as panelist assessor plots and is used as an indicator technique only.

Panelist performance was also evaluated using a generalized Procrustes analysis assessor plot. No panelists were found to be significantly different from each other by ANOVA $p<0.05$ on either the first or second axis (Figure 3.2). An assessment of the ability of the panel as a whole to replicate evaluations can be made from examining the principal components analysis plot of the five replicated samples (figure 3.3). Axis 1 and 2 of this plot explain 31.5% of the total variation among the samples. The D NT 0N samples are very close together in this plot, being characterized by spice, floral, acidity, vegetative, fruit and flavor intensity. The remaining four pairs show less homology.

Outlier detection

Initial exploration of the data involved considering the samples as 35 unique entities. Data exploration began with Principal Components Analysis (PCA). Figure 3.4 contains a plot of the first two principal components, which explain 37.22% of the total variation among the samples. The first principal component is the x-axis and is anchored on the positive end by the descriptors spicy aroma & flavor, floral aroma & flavor, overall aroma & flavor intensity and fruity aroma &

Figure 3.2: Generalized Procrustes analysis panelist plot for 16 Oregon winemakers evaluating 1999 vintage Pinot noir wines. No significant differences by ANOVA $p < 0.05$.

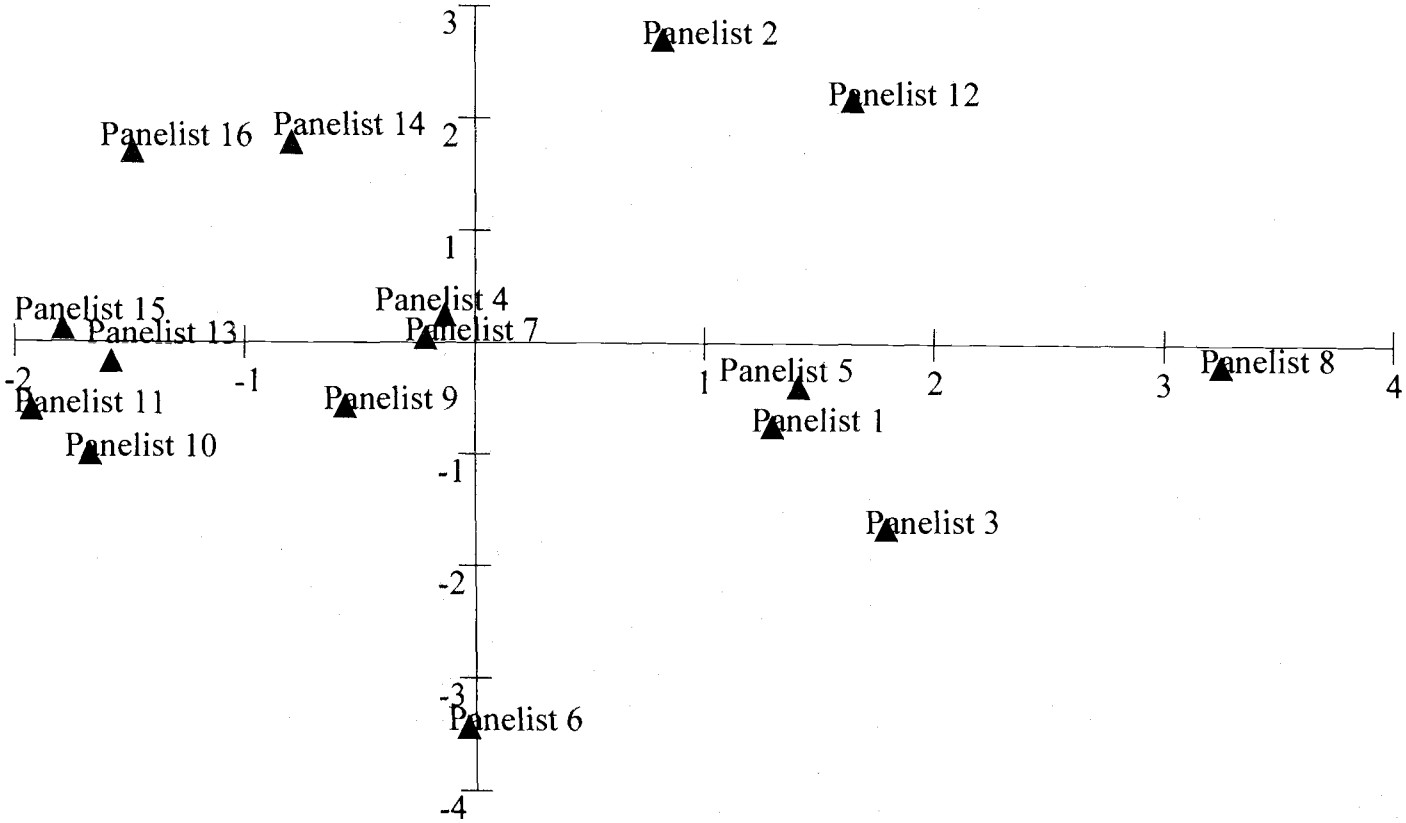


Figure 3.3: Generalized Procrustes analysis of 5 replicated samples from winemaker panel evaluation of 1999 Pinot noir wines. No significant differences on axis 1 or 2 by ANOVA ($p < 0.05$).

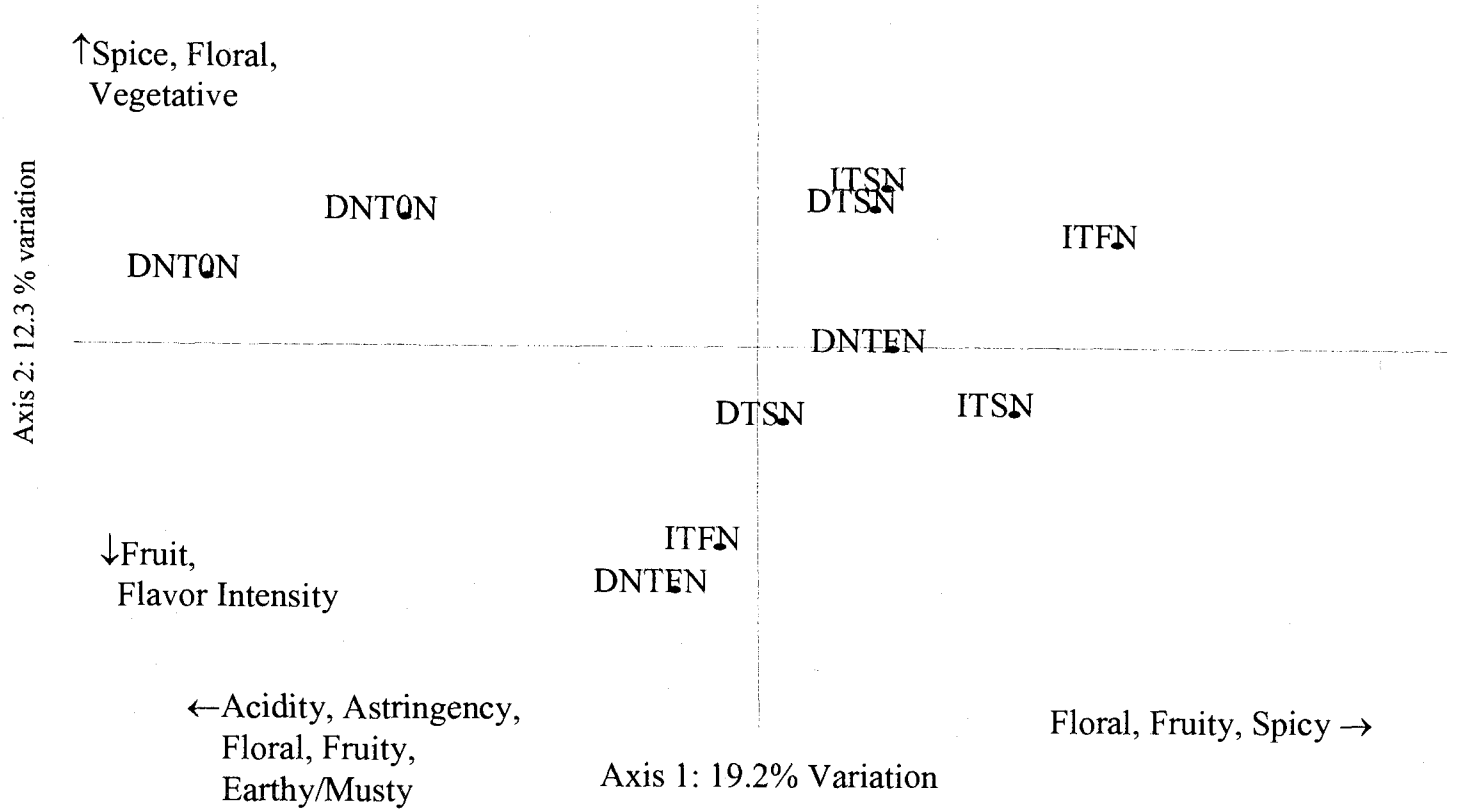
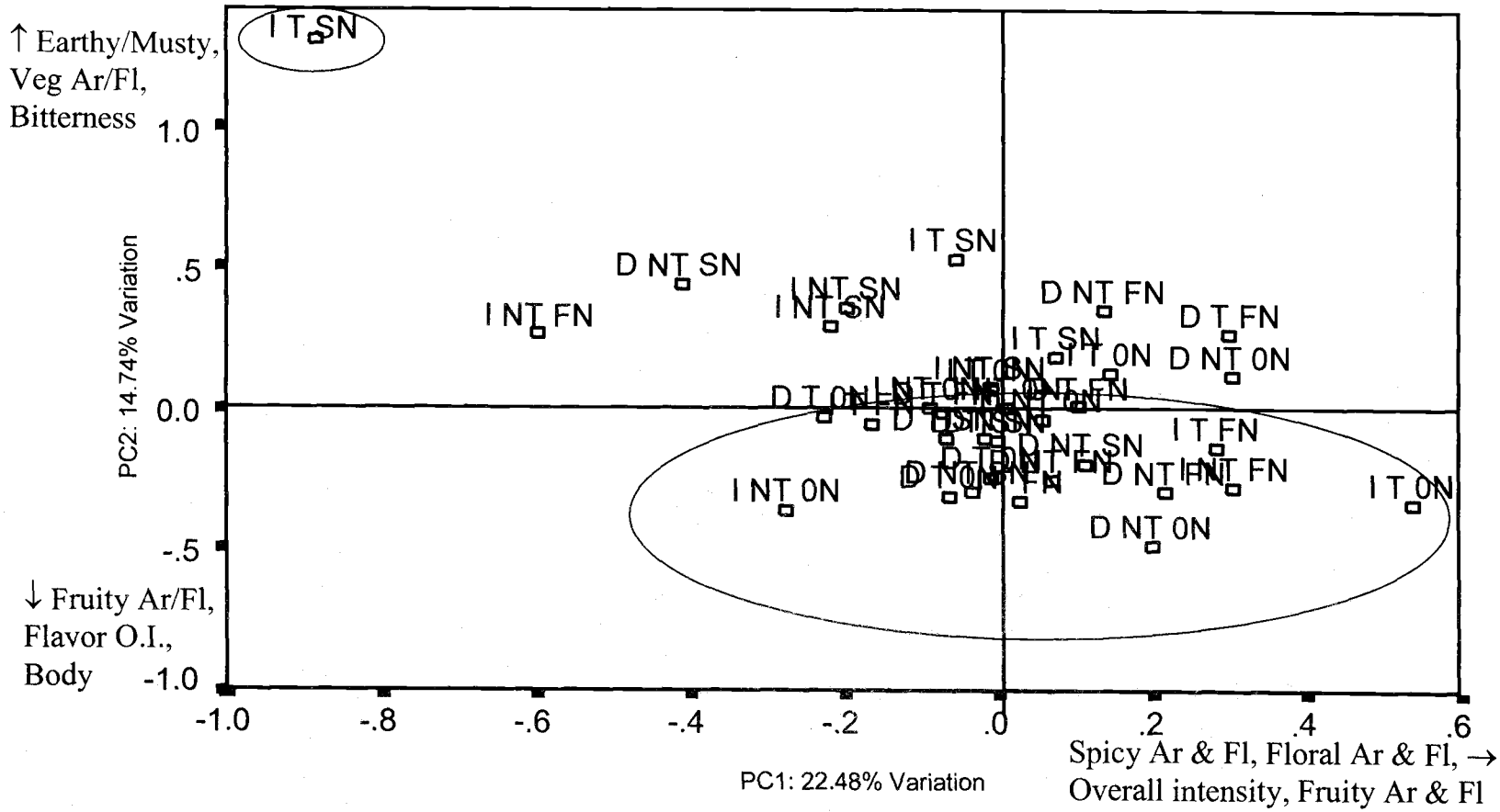


Figure 3.4: Principal Components Analysis with ITSN field lot #42 from the winemaker panel evaluation of the 1999 Pinot noir wines Samples in different circles are significantly different by ANOVA along PC2, separations by Tukey HSD at p=0.05.

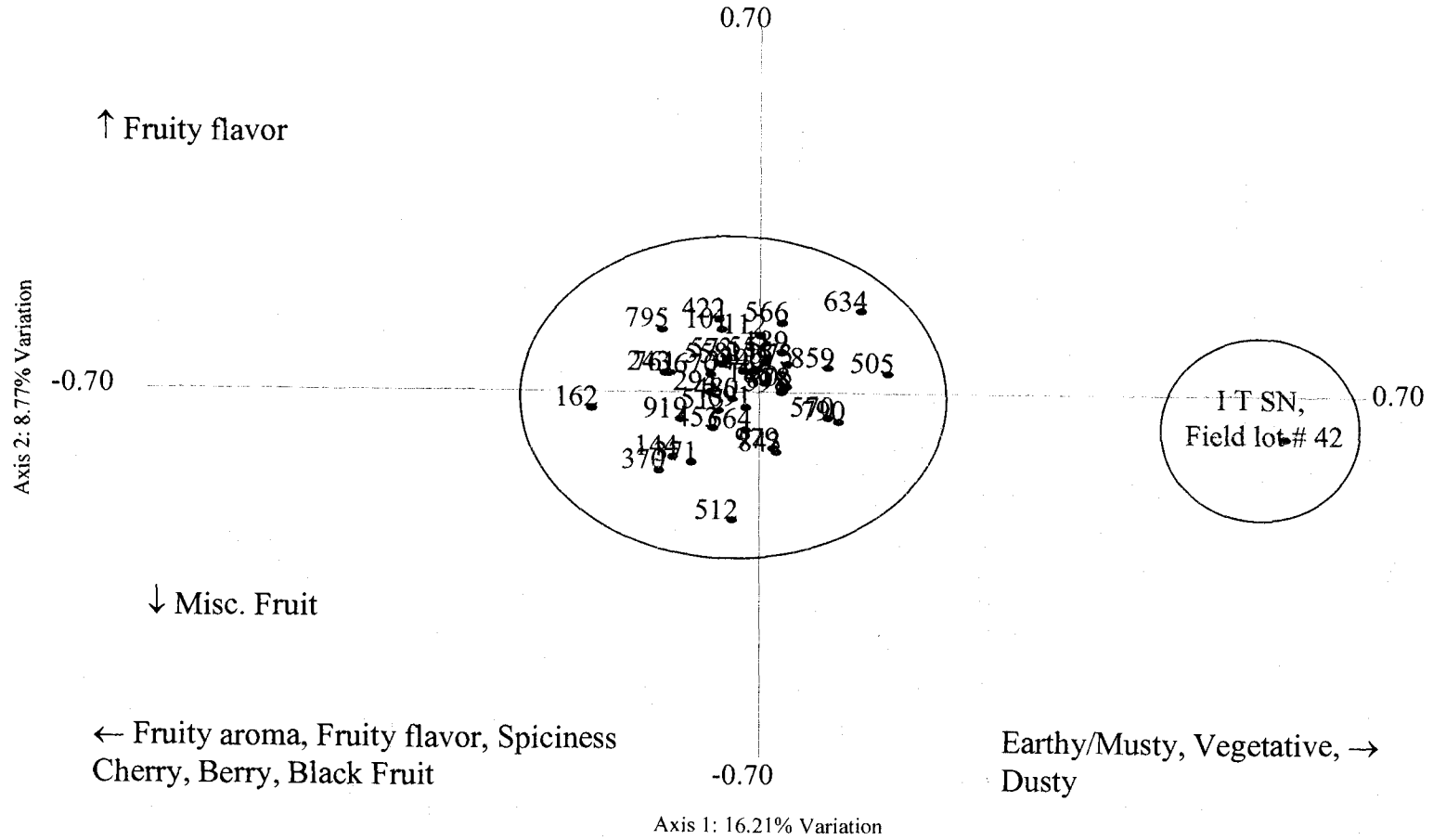


flavor. The negative end of the x-axis has no significant anchor terms. The y-axis represents the second principal component. This axis is anchored on the positive end by the descriptors earthy/musty, vegetative aroma & flavor and bitterness. The negative end of this axis is anchored by the descriptors fruity aroma & flavor, flavor overall intensity and the mouthfeel term body.

Analysis of Variance of the regression factor scores for the principal components showed that there were no significant differences between groups for the first PC ($F=1.179$, $p=0.227$), but that there were significant between group differences for the second principal component ($F=20.59$, $p= 0.000$). Tukey HSD post-hoc test was used to determine homogonous subsets. Field lot #42 (ITSN) was found to be significantly higher on the second PC than more than the majority of the other wine lots; it was characterized as having earthy/musty and vegetative character and bitter taste.

The Generalized Procrustes analysis evaluation of the samples as 35 unique wine lots showed similar results to the PCA plot (figure 3.5). The first axis describes 16.21 % of the variation among the samples and is anchored on the positive end of the axis by the descriptors earthy/musty, vegetative and dusty. Wine made from field lot 42 (ITSN) was found to be significantly higher in earthy/musty, vegetative and dusty character than the remaining 34 wine lots by analysis of variance along axis 1 (separations by Tukey's HSD at $p=0.05$).

Figure 3.5: Generalized Procrustes analysis with field lot #42, ITSN from winemaker panel evaluation of 1999 Pinot noir wines



During the winemaker panel, several panelists perceived the wine from field lot #42 to be 'corked'. Other bottles of this wine lot were opened, but all were determined to have the same character. Thus, it was decided that this was a character of the wine lot and not of a specific bottle from that lot. Based on the accumulation of evidence, the wine made from field lot# 42, an I T SN sample, was determined to be an outlier and removed from the remainder of the data analysis.

MANOVA:

Table 3.3 contains the MANOVA table that uses the same model as the univariate ANOVA results. This model shows that the irrigation * tillage * fertilization interaction is significant at $p < 0.001$. The fact that this interaction is significant is not surprising because this is the level that the experiment was applied in the vineyard. The only significant two-way interaction was for irrigation*fertilization ($p<0.003$). Tillage was found to be significant as a main effect ($p<0.042$). However, the fact that the three way interaction of irrigation * tillage * fertilization was significant suggests that the effect of tillage is not independent of irrigation and fertilization.

ANOVA:

Table 3.6 contains means and standard deviations across the twelve treatment combinations for overall aroma intensity and the aroma descriptors fruity, floral,

Table 3.6: Aroma intensity means* and standard deviation by 12 treatment combinations across 16 panelists by three field reps for the winemaker panel evaluation of 1999 vintage Pinot noir wines

		Overall Intensity	Fruity	Floral	Spicy	Vegetative	Earthy/Musty
D NT 0N	Mean	8.95	6.94	4.81	5.42	3.64	4.17
	Std. Deviation	*2.06*	*2.34*	*2.54*	*2.2*	*2.65*	*2.93*
D NT FN	Mean	9.5	7.14	4.86	5.03	4.13	4.2
	Std. Deviation	*1.96*	*2.17*	*2.58*	*2.49*	*2.87*	*3.41*
D NT SN	Mean	8.56	7	4.73	4.79	3.25	4.13
	Std. Deviation	*1.79*	*2.05*	*2.18*	*2.13*	*2.66*	*2.74*
D T 0N	Mean	8.27	6.71	4.21	4.73	3.81	3.83
	Std. Deviation	*1.91*	*1.82*	*2.27*	*2.2*	*2.46*	*2.68*
D T FN	Mean	8.73	6.79	4.62	5.06	3.85	4.71
	Std. Deviation	*1.89*	*2.15*	*2.18*	*2.37*	*2.8*	*2.75*
D T SN	Mean	8.86	7.05	4.48	4.67	3.55	3.89
	Std. Deviation	*2.02*	*2.11*	*2.33*	*2.12*	*2.51*	*2.53*
I NT 0N	Mean	8.4	6.88	4.71	4.5	3.56	4.02
	Std. Deviation	*1.8*	*1.92*	*2.29*	*2.07*	*2.45*	*2.77*
I NT FN	Mean	8.28	6.41	4.47	5.09	3.56	4.13
	Std. Deviation	*1.82*	*2.23*	*2.5*	*2.49*	*2.69*	*2.6*
I NT SN	Mean	8.81	6.79	4.04	4.88	4.1	4.44
	Std. Deviation	*1.92*	*2.19*	*2.24*	*2.2*	*2.64*	*2.88*
IT0N	Mean	8.69	6.73	4.44	5.06	4.19	4.27
	Std. Deviation	*1.61*	*1.73*	*2.46*	*2.36*	*2.89*	*3.04*
ITFN	Mean	8.48	7.02	4.59	4.77	3.58	3.81
	Std. Deviation	*1.84*	*1.87*	*2.52*	*2.19*	*2.55*	*2.85*
ITSN	Mean	8.92	6.6	4.48	4.81	4.58	4.52

* 16-point intensity scale used where 0 = (none) and 15 = (extreme).

vegetative and earthy/musty. No significant differences were noted for the pre-determined aroma descriptors for the irrigation*tilling*nitrogen by Analysis of Variance. It is important to remember that these mean scores represent scores averaged across all panelists as well as across the three vineyard replications. The irrigation*tilling*nitrogen interaction is important because this represents the level that the 12 factorial treatment combinations of irrigation, tilling and fertilization which were applied in the vineyard.

Intensity means of flavor and mouthfeel descriptors for the twelve treatment combinations are found in Table 3.7. Significant ($p<0.05$) irrigation*tilling*nitrogen interactions were found for three of the pre-determined flavor descriptors spicy flavor, vegetative flavor and acidity. For spicy flavor, the I NT 0N treatment was significantly less spicy than the I T 0N treatment. The I T SN treatment was significantly higher in vegetative flavor than I T FN and D T SN. The D NT FN treatment had the lowest acidity while the D NT 0N had the highest.

Significant differences among samples for the main effects were determined using individual univariate analysis of variance for each of the pre-determined descriptors. Means tables were also prepared for the main effects (Irrigation, Tilling and Nitrogen), averaged across all levels of other effects (Tables 3.8 and 3.9). Main effects were only considered significantly different in the absence of significant interaction terms. No aroma descriptors had significant differences across main

Table 3.7: Flavor & mouthfeel intensity means* by 12 treatment combinations across 16 panelists by three field reps for winemaker panel evaluation of 1999 Pinot noir wines.

	Overall Intensity	Fruity	Floral	Spicy	Veg	Acidity	Bitterness	Astringency	Body
D NT 0N	9.00	7.17	3.77	5.66 ^{ab}	3.91 ^{ab}	7.00 ^{c}	4.41	5.80	6.77
D NT FN	9.22	7.23	3.81	4.88 ^{ab}	3.58 ^{ab}	5.97 ^{a}	4.22	5.42	6.72
D NT SN	8.75	6.96	3.52	5.04 ^{ab}	3.92 ^{ab}	6.15 ^{ab}	3.85	5.56	6.38
D T 0N	8.75	7.48	3.73	5.00 ^{ab}	3.71 ^{ab}	6.08 ^{ab}	3.58	5.21	6.58
D T FN	9.04	6.92	3.79	5.60 ^{ab}	3.96 ^{ab}	6.50 ^{abc}	4.42	5.48	6.92
D T SN	8.89	7.38	3.39	5.33 ^{ab}	3.31 ^{a}	6.38 ^{abc}	4.05	5.89	6.94
I NT 0N	8.56	7.00	3.65	4.79 ^{a}	3.37 ^{ab}	6.27 ^{abc}	4.13	5.88	6.63
I NT FN	8.66	6.59	3.59	5.13 ^{ab}	3.56 ^{ab}	6.38 ^{abc}	3.78	5.34	6.69
I NT SN	8.56	6.42	3.60	5.02 ^{ab}	3.94 ^{ab}	6.33 ^{abc}	4.46	5.50	6.42
IT0N	9.38	7.33	3.75	5.83 ^{b}	3.96 ^{ab}	6.81 ^{bc}	4.54	5.46	7.19
ITFN	9.19	7.45	3.70	5.38 ^{ab}	3.31 ^{a}	6.48 ^{abc}	4.25	5.34	6.97
ITSN	8.77	6.90	3.69	5.19 ^{ab}	4.46 ^{b}	6.38 ^{abc}	4.56	5.65	6.83

Samples bearing different superscripts are significantly different at $p < 0.05$ by ANOVA and Tukey's HSD.

*16-point intensity scale used where 0 = (none) and 15 = (extreme).

Table 3.8: Mean aroma descriptor intensity ratings* for the main effects of nitrogen, tillage and irrigation for winemaker panel evaluation of 1999 vintage Pinot noir wines.

Nitrogen	Overall Intensity	Fruity	Floral	Spicy	Vegetative	Earthy/Musty
None	8.61	6.82	4.56	4.97	3.79	4.08
Foliar	8.82	6.91	4.66	4.97	3.81	4.19
Soil	8.79	6.87	4.44	4.78	3.85	4.22

Tillage	Overall Intensity	Fruity	Floral	Spicy	Vegetative	Earthy/Musty
Not Tilled	8.83	6.9	4.63	4.97	3.73	4.18
Tilled	8.66	6.84	4.48	4.84	3.89	4.14

Irrigation	Overall Intensity	Fruity	Floral	Spicy	Vegetative	Earthy/Musty
Dry	8.85	6.95	4.63	4.96	3.71	4.15
Irrigated	8.61	6.77	4.46	4.83	3.93	4.18

* 16-point intensity scale used where 0 = (none) and 15 = (extreme).

Table 3.9: Mean flavor and mouthfeel intensity ratings* for the main effects of nitrogen, tillage and irrigation for winemaker panel evaluation of 1999 Pinot noir wines
(*Main effects significantly different by ANOVA at $p<0.05$).

Nitrogen	Overall Intensity	Fruity	Floral	Spicy	Vegetative	Acidity	Bitterness	Astringency	Body
None	8.93	7.24	3.73	5.35	3.75	6.58	4.18	5.60	6.79
Foliar	9.08	7.13	3.74	5.24	3.58	6.31	4.21	5.40	6.84
Soil	8.75	6.95	3.54	5.16	3.86	6.31	4.22	5.67	6.66

Tillage	Overall Intensity	Fruity	Floral	Spicy	Vegetative	Acidity	Bitterness	Astringency	Body
Not Tilled	8.83	6.94	3.67	5.10	3.72	6.36	4.18	5.6	6.61
Tilled	9.01	7.26	3.66	5.38	3.74	6.44	4.23	5.52	6.91
				*					*

Irrigation	Overall Intensity	Fruity	Floral	Spicy	Vegetative	Acidity	Bitterness	Astringency	Body
Dry	8.96	7.20	3.67	5.26	3.71	6.36	4.11	5.58	6.73
Irrigated	8.88	7.00	3.67	5.24	3.75	6.45	4.31	5.53	6.80

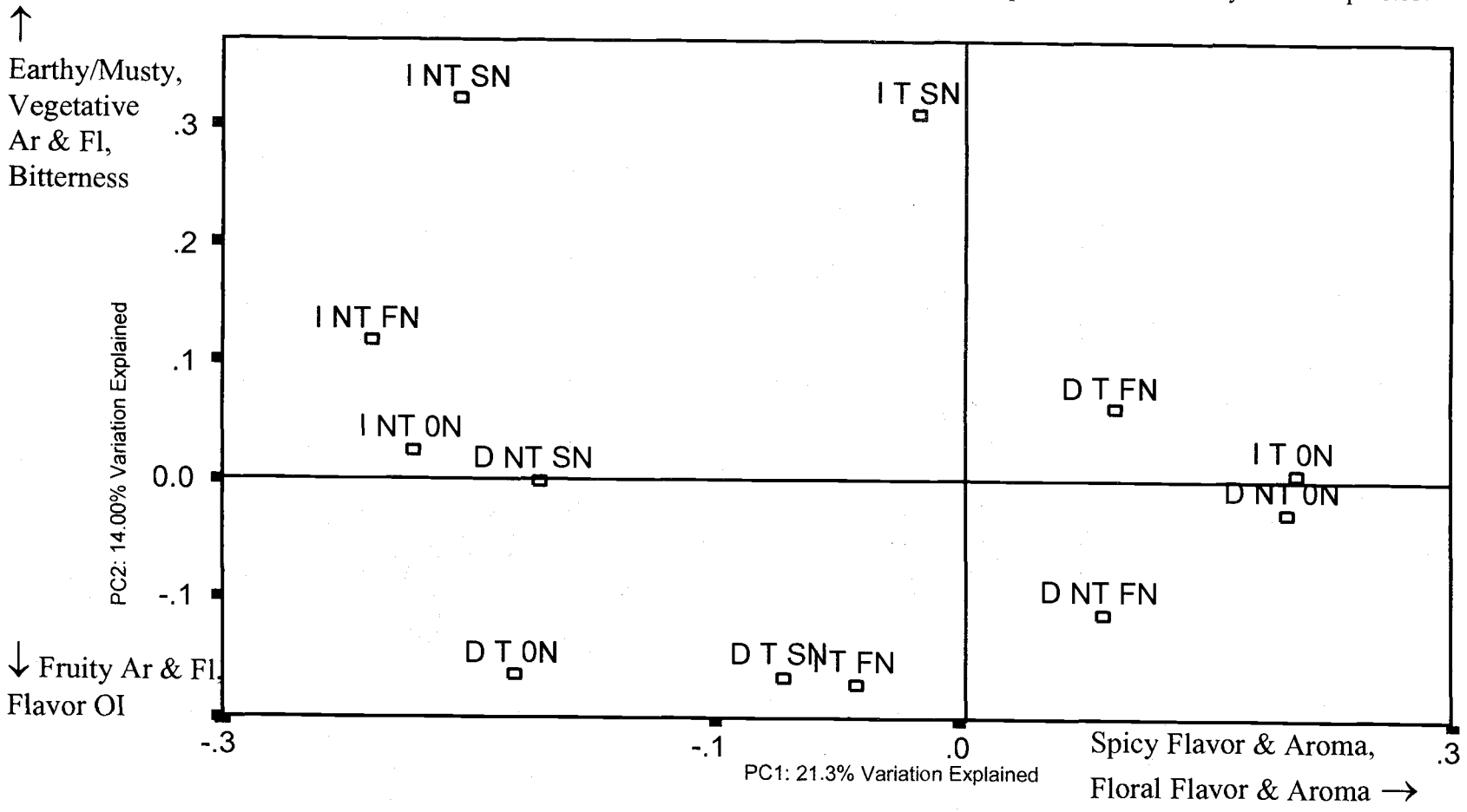
* 16-point intensity scale used where 0 = (none) and 15 = (extreme).

effects. Tilling was the only main effect to manifest differences among the samples for descriptors outside of interaction terms; it was found to increase both fruity flavor and body. Tilling was also found to be significant (in addition to a variety of interaction terms) for the descriptors vegetative aroma and spicy flavor. For both of these descriptors, the panelist effect was also significant. Appendix 3.1 – 3.15 contains the ANOVA tables for fifteen first tier descriptors.

Principal Components Analysis:

Separate principal component analyses were performed on the 15 pre-determined descriptors for the dataset treated as 35 winelots as well as on the means of the 12 treatments combinations. Figure 3.6 is the plot of principal component PC1 vs. PC2 for the 12 treatment combinations. The first 2 principal components explain 35.3% of the total variation among the samples. The positive end of the first principal component (the x-axis) is anchored with the descriptors spicy flavor & aroma and floral flavor & aroma. The positive end of the second PC (the y-axis) is anchored with the descriptors earthy/musty, vegetative aroma & flavor and bitterness. The negative end of this axis is anchored by fruity aroma & flavor and flavor overall intensity. A trend can be noted where irrigated treatments tend to be further toward the end of the second PC corresponding with more earthy/musty, vegetative and bitter character than the dry treatments. The irrigation/soil nitrogen combination stands out, with both the tilled and untilled combinations of these treatments

Figure 3.6: Principal Components analysis: PC1 vs. PC2 of 12 treatments averaged across 3 field reps from winemaker panel evaluation of 1999 Pinot noir wines (without field lot # 42, ITSN). No significant differences between samples on PC1 or PC2 by ANOVA $p < 0.05$.



together at the positive end of PC2 corresponding with earthy/musty and vegetative aroma and flavor.

The plot of PC1 vs. PC3 for the 12 treatment combinations explains 29.45% of the variation among the samples (Figure 3.7). The positive end of the first principal component (the x axis) is anchored with the descriptors spicy flavor & aroma and floral flavor & aroma. The third principal component explains 8.15% of the total variation among the samples and is anchored on the positive end by aroma & flavor overall intensity and earthy/musty aroma and on the negative end by floral flavor and acidity. The dry treatments show a trend indicating increased aroma and flavor intensity.

Generalized Procrustes Analysis:

GPA was performed treating the data as 34 unique samples as shown in Figure 3.8 (axis 1 vs. axis 2). The first axis is anchored on the positive end by the descriptors fruity, spicy and acidity, and on the negative end by vegetative, earthy/musty, and astringency. The second axis is anchored by bitterness, vegetative, earthy/musty and dust descriptors on the positive end and plum on the negative end.

GPA was also preformed averaging the 12 treatment combinations over the three blocks. These are shown in Figure 3.9 (axis 1 vs. axis 2) and Figure 3.10 (axis 1 vs.

Figure 3.7: Principal components analysis: PC1 vs. PC3 from winemaker panel evaluation of 1999 Pinot noir wines (without field lot # 42) No significant differences between samples on PC1 or PC3 by ANOVA $p < 0.05$.

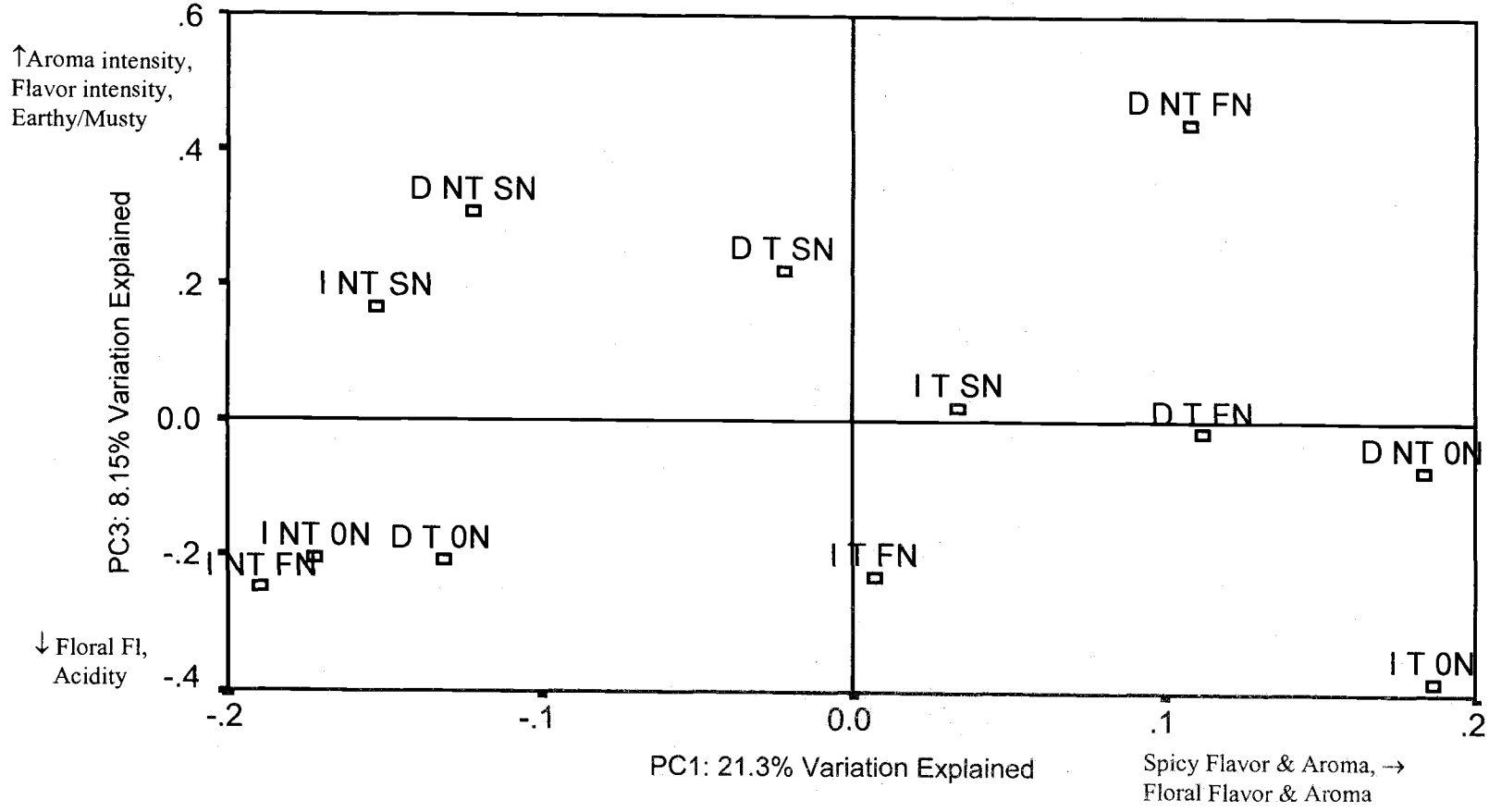


Figure 3.8: Generalized Procrustes analysis of 34 wine lots (without #42) from winemaker panel evaluation of 1999 Pinot noir wines. No significant differences between samples on axis1 or axis2 by ANOVA $p < 0.05$.

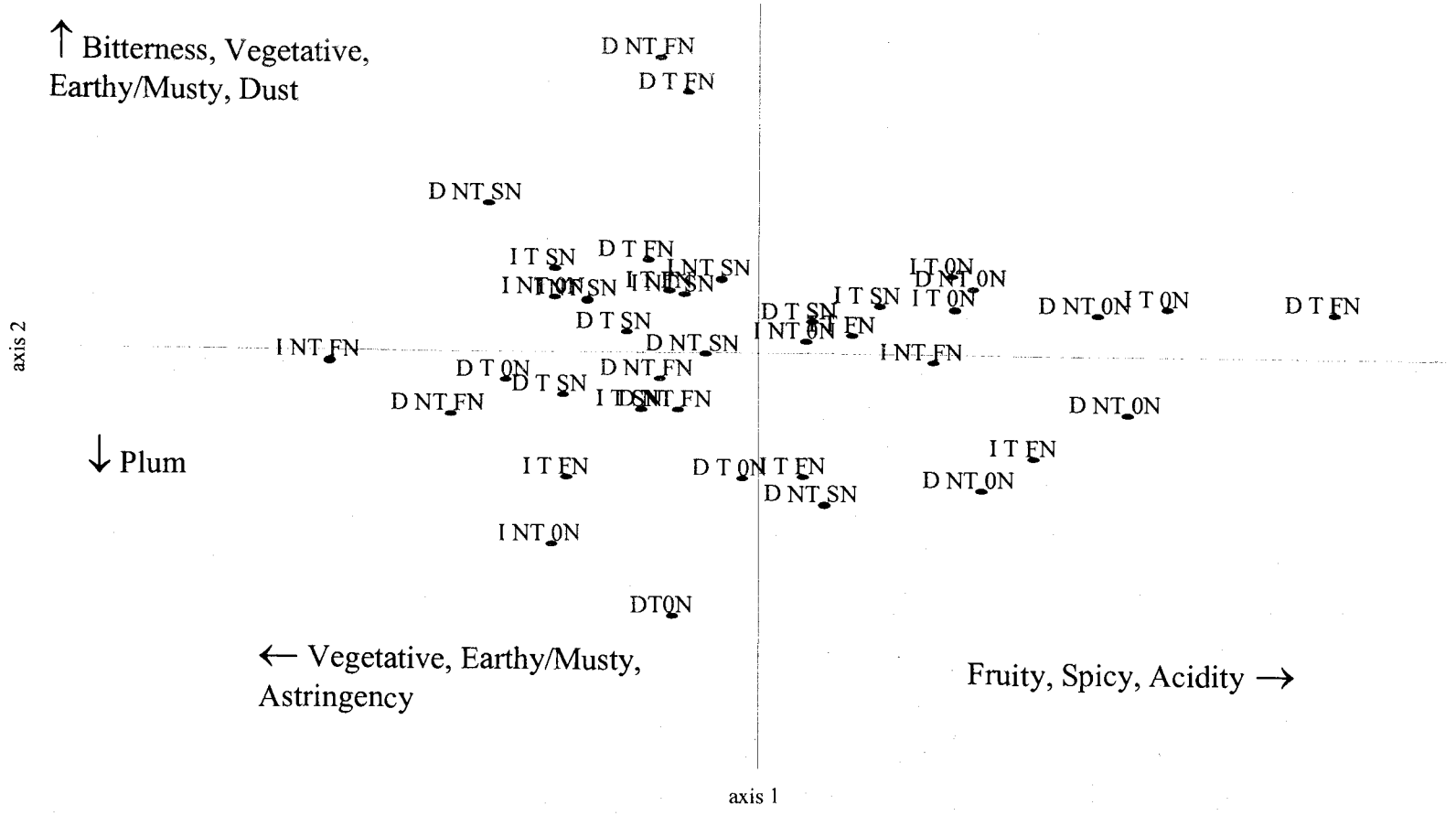


Figure 3.9: Generalized Procrustes analysis of 12 treatment combinations averaged across three field replications from winemaker panel evaluation of 1999 Pinot noir wines No significant differences between samples on axis1 or axis2 by ANOVA $p < 0.05$.

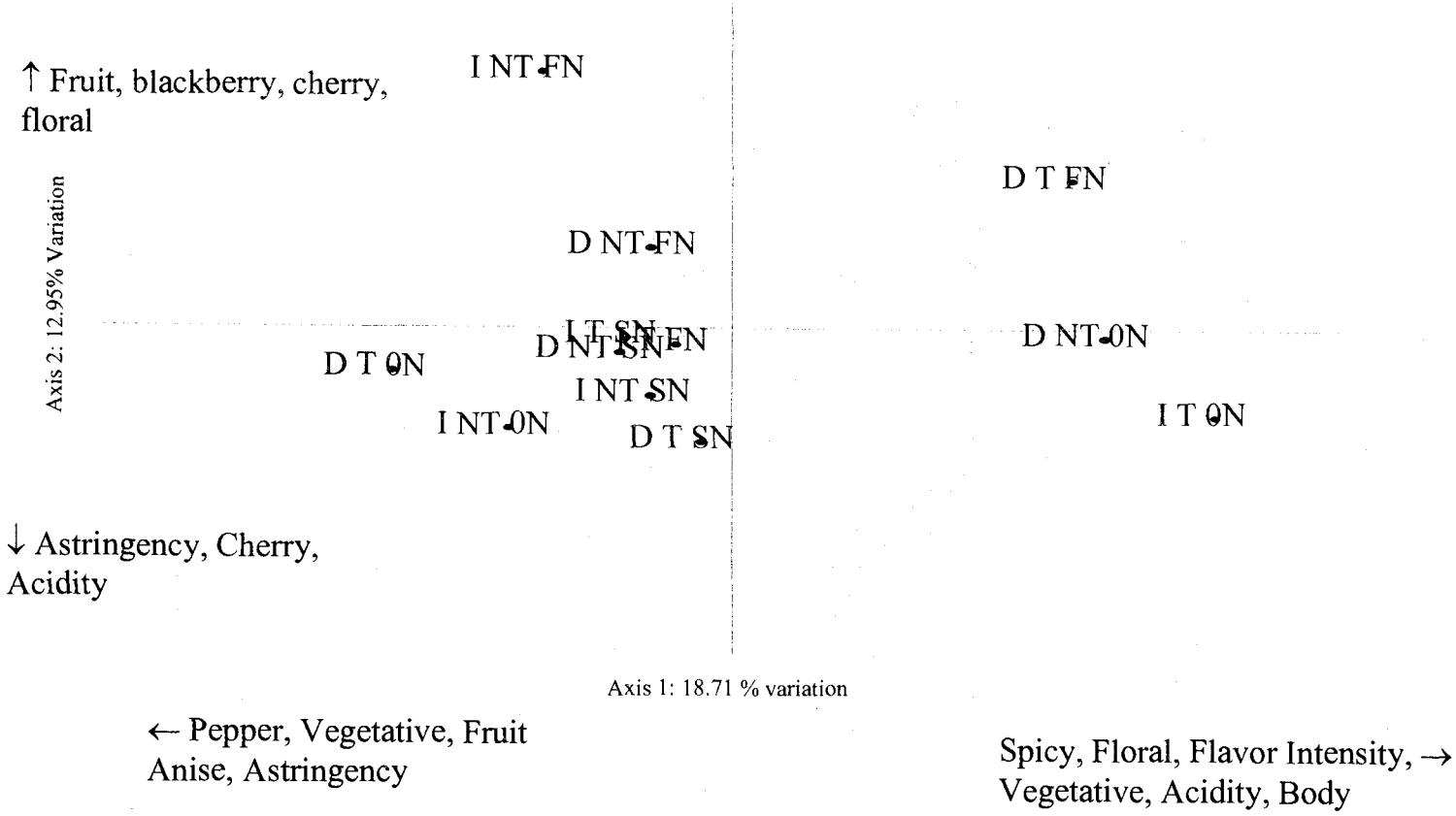
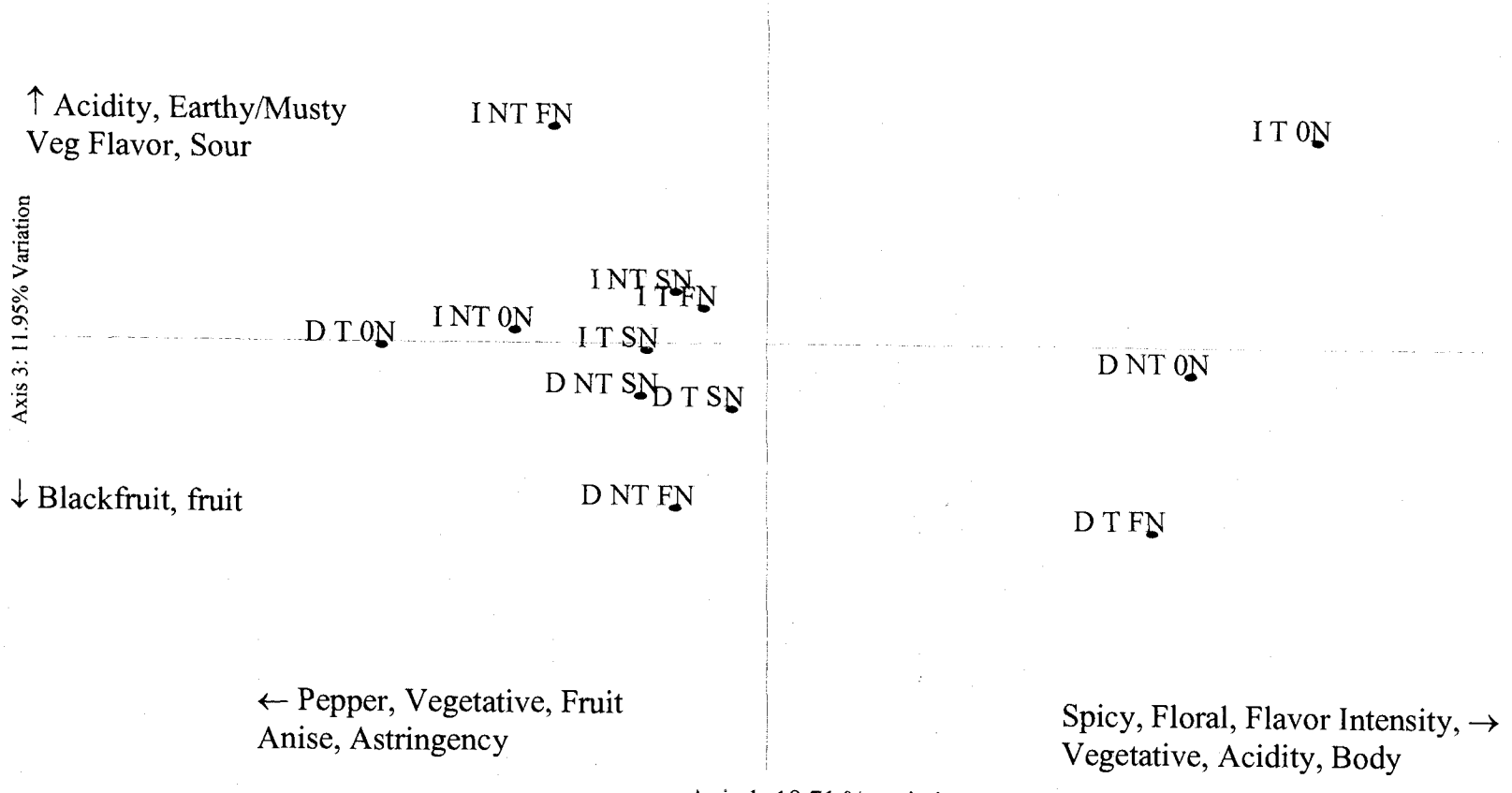


Figure 3.10: Generalized Procrustes analysis of 12 treatment combinations averaged across three field replications from winemaker panel evaluation of 1999 Pinot noir wines: Axis 1 vs. Axis 3 No significant differences between samples on axis 1 or axis3 by ANOVA $p < 0.05$.



axis 3). The first axis accounts for 18.71% of the variation among samples and is anchored on the positive end by the descriptors spicy, floral, flavor intensity, vegetative, acidity and body. The descriptors pepper, vegetative, fruit, anise, and astringency anchor the negative end of the first axis. The second axis explains 12.95% of the variation among samples and is anchored by the descriptors fruit, blackberry, cherry and floral on the positive end and astringency, cherry and acidity on the negative end. The third axis explains11.95% of the variation among samples and is anchored by acidity, earthy/musty, vegetative flavor and sour on the positive end and the descriptors blackfruit and fruit on the negative end. I T 0N stands out as being farthest along axis 1, associated with spicy, floral, flavor intensity, vegetative, acidity and body. This treatment also had the highest mean spicy panel rating.

Color Evaluations:

Tables 3.10 and 3.11 show the means across panelists for the three pre-determined descriptors for the twelve treatment combinations and main effects respectively. Panelist attrition was a problem during this segment of testing, resulting in an unbalanced data set. Thus, analysis of variance data is not presented here. A trend can be noted where irrigated treatments tend to be lower in color intensity than dry treatments. Dry treatments also tended to be higher in Purple hue.

Table 3.10: Color means* by 12 treatment combinations of irrigation, nitrogen and tillage across 16 panelists by three field reps from winemaker panel evaluation of 1999 Pinot noir wines.

12 Treatment Combinations

Field treatment	Overall color intensity	Purple hue	Garnet hue
D NT 0N	9.61	7.25	6.21
D T 0N	8.55	6.24	6.44
D NT FN	6.34	6.52	6.52
D T FN	9.07	6.59	6.59
D NT SN	8.90	6.50	6.76
D T SN	10.73	8.59	6.61
I NT 0N	8.50	6.17	6.47
I T 0N	8.72	6.10	6.42
I T FN	8.84	6.44	6.67
I NT FN	9.00	5.79	6.21
I NT SN	9.50	8.20	7.40
I T SN	9.42	8.00	6.50

* 16-point intensity scale used where 0 = (none) and 15 = (extreme).

Table 3.11: Color means* by main effects of irrigation, nitrogen and tillage across 16 panelists by three field reps from winemaker panel evaluation of 1999 Pinot noir wines.

Irrigation Main Effect

Treatment	Overall color intensity	Purple hue	Garnet hue
Dry	9.02	6.68	6.48
Irrigated	8.74	6.34	6.49

Nitrogen Main Effect

Treatment	Overall color intensity	Purple hue	Garnet hue
No Nitrogen	8.75	6.50	6.25
Foliar Nitrogen	8.61	6.29	6.56
Soil Nitrogen	9.63	7.21	6.62

Tillage Main Effect

Treatment	Overall color intensity	Purple hue	Garnet hue
Tilled	9.01	6.73	6.46
Not Tilled	9.03	6.64	6.50

* 16-point intensity scale used where 0 = (none) and 15 = (extreme).

Research gathered by Helms on this vintage of wines at the time of bottling is in keeping with the trends noted above (Helms, 2000). A summary of these findings is in Table 3.12. Significant differences were seen among the twelve treatment combinations. In general, irrigated treatments had lower color intensity and purple hue than dry treatments. No general trend was noted for garnet hue. The D T SN treatment stands out as higher in both color intensity and purple hue than all of the other treatment combinations. New wine analysis found that dry treatments had significantly higher anthocyanins than irrigated treatments (Watson et al., 2000b). Tilling seemed to make almost no difference for color intensity with mean scores of 8.76 vs. 8.77 on the 16-point intensity scale for tilled and non-tilled respectively. The impact of irrigation was a little more pronounced for color intensity with mean scores of 9.44 for non-irrigated treatments and 8.05 for irrigated treatments. This may be related to the significant difference in berry weight noted in this vintage, where irrigated berries were found to be significantly heavier than dry berries (Howe and Vasconcelos, 2000).

Flavor Chemistry:

Compounds were evaluated by GC-olfactometry repeatedly to characterize the aroma character of peaks eluting at different times. GC-olfactometry was coupled with Mass Spectroscopy and several of the aroma active peaks were identified. These included peaks identified by prior researchers (Miranda-Lopez, 1990;

Table 3.12: Summary of 1999 vintage Pinot noir wine color information from new wine at the time of bottling, mean* values across 10 panelists.

	Color Intensity	Purple Hue	Garnet Hue
I T 0N	7.44 [a]	6.95 [ab]	7.45
I T SN	8.83 [bcd]	8.35 [bcd]	8.17
I T FN	7.10 [a]	6.83 [ab]	7.39
I NT 0N	8.17 [abc]	7.45 [abc]	7.85
I NT SN	9.20 [cd]	8.72 [cd]	8.20
I NT FN	7.27 [ab]	6.73 [a]	7.50
DT 0N	7.24 [a]	6.76 [a]	7.50
DT SN	12.32 [e]	11.73 [e]	8.55
DT FN	9.53 [cd]	8.67 [cd]	8.27
DNT 0N	8.38 [abcd]	8.28 [abcd]	7.40
DNT SN	9.17 [cd]	8.69 [cd]	7.88
DNT FN	9.95 [d]	9.27 [d]	7.86

	Color Intensity	Purple Hue	Garnet Hue
Till	8.76	8.23	7.89
No Till	8.77	8.27	7.8

	Color Intensity	Purple Hue	Garnet Hue
0 Nitrogen	7.81	7.37	7.55
Foliar N	8.57	7.98	7.78
Soil N	9.88	9.38	8.2

	Color Intensity	Purple Hue	Garnet Hue
No Irrigation	9.44	8.91	7.91
Irrigation	8.05	7.55	7.78

* 16-point intensity scale used where 0 = (none) and 15 = (extreme).

[abc] Treatments bearing different superscripts are significantly different by ANOVA at $p<0.05$.

Miranda-Lopez et al., 1992b). An example of GC-olfactometry run on the Agilent 5790 instrument is included in figure 3.11. The aroma characterizations are based on a combination of several subjects' descriptors. Table 3.13 lists compounds identified as present in the wine extracts. Further analysis would be required to ascertain the importance of these compounds at their relative concentrations in wine. Some compounds identified have been shown by prior investigations to be important contributors to the aroma and flavor profile of wines (McDaniel et al., 1987; Miranda-Lopez et al., 1992a; Miranda-Lopez et al., 1992b). One example is diacetyl, a compound with a buttery aroma that was found to be important in wines fermented with malolactic bacteria (McDaniel et al., 1987).

CHAPTER SUMMARY:

Tilling was the only main effect to significantly impact wine ratings outside of interaction terms. Tilling was also found to be the most influential factor in the field and laboratory analysis of these grapes (Howe and Vasconcelos, 2000), (Watson et al., 2000b). Howe found that tilling reduced the Ravaz index in this vintage. Both tilled and untilled treatments had low Ravaz indexes, 2.32 for tilled versus 2.68 for non-tilled treatments.

Ravaz index is a yield/pruning ratio. A Ravaz index between 4 and 6 is considered ideal for Pinot noir in Oregon. A Ravaz index above 6 indicates a situation where vines may not be able to ripen fruit while indexes below 4 indicate excessive

Figure 3.11: Chromatogram from Gas Chromatography-olfactometry for ITSN wine extract from 1999 vintage.

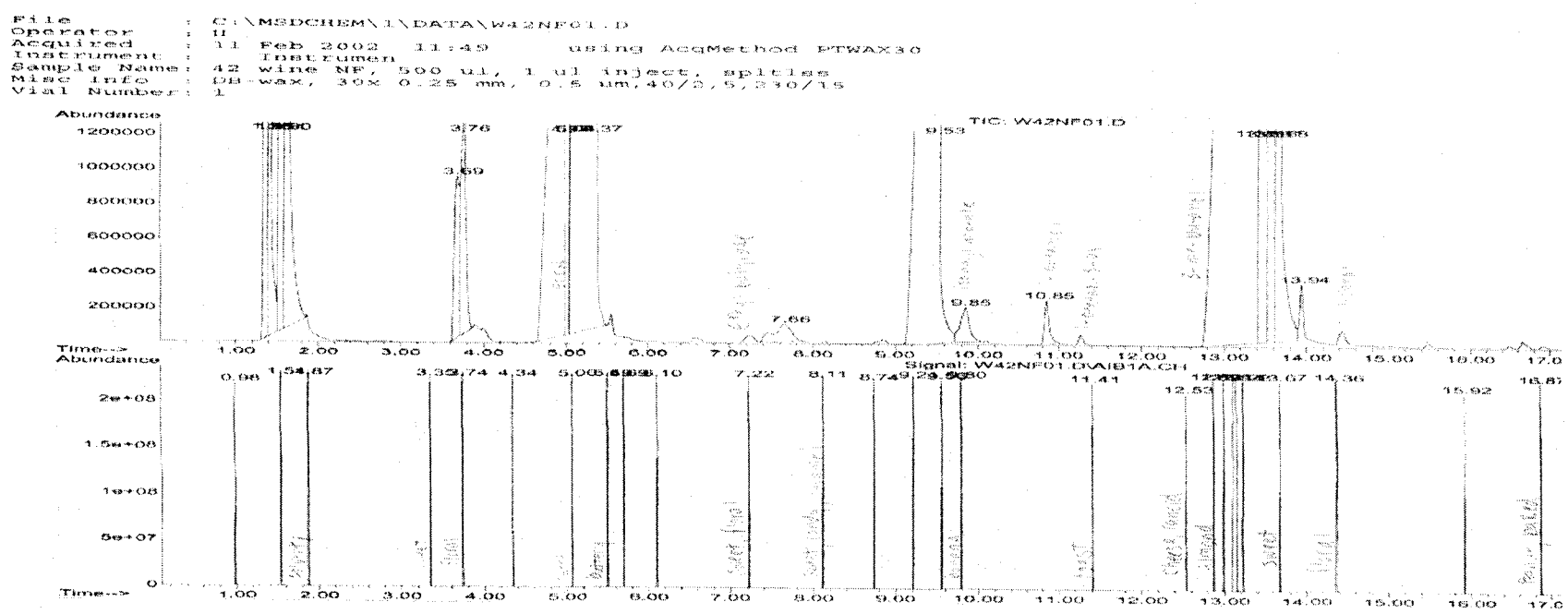


Table 3.13: 1999 wine extraction analysis of I T SN treatment extract: Aroma compounds identified in neutral fraction

Fruity, sweet
Ethyl propanoate
Ethyl isobutyrate
Ethyl butyrate
Ethyl 2-methylbutyrate
Ethyl 3-methylbutyrate
Isoamyl acetate
Ethyl hexanoate
Ethyl octanoate

Buttery:
Diacetyl

Malty:
3-Methylbutanal

Sulfury/Earthy:
Methionol

Floral, rosy
phenylethanol

Winey:
Isobutanol
3-methyl-1-butanol
2-methyl-1-butanol

Sour, sweaty, cheesy
Acetic acid
Isobutyric acid
Butyric acid
Pentanoic acid
Hexanoic acid
Heptanoic acid
Decanoic acid

vegetative growth. Howe found that tilling significantly increased cane weight in this vintage. This increase indicates vigor and may associated with increased moisture and nutrient availability. Tilled treatments were scored significantly higher in fruity flavor and the mouth-feel term body than non-tilled treatments. The multivariate mapping techniques show a trend where irrigated treatments have more earthy/musty character than non-irrigated treatments.

(Howe and Vasconcelos, 2000) found that irrigation significantly decreased the number of berries per cluster and increased berry weight. This skin to berry ratio is important from a sensory standpoint because more skins per unit of juice provide the opportunity for enhanced extraction of phenolic compounds from the grape skins. This is reflected in the new wine analysis of this vintage (Watson et al., 2000b) found significantly higher anthocyanins in dry versus irrigated treatments. The D T SN wine was found to have the lowest mean vegetative flavor, and along with I T FN was found to be significantly lower than I T SN. The D T SN treatment was found to have low berry weight(Howe and Vasconcelos, 2000). This treatment also stands out in the color analysis and was rated significantly higher than all of the other treatments for the descriptors overall color intensity and purple hue.

The color evaluations illustrate a trend for lower color intensity and lower purple hue in wines from irrigated treatments. No significant differences were noted for yield. This may be related to the significantly larger berry size, which was found

for irrigated versus dry treatments in the viticultural phase of this trial (Howe and Vasconcelos, 2000). Tilling, which was most influential on the aroma and flavor character of these wines, had no impact on wine color in this vintage. The impacts of tilling are probably indirect and related to changes in vegetative growth and the concurrent viticultural practices, such as canopy management.

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CHAPTER IV. DESCRIPTIVE ANALYSIS OF 2000 VINTAGE PINOT NOIR WINES AS EFFECTED BY IRRIGATION, TILLING AND NITROGEN SUPPLEMENTATION IN THE VINEYARD

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CONTRIBUTION OF AUTHORS

Carmo Vasconcelos and Jessica Howe designed and executed the fieldwork for this experiment. Patrick Taylor collected the data for the color panel and assisted in the analysis. All wines were produced under the direction of Barney Watson in the OSU experimental winery. Barney Watson assisted with interpretation of the data.

ABSTRACT:

2000 vintage Oregon Pinot noir wines from a viticulture project investigating the effect of manipulating soil moisture and nitrogen availability through vineyard irrigation, tilling and nitrogen supplemention underwent descriptive analysis by a panel of 11 semi-trained panelists. Wines were evaluated for differences in aroma and flavor. A color panel was conducted concurrently. Analysis of variance and multivariate mapping data are presented here. Only nitrogen application was found to be significant as a main effect with the non-fertilized treatment being rated significantly higher in floral aroma than the soil or foliar fertilized treatments. Generalized Procrustes analysis of the data suggests that irrigation is associated with vegetative, spicy character while non-irrigated treatments had more fruit, cherry and berry character. Wines from tilled treatments were higher in vegetative character than non-tilled treatments. The effects of vineyard practice on wine quality seem to be driven indirectly, through effects on the vegetative parameters of the vines.

INTRODUCTION:

A survey of the amino acid composition of wine grapes grown in the Pacific Northwest found that 90% of the samples surveyed had less than 400 mg free α-amino N/L of juice and 39% had less than 150 mg (Spayd and Andersen-Bagge, 1996). A yeast assimilable nitrogen content of 140 mg/L has been cited as required for musts with low solids content and normal sugar concentrations (Kunkee, 1991) (Butzke, 1998) (Watson et al., 2000a). Nitrogen deficiencies can limit yeast growth, lead to stuck or sluggish fermentations and result in the release of hydrogen sulfide (Spayd and Andersen-Bagge, 1996) (Hallinan et al., 1999) (Kunkee, 1991).

This is the second vintage of a study investigating how irrigation, tilling, and nitrogen fertilization impact fruit quality, fermentation behavior and wine quality of Pinot noir. The study was a 3x2x2 factorial design of Nitrogen (none, foliar applied, soil applied), Irrigation (dry or irrigated) and Tilling (alternate in-row tilling, not tilled). This design yields 12 treatment combinations (Table 4.1). Appendix 1 is a cross reference with treatment codes and the field lot numbers. These twelve treatment combinations were laid out in five field blocks in a complete randomized block design (Howe and Vasconcelos, 2000). See (Howe and Vasconcelos, 2000) and (Howe and Vasconcelos, 2001) for a discussion of the

Table 4.1: 12 Treatment combinations from the 3x2x2 factorial design of irrigation, tilling and nitrogen main effects for the 2000 vintage Pinot noir wines

	Irrigated		Dry (Not Irrigated)	
	Tilled	**Not Tilled**	**Tilled**	**Not tilled**
Zero Nitrogen	I T 0N	I NT ON	D T 0N	D NT 0N
Foliar Nitrogen	I T FN	I NT FN	D T FN	D NT FN
Soil Nitrogen	I T SN	I NT SN	D T SN	D NT SN

horticultural aspects of this study. The enological aspects of this study are discussed in (Watson et al., 2000b) and (Watson, 2001).

MATERIALS AND METHODS:

Samples:

Grapes were grown in an experimental plot established at Benton Lane vineyards, Monroe, Oregon. This vineyard is at approximately 425 ft elevation and has predominately Bellpine soil (Howe, 2001#111). Pinot noir clone FPMS 2A vines grafted on Teleki 5C rootstocks that were 7-year-old at the start of this project were used (Howe and Vasconcelos, 2000). Irrigated treatments received drip irrigation at the rate of 0.5gal/hour for 4 hours daily for a total of 200 hours during ripening. Tilled treatments received alternate row in-row tilling on May 22, 2000. Harvest occurred October 12, 2000. Nitrogen supplementation involved foliar treatments where wetted urea was sprayed on the leaves at twice: once at the beginning of veraison, on August 30, and again at 50% color change, on September 6.

Harvest occurred on October 12, 2000. Fruit was transported to Oregon State University for processing. Thirty-six unique winelots were produced, representing three replications of the 12 treatment combinations. Grapes were crushed, stemmed

and 50mg/L sulfur dioxide was added. 1g/L Lalvin RC 212 Bourgorouge yeast was used. Wines were punched down twice daily and pressed at dryness after seven days. Wines were settled and racked off the primary yeast lees. 0.025g/gallon OSU 1-step (Lalvin) malo-lactic bacteria were used to induce malo-lactic fermentation. Wines were cold stabilized prior to bottling. For a complete discussion of winemaking protocol, see Watson et al. (2000). One wine lot, field lot# 56, an I T SN sample, was lost during vinification. A complete list of treatment and field lot numbers is in appendix 1.

Wines were bottled at nine months of age and stored in the pilot winery at Withycombe Hall, Oregon State University. Wines had been in the bottle 7 months at the time of evaluation, a total of 15 months after crush. Wines were brought to room temperature (69-72 °F) prior to serving. Samples were served in 8oz tulip shaped wineglasses covered with clear plastic lids (Sweetheart USL3). Two-ounce (60ml) samples were measured using stainless steel measuring cups. Wines were opened and the neck was wiped with a clean cloth and a small volume was decanted to ensure no cork was inadvertently served. Wines were served within an hour of opening.

Subjects:

Eleven panelists participated in this study including students and faculty from the Food Science and Horticulture departments at Oregon State University, three members of a professional sensory evaluation panel and a local winemaker. Panelists included six women and five men. All panelists had prior experience with formal descriptive analysis proceedings.

Training:

Training consisted of three one-hour sessions. All subjects signed an informed consent form (on file). Panelists were presented with representative samples, the intensity scale and the ballot of pre-determined descriptors. A modified version of the descriptive analysis technique Free-choice profiling was used (Williams and Langron, 1984). Panelists were required to evaluate all samples for 15 pre-determined descriptors and were also allowed to generate their own additional descriptors. Panelists were allowed two sessions to develop and refine their ballots. Table 4.2 contains the pre-determined descriptors as well as the additional descriptors and their frequency of use. After testing commenced, panelists were not allowed to add or remove any descriptors from their ballots. Panelists recorded their ratings on a paper ballot (table 4.3).

Table 4.2: Additional descriptors generated by free-choice profiling descriptive analysis panel to Describe 2000 vintage Pinot noir wines

Additional Descriptors for 2000 Vintage BLPN Panel		
Pre-Determined Descriptors	**Additional Descriptors**	**Frequency***
Aroma Attributes	cherry	8
Overall Intensity	strawberry	4
Overall Fruitiness	black pepper	4
Overall Floral	resinous/cedar	3
Overall Spiciness	pepper	3
Overall Vegetative	raisin	3
Earthy/Musty	blackberry	2
	canned green bean	2
Flavor Attributes:	mint	2
Overall Intensity	berry	2
Overall Fruitiness	dusty	2
Overall Floral	grape	2
Overall Spiciness	rose	2
Overall Vegetative	mushroom	2
Acidity	chemical	1
Bitterness	meaty	1
Astringency	plum	1
Body	red berry	1
	cinnamon	1
	cooked cabbage	1
	dried fruit	1
	ethyl acetate	1
	licorice	1
	leather	1
	phenolic	1
	white pepper	1
	*Out of 11 total panelists	

Table 4.3: Ballot template used for descriptive analysis of 2000 vintage Pinot noir wines

Name: _____
Date: _____
Session: _____

Please evaluate the samples using the 16 point intensity scale.

Sample			
AROMA			
Overall Intensity			
Overall Frutiness			
Overall Floral			
Overall Spiciness			
Overall Vegetative			
Earthy/Musty			
FLAVOR			
Overall Intensity			
Overall Frutiness			
Overall Floral			
Overall Spiciness			
Overall Vegetative			
Acidity			
Bitterness			
Astringency			
Body			

Panelists were provided with intensity standards to anchor the 16-point intensity scale:

(3) Safflower oil (2 Tablespoons, Saffola Quality Foods, Los Angeles, CA)
(7) Hi-C Orange drink (1Tablespoon + 1 teaspoon, Coca Cola Co., Houston, TX)
(11) Welches' grape juice (1Tablespoon + 1 teaspoon, Welches Foods Inc., MA)
(15) Big Red Cinnamon gum (1 stick unwrapped, Wm. Wrigley Jr. Co., Chicago, IL)

This scale runs from 0 (no perceived intensity) to 15 (as intense as can be perceived). Many panelists had prior experience using this scale. The third training session was devoted to practice.

Testing

Testing occurred in six two-hour sessions over a two-week period. Panelists were seated in individual testing booths and provided with filtered water and containers for expectoration. During each session, panelists received a tray with three wines to evaluate, followed by a 10-minute break and another tray of three wines. Then panelists were given a 45-minute break during which they were instructed to eat unsalted oil-free crackers (Streit's brand Matzo crackers) and drink ample amounts of filtered water (Aqua-Cool brand purified drinking water.) Panelists repeated the process with another two trays after the break. Panelists rated each wine (n=35) twice in a randomized block design.

Statistics

Data were entered and sorted using Excel spreadsheets. Principal components analysis was performed using SPSS (SPSS, Inc., Chicago, IL). Multivariate analysis of variance for this vintage was performed and the results are presented in table 4.4. Univariate analysis of variance (ANOVA) was performed on the data from the pre-determined aroma and flavor descriptors and the color data using SAS (SAS Institute Inc., Cary, NC). Appendix 4.1 – 4.15 contains the ANOVA tables from this analysis. Note that panelist was considered a random effect (Lundahl and McDaniel, 1988). Significance levels were set at $p<0.05$. Where significant differences were found, means were grouped into homogeneous subsets using Tukey's HSD at $p<0.05$.

Generalized Procrustes analysis (GPA) was performed using Sensetool (Compusense, Guelph, Canada). A full GPA was run using the classical Gower full GPA in which individual columns are padded with zeros to account for differing number of descriptors used per panelist. No rotation was used.

Color Evaluations:

10 panelists evaluated each sample (n=35) twice. The evaluation occurred on the same days as the aroma, flavor and mouthfeel panel. Wines were evaluated for

Table 4.4: MANOVA table for 2000 vintage Pinot noir wines evaluated by semi-trained panel.

Effect	F	Hypothesis df	Sig.
Intercept	7299.286	15	0.000
PANELIST	80.927	150	0.000
FIELD_RE	1.279	30	0.145
PAN_REP	0.831	15	0.644
IRRIGATI	1.617	15	0.065
TILLAGE	0.883	15	0.584
FERT	1.106	30	0.318
PANELIST * FIELD_RE	0.903	300	0.881
PANELIST * PAN_REP	0.916	150	0.757
PANELIST * IRRIGATI	1.297	150	0.009
PANELIST * TILLAGE	1.225	150	0.034
PANELIST * FERT	1.151	300	0.041
FIELD_RE * PAN_REP	1.112	30	0.311
FIELD_RE * IRRIGATI	1.395	30	0.078
FIELD_RE * TILLAGE	1.297	30	0.132
FIELD_RE * FERT	1.123	60	0.243
PAN_REP * IRRIGATI	0.720	15	0.766
PAN_REP * TILLAGE	0.868	15	0.601
PAN_REP * FERT	1.102	30	0.323
IRRIGATI * TILLAGE	0.889	15	0.577
IRRIGATI * FERT	0.836	30	0.719
TILLAGE * FERT	1.997	30	0.001
IRRIGATI * TILLAGE * FERT	1.677	30	0.013
PANELIST * IRRIGATI * TILLAGE	1.069	150	0.270
PANELIST * IRRIGATI * FERT	0.920	300	0.832
PANELIST * TILLAGE * FERT	0.977	300	0.598
FIELD_RE * IRRIGATI * TILLAGE * FERT	1.246	195	0.013
PANELIST * IRRIGATI * TILLAGE * FERT	1.065	300	0.215

overall color intensity, purple hue and garnet hue. Panelists used the same 16-point intensity scale used in the aroma and flavor descriptive pane to score the descriptors. 2 oz (60mL) of each sample was presented in a crystal tulip shaped 8 oz wineglass. Samples were presented against a white paper background. Panelists were instructed to observe the "wine ring" by tilting the glass at a 45-degree angle.

Instrumental measurements of color included color intensity and hue. Samples of each wine were taken immediately after opening the wines for the first day of the color evaluation panel. Samples were centrifuged for 7 minutes and spectrophotometer measurements were taken using a Varian/Cary 50 Conc UV-Visible spectrophotometer. Color intensity was calculated as the sum of absorbance at 420 + 520 nm. Absorbance at 520 nm corresponds to the dark purple/red part of the spectrum and absorbance at 420 corresponds to the yellow/brown part of the spectrum. Increasing values correspond with increasing overall color intensity. Instrumental hue is calculated as the ratio of absorbance at 420/520 nm. Increasing hue values correspond to wines with increasing brick-red coloration.

RESULTS & DISCUSSION

Other summaries of the data can be found in (Hjorth and McDaniel, 2002).

Panelist Performance:

No panelists' data were excluded from the analysis. The mean error per descriptor was calculated for each panelist (Table 4.5). This was calculated as the absolute value of the difference between scores for each descriptor was calculated for each panelist. For each panelist, this was summed and divided by the number of descriptors used by that panelist to calculate the absolute mean error per descriptor per panelist. This ranged from 0.849 to 3.352. The assessor plot from the Generalized Procrustes analysis plot is shown in Figure 4.1. Analysis of variance on both axes found no panelists to be significantly different from each other at $p < 0.05$.

Multivariate Analysis of Variance (MANOVA):

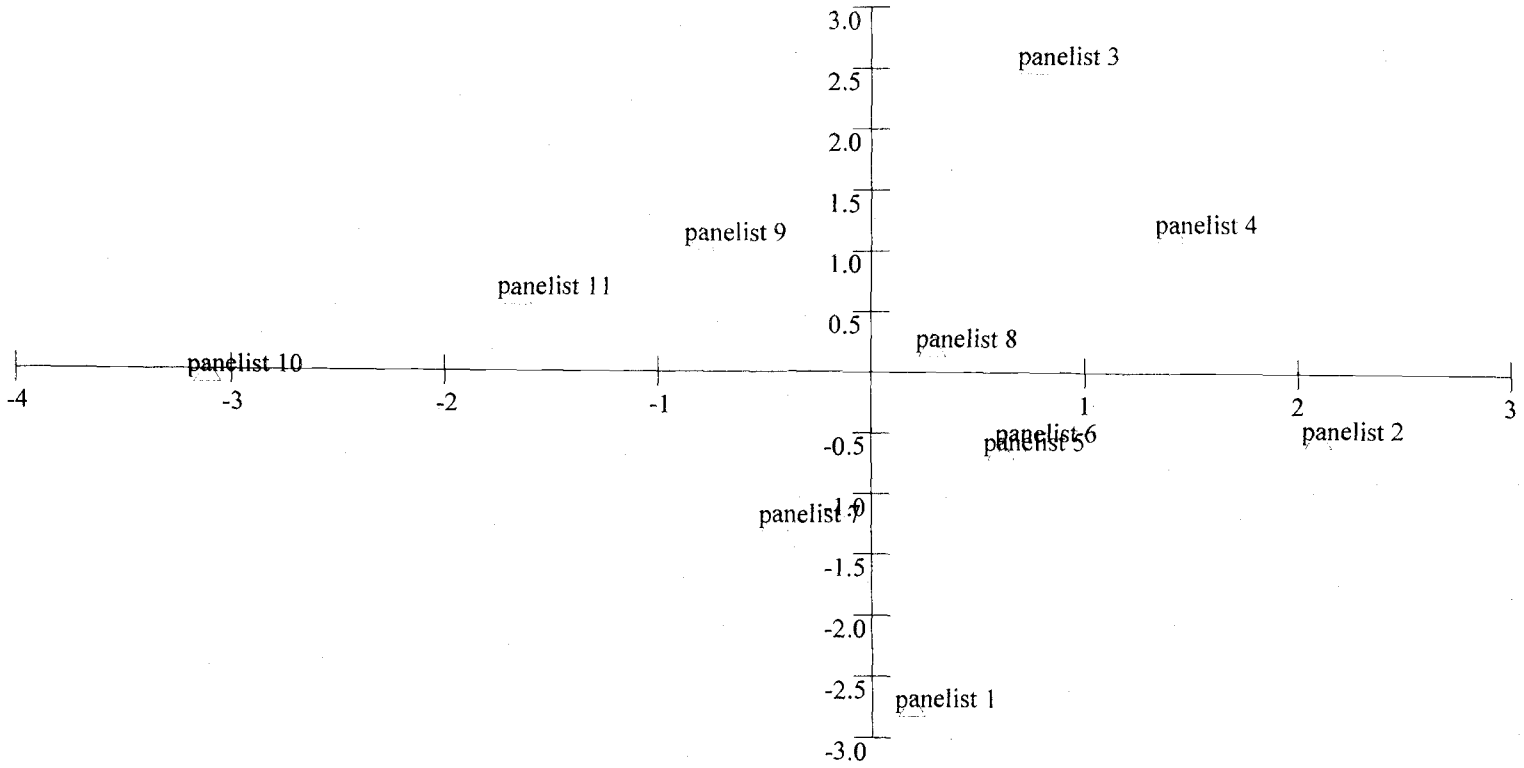
A multivariate analysis of variance was first run because of the inherently multivatiate nature of sensory data. MANOVA was run using SPSS software (SPSS, Inc., Chicago, IL). A summary of results for this vintage is in Table 4.4. Because MANOVA shows that there are significant interactions among the response variables, the univariate results must be interpreted with caution.

Table 4.5: Absolute mean error per panelist per descriptor, averaged over all descriptors for each panelist. Values are on the 16-point intensity scale.

Panelist	Error
1	1.408
2	1.932
3	2.721
4	3.053
5	2.982
6	2.981
7	0.849
8	3.352
9	1.113
10	0.761
11	2.497

Mean error = 2.15
Variance = 0.98

Figure 4.1: Assessor plot from Generalized Procrustes analysis of descriptive panel results of 12 treatments (averaged) averaged across three field replications of 2000 vintage Pinot noir wines No significant differences between samples on axis1 or axis 2 by ANOVA $p < 0.05$.



Analysis of Variance:

The ANOVA tables for significant terms for the fifteen pre-determined descriptors rated by all panelists table are in Appendix 4.1 – 4.15. The panel means for the twelve treatment combinations are in Table 4.6 for aroma and Table 4.7 for flavor and mouthfeel descriptors. Significant differences between treatments were discerned using Tukey's HSD post-hoc test ($p < 0.05$). A model was fit including all two and three way interactions of the main effects. Nitrogen supplementation was the only main effect found to create significant differences between samples. Treatments receiving no nitrogen in the vineyard were significantly higher in floral aroma than treatments receiving foliar or soil applied nitrogen.

Significant differences between the twelve treatment combinations were found for three flavor attributes (Table 4.7). For Spicy flavor, the I NT SN treatment was significantly higher than the I T SN (4.24 versus 3.29, $p < 0.05$). The D T SN treatment was significantly less Acidic than the I NT FN treatment (6.57 versus 7.27, $p < 0.05$). Not tilled treatments had lower must pH than tilled treatments for this vintage and treatments receiving soil nitrogen were found to have the lowest juice titratable acidity (Watson, 2001). The I T FN treatment was significantly higher in Bitterness than the D T SN treatment (3.18 versus 2.43, $p<0.05$). Tables 4.8 and 4.9 show means for all pre-determined descriptors across the main effects

Table 4.6: Descriptive panel aroma means* by 12 treatment combinations for descriptive analysis of 2000 vintage Pinot noir wines

	Overall Intensity	Fruity	Floral	Spicy	Vegetative	Earthy/Musty
D NT 0N	9.44	7.68	3.06	3.79	2.38	3.49
D NT FN	9.85	7.46	2.61	3.96	2.58	3.55
D NT SN	9.73	6.94	2.64	3.68	3.35	3.29
D T 0N	9.89	7.74	2.83	3.36	3.09	3.53
D T FN	9.76	7.32	2.39	3.46	3.56	3.59
D T SN	9.41	7.59	2.82	3.55	2.75	3.30
I NT 0N	9.67	7.38	2.74	3.33	3.23	3.68
I NT FN	9.56	6.96	2.50	3.65	3.41	3.70
I NT SN	9.86	7.70	2.94	4.08	3.44	3.26
I T 0N	9.73	7.17	2.89	3.83	3.26	3.52
I T FN	9.97	7.21	2.73	3.52	3.33	3.80
I T SN	9.85	6.85	2.42	3.62	3.73	4.33

*16-point intensity scale used where 0 = (none) and 15 = (extreme).

Table 4.7: Flavor & mouth-feel descriptive panel means* by 12 treatment combinations averaged across three field replications for 2000 vintage wines

Field Treatment	Overall Intenisty	Fruit	Floral	Spicy	Vegetative	Acidity	Bitterness	Astringency	Body
D NT 0N	9.64	7.30	3.08	3.96	2.59	7.24	2.76	6.76	4.94
D NT FN	9.49	7.27	3.08	3.83	2.55	6.77	2.83	6.50	4.64
D NT SN	9.11	6.47	2.67	3.86	2.94	6.82	2.83	6.49	4.55
D T 0N	9.44	7.27	3.05	4.06	2.38	6.80	2.79	6.62	4.53
D T FN	9.64	7.00	2.86	3.38	3.03	7.02	3.11	6.71	4.73
D T SN	9.32	7.05	2.93	3.36	2.50	6.57 [a]	2.43 [a]	6.07	4.48
I NT 0N	9.59	7.14	2.86	3.77	2.82	7.17	2.86	6.59	4.65
I NT FN	9.42	6.91	3.06	3.70	2.71	7.27 [b]	2.82	6.50	4.88
I NT SN	9.89	7.33	2.92	4.24 [b]	2.89	6.80	2.83	6.50	4.91
I T 0N	9.56	7.32	2.82	4.03	2.56	6.77	2.56	6.27	4.77
I T FN	9.47	6.88	3.02	4.08	3.32	7.09	3.18 [b]	6.56	4.70
I T SN	9.65	7.21	3.15	3.29 [a]	2.89	7.18	2.80	6.39	4.79

Treatments bearing different letters are significantly different through ANOVA and Tukey HSD at $p < 0.05$.

* 16-point intensity scale used where 0 = (none) and 15 = (extreme).

for aroma and flavor/mouthfeel descriptors respectively. No significances were found by ANOVA $p < 0.05$.

Significant treatments by field block interactions (Field block * Irrigation * Tillage * Fertilization) were seen for four of the fifteen pre-determined descriptors: Acidity, Vegetative Flavor, Astringency and Body. This significant treatment by field block interaction suggests heterogeneity of the vineyard.

Generalized Procrustes Analysis:

Generalized Procrustes analysis was used to create spatial maps of the samples from the free-choice profiling data, using both the 15 pre-determined descriptors and the unique descriptors generated by each panelist. Plots of the twelve treatment combinations averaged over the three blocks are presented in Figures 4.2 and 4.3. Dimension 1 explains 18% of the total variation (Figure 4.2) with fruitiness, cherry and berry characterizing samples on the positive end of dimension 1 while vegetative, spiciness, pepper, floral and body characterize samples on the negative end. Dimension 1 shows a trend where wines from non-irrigated treatments tend to be higher in fruitiness, cherry and berry while irrigated wines tend toward the vegetative, spiciness, pepper, floral and body end of the axis. This effect may be due to increased vigor in irrigated treatments, which relates to shading of the fruit.

Figure 4.2: Generalized Procrustes analysis of aroma, flavor and mouthfeel descriptors for 2000 Vintage Pinot noir Wines: axis 1 vs. axis 2 (averaged across panelist and field replications) No significant differences between samples on axis1 or axis2 by ANOVA $p < 0.05$.

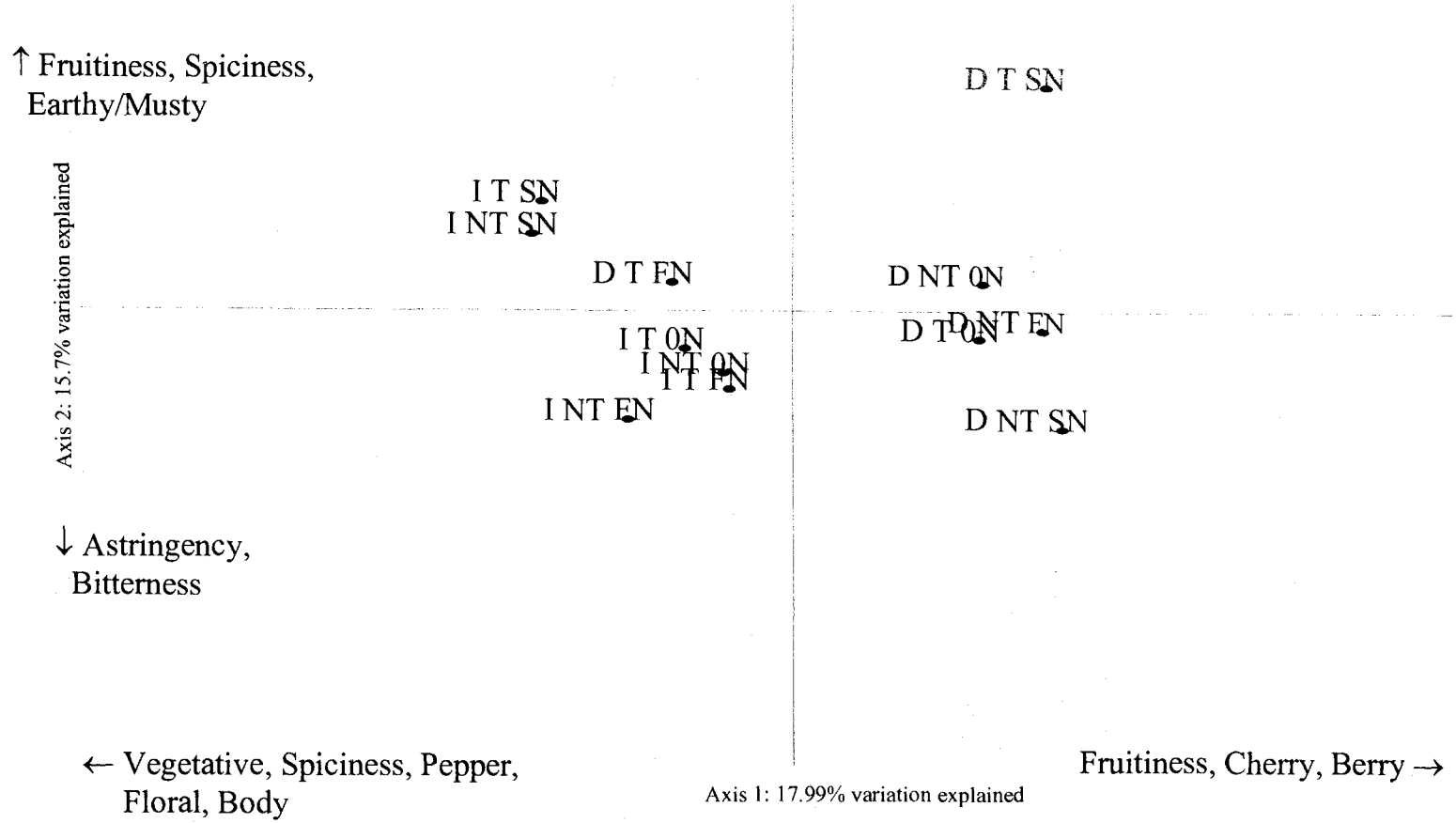


Table 4.8: Main effects descriptive analysis panel aroma means* from 2000 vintage Pinot noir wines

		Aroma intensity	Fruity Ar	Floral Ar	Spicy Ar	Veg Ar	Earthy/Musty
Irrigation	Dry	9.68	7.46	2.73	3.63	2.95	3.46
	Irrigated	9.77	7.21	2.71	3.67	3.40	3.72
		Aroma intensity	Fruity Ar	Floral Ar	Spicy Ar	Veg Ar	Earthy/Musty
Nitrogen	None	9.68	7.49	2.88	3.58	2.99	3.55
	Foliar	9.78	7.24	2.56	3.64	3.22	3.66
	Soil	9.71	7.27	2.71	3.73	3.32	3.54
		Aroma intensity	Fruity Ar	Floral Ar	Spicy Ar	Veg Ar	Earthy/Musty
Tillage	No Till	9.68	7.35	2.75	3.75	3.06	3.49
	Till	9.77	7.31	2.68	3.56	3.29	3.68

* 16-point intensity scale used where 0 = (none) and 15 = (extreme).

Table 4.9: Main effects descriptive analysis panel flavor & mouth-feel mean scores* from 2000 vintage Pinot noir

FLAVOR MEANS

Irrigation		Flavor OI	Fruit FI	Floral FI	Spicy FI	Veg FI	Acidity	Bitterness	Astringency	Body
	Dry	9.44	7.06	2.94	3.74	2.66	6.87	2.79	6.52	4.64
	Irrigated	9.60	7.13	2.97	3.85	2.87	7.05	2.84	6.47	4.78

Nitrogen		Flavor OI	Fruit FI	Floral FI	Spicy FI	Veg FI	Acidity	Bitterness	Astringency	Body
	None	9.56	7.26	2.95	3.96	2.59	7.00	2.74	6.56	4.72
	Foliar	9.50	7.02	3.00	3.75	2.90	7.04	2.99	6.57	4.74
	Soil	9.49	7.02	2.92	3.69	2.81	6.84	2.73	6.36	4.68

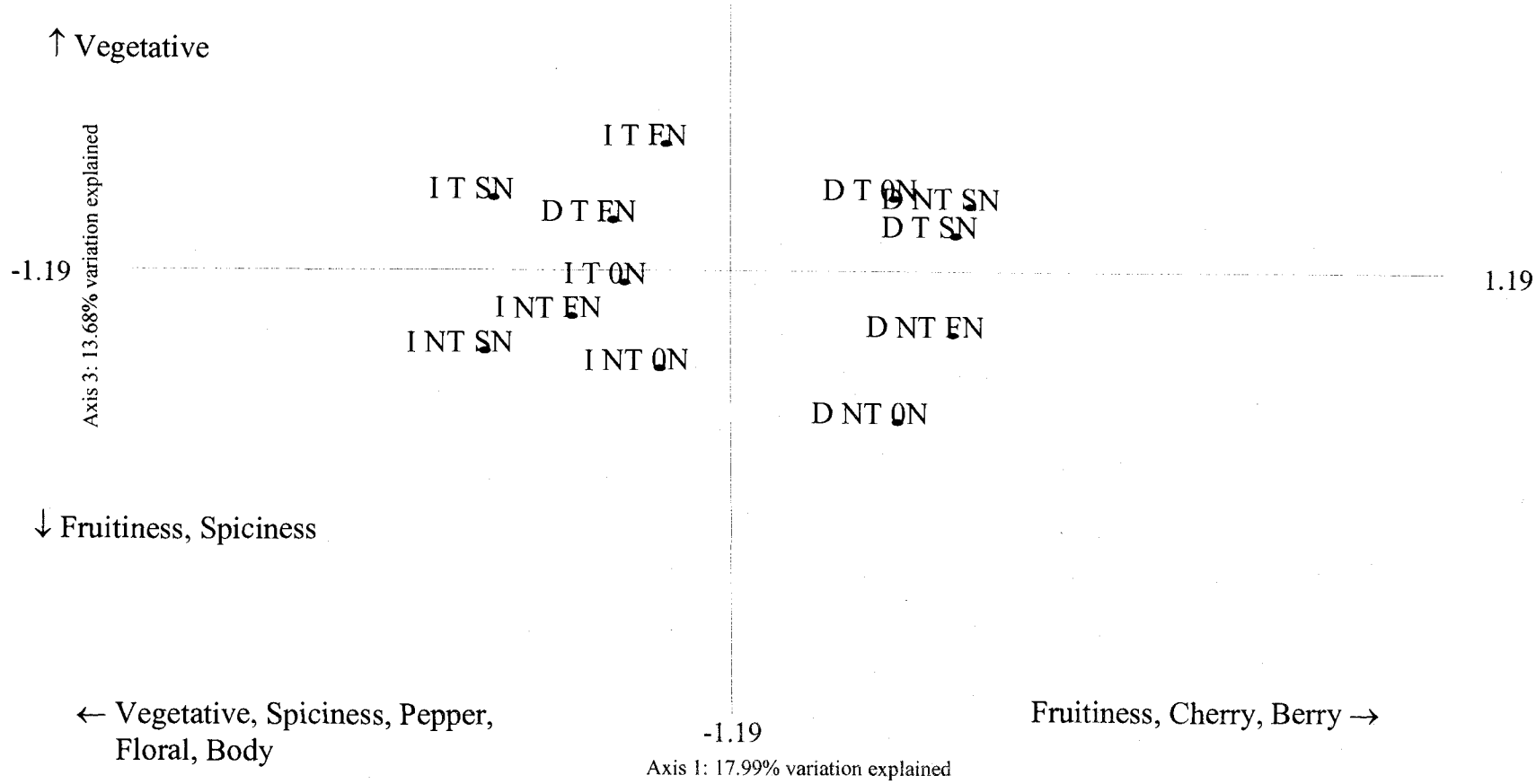
Tillage		Flavor OI	Fruit FI	Floral FI	Spicy FI	Veg FI	Acidity	Bitterness	Astringency	Body
	No Till	9.52	7.07	2.94	3.89	2.75	7.01	2.82	6.56	4.76
	Till	9.51	7.12	2.97	3.70	2.78	6.91	2.81	6.44	4.67

* 16-point intensity scale used where 0 = (none) and 15 = (extreme).

Dimension 2 is characterized by spiciness, fruitiness and earthy/musty character on the positive end and astringency and bitterness on the negative end of the axis. The D T SN sample stands out as being highest on the positive end of PC2. This treatment had the lowest panel mean score for bitterness and was significantly less bitter than the I T FN panel mean. The D T SN treatment is also notable for having consistently among the highest phenols and anthocyanins in both the 1999 and 2000 vintages of this trial (Watson et al., 2000b), (Watson, 2001). This treatment has also been consistently at the low end of yield (Howe and Vasconcelos, 2000; Howe and Vasconcelos, 2001). One possible explanation is that tilling combined with soil nitrogen causes too much vigor too early, inducing poor fruit set (Watson, 2002).

Dimension 3 (Figure 4.3) shows a trend where tilled treatments tend to be higher in Vegetative character while not tilled treatments are higher in Fruitiness and Spiciness. In this trial, tilling as a main effect was found to significantly effect grapevine vigor. Tilling significantly increased cane weight and decreased Ravaz index for this vintage (Howe and Vasconcelos, 2001). Ravaz index is a ratio of fruit to pruning weight, and is a measure of vine balance. This vigorous vegetative growth leads to increased shading of the grape clusters. Increased shading of fruit clusters has been found to be associated with increased sensory vegetal character (Price et al., 1995).

Figure 4.3: Generalized Procrustes analysis of aroma, flavor and mouthfeel descriptors for 2000 Vintage Pinot noir wines: axis 1 vs. axis 3 (averaged across panelist and field replications) No significant differences between samples on axis 1 or axis 3 by ANOVA $p < 0.05$.



Analysis of Variance of Color Data:

Data were collected and analyzed by Patrick Taylor. Analysis of the color data yielded more significant differences between wine samples than analysis of the sensory panel data. For the sensory panel color data, color intensity and purple hue both show significant three way interactions between the main effects of nitrogen, irrigation and tilling. For color intensity, the interaction of these treatments was significant ($p < 0.001$) with the I T FN treatment being rated as the lowest and I NT SN being among the highest for color intensity. For Purple hue, D T SN had the highest mean purple hue scores and the I T SN treatment had the lowest mean purple hue ratings. Table 4.10 shows the color panel means and significant differences for each treatment averaged across the three field blocks. Irrigated treatments tend to be lower in color intensity than non-irrigated treatments.

Table 4.11 shows main effects for the panel color data. No significant three-way interaction was seen for the descriptor Garnet Hue. The main effects of irrigation and nitrogen were found to be significant ($p<0.01$ and $p<0.05$ respectively.) Irrigated vines were rated lower for garnet hue than were dry vines (Table 4.11). Vines receiving soil nitrogen received the highest mean garnet hue scores from the panel, followed by foliar fed vines and vines receiving no fertilizer.

Table 4.10: Panel color means* by 12 treatments averaged across three field replications for 2000 vintage Pinot noir wines

Treatment	Purple Hue	Color Intensity	Garnet Hue
D NT FN	7.00 ^{bcd}	10.67 ^{bc}	8.50
I NT FN	4.72 ^{a}	8.93 ^{a}	8.77
D T FN	5.53 ^{ab}	9.32 ^{a}	8.17
I T FN	4.62 ^{a}	8.92 ^{a}	8.52
D NT SN	4.97 ^{a}	9.58 ^{ab}	8.98
I NT SN	7.37 ^{cd}	11.88 ^{d}	9.05
D T SN	7.58 ^{d}	11.03 ^{cd}	7.75
I T SN	4.55 ^{a}	9.38 ^{a}	9.17
D NT 0N	7.53 ^{cd}	10.83 ^{cd}	8.02
I NT 0N	5.80 ^{ab}	9.52 ^{a}	8.40
D T 0N	6.05 ^{abc}	9.52 ^{a}	7.98
I T 0N	5.67 ^{ab}	9.68 ^{ab}	8.38

* 16-point intensity scale used where 0 = (none) and 15 = (extreme).

Table 4.11: Panel color means* by main effect for 1999 Pinot noir wines evaluated at approximately 15 months of age.

Panel Main Effects

Irrigation	Color Intensity	Purple Hue	Garnet Hue
Dry	10.11	6.38	8.26 [a]
Irr	9.72	5.45	8.71 [b]

Tilling	Color Intensity	Purple Hue	Garnet Hue
None	10.24	6.23	8.62
Tilled	9.56	5.55	8.36

Nitrogen	Color Intensity	Purple Hue	Garnet Hue
Foliar	9.46	5.47	8.49 [ab]
Soil	10.42	5.98	8.83 [b]
None	9.89	6.26	8.20 [a]

* 16-point intensity scale used where 0 = (none) and 15 = (extreme).

The spectrometric color results (Table 4.12) show significant differences for both instrumental hue and intensity across the twelve treatment combinations. Although no significant differences in yield were noted in either tons/acre or kg/vine, a trend can be seen for irrigation increasing yield. The I NT SN treatment stands out as highest in instrumental color intensity (420+520 nm) and the I NT FN treatment was lowest. Means for the descriptors by the main effects of irrigation, tilling and nitrogen supplementation are in Table 4.13. In general, dry treatments tend to have more color intensity than irrigated treatments.

Multivariate Analysis of Color Data:

Principal components analysis was used to create spatial maps illustrating the relationship between samples for the color data. The principal component plot produced from the panel and spectrometric color measurements explains 73.3% of the variation among samples (Figure 4.4). The first principal component explains 52.8% of the data and is anchored on the positive end of the axis by the descriptors Color intensity (panel), Purple hue (panel), and the instrumental intensity measure (420+520nm). The negative end of the first PC is anchored by instrumental hue (420/520nm). The second principal component is anchored on the positive end by the panel term Garnet hue. A trend can be noted where the dry treatments tend to be further toward the positive side of the first PC while the irrigated treatments were more associated with the negative side of this axis. This indicates that dry

Table 4.12: Instrumental color means by 12 treatment combinations averaged across three field replications for 2000 vintage Pinot noir wines at 15 months of age.

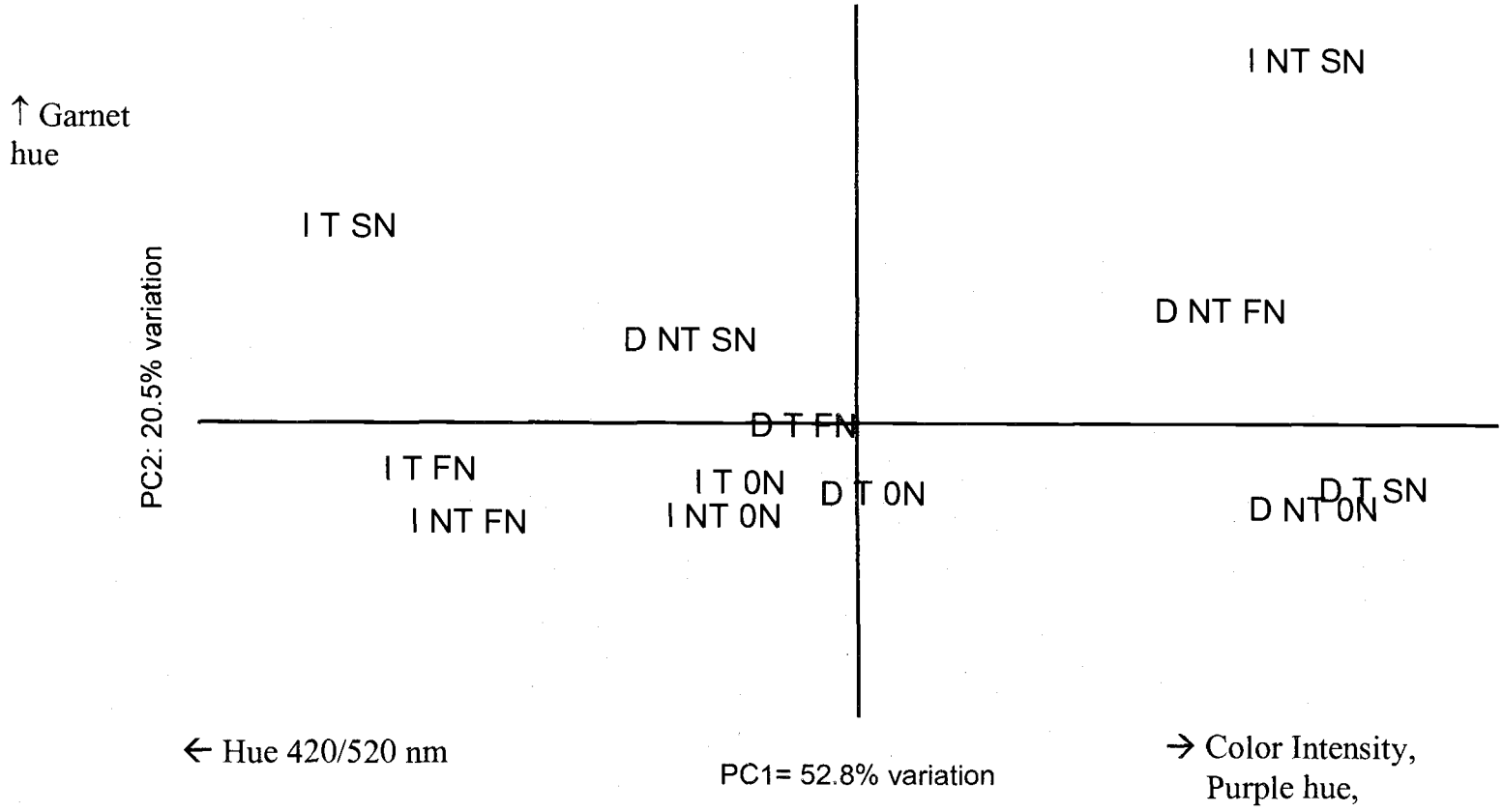
Treatment	sum 420+520	ratio 420/520
D NT FN	5.05 ^{gh}	0.880 ^{bcd}
I NT FN	3.62 ^{a}	0.883 ^{cde}
D T FN	4.74 ^{efg}	0.911 ^{def}
I T FN	3.87 ^{ab}	0.931 ^{f}
D NT SN	4.33 ^{cd}	0.906 ^{cdef}
I NT SN	5.17 ^{h}	0.922 ^{ef}
D T SN	4.92 ^{fgh}	0.840 ^{ab}
I T SN	4.01 ^{bc}	0.996 ^{g}
D NT 0N	4.67 ^{ef}	0.822 ^{a}
I NT 0N	4.06 ^{bc}	0.869 ^{bc}
D T 0N	4.45 ^{de}	0.898 ^{cdef}
I T 0N	4.10 ^{bc}	0.881 ^{bcde}

Treatments bearing different letters are significantly different by Tukey's HSD at $p < 0.05$.

Table 4.13: Color main effects of irrigation, tilling, and nitrogen supplementation on 2000 vintage Pinot noir wine

Spectrophotometric Results by Main Effect		
Irrigation	**Ratio 420/520 nm**	**Sum 420+520 nm**
Dry	0.878	4.68
Irr	0.914	4.14
Tilling	**Ratio 420/520 nm**	**Sum 420+520 nm**
None	0.880	4.48
Tilled	0.914	4.31
Nitrogen	**Ratio 420/520 nm**	**Sum 420+520 nm**
Foliar	0.901	4.32
Soil	0.923	4.58
None	0.868	4.32

Figure 4.4: Principal components analysis plot of panel color evaluations & spectrometric color data for 2000 Pinot noir wines: PC1+PC (averaged across panelist and field replications). No significant differences between samples on PC1 or PC2 by ANOVA $p < 0.05$.



treatments tend to be higher in color intensity and lower in instrumental hue than irrigated treatments. Wines receiving the ITSN treatment stand out as being higher on the second PC, corresponding with the descriptor garnet hue.

Multivariate Analysis of Sensory, Color, Wine Analysis & Harvest Data

Principal components analysis was used to create spatial maps relating information from the sensory evaluations of aroma, flavor and mouth-feel with the sensory panel color data, instrumental color data and harvest data. Figure 4.5 contains a plot of PC1 vs. PC2 and made from data from the sensory aroma and flavor evaluations, sensory color evaluations, spectrometric color evaluations and selected harvest data. The I T SN treatment stands out on this plot, especially along PC2 where it is strongly correlated with the end of the axis anchored by wine and juice pH, brix, wine volatile acidity, alcohol, vegetative character, earthy/musty aroma and spiciness. This treatment had the lowest panel mean value for spicy flavor by analysis of variance. Figure 4.6 contains a plot of PC1 vs. PC3. I T SN stands out as being farthest toward the negative end of axis 1, corresponding with high harvest weight, high berry weight and the instrumental measure of hue.

Figure 4.5: Sensory, Color, Instrumental & Harvest Data PCA averaged across three field replications of 2000 vintage Pinot noir wine. PC1 vs. PC2= 29.77% variation explained No significant differences between samples on PC1 or PC2 by ANOVA $p < 0.05$.

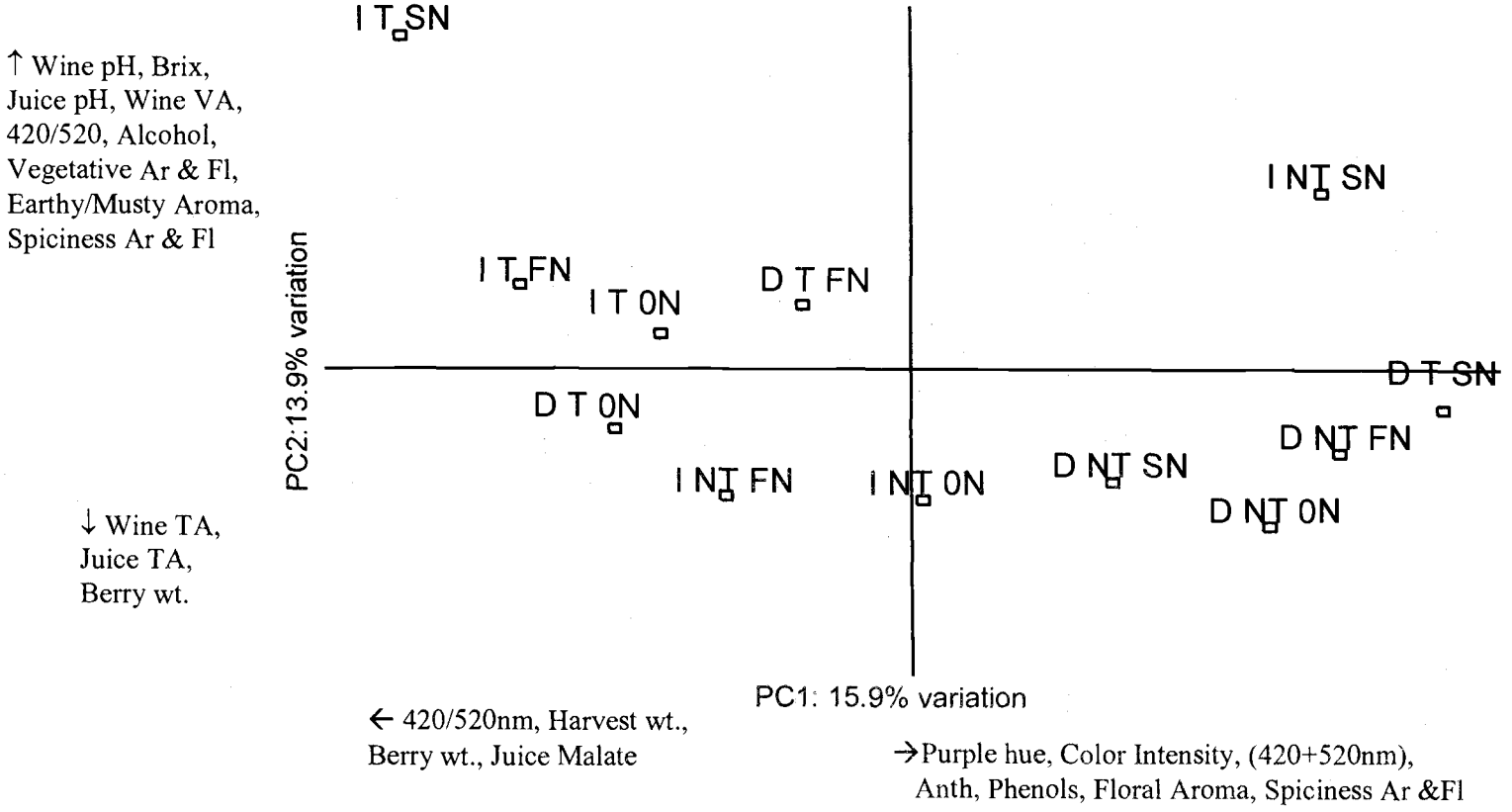
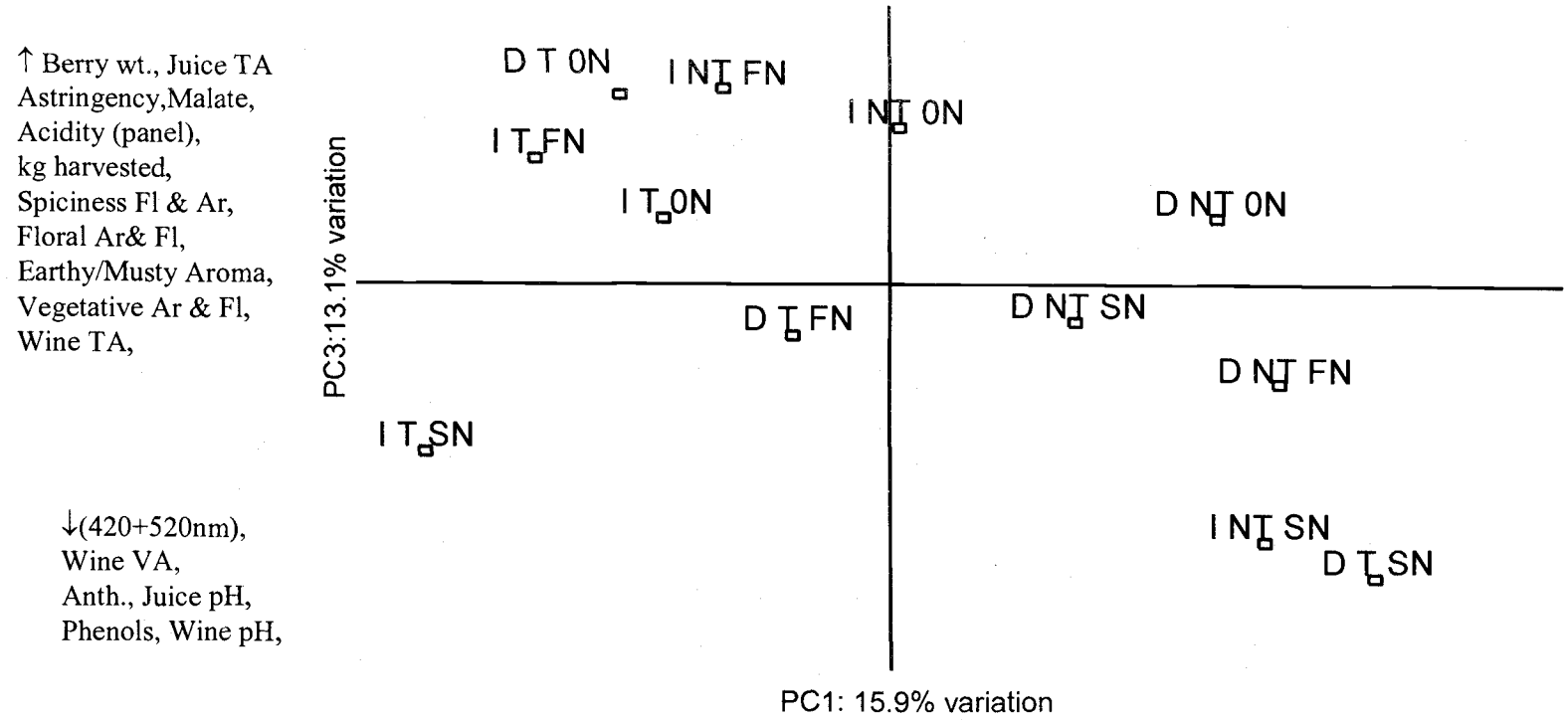


Figure 4.6: Sensory, Color, Instrumental & Harvest Data PCA for 2000 vintage Pinot noir wines
PC1 vs. PC3= 29.77% variation explained No significant differences between samples on PC1 or PC3 by ANOVA $p < 0.05$.



CHAPTER SUMMARY:

Only nitrogen supplementation as a main effect was found to significantly impact a descriptor, floral aroma, outside of interaction terms. Treatments receiving no nitrogen were significantly rated higher for floral aroma than either the foliar or soil applied nitrogen treatments. Three flavor descriptors showed significant differences among the twelve treatment combinations including spicy flavor, acidity and bitterness. I T SN was significantly less spicy in flavor than the I NT SN wines. D T SN wines were significantly less acidic than I NT FN wines. D T SN wines were also significantly less bitter than I T FN wines. No significant differences in yield components were noted for this vintage, but tilling was found to significantly increase vine vigor, reflected by significantly higher cane weight and more balanced Ravaz index (Howe and Vasconcelos, 2001).

Generalized Procrustes analysis shows a trend where irrigated samples are higher in vegetative, spiciness, pepper, floral and body; while non-irrigated samples are higher in fruitiness, cherry and berry characteristics. Tilled treatments tend to be higher in vegetative character than non-tilled treatments, which are more characterized by fruitiness and spiciness.

The principal components plot combining spectrometric and panel color data is in close accordance with the analysis of variance of the panel color data. The I NT

SN, which had the highest mean panel color intensity score and the D T SN treatment, which had the highest mean purple hue are at the extreme positive end of PC1, corresponding with the anchor terms color intensity and purple hue. Color data were successful in characterizing differences between the treatments. Irrigated treatments were rated as higher in garnet hue than non-irrigated treatments. Wines receiving no nitrogen were significantly lower in garnet hue than wines receiving soil applied nitrogen. In general, irrigated treatments tended to be lower than non-irrigated treatments for purple hue and color intensity.

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V. THESIS SUMMARY:

Tilling had the largest impact of the three main effects from a horticultural standpoint (Howe and Vasconcelos, 2000; Howe and Vasconcelos, 2001; Silva et al., 2002). The effects of tilling on the sensory properties of wine appear to be indirect, acting through the impact on vegetative growth. Tilled treatments had significantly higher cane weight than non-tilled treatments in both the 1999 and 2000 vintages (Howe and Vasconcelos, 2001). Even larger increases in vine vigor in the tilled versus un-tilled treatments were reported in the 2001 vintage (Silva et al., 2002). In both vintages, a trend toward increased yield was seen for the tilled treatments. This progressive effect reflects the delayed impact of tilling and the subsequent impacts on vigor on aspects of grapevine physiology.

The impact of cultural practices on the vegetative growth of these vines is difficult to interpret because balanced pruning was applied to all vines in the vineyard (Howe, 2002). Balanced pruning involves using the weight of the new wood produced by each vine in the previous growing season to calculate the appropriate number of buds to leave on each vine. Tilled treatments had significantly higher brix than non-tilled treatments in both the 1999 and 2000 vintages. In the 2000 vintage, tilling significantly increased the must pH. In the 1999 vintage, tilling was found to increase fruity flavor and body. In the 2000 vintage, tilling was associated

with increased vegetative character while untilled treatments had more fruitiness and spicy character.

Irrigation led to relatively larger berries and lower skin to fruit ratios. When water is available, the grapevine incorporates some of this water into fruit, having a dilution effect. This was seen in the 1999 vintage, where berry weights from irrigated treatments were found to be significantly higher than non-irrigated treatments (Howe and Vasconcelos, 2000). During the 2000 vintage, rainfall toward the end of veraison may have dampened the impact of the irrigation treatment. Irrigated treatments had significantly lower phenols and total anthocyanins in the 1999 vintage; this trend continued in the 2000 vintage. Irrigation was associated with a decrease in both panel and instrumental color intensity in the 1999 vintage and was found to significantly increase garnet hue in the 2000 vintage. Irrigation is associated with increased vigor in grapevines, leading to more shading of the fruit. Shading is associated with increased vegetative character and reduced fruitiness in wines. In the 2000 vintage, irrigated wines showed more vegetative character, spiciness, pepper and floral character than non-irrigated wines, which were characterized by fruit, cherry and berry character.

The effects of nitrogen supplementation were less pronounced than the effects of irrigation and tillage. In the 1999 vintage, nitrogen did not significantly impact the aroma, flavor or mouthfeel characteristics of the wine. Non-fertilized treatments

were found to have a significantly lower must pH and higher titratable acidity in the 1999 vintage. In the 2000 vintage, the non-fertilized wines had a significantly higher titratable acidity than the soil or foliar applied nitrogen treatments. Nitrogen had a significant impact on floral aroma in the 2000 vintage with treatments receiving no supplemental nitrogen having significantly higher mean floral aroma scores than treatments receiving foliar or no soil applied nitrogen. Nitrogen did not significantly impact yield in either vintage, but treatments receiving no supplemental nitrogen were found to have the highest must titratable acidity in both vintages (Howe and Vasconcelos, 2001).

In this trial, treatments were applied at the level of the three way interaction of irrigation, tilling and fertilization, thus it is not surprising to find significant three way irrigation x tillage x fertilization interactions. Significant block*irrigation*tilling*fertilization interactions indicate treatment differences which may stem from differences in vineyard blocks. Because winemaking lots were not replicated there was no way to determine how much of the difference between samples could be attributed to differences in wine lot versus block in the vineyard. Visible homogeneity can be noted in this vineyard site. The experimental plot is a plot in a commercial vineyard that has historically been challenging for vineyard managers to produce fruit with satisfactory fruit. Strict wine making protocol was followed to ensure uniform wines.

The differences in color were more pronounced than the differences in the aroma, flavor and mouthfeel evaluations. Irrigation had a negative effect on purple hue, color intensity and the instrumental measure of color intensity. This may be a dilution effect as berries take up more of the water made available to them through irrigation. Nitrogen supplementation impacted phenolic content in the 1999 vintage, with wines receiving soil-applied nitrogen being significantly higher in phenolic content.

Understanding the relationship between viticultural practices and wine quality is complex, and considered by many to be an art as well as a science. The most successful strategies can be adopted when vineyard managers combine an understanding of vine physiology with an intimate understanding of their terroir. Giving vineyard managers tools to predictably alter grape and wine parameters is a step toward reliably crafting a product that will be accepted by the audience as appropriate for varietal style.

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APPENDICES

Appendix 1: Treatments sorted by trial lot and by treatment combination for Pinot noir wines

trial lot #	treatment
1	D NT FN
2	I T 0N
3	D NT 0N
4	I NT 0N
5	I T 0N
6	I NT 0N
7	D T 0N
18	D NT 0N
19	I NT FN
20	D NT SN
21	I NT FN
22	I T FN
23	D T 0N
24	D NT 0N
26	D T FN
27	I NT SN
28	D NT FN
29	I T SN
30	D NT SN
31	D T FN
42	I T SN
43	D NT FN
44	D T 0N
45	I T 0N
46	I T SN
47	D T SN
48	D NT SN
49	I NT SN
50	I T FN
51	I NT 0N
52	D T SN
53	D T FN
54	I T FN
55	I NT SN
56	D T SN

trial lot #	treatment
18	D NT 0N
3	D NT 0N
24	D NT 0N
1	D NT FN
28	D NT FN
43	D NT FN
48	D NT SN
30	D NT SN
20	D NT SN
23	D T 0N
44	D T 0N
7	D T 0N
26	D T FN
53	D T FN
31	D T FN
52	D T SN
56	D T SN
47	D T SN
6	I NT 0N
4	I NT 0N
51	I NT 0N
21	I NT FN
19	I NT FN
55	I NT SN
27	I NT SN
49	I NT SN
45	I T 0N
5	I T 0N
2	I T 0N
22	I T FN
50	I T FN
54	I T FN
42	I T SN
29	I T SN
46	I T SN

D = Non-irrigated
I = Irrigated

T = Tilling in alternate rows
NT = Not tilled

0N = No nitrogen supplementation
FN = Foliar nitrogen application
SN = Soil nitrogen application

Appendix 2: Ballot for winemaker panel evaluation of 1999 BLPN wines

Panelist#_____
Session# _____

Sample#						
AROMA						
Overall intensity						
Overall fruitiness						
_____						
_____						
Overall Floral						
_____						
_____						
Overall Spiciness						
_____						
_____						
Overall vegetative						
_____						
_____						
Earthy/Musty						
FLAVOR						
Overall Intensity						
Overall fruitiness						
_____						
Overall Floral						
_____						
Overall Spicy						
_____						
_____						
Overall Vegetative						
_____						
_____						
Acidity						
Bitterness						
Astringency						
Body						
_____						

Appendix 3.1: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor aroma intensity

Aroma Overall Intensity			
Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.453	
Irrigation	1	0.029	a
Tillage	1	0.964	
Fertilization	2	0.184	
Panelist	15	0.022	a
Field rep*Irrigation	2	0.016	a
Field rep*Tillage	2	0.785	
Field rep*Fertilization	4	0.009	b
Field rep*Panelist	30	0.352	
Irrigation*Tillage	1	0.003	b
Irrigation*Fertilization	2	0.000	c
Irrigation*Panelist	15	0.815	
Tillage*Fertilization	2	0.420	
Tillage*Panelist	15	0.677	
Fertilization*Panelist	30	0.403	
Irrigation*Tillage*Fertilization	2	0.136	
Irrigation*Tillage*Panelist	15	0.848	
Irrigation*Fertilization*Panelist	30	0.979	
Tillage*Fertilization*Panelist	30	0.461	
Irrigation*Tillage*Fertilization*Panelist	30	0.462	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.2: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor fruity aroma

Fruity Aroma			
Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.438	
Irrigation	1	0.237	
Tillage	1	0.961	
Fertilization	2	0.903	
Panelist	15	0.014	a
Field rep*Irrigation	2	0.283	
Field rep*Tillage	2	0.581	
Field rep*Fertilization	4	0.218	
Field rep*Panelist	30	0.169	
Irrigation*Tillage	1	0.340	
Irrigation*Fertilization	2	0.344	
Irrigation*Panelist	15	0.279	
Tillage*Fertilization	2	0.625	
Tillage*Panelist	15	0.580	
Fertilization*Panelist	30	0.270	
Irrigation*Tillage*Fertilization	2	0.261	
Irrigation*Tillage*Panelist	15	0.543	
Irrigation*Fertilization*Panelist	30	0.932	
Tillage*Fertilization*Panelist	30	0.838	
Irrigation*Tillage*Fertilization*Panelist	30	0.590	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.3: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor floral aroma

Floral Aroma			
Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.060	
Irrigation	1	0.241	
Tillage	1	0.174	
Fertilization	2	0.609	
Panelist	15	0.040	a
Field rep*Irrigation	2	0.283	
Field rep*Tillage	2	0.928	
Field rep*Fertilization	4	0.989	
Field rep*Panelist	30	0.027	a
Irrigation*Tillage	1	0.187	
Irrigation*Fertilization	2	0.537	
Irrigation*Panelist	15	0.693	
Tillage*Fertilization	2	0.404	
Tillage*Panelist	15	0.932	
Fertilization*Panelist	30	0.909	
Irrigation*Tillage*Fertilization	2	0.917	
Irrigation*Tillage*Panelist	15	0.172	
Irrigation*Fertilization*Panelist	30	0.005	b
Tillage*Fertilization*Panelist	30	0.211	
Irrigation*Tillage*Fertilization*Panelist	30	0.944	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.4: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor spicy aroma

Spicy Aroma			
Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.064	
Irrigation	1	0.219	
Tillage	1	0.166	
Fertilization	2	0.298	
Panelist	15	0.001	c
Field rep*irrigation	2	0.836	
Field rep*Tillage	2	0.742	
Field rep*Fertilization	4	0.241	
Field rep*Panelist	30	0.528	
Irrigation*Tillage	1	0.263	
Irrigation*Fertilization	2	0.533	
Irrigation*Panelist	15	0.391	
Tillage*Fertilization	2	0.843	
Tillage*Panelist	15	0.470	
Fertilization*Panelist	30	0.321	
Irrigation*Tillage*Fertilization	2	0.062	
Irrigation*Tillage*Panelist	15	0.685	
Irrigation*Fertilization*Panelist	30	0.671	
Tillage*Fertilization*Panelist	30	0.837	
Irrigation*Tillage*Fertilization*Panelist	30	0.271	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.5: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor vegetative aroma

Vegetative Aroma			
Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.196	
Irrigation	1	0.055	
Tillage	1	0.009	b
Fertilization	2	0.883	
Panelist	15	0.000	c
Field rep*Irrigation	2	0.620	
Field rep*Tillage	2	0.146	
Field rep*Fertilization	4	0.199	
Field rep*Panelist	30	0.207	
Irrigation*Tillage	1	0.306	
Irrigation*Fertilization	2	0.007	
Irrigation*Panelist	15	0.583	
Tillage*Fertilization	2	0.241	
Tillage*Panelist	15	0.724	
Fertilization*Panelist	30	0.312	
Irrigation*Tillage*Fertilization	2	0.965	
Irrigation*Tillage*Panelist	15	0.858	
Irrigation*Fertilization*Panelist	30	0.827	
Tillage*Fertilization*Panelist	30	0.924	
Irrigation*Tillage*Fertilization*Panelist	30	0.026	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.6: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor earthy/musty aroma

earthy/musty			
Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.027	a
Irrigation	1	0.947	
Tillage	1	0.622	
Fertilization	2	0.581	
Panelist	15	0.000	c
Field rep*Irrigation	2	0.681	
Field rep*Tillage	2	0.739	
Field rep*Fertilization	4	0.170	
Field rep*Panelist	30	0.078	
Irrigation*Tillage	1	0.638	
Irrigation*Fertilization	2	0.019	a
Irrigation*Panelist	15	0.711	
Tillage*Fertilization	2	0.816	
Tillage*Panelist	15	0.961	
Fertilization*Panelist	30	0.000	c
Irrigation*Tillage*Fertilization	2	0.670	
Irrigation*Tillage*Panelist	15	0.810	
Irrigation*Fertilization*Panelist	30	0.985	
Tillage*Fertilization*Panelist	30	0.995	
Irrigation*Tillage*Fertilization*Panelist	30	0.014	a

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.7: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor flavor overall intensity

Flavor Overall Intensity			
Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.229	
Irrigation	1	0.374	
Tillage	1	0.072	
Fertilization	2	0.315	
Panelist	15	0.000	c
Field rep*Irrigation	2	0.841	
Field rep*Tillage	2	0.022	a
Field rep*Fertilization	4	0.117	
Field rep*Panelist	30	0.670	
Irrigation*Tillage	1	0.000	c
Irrigation*Fertilization	2	0.219	
Irrigation*Panelist	15	0.000	c
Tillage*Fertilization	2	0.858	
Tillage*Panelist	15	0.000	c
Fertilization*Panelist	30	0.762	
Irrigation*Tillage*Fertilization	2	0.260	
Irrigation*Tillage*Panelist	15	0.992	
Irrigation*Fertilization*Panelist	30	0.953	
Tillage*Fertilization*Panelist	30	0.954	
Irrigation*Tillage*Fertilization*Panelist	30	0.301	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.8: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor fruity flavor

Fruity Flavor			
Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.357	
Irrigation	1	0.057	
Tillage	1	0.030	a
Fertilization	2	0.217	
Panelist	15	0.013	a
Field rep*Irrigation	2	0.894	
Field rep*Tillage	2	0.557	
Field rep*Fertilization	4	0.256	
Field rep*Panelist	30	0.466	
Irrigation*Tillage	1	0.086	
Irrigation*Fertilization	2	0.315	
Irrigation*Panelist	15	0.992	
Tillage*Fertilization	2	0.909	
Tillage*Panelist	15	0.629	
Fertilization*Panelist	30	0.562	
Irrigation*Tillage*Fertilization	2	0.221	
Irrigation*Tillage*Panelist	15	0.921	
Irrigation*Fertilization*Panelist	30	0.967	
Tillage*Fertilization*Panelist	30	0.895	
Irrigation*Tillage*Fertilization*Panelist	30	0.185	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.9: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor floral flavor

Floral Flavor			
Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.921	
Irrigation	1	0.950	
Tillage	1	0.764	
Fertilization	2	0.568	
Panelist	15	0.048	a
Field rep*Irrigation	2	0.965	
Field rep*Tillage	2	0.343	
Field rep*Fertilization	4	0.400	
Field rep*Panelist	30	0.136	
Irrigation*Tillage	1	0.536	
Irrigation*Fertilization	2	0.494	
Irrigation*Panelist	15	0.414	
Tillage*Fertilization	2	0.997	
Tillage*Panelist	15	0.890	
Fertilization*Panelist	30	0.770	
Irrigation*Tillage*Fertilization	2	0.957	
Irrigation*Tillage*Panelist	15	0.577	
Irrigation*Fertilization*Panelist	30	0.573	
Tillage*Fertilization*Panelist	30	0.259	
Irrigation*Tillage*Fertilization*Panelist	30	0.240	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.10: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor spicy flavor

Spicy Flavor			
Effect	df	p-value	sig
intercept	1	0.000	c
Field Rep	2	0.842	
Irrigation	1	0.800	
Tillage	1	0.030	a
Fertilization	2	0.425	
Panelist	15	0.420	
Field rep*Irrigation	2	0.467	
Field rep*Tillage	2	0.976	
Field rep*Fertilization	4	0.727	
Field rep*Panelist	30	0.014	a
Irrigation*Tillage	1	0.253	
Irrigation*Fertilization	2	0.990	
Irrigation*Panelist	15	0.935	
Tillage*Fertilization	2	0.549	
Tillage*Panelist	15	0.684	
Fertilization*Panelist	30	0.713	
Irrigation*Tillage*Fertilization	2	0.017	a
Irrigation*Tillage*Panelist	15	0.258	
Irrigation*Fertilization*Panelist	30	0.521	
Tillage*Fertilization*Panelist	30	0.906	
Irrigation*Tillage*Fertilization*Panelist	30	0.081	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.11: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor vegetative flavor

Vegetative Flavor			
Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.082	
Irrigation	1	0.348	
Tillage	1	0.306	
Fertilization	2	0.119	
Panelist	15	0.000	c
Field rep*Irrigation	2	0.569	
Field rep*Tillage	2	0.710	
Field rep*Fertilization	4	0.265	
Field rep*Panelist	30	0.652	
Irrigation*Tillage	1	0.130	
Irrigation*Fertilization	2	0.043	a
Irrigation*Panelist	15	0.805	
Tillage*Fertilization	2	0.849	
Tillage*Panelist	15	0.953	
Fertilization*Panelist	30	0.966	
Irrigation*Tillage*Fertilization	2	0.036	
Irrigation*Tillage*Panelist	15	0.609	
Irrigation*Fertilization*Panelist	30	0.453	
Tillage*Fertilization*Panelist	30	0.251	
Irrigation*Tillage*Fertilization*Panelist	30	0.364	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.12: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor acidity

Acidity			
Effect	**df**	**p-value**	**sig**
Intercept	1	0.000	c
Field Rep	2	0.307	
Irrigation	1	0.743	
Tillage	1	0.075	
Fertilization	2	0.078	
Panelist	15	0.000	c
Field rep*Irrigation	2	0.820	
Field rep*Tillage	2	0.170	
Field rep*Fertilization	4	0.001	c
Field rep*Panelist	30	0.462	
Irrigation*Tillage	1	0.031	a
Irrigation*Fertilization	2	0.799	
Irrigation*Panelist	15	0.317	
Tillage*Fertilization	2	0.033	a
Tillage*Panelist	15	0.635	
Fertilization*Panelist	30	0.396	
Irrigation*Tillage*Fertilization	2	0.009	b
Irrigation*Tillage*Panelist	15	0.843	
Irrigation*Fertilization*Panelist	30	0.759	
Tillage*Fertilization*Panelist	30	0.942	
Irrigation*Tillage*Fertilization*Panelist	30	0.177	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.13: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor bitterness

Bitterness			
Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.161	
Irrigation	1	0.082	
Tillage	1	0.276	
Fertilization	2	0.761	
Panelist	15	0.000	c
Field rep*Irrigation	2	0.033	a
Field rep*Tillage	2	0.654	
Field rep*Fertilization	4	0.475	
Field rep*Panelist	30	0.936	
Irrigation*Tillage	1	0.025	a
Irrigation*Fertilization	2	0.069	
Irrigation*Panelist	15	0.657	
Tillage*Fertilization	2	0.243	
Tillage*Panelist	15	0.727	
Fertilization*Panelist	30	0.932	
Irrigation*Tillage*Fertilization	2	0.202	
Irrigation*Tillage*Panelist	15	0.728	
Irrigation*Fertilization*Panelist	30	0.164	
Tillage*Fertilization*Panelist	30	0.550	
Irrigation*Tillage*Fertilization*Panelist	30	0.495	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.14: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor astringency

Astringency			
Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.335	
Irrigation	1	0.556	
Tillage	1	0.776	
Fertilization	2	0.287	
Panelist	15	0.000	c
Field rep*Irrigation	2	0.725	
Field rep*Tillage	2	0.786	
Field rep*Fertilization	4	0.002	b
Field rep*Panelist	30	0.830	
Irrigation*Tillage	1	0.596	
Irrigation*Fertilization	2	0.194	
Irrigation*Panelist	15	0.288	
Tillage*Fertilization	2	0.021	a
Tillage*Panelist	15	0.386	
Fertilization*Panelist	30	0.147	
Irrigation*Tillage*Fertilization	2	0.698	
Irrigation*Tillage*Panelist	15	0.532	
Irrigation*Fertilization*Panelist	30	0.695	
Tillage*Fertilization*Panelist	30	0.681	
Irrigation*Tillage*Fertilization*Panelist	30	0.524	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 3.15: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor body

Body			
Effect	df	p-value	sig
Intercept		0.000	c
Field Rep	2	0.597	
Irrigation	1	0.446	
Tillage	1	0.036	a
Fertilization	2	0.608	
Panelist	15	0.000	c
Field rep*Irrigation	2	0.344	
Field rep*Tillage	2	0.152	
Field rep*Fertilization	4	0.675	
Field rep*Panelist	30	0.375	
Irrigation*Tillage	1	0.194	
Irrigation*Fertilization	2	0.538	
Irrigation*Panelist	15	0.000	c
Tillage*Fertilization	2	0.170	
Tillage*Panelist	15	0.711	
Fertilization*Panelist	30	0.999	
Irrigation*Tillage*Fertilization	2	0.372	
Irrigation*Tillage*Panelist	15	0.910	
Irrigation*Fertilization*Panelist	30	0.988	
Tillage*Fertilization*Panelist	30	0.934	
Irrigation*Tillage*Fertilization*Panelist	30	0.330	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.1: ANOVA table for winemaker evaluation of 2000 vintage Pinot noir wines for descriptor aroma overall intensity

Aroma Intensity

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.458	
Panelist	10	0.000	c
Panelist Rep	1	0.857	
Irrigation	1	0.420	
Tillage	1	0.439	
Fertilization	2	0.740	
Irrigation*Tillage	1	0.561	
Irrigation*Fertilization	2	0.491	
Tillage*Fertilization	2	0.301	
Irrigation*Tillage*Fertilization	2	0.224	
Irritation*Tillage*Fertilization*Panelist	110	0.000	c

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.2: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor fruity aroma

Fruity Aroma

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.559	
Panelist	10	0.000	c
Panelist Rep	1	0.145	
Irrigation	1	0.064	
Tillage	1	0.712	
Fertilization	2	0.176	
Irrigation*Tillage	1	0.082	
Irrigation*Fertilization	2	0.304	
Tillage*Fertilization	2	0.824	
Irrigation*Tillage*Fertilization	2	0.014	a
Irritation*Tillage*Fertilization*Panelist	110	0.850	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.3: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor floral aroma

Floral Aroma

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.591	
Panelist	10	0.000	c
Panelist Rep	1	0.861	
Irrigation	1	0.900	
Tillage	1	0.485	
Fertilization	2	0.035	a
Irrigation*Tillage	1	0.793	
Irrigation*Fertilization	2	0.622	
Tillage*Fertilization	2	0.733	
Irrigation*Tillage*Fertilization	2	0.065	
Irritation*Tillage*Fertilization*Panelist	110	0.966	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.4: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor spicy aroma

Spicy Aroma

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.773	
Panelist	10	0.000	c
Panelist Rep	1	0.198	
Irrigation	1	0.765	
Tillage	1	0.149	
Fertilization	2	0.642	
Irrigation*Tillage	1	0.224	
Irrigation*Fertilization	2	0.551	
Tillage*Fertilization	2	0.459	
Irrigation*Tillage*Fertilization	2	0.163	
Irritation*Tillage*Fertilization*Panelist	110	0.432	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.5: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor vegetative aroma

Vegetative Aroma

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.008	b
Panelist	10	0.000	c
Panelist Rep	1	0.015	a
Irrigation	1	0.012	a
Tillage	1	0.174	
Fertilization	2	0.253	
Irrigation*Tillage	1	0.371	
Irrigation*Fertilization	2	0.856	
Tillage*Fertilization	2	0.353	
Irrigation*Tillage*Fertilization	2	0.073	
Irritation*Tillage*Fertilization*Panelist	110	0.029	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.6: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor earthy/musty aroma

Earthy/Musty Aroma

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.527	
Panelist	10	0.000	c
Panelist Rep	1	0.620	
Irrigation	1	0.166	
Tillage	1	0.286	
Fertilization	2	0.857	
Irrigation*Tillage	1	0.422	
Irrigation*Fertilization	2	0.663	
Tillage*Fertilization	2	0.348	
Irrigation*Tillage*Fertilization	2	0.357	
Irritation*Tillage*Fertilization*Panelist	110	0.081	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.7: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor flavor overall intensity

Flavor Overall Intensity

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.449	
Panelist	10	0.000	c
Panelist Rep	1	0.977	
Irrigation	1	0.095	
Tillage	1	0.959	
Fertilization	2	0.854	
Irrigation*Tillage	1	0.447	
Irrigation*Fertilization	2	0.014	*a*
Tillage*Fertilization	2	0.636	
Irrigation*Tillage*Fertilization	2	0.368	
Irritation*Tillage*Fertilization*Panelist	110	0.408	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.8: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor fruit flavor

Fruit Flavor

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.366	
Panelist	10	0.000	c
Panelist Rep	1	0.744	
Irrigation	1	0.593	
Tillage	1	0.604	
Fertilization	2	0.150	
Irrigation*Tillage	1	0.667	
Irrigation*Fertilization	2	0.033	a
Tillage*Fertilization	2	0.359	
Irrigation*Tillage*Fertilization	2	0.149	
Irritation*Tillage*Fertilization*Panelist	110	0.716	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.9: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor floral flavor

Floral Flavor

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.673	
Panelist	10	0.000	c
Panelist Rep	1	0.821	
Irrigation	1	0.759	
Tillage	1	0.782	
Fertilization	2	0.762	
Irrigation*Tillage	1	0.841	
Irrigation*Fertilization	2	0.144	
Tillage*Fertilization	2	0.261	
Irrigation*Tillage*Fertilization	2	0.889	
Irritation*Tillage*Fertilization*Panelist	110	0.335	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.10: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor spicy flavor

Spicy Flavor

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.957	
Panelist	10	0.000	c
Panelist Rep	1	0.870	
Irrigation	1	0.369	
Tillage	1	0.111	
Fertilization	2	0.174	
Irrigation*Tillage	1	0.463	
Irrigation*Fertilization	2	0.407	
Tillage*Fertilization	2	0.009	b
Irrigation*Tillage*Fertilization	2	0.110	
Irritation*Tillage*Fertilization*Panelist	110	0.102	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.11: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor vegetative flavor

Vegetative Flavor

Effect	df	p-value	sig
Intercept	1	0.001	c
Field Rep	2	0.122	
Panelist	10	0.000	c
Panelist Rep	1	0.524	
Irrigation	1	0.133	
Tillage	1	0.759	
Fertilization	2	0.109	
Irrigation*Tillage	1	0.548	
Irrigation*Fertilization	2	0.967	
Tillage*Fertilization	2	0.020	c
Irrigation*Tillage*Fertilization	2	0.791	
Irritation*Tillage*Fertilization*Panelist	110	0.471	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.12: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor acidity

Acidity

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.546	
Panelist	10	0.000	c
Panelist Rep	1	0.338	
Irrigation	1	0.056	
Tillage	1	0.239	
Fertilization	2	0.200	
Irrigation*Tillage	1	0.625	
Irrigation*Fertilization	2	0.209	
Tillage*Fertilization	2	0.075	
Irrigation*Tillage*Fertilization	2	0.074	
Irritation*Tillage*Fertilization*Panelist	110	0.053	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.13: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor bitterness

Bitterness

Effect	df	p-value	sig
Intercept	1	0.001	c
Field Rep	2	0.040	a
Panelist	10	0.000	c
Panelist Rep	1	0.335	
Irrigation	1	0.462	
Tillage	1	0.781	
Fertilization	2	0.021	a
Irrigation*Tillage	1	0.694	
Irrigation*Fertilization	2	0.415	
Tillage*Fertilization	2	0.021	a
Irrigation*Tillage*Fertilization	2	0.201	
Irritation*Tillage*Fertilization*Panelist	110	0.420	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.14: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor astringency

Astringency

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.121	
Panelist	10	0.000	c
Panelist Rep	1	0.154	
Irrigation	1	0.601	
Tillage	1	0.144	
Fertilization	2	0.072	
Irrigation*Tillage	1	0.950	
Irrigation*Fertilization	2	0.105	
Tillage*Fertilization	2	0.095	
Irrigation*Tillage*Fertilization	2	0.364	
Irritation*Tillage*Fertilization*Panelist	110	0.611	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$

Appendix 4.15: ANOVA table for winemaker evaluation of 1999 vintage Pinot noir wines for descriptor body

Body

Effect	df	p-value	sig
Intercept	1	0.000	c
Field Rep	2	0.256	
Panelist	10	0.000	c
Panelist Rep	1	0.506	
Irrigation	1	0.059	
Tillage	1	0.196	
Fertilization	2	0.801	
Irrigation*Tillage	1	0.362	
Irrigation*Fertilization	2	0.139	
Tillage*Fertilization	2	0.859	
Irrigation*Tillage*Fertilization	2	0.074	
Irritation*Tillage*Fertilization*Panelist	110	0.223	

Significance (a) $p < 0.05$
(b) $p < 0.01$
(c) $p < 0.001$