Seasonal Dynamics of Roots, Mycorrhizal Fungi and the Mineral Nutrition of Pinot noir.

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Objectives of Research:

1) Determine when and where grapevine roots and mycorrhizal fungi are actively growing in an established vineyard block in relation to above-ground plant development.

2) Establish how seasonal nutrient concentrations in the canopy are related to root and mycorrhizal fungal development and soil nutrient levels.

ABSTRACT

The spatial and temporal development of grapevine root systems and associated mycorrhizal fungi was studied over the 1999 & 2000 growing seasons in a 20-year-old block of Pinot noir vines at Woodhall Research Vineyard. We determined the root length density of woody roots and fine roots deemed to be physiologically active (based on color and cellular integrity) at monthly intervals throughout the year. The majority of fine roots occurred within the upper 50 cm of the soil profile. Fifty-nine percent of fine roots occurred within the vine row and 31% occurred in the alley-way at 0-50 cm depth. Only 10% of the fine roots were found below 50 cm. Woody roots were more evenly distributed with 34% found between 50-100 cm depth. Fine root density did not change dramatically over the 1999 or 2000 seasons until after harvest. Apparently, new root growth kept pace with turnover (death) until after the fruit was removed, when new root growth was faster than turnover. Colonization of fine roots by vesicular arbuscular mycorrhizal (VAM) fungi was consistently high in the vine row all year long but was lower in roots growing in the alley-way. Arbuscular colonization (a measure of the "activity" of the mycorrhiza) increased throughout the growing season and did not decline until after leaf fall. Arbuscular colonization was also lower in roots from the alley-ways compared to roots from the vine rows. Relationships between mycorrhizal fungi, roots, and tissue minerals showed that fine roots alone supplied the majority of N, P, & K needed by the canopy in June and July. Minerals were re-allocated from stored reserves in fine roots during this time. In August and September, when roots had high levels of VAM activity and soil minerals were at higher concentrations, the supply of minerals to the shoot came from root uptake. After harvest, mineral uptake from soil continued resulting in the accumulation of reserves for the next year. The extent of the post harvest activity below-ground and the quantity of minerals taken up after harvest appears to be dependent on the length of time between harvest and leaf-fall and on the extent of autumn rains.

INTRODUCTION

The role of VAM fungi in the growth and nutrition of grapevines is largely unknown. Past work has shown that grapevines are heavily colonized by VAM fungi (Possingham & Obbink 1971, Schubert & Cravero 1985, Schreiner unpublished) and that VAM fungi are necessary for grapevine survival in fumigated soils (Menge et al.1983). Little is known, however, about the

timing and spatial development of mycorrhizal fungi in grape roots over the growing season, and how these beneficial fungi influence grapevine performance under field conditions. In addition, little is known about the spatial and temporal dynamics of grape root development and the acquisition of minerals by grapevines grown in Oregon. This knowledge will provide information to better manage the below-ground ecosystem of vineyards to maximize plant health and produce high quality winegrapes.

METHODS

The study took place within the Pinot noir maturity block (C block) at Woodhall Research Vineyard in Alpine, OR. This site was chosen because the soil is representative of many Oregon vineyards, and because this block is managed as a commercial vineyard. We monitored root and VAM-fungal development in the topsoil (approximately 0-50 cm) and the subsoil (50-100cm) both within and between the vine rows at monthly intervals from April through December. We confined our alley-way samples to those that were tilled the year before (power-spader tillage to approximately 30 cm depth in every other alley-way) to avoid possible tillage effects on roots and mycorrhizae that would have occurred during the season. Vine growth parameters, leaf nutrient levels, root nutrient levels, and soil nutrients were determined at different times during the season. Data were collected from 4 replicate blocks of 10 vines each.

Below-Ground Variables

Root and soil samples were obtained with a soil corer (3.1 cm diameter), capable of sampling to a depth of one meter. Six cores (1999) or ten cores (2000) per replicate block were pooled and used as a single replicate at each sampling date. Samples were taken from within the vine row (sprayed with roundup in April) and from the alley-way between vine rows. Samples were further divided into 0-50 cm and 50-100 cm depths in the laboratory. Grape roots were hand-sorted from the soil and separated from weed roots based on color and morphology. Primary (fine) and woody root length, the extent of primary roots colonized by VAM fungi, and the lengths of external hyphae were determined using a combination of microscopic procedures (Schreiner & Bethlenfalvay, 1996). Soil moisture was measured gravimetrically. Soil samples collected in May (1999, 2000) and in August (2000) were analyzed for pH and available mineral contents. During the 2000 season we collected large quantities of primary root and small diameter (0.5-3 mm) woody root tissue from June through December to determine mineral concentrations. Roots collected for mineral tests were obtained from 2-4 vines per replicate sample (0-50 cm depth) by hand. Four replicate samples were analyzed at each sample date.

Above-Ground Variables

The timing of budbreak, bloom, veraison and harvest was noted to the nearest day. Cane lengths were measured from June through August. Leaf samples were collected from each ten-vine replicate set at random positions in the canopy from June through October and analyzed for mineral nutrient concentrations. Fruit yield was measured at harvest. The total fresh and dry biomass of leaves and petioles per vine were estimated on September 19, 2000 by defoliating four randomly selected vines within the block.

Soil and Plant Tissue Nutrient Analysis

Plant tissue and available soil mineral concentrations were determined by the Central Analytical Laboratory (Oregon State University) using standard procedures. Soil test variables measured included pH, NH_4, NO_3, P, K, Ca, Mg, Zn, Mn, Fe, Cu, and B. Leaf and root tissues were analyzed for N, P, K, Ca, Mg, Zn, Mn, Fe, Cu, and B.

Data Analysis and Modeling of Mineral Allocation

Data were analyzed by ANOVA at each sampling time, and means were compared using Fisher's protected LSD. Leaf and root mineral contents (June-Dec, 2000) for N, P, K, Ca, & Mg were calculated by multiplying tissue concentration by the estimated dry mass of the given tissue. Dry mass estimates for leaves, petioles, and clusters at each sampling time were obtained by fitting our final dry mass values measured in 2000 into a published dry matter accumulation model for grapevines (Mullins et al. 1992). Dry mass estimates for fine and small diameter woody roots were derived from the two-year means of this study. Published values were used to estimate cluster mineral concentrations (Williams & Biscay 1991, Winkler et al. 1974). Shoot demand for each element was defined as the change in total mineral content (concentration x dry mass) of leaves, petioles and fruit per vine between two sampling dates. Root export for each element was similarly defined as the negative change in mineral content of fine roots per vine between sampling dates.

RESULTS

Climate

There were significant differences in weather patterns between 1999 and 2000. Rainfall prior to budbreak was higher in 1999, while rainfall in May and June of 2000 was 1.4 inches greater than that of 1999. Rainfall from July through October was very similar in both years, but rainfall was again greater in 1999 after harvest. More importantly, temperatures were very different between the two years of this study. Both soil and air temperatures recorded at Hyslop Farm in Corvallis showed a much warmer spring and early summer in 2000, as compared to 1999 (Fig. 1). Warmer temperatures in 2000 resulted in an accumulation of ~200 more Growing Degree Days (°F base 50) by July, compared to 1999.

Soil Nutrient Availabilities

Analysis of the available soil nutrients in May 1999 showed that most macro- and micro-nutrients occurred within the upper 50 cm of the soil profile, and that mineral concentrations in soil were generally higher in the vine row than in the alley-way. Magnesium was the only nutrient evenly distributed throughout the soil profile (1999, data not shown). In 2000, we examined plant-available minerals from 0-50 cm depth in May and in August. Our analysis showed that soil P availability was much higher in August than in May, which is most likely due to increased turnover of organic P by the soil micoflora (Table 1). Soil Cu, Zn, Fe, and Mn, were also at higher concentrations in August as compared to May (Table 1).

Table 1. Soil Nutrient Availabilities at Woodhall in 2000

Sample Date	pH	NH_4 ppm	NO_3 ppm	P ppm	K ppm	Ca meq
May 1	5.6	2.5	4.5	14	174	2.3
Aug. 1	5.6	4.0	5.1	31	173	2.4
ANOVA sig. level (p)	ns	ns	ns	0.018	ns	ns

Sample Date	Mg meq	Fe ppm	Mn ppm	B ppm	Cu ppm	Zn ppm
May 1	0.62	15	5	0.62	0.65	0.41
Aug. 1	0.58	33	12	0.85	2.70	1.37
ANOVA sig. level (p)	ns	0.003	0.005	ns	0.001	0.012

Root Distribution and Density

We obtained a robust measure of where the roots were in relation to soil depth and location in both years of our study. The distribution of roots averaged over two growing seasons (18 sampling dates) showed that 59% of the fine roots occurred in the vine row and 31% occurred in the alley-way at the 0-50 cm depth (Table 2). Only 10% of the fine roots occurred below 50 cm. This is logical given that most of the available nutrients were also in the upper part of the profile. Woody roots were more evenly distributed in relation to depth and location than the fine roots (Table 2). Data between 1999 and 2000 was very consistent, varying less than 4% at any given location between years.

Table 2. Relative Distribution of Roots in the Soil Profile at Woodhall April 1999 - December 2000 (n=72).

Location	Woody Roots (%)	Fine Roots (%)
Vine row 0-50cm	39	59
Vine row 50-100cm	23	6
Alley 0-50cm	27	31
Alley 50-100cm	11	4

Root density measurements for a particular sampling date showed large variation in 1999. We hoped to increase our precision in 2000 by including more cores per replicate sample. Variability was decreased in 2000 (see Fig. 2), but measurement error was still relatively high. Fine root density did not change dramatically in either year until after harvest (Fig. 2). We interpret these results as follows; the growth of new fine roots generally keeps pace with the death of existing fine roots until after harvest, when increased carbon flow to the root system produces new roots faster than they turnover.

Fine root densities between 1999 and 2000 showed 2 major differences (Fig 2). Fine root densities prior to veraison were greater in 1999, while fine root densities after veraison were greater in 2000. These differences are most likely due to the weather and to the prior years post harvest growth period. Greater root density in the early part of 1999 was due to a longer post harvest growth period in 1998 (fruit was harvested on September 28, 1998). A late harvest in 1999 (October 16) coupled with high rainfall in November reduced post harvest root growth. The low root density from 1999 was carried over to the early part of 2000, but the warmer weather

and earlier harvest in 2000 (October 4) resulted in a larger post harvest growth of roots. I suspect that the beginning of the 2001 season will show a pattern more like 1999, which followed an earlier harvest year.

Mycorrhizal Colonization of Roots

The seasonal changes in root colonization by mycorrhizal fungi were consistent from year to year. The presence of VAM fungi in fine roots was high (70-90%) all year for those roots growing in the upper 50 cm of soil in the vine row (Fig. 3). Roots growing in the alley-way, that had been tilled the previous year, were not as heavily colonized as those in the vine row, except late in the 2000 season. Fine roots growing below 50 cm were not as heavily colonized as roots in the topsoil (Fig. 3).

The activity of VAM fungi in roots (arbuscular colonization) showed much greater variation than the mere presence of the fungi in roots. In both years arbuscular colonization increased from essentially zero in February to high levels by June or July (Fig. 4). Arbuscular colonization remained at high levels until after leaf fall in November (Fig. 4). Small differences in arbuscular colonization were found between 1999 and 2000. Arbuscular colonization rose more quickly in 2000 (most likely a result of the warmer temperatures, and greater carbon flow to the roots system) and stayed at a high level well into the month of December (due to a longer and drier post harvest period) compared to 1999. Levels of arbuscular colonization were again lower in the alley-way as compared to the vine row. These data show that roots growing in the vine row are playing a more important role in nutrient uptake by vines in this vineyard and that tillage is reducing mycorrhiza formation in the alley-way.

The length of VAM hyphae outside the roots did not change dramatically over the 1999 growing season and these data were not collected in 2000. The average values of VAM hyphae over three sampling dates in 1999 were 13.3 m/cc soil in the vine row at 0-50 cm depth, 1.3 m/cc soil in the vine row at 50-100 cm depth, 5.8 m/cc soil in the alley-way at 0-50 cm depth, and 1.0 m/cc soil in the alley-way at 50-100 cm depth. The length of VAM hyphae in soil is ~20,000 times greater than the length of the fine roots.

Leaf and Root Nutrient Dynamics

Leaf nutrient concentrations were measured from June-October in both years and results were essentially identical. N and P concentrations were highest at the beginning of the season and declined dramatically over the summer (Fig. 5). The opposite trend occurred for Ca and Mg, while K concentrations in leaves showed little change over the season (Fig. 5). Note that P and Mg are represented on a different scale from N, K, and Ca. Leaf micronutrients B, Zn, and Cu showed small changes over the season, while Fe and Mn increased late in the season (data not shown). Changes in the root mineral concentrations over the course of the season were very striking (Fig. 6). N, P, and K concentrations in roots were at high levels on June 1, but declined precipitously by July or August. Mg concentration in fine roots also declined over the summer months but not as dramatically as N, P, and K. Calcium concentrations increased over the summer in roots (Fig. 6).

The large changes in root mineral concentrations that occurred over the season prompted an examination of the allocation of minerals within the canopy and root system of these vines. A nutrient budget for macro-elements was constructed based on changes in total mineral contents of the shoot and root system (excluding the permanent wood and fruiting canes). Shoot demand and

root supply for P and K are shown in Figures 7 & 8. For both P and K, the supply of minerals that left the root system between June 1 and July 1 far exceeded the demand for these minerals in the canopy. Root K supply from roots continued to exceed shoot demand through the end of July. It is not until August and September that root supply of P and K to the shoot must largely come from soil uptake. Summarizing these mineral budgets from June 1 to the time of fruit harvest showed that fine root re-allocation of stored minerals could account for 37% of shoot P, 52% of shoot K, and 26% of shoot N. Ca and Mg were apparently not supplied to the shoot from stored reserves in fine roots.

After harvest, we compared nutrient concentrations between senescent (yellow) and healthy (green) leaves that were still attached to the canes to determine which nutrients were actively re-absorbed from leaves for storage. In 1999, N and K had significantly lower concentrations in senescent leaves, thus demonstrating active remobilization from leaves. In 2000, N and P were lower in senescent leaves, but K was not. Therefore, N, P, and K appear to be the only minerals that are actively remobilized from the leaves before abscission, with N given priority over P and K. Other mineral elements must be recycled through soil as leaves fall and are degraded over time.

The fruit yield from this block of Pinot noir averaged 2.73 and 2.78 kg per vine in 1999 and 2000, respectively. This is equivalent to 2.4 tons per acre. Differences in the yield between replicates within the block were significant in both years. Yield within our 4 replicates in 1999 was correlated to the season-long average root length ($r=0.998$), the season-long average arbuscular root length ($r=1.0$), the number of fruiting canes per vine ($r=0.993$), and the average cane lengths in July ($r=0.996$).

CONCLUSIONS

Functional roots of mature grapevines growing in a red-hill soil mostly occur in the upper ½ meter of the soil profile within the vine row. The activity of VAM fungi within roots increases prior to budbreak, reaches a maximum in June, and stays at high levels until well after harvest. Tillage reduced VAM colonization of roots growing in the alley-ways, but since tillage also reduces competition from other plants, increases soil temperatures, and releases minerals, the negative impact on VAM in the alley-ways was probably not detrimental to the vines. Modeling the mineral nutrition of whole vines suggest that fine roots are taking up N, P, and K late in the summer and after harvest, storing these minerals over-winter, and re-allocating these reserves to the shoot the following spring and early summer. Uptake of minerals from soil may not occur until July or August when soil availability increases. Nutrient uptake from soil after harvesting fruit is probably more critical to the next year's growth than previously thought.

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Figure 1. Monthly Average Air and Soil Temperatures in 1999 & 2000

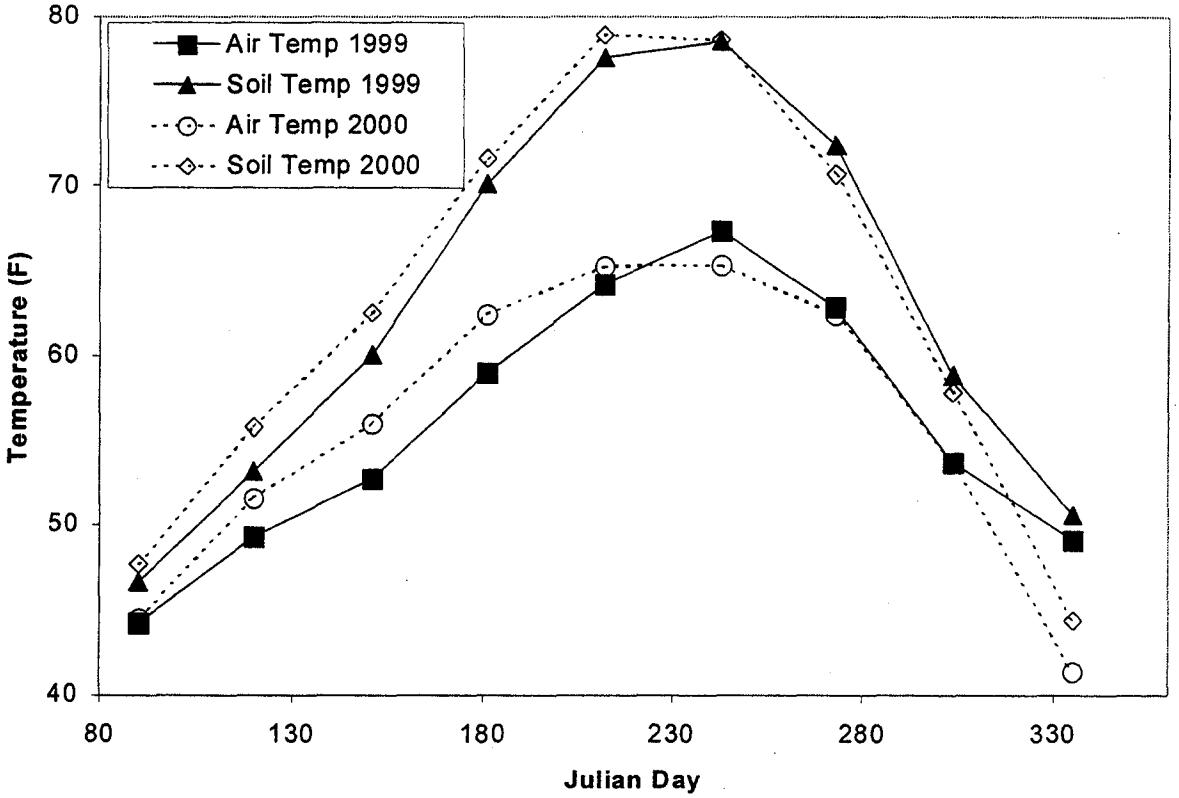

Figure 2. Fine Root Density of 20 yr Pinot noir Vines in 1999 & 2000

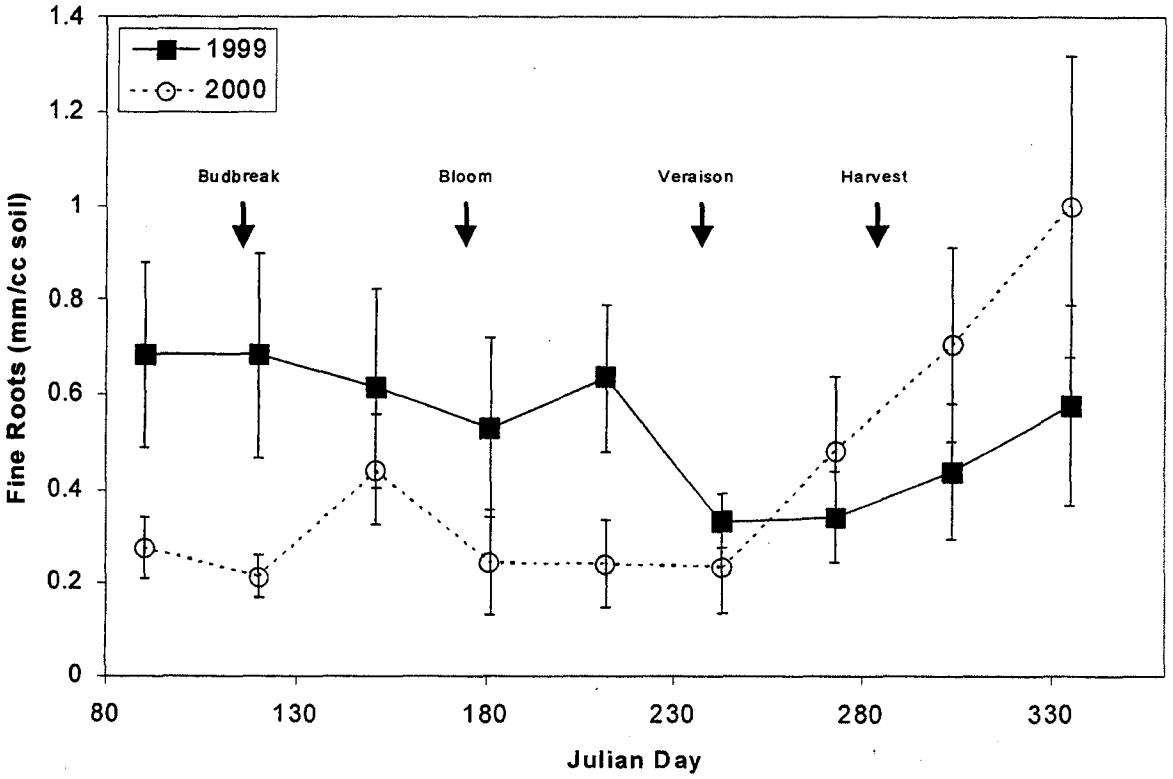

Figure 3. Changes in Total VAM Colonization at Woodhall 2000

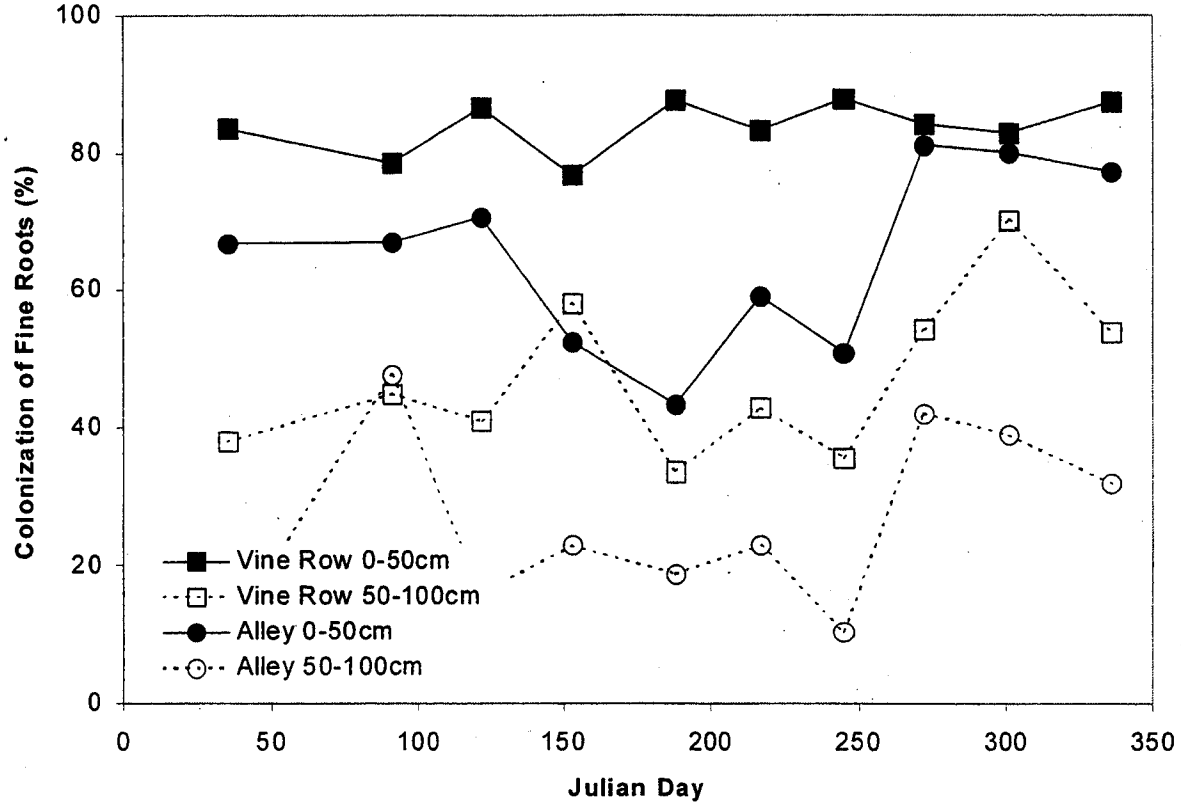

Figure 4. Changes in Active VAM Colonization at Woodhall 2000

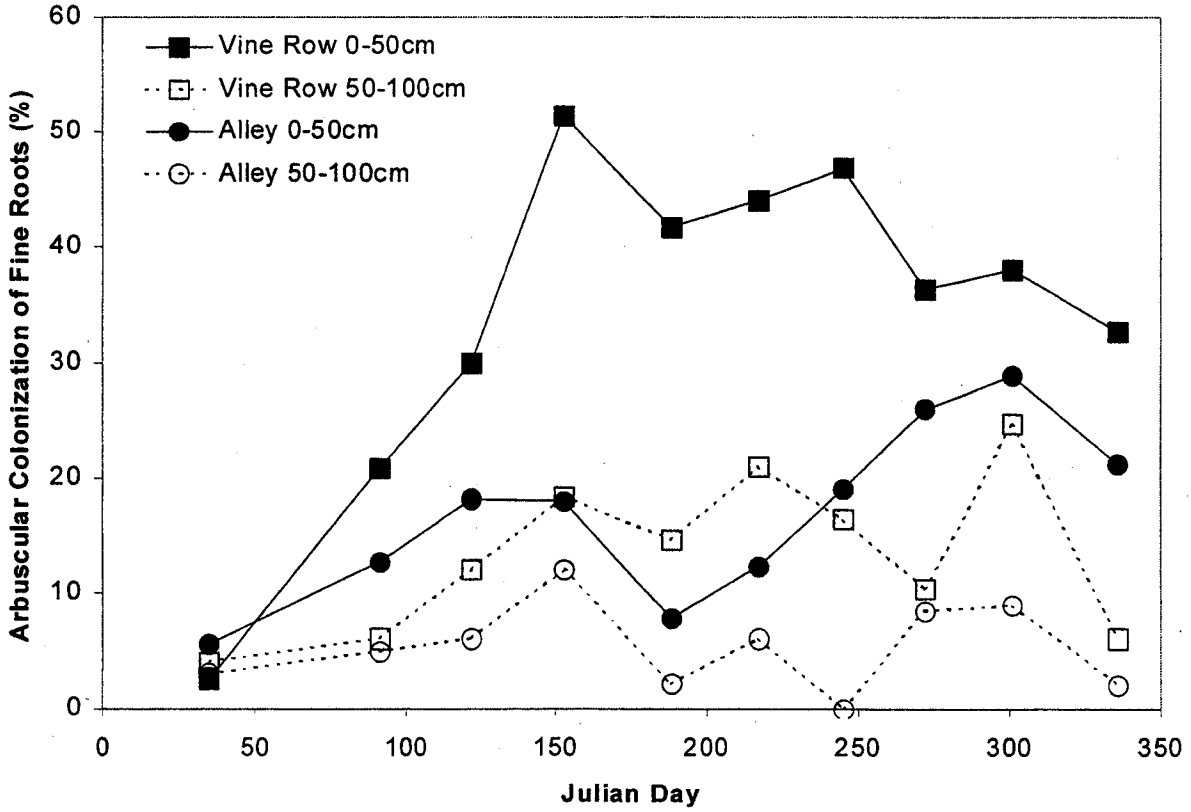

Figure 5. Changes in Leaf MacroNutrients at Woodhall 2000

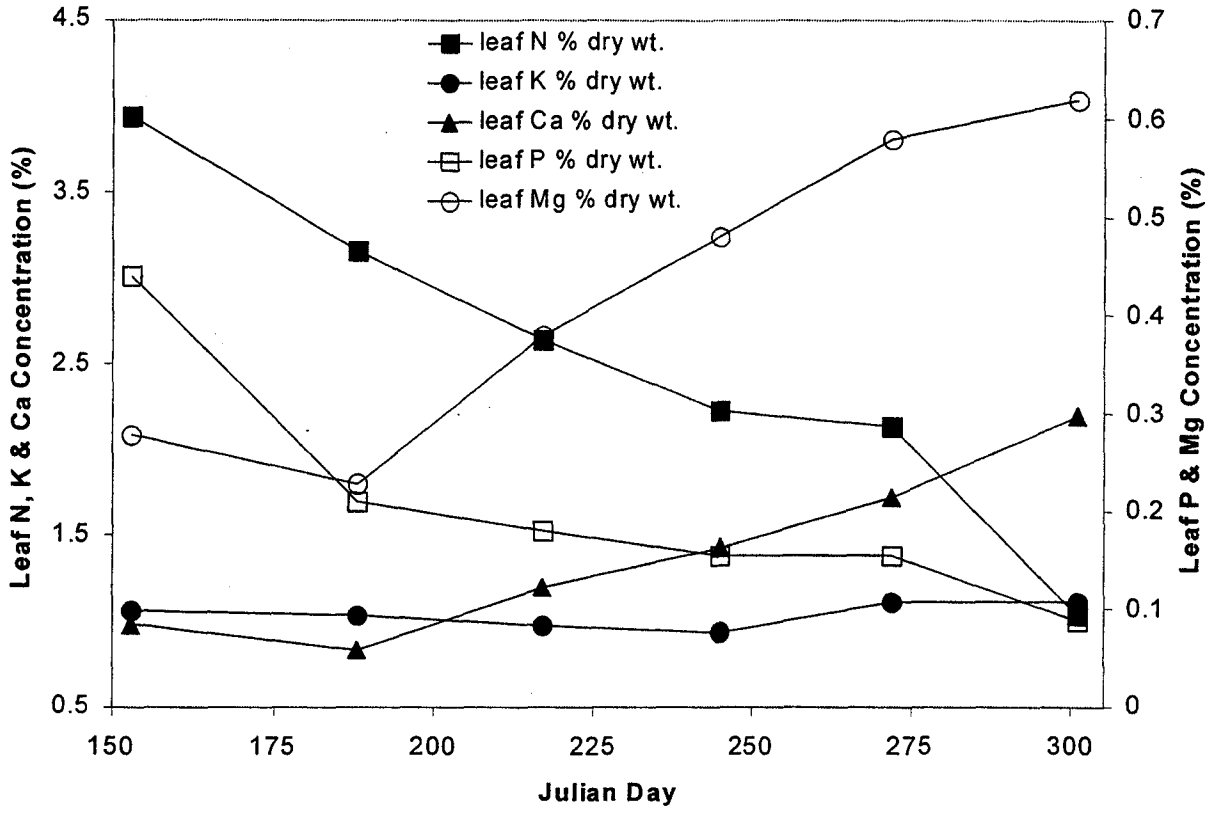

Figure 6. Changes in Fine Root Macronutrients at Woodhall 2000

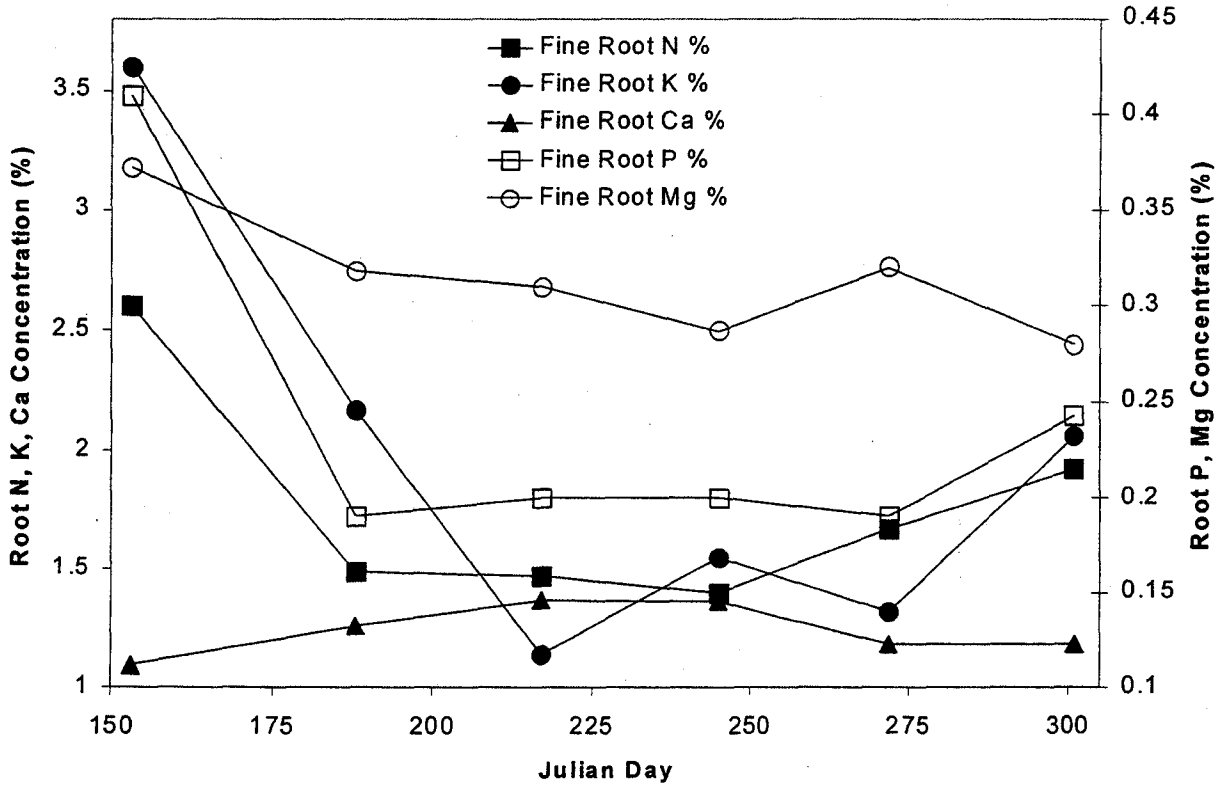

Figure 7. Phosphorus Allocation in Pinot noir Vines at Woodhall 2000

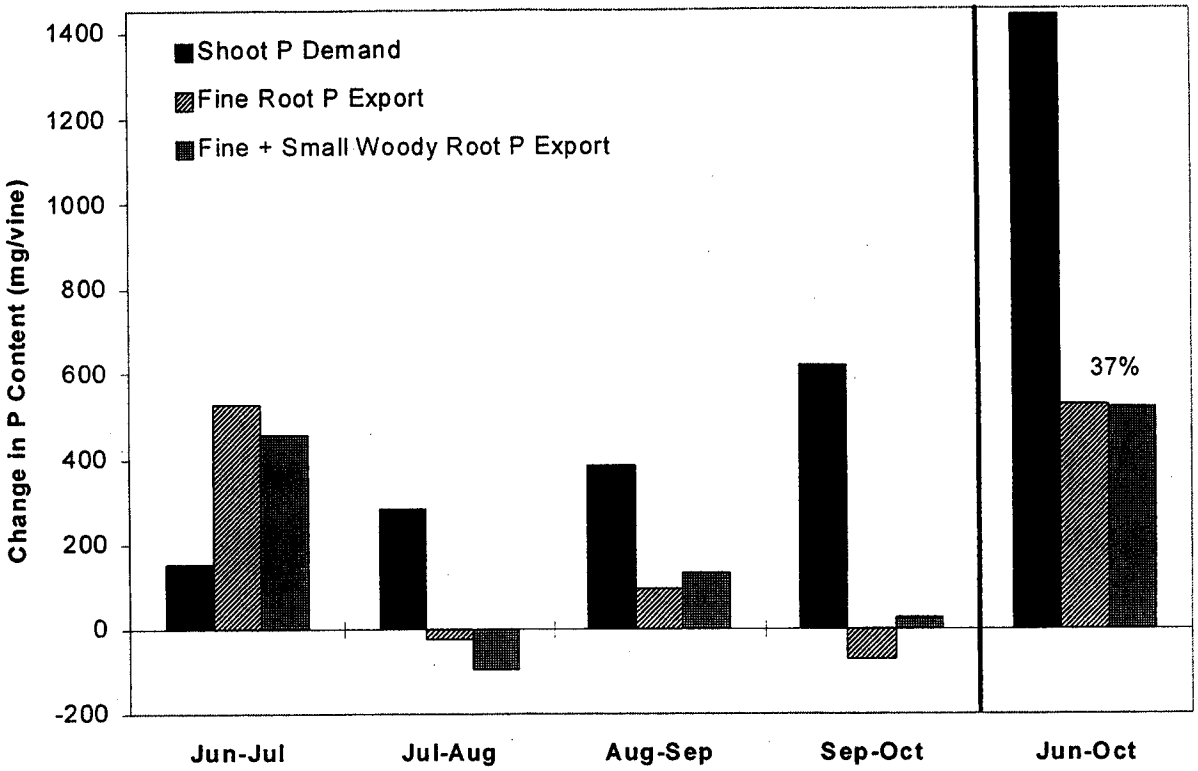

Figure 8. Potassium Allocation in Pinot noir Vines at Woodhall 2000

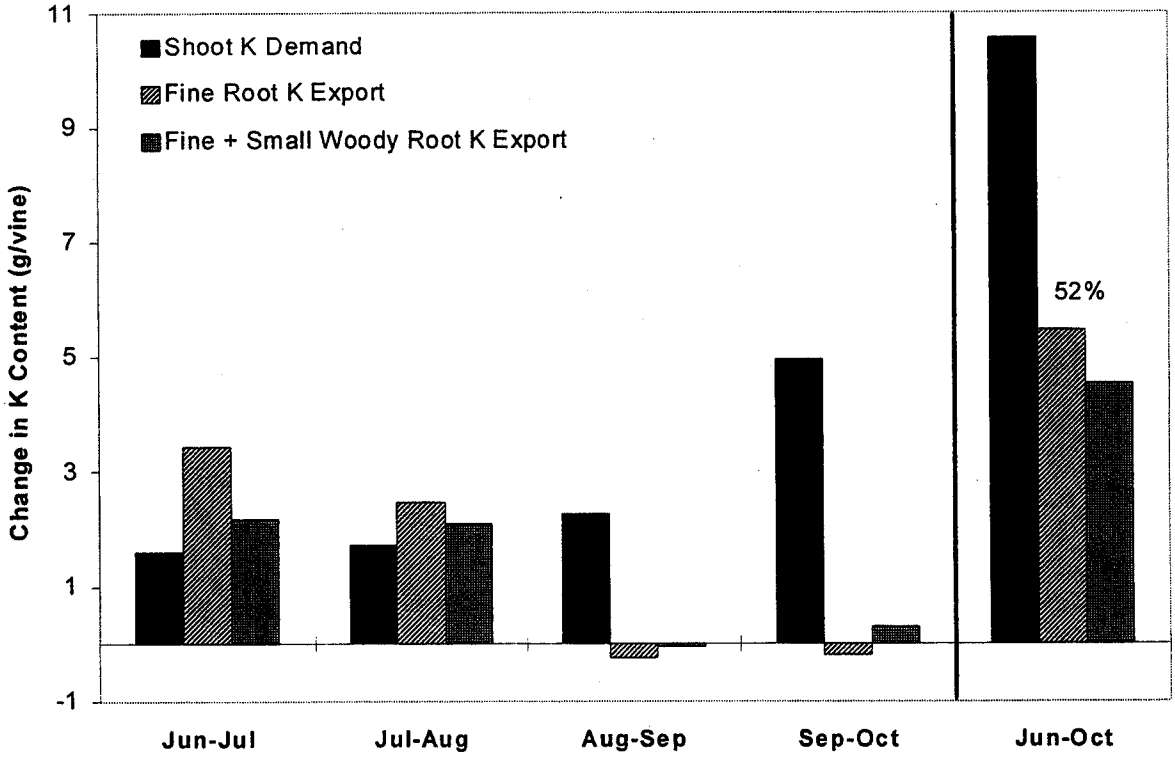

Figure 9. Average Fine Root Density and Active VAM Colonization in Pinot noir Vines over 2 Seasons at Woodhall