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Seasonal dynamics of mineral uptake and allocation in whole Pinot noir vines in a red-hill soil.

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Objectives of Research:

1) Construct a whole-vine dry matter and mineral allocation budget for mature grapevines grown in Jory (basaltic parent material) soil.
2) Determine the associated seasonal dynamics of plant-available soil minerals.
3) Model the timing of uptake and allocation of mineral nutrients in different vine tissues.

Introduction

Our current understanding of the mineral nutrition of grapevines is based largely on two types of prior studies. The first type are studies based on broad sampling of the mineral concentrations of grapevine petioles or leaves which are then normalized to establish high and low values for each mineral (Winkler et al. 1974, Christensen 1984, Cummings 1977). Often, this type of information is not associated with any physiological measurements and provides a reference only to identify extreme levels (high or low) of various mineral nutrients. The second type of studies directed at understanding mineral nutrition of grapevines are based on dry matter and mineral allocation patterns of whole vines grown in pots (Conradie 1988, Varnai et al. 1985) or in the field (Araujo & Williams 1988, Hyroyasu 1961, Williams & Biscay, 1991). These studies often do not agree as to when grapevines are taking up various minerals from soil or how those minerals are allocated within different vine tissues. The differences between these studies (and others not mentioned) can be explained by numerous factors including the age of vines used, differences in plant genotype and soils, the time of sampling, fertilizer treatments, etc. In addition, the field studies conducted to date have not taken into account the role of fine roots, because fine roots are extremely difficult to retrieve from soil. Data that we collected from this Pinot noir block in 2000 showed that fine roots can be important in storing minerals in grapevines in addition to their role in uptake (Schreiner, 2001). However, our findings were based only on nutrients in leaves and roots. A more careful mineral budget for whole grapevines (including all of the different vine tissues) grown under Oregon conditions was needed.

Methods

Objective 1). Whole vine mineral budgets were determined by destructively harvesting vines at 7 dates during the season. The vines used in the study were 21-yr-old Pinot noir vines in C block at Woodhall Research Vineyard. Vines were harvested at budbreak, at monthly intervals up to harvest, and again after leaf-fall. The following tissues were separated by hand and analyzed to determine dry matter and mineral concentrations after oven drying entire tissues or sub-samples thereof: 1) fine roots (primary roots with cortex), 2) small woody roots 1-4 mm diam., 3) large woody roots >4 mm diam., 4) vine trunks (below ground and above ground pooled), 5) fruiting canes (1 yr wood), 6) new canes (green), 7) leaf blades 8) petioles, and 9) flowers or fruit clusters (including stems). Four replicate vines were harvested at each sample date.

Roots were estimated for each vine by collecting those roots in 50 cm square soil blocks dug to a depth of 70 cm. Four soil blocks were dug around each vine at random locations within

each of four defined locations (1 in the vine row adjacent to the trunk, 1 in the vine row removed from the trunk, and 2 in the alleyway). Large and small woody roots were easily extracted from the soil, while fine roots were first hand-picked from the soil followed by extraction from soil sub-samples using a flotation technique at the lab. In this way we could estimate the fine roots that were missed by our hand-picking method in the field. Only those roots that were deemed to be physiologically active were included in our analysis. Woody roots were examined for the presence of a healthy, white cambium. Fine roots were examined for both color (white to brown) and turgor. All plant tissues were stored in air-tight, plastic bags after oven drying and submitted in bulk to the OSU central analytical lab for mineral concentration determinations. The following minerals in plant tissues were analyzed: N, P, K, Mg, Ca, Fe, Zn, Cu, B, and Mn.

Objective 2). Soil samples were collected just prior to sampling vines using a soil core sampler (12 cores per replicate, mixed and pooled) to a depth of 50 cm. Soil samples were air-dried, stored in plastic bags, and submitted in bulk to the OSU central analytical lab for analysis of the following mineral availabilities: NO_3, NH_4, P, K, Mg, Ca, Fe, Zn, Cu, B, and Mn.

Objective 3). Modeling the timing of mineral uptake and allocation within various tissues of vines was accomplished by calculating the mineral contents for each element (dry matter × concentration) at each sampling time. Mean values for tissue dry mass and mineral concentration were used to determine the content of each mineral within each tissue. Canopy demand at different times was calculated from the change in combined mineral contents of the green canes, leaves & petioles, and fruit. Actual vine uptake from soil was determined from the change in total vine content between harvest dates. Rates for canopy demand and total vine uptake were calculated by dividing the change in content by the number of days between harvests.

Results

Dry matter partitioning among the different tissues of Pinot noir from budbreak to leaf-fall are shown in **Figure 1**. All of the above ground tissues with the exception of the trunks showed significant changes in dry matter as the season progressed. Dry matter within the three different classes of roots did not significantly change over the course of the season. This was probably a result of the large variance in vine size within this block, as can be seen in the size of the standard error bars in the above-ground tissues as well (**Fig. 1**). Nonetheless, the root dry mass results support our earlier findings in this block (Schreiner 2000, 2001 - using a coring approach to estimate root lengths), suggesting that little real change in functioning roots are occurring in this older block of Pinot noir vines. In ecological terms, the "standing crop" of roots in this vineyard is not changing, which is reasonable considering how the growth of grapevines are controlled by pruning.

Changes in the concentrations of various minerals within different vine tissues were highly significant and in many cases much less variable than the dry matter. While there were minor differences in the concentrations of various minerals in fine roots and leaves this year as compared to 2000, the trends were the same for all minerals examined. Unfortunately, there is too much data to present in this report. Concentration data for each mineral in each tissue will be available for those who are interested at the following website: www.ars-grin.gov/hcrl/plantphys.htm (follow links to Schreiner and 2001 Pinot noir Nutrient Budget).

The results of the analysis of variance for each mineral concentration within each tissue are shown in **Table 1**. These results show which mineral concentrations in specific tissues significantly changed over the season (p-values below 0.05 are considered significant). For example, all minerals tested in fine roots significantly changed in concentration except Ca, Mg and Cu. Therefore, fine roots did not store significant quantities of Ca, Mg or Cu, because biomass also did not change. Since mineral contents are based on both biomass and concentration, if neither changes over the season, then there is no net movement into or out of the given tissue. If either concentration or dry mass changes, then there is a significant movement of that mineral in or out of the given tissue.

Movement of macroelements into the canopy and their uptake from soil over the course of the season are shown in **Figure 2**. The plots for each mineral show the rate of movement to the canopy (defined as canopy demand) and the rate of uptake into the whole vine. The interpretation of these plots is straightforward. When the demand curve is greater than the uptake curve, the difference represents re-allocation from stored reserves. N, P, K and Mg were re-allocated from stored reserves up until about veraison when the canopy demand for these nutrients was high. When the two curves are the same, as was the case for Ca, then none of the canopy needs were supplied from stored reserves. Uptake for most macroelements was very closely tied with canopy demand. N and P were taken up earlier in the season peaking near bloom, while K, Ca, and Mg uptake was extended closer to veraison. This makes sense for K because there is a relatively high demand for K in fruit (relative to other tissues) compared to N and P, which are needed more in the leaves. Ca and Mg concentrations in the fruit remained low up until harvest. It is unclear whether the increase in Ca and Mg in the leaves and/or petioles that developed towards the end of the season represents vines attempting to reach concentrations that are "normal", or whether Ca and Mg accumulation late in the season is at luxury levels. The case with Ca is interesting because it's movement into the fruit becomes restricted during the ripening period, as Ca movement within plants is restricted to xylem transport. If fruit quality is (in any way) limited by low Ca concentrations, then increasing fruit Ca would most likely require a greater Ca supply early in the growing season, when the developing fruit is still transpiring.

Uptake of microelements Fe, Mn, B, Zn, and Cu in whole vines could not be accurately determined from our data because their concentrations simply varied too much within different replicate vines harvested on different dates. These data are available at the website mentioned above.

A summary of canopy demand and whole vine uptake of macroelements is shown in **Table 2**. We have expressed this data on a pound per acre basis. Canopy demand for K was greater than any other macroelement, and the vast majority of vine K came from soil uptake. Nitrogen was needed in second greatest quantity, but a very large proportion of N came from reserves. Calcium was needed in third greatest quantity and essentially all Ca came from uptake. Mg and P were needed in least quantity and were mostly taken up from soil. Approximately 11 pounds of K, 6 pounds of N, 1 pound of P & Ca, and a half-pound of Mg per acre were lost from the vineyard with the fruit. After harvest, about 8 pounds per acre of N was remobilized from leaves and petioles before leaf fall.

Table 3 summarizes the relative importance of the trunk and various roots in supplying minerals from stored reserves. The data are presented from budbreak to veraison because some re-charging of these tissues had begun even before harvest. Overall, the trunk was probably most important in storing macroelements. The trunk was particularly important in re-allocating K and Mg. Large woody roots were most important in re-allocating N and P with no re-allocation of K,

while fine roots were responsible for almost half of the K re-allocated to the canopy. Small woody roots did not play a significant role in storage and re-allocation of macroelements.

Changes in the availability of minerals in soil over the season are shown in **Table 4**. Only NO_3, NH_4, Mn, and B had significantly changed over the 2001 season. Our findings this year were not consistent with soil analysis in 2000. In 2000, we found a significant increase in the soil availabilities of P, Fe, Mn, Cu, and Zn within the vine row soil as the season progressed (Schreiner 2001). Unfortunately, we did not separate vine row soil from alley soil in this study. The most interesting finding from our soil analysis in 2001 was that soil NO_3 availability over the season was correlated to times of whole-vine N uptake (**Figure 3**). These results support findings from other studies showing that nitrate is the preferred nitrogen source for grapevines (Mullins et al. 1992).

Changes in leaf and petiole nutrient concentrations over the growing season are shown in **Figure 4**. There were very large differences between leaf and petiole concentrations for 8 out of 10 of the minerals examined. In addition, some elements rise in concentration while others fall as the season progresses. The take home message from these data is that the choice of tissue type (leaf or petiole) and the best time to sample grapevines in Oregon for routine nutritional evaluation are clearly different for different minerals. For example, it does not make sense to evaluate N and P early in the season (bloom) because there are potentially luxury levels at this time, while examining Ca and Mg at bloom is appropriate because they seem to be limited at this time. In addition, the accumulation of some nutrients in petioles (Mg, Mn, Zn) and others in leaves (Ca, Fe) shows that relying on one tissue type may be problematic. The erratic levels of K that occurred in petioles over the season suggest that petioles are not an appropriate tissue for evaluating K nutrition in vines. Leaf blade samples ought to be the tissue of choice in evaluating grapevine nutrition, since leaves are the primary working organ of the canopy.

Conclusions

Uptake of macroelements was generally tied with canopy demand. N was taken up early in the season (peaking near bloom), while P, K, Ca, and Mg were taken up a little later in the season (peaking between bloom and veraison). Nitrogen showed the largest dependence on stored reserves, both in supplying N to the developing canopy and in re-capturing N from leaves prior to leaf-fall. In addition, N was the only mineral to be taken up in significant quantity after harvest. Supply of P and Mg from stored reserves was also important, particularly before bloom when canopy demand exceeded uptake. Reserves of K and Ca were less important in supplying canopy needs. The most important reserve tissue for N and P was the large woody roots, followed by the trunk. The trunk was most important in supplying reserves of K and Mg, although fine roots also re-allocated significant K and P to the canopy. Identifying which mineral nutrient was limiting the growth of these vines was not possible, even though we have spent significant time in the attempt to do so. There is clearly a need to define critical values for mineral concentrations in grapevines which are based on physiological performance and ultimately fruit quality.

Literature Cited:

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Table 1. Significance of sampling date on tissue nutrient concentrations in 21-yr-old Pinot noir vines at Woodhall, OR 2001 (n=4). Specific tissue nutrient concentrations throughout the 2001 season are available at www.ars-grin.gov/hcrl/plantphys.htm follow links to Schreiner and 2001 Pinot noir Nutrient Budget.

Plant Tissue	N	P	K	Ca	Mg	Fe	Mn	Cu	B	Zn
Fine Roots	0.001	0.004	<0.001	0.630	0.448	<0.001	<0.001	0.552	0.001	0.008
Sm. Woody Roots	0.011	0.495	0.195	0.114	0.327	0.008	0.405	0.219	<0.001	0.137
Lg. Woody Roots	0.037	0.237	0.889	0.034	0.871	0.019	0.366	0.212	0.002	0.266
Trunk	0.019	0.089	0.001	0.085	0.018	0.001	0.063	0.382	<0.001	0.544
Woody Canes	<0.001	0.002	<0.001	<0.001	<0.001	0.096	0.005	0.016	<0.001	0.785
Green Canes	<0.001	<0.001	<0.001	0.063	<0.001	0.066	0.019	<0.001	<0.001	<0.001
Petioles	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Leaves	<0.001	<0.001	<0.001	<0.001	<0.001	0.673	<0.001	<0.001	<0.001	<0.001
Clusters	<0.001	<0.001	<0.001	<0.001	<0.001	0.094	<0.001	<0.001	<0.001	<0.001

Table 2. Summary of Macronutrient Use in 21-yr-old Pinot noir vines at Woodhall, OR 2001. Data were calculated from mean dry mass and mean concentration values and are reported in **pounds per acre**.

Element	Canopy Demand by Harvest	Uptake from soil by Harvest	Fruit Losses	Re-Allocation from leaves	Uptake from soil after Harvest
N	25.8	12.7	5.9	7.9	1.0
P	2.8	2.3	1.0	0.6	-0.3
K	28.0	26.6	10.8	1.8	0.8
Ca	21.8	21.3	1.0	-0.4	-0.7
Mg	7.4	6.2	0.6	0.1	0

Table 3. Relative Contribution of Root Tissues and Trunk in Supplying Macroelements from Stored Reserves. Data were calculated from the change in mineral content from budbreak to veraison in each tissue divided by the total content re-allocated to the canopy.

	% Nutrient Remobilized to Canopy by veraison				% of Total Demand
Nutrient	Fine Roots	Sm. Woody Roots	Lg. Woody Roots	Trunk	Re-allocated to Shoot
N	13.3	13.9	47.2	25.5	51.0
P	25.0	0	45.8	29.2	27.0
K	45.3	0	0	54.7	10.5
Mg	3.5	0	9.6	86.9	17.8
Ca	8.9	0	27.8	63.3	2.0

Table 4. Mean Nutrient Availabilities in Soil (0-50 cm) at Woodhall, OR 2001. Data represent pooled cores from vine rows and alleys (n=4). Values for Cu and Zn were below 1ppm throughout season.

Day of Year	NO_3 ppm	NH_4 ppm	P ppm	K ppm	Ca meq	Mg meq	Fe ppm	Mn ppm	B ppm
108	1.5	5.4	13.0	223	3.1	0.63	21.1	13.9	0.63
155	4.8	2.7	11.5	222	2.7	0.63	25.9	14.5	0.52
190	5.1	3.7	12.2	239	2.8	0.65	22.5	15.7	0.54
218	2.8	2.6	10.7	239	3.2	0.72	30.3	12.6	0.59
253	4.0	3.0	9.9	197	2.6	0.65	18.8	10.5	0.64
281	6.6	3.4	9.9	206	2.9	0.58	25.7	10.0	0.77
316	7.5	2.4	10.0	202	2.6	0.60	36.8	8.8	0.68
p-value	0.002	0.001	0.084	0.134	0.900	0.650	0.145	0.007	0.004

FIGURE 1A . Shoot Dry Matter Changes in 21 yr old Pinot noir vines at WH 2001

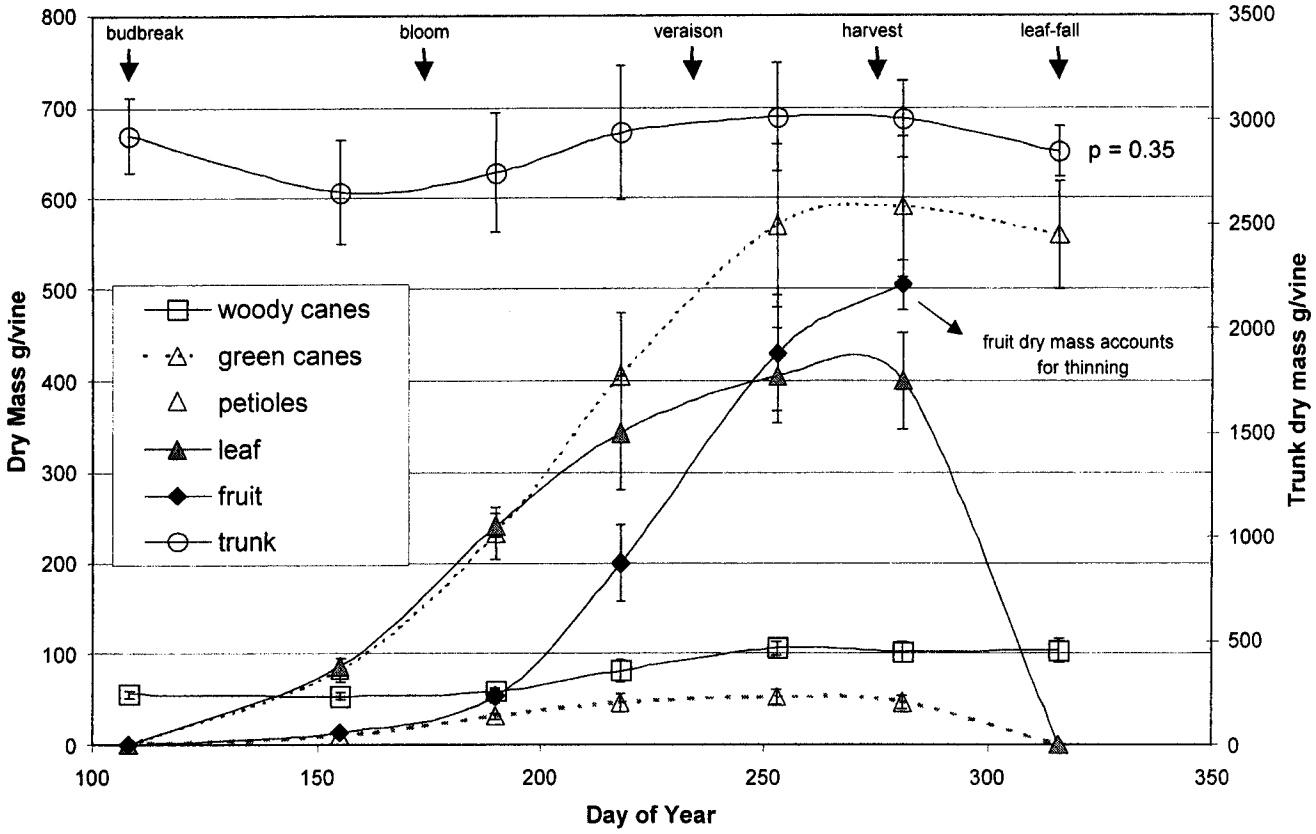


FIGURE 1B . Root Dry Matter Changes in 21 yr old Pinot noir vines at WH 2001

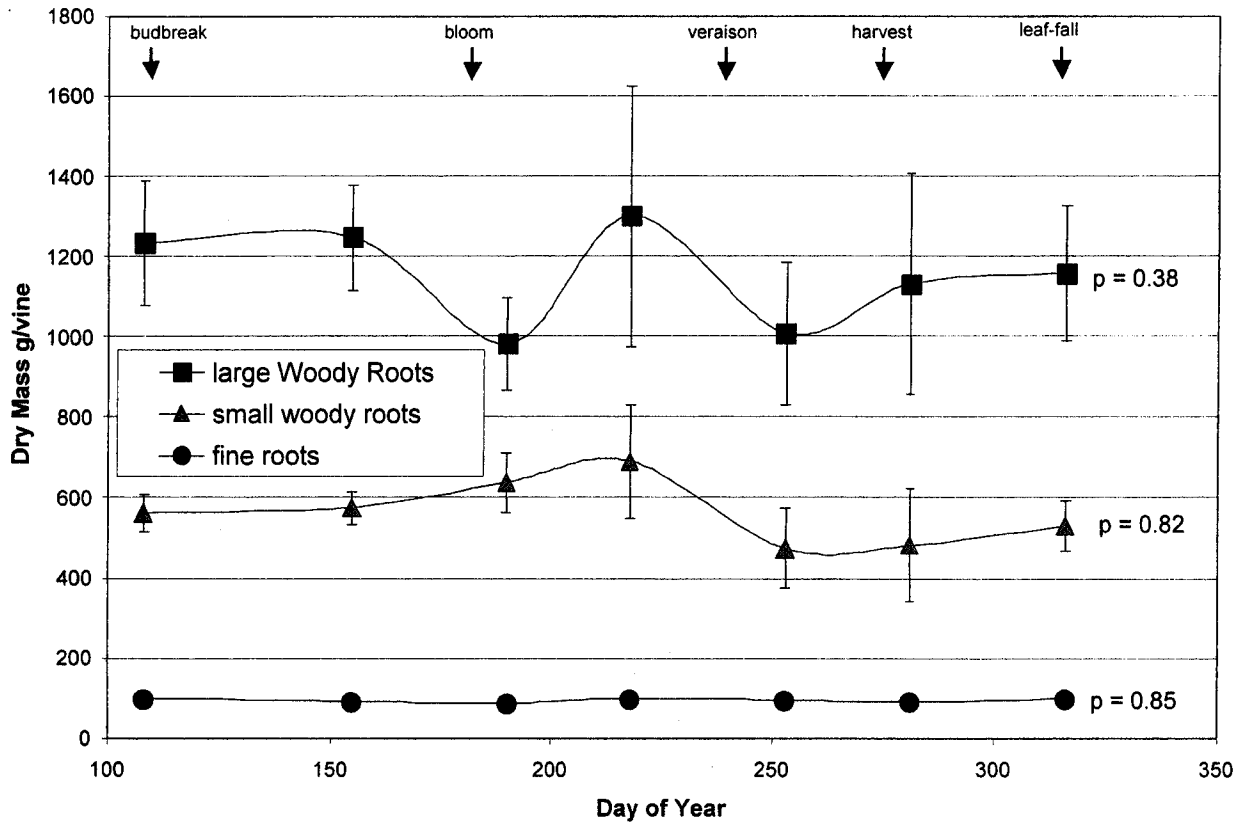
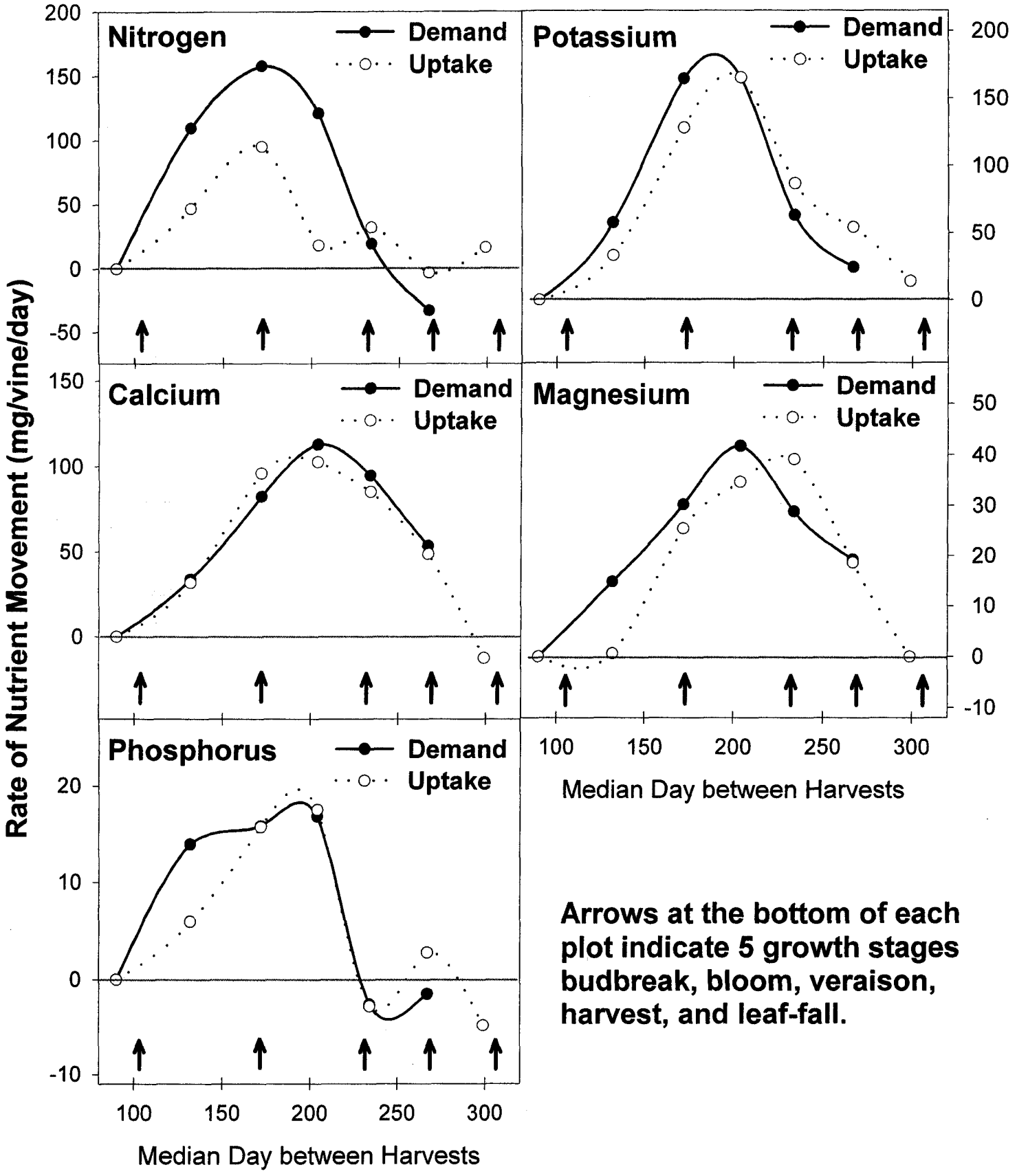


Figure 2. Canopy Demand and Whole-Vine Uptake of Macronutrients



Arrows at the bottom of each plot indicate 5 growth stages budbreak, bloom, veraison, harvest, and leaf-fall.

FIGURE 3 . Whole Vine N Uptake & Soil N Availability for Pinot noir - Woodhall, OR 2001

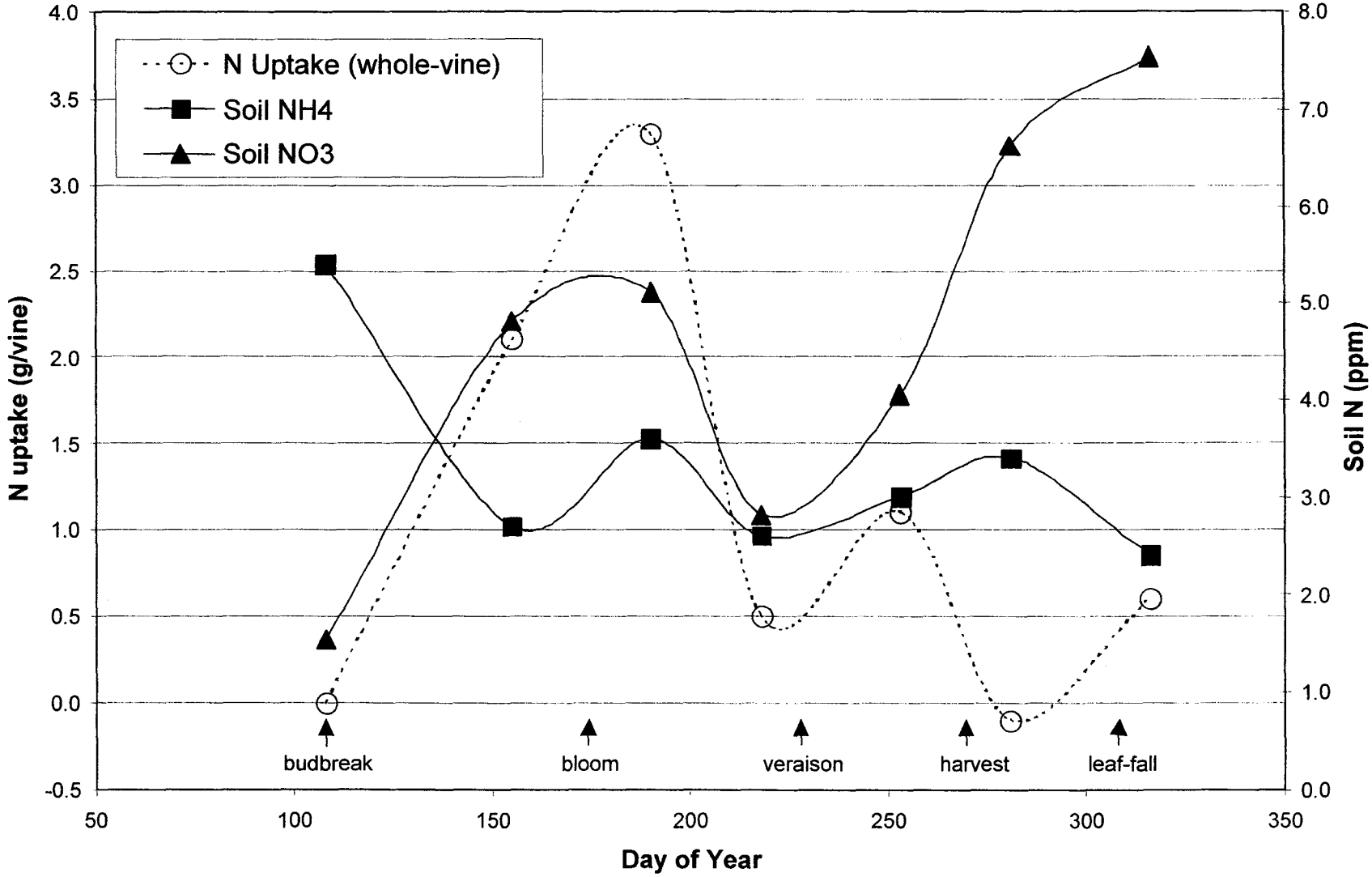


FIGURE 4 . Leaf and Petiole Nutrient Concentrations in Pinot noir at WH 2001