Progress Report - Oregon Wine Advisory Board 2002-2003

Seasonal Dynamics of Mineral Uptake and Allocation in whole Pinot noir vines in a Red-Hill Soil over 2 Years.

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Year Funding of Project: 2nd year

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

We repeated this mineral budget study of Pinot noir grapevines for a second season for two important reasons. First, we wanted to determine if nutrient uptake and allocation would be significantly different from year to year due to differences in climate or management practices. Second, we wanted to extend the study to include potential changes in vine nutrient use that may occur over the winter during the "dormant" period.

Our results from 2001 showed that uptake of macroelements were generally tied with canopy demand. N and P were taken up early in the season (peaking near bloom), while 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. An interesting question that we could not answer in 2001 was whether or not nutrients would be taken up during the winter. This appeared to be plausible for N, because reserves of N in permanent vine tissues were not replenished by leaf-fall in 2001.

Methods

Significant differences in management, climate, and our experimental approach occurred between 2001 and 2002. These differences are summarized in **Table 1.** Noteworthy differences are as follows: 1) No fertilizer was used in 2002, except for the application of gypsum ($CaSO_4$) in the subsoil of half of the vines removed in 2002, 2) Shoot numbers per vine and crop load was increased in 2002 and fruit thinning occurred earlier in 2002, 3) Vines were harvested (removed) to determine dry mass and nutrient concentrations only at the major phonological stages in 2002 allowing for the addition of winter sampling dates, 4) Temperatures were warmer in 2002 (mainly in June and July) and rainfall was lower in 2002.

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 23-yr-old Pinot noir vines in

C block at Woodhall Research Vineyard. Vines were harvested at pruning 2002, budbreak, bloom, veraison, harvest, leaf-fall and pruning 2003. 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). Six replicate vines (3 treated with gypsum and 3 untreated controls) were harvested at each sample date.

Fine roots and small woody roots were estimated for each vine by collecting roots from 6 random holes (18 cm diameter) dug to a depth of 80 cm. Three holes were dug from the vine row (area sprayed with roundup to control weeds) and three from the alleyway. Large woody roots were completely removed from the soil profile by first digging around the vine trunk and following individual roots away from each plant. Large and small woody roots were 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 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, S, Fe, Zn, Cu, B, Mn, and Al.

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 collected at budbreak, bloom, veraison, and harvest in 2002. 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, SO_4, Fe, Al, 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 data 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

Vine growth and fruit development were different between the two years of this study. This was due in part to climatic differences between years (2002 was warmer and drier than 2001) and also to management practices (more buds were left in 2002, fruit was thinned earlier in 2002, and crop load was increased in 2002). Differences between 2001 and 2002 on canopy growth and fruit quality measures are summarized in **Table 2.** Dry matter accumulation in the canes, leaves, and fruit was higher in 2002, although only the fruit was statistically significant. Carrying more fruit on the vines in 2002 improved fruit quality in this vineyard. The pH of juice was significantly reduced from 3.8 in 2001 to 3.3 in 2002, even though acidity was higher in 2002. The reduction in juice pH was most likely due to lower K concentration in the fruit in 2002

which buffers acidity. It appears that the higher fruit load carried on the vines in 2002 (2.4 tons/acre) was a better target for crop load for this vineyard, than was the crop load in 2001 (1.8 tons/acre). In addition, thinning fruit at a later date in 2001 may have contributed to the higher K concentration in the clusters by harvest in that year. Cluster P and cluster B concentrations were also reduced in 2002 which may have decreased fruit quality.

Changes in the dry matter accumulation for all tissues over both years of this study are shown in **Figure 1.** The only significant difference between 2001 and 2002 was the fruit mass, which we controlled. Overall, the trends for the rest of the tissues were very consistent between 2001 and 2002.

Changes in the concentrations of mineral nutrients within different vine tissues were highly significant in 2002, similar to our 2001 findings (**Table 3**). The concentration of nearly every mineral nutrient in each of the 9 tissue types we examined changed over the course of the 2002 growing season. Because there is too much data to present here, the concentration data for all the minerals in all the tissues we have studied will be made available at the following website: www.ars-grin.gov/hcrl/plantphys.htm (follow links to Schreiner and 2001-2002 Pinot noir Nutrient Budget).

The mineral concentration and content data for N, K, and P for both years of this study are shown in **Figures 2-7.** Remember that we spread out our sampling times in 2002 as compared to 2001 when looking at these figures. For Nitrogen, the concentrations in the canopy tissues were very similar in 2001 and 2002 (**Figure 2A**). Concentrations of N in the roots and woody tissues also followed similar trends in both years, with the exception of slightly less N in the large woody roots in 2002 that occurred as the fruit approached maturity (**Figure 2B**). Of particular interest is that N concentrations went up a great deal in all the roots and woody tissues between leaf-fall of 2001 and pruning in 2002 (the dead of winter). These data show that substantial recharging of vine nitrogen reserves in woody tissues occurs during our wettest months after leaf-fall. Indeed, the N contents (concentration X dry mass) in the roots and trunk during this time period showed significant movement of N into these tissues (**Figure 3**). We have accounted for the re-capture of N from the leaves and petioles in our analysis, so these changes in N content during the months of November, December, and January reflect uptake from soil!

Changes in Potassium concentrations over 2 years are shown in **Figure 4**. Again, we saw the same general trends for K between 2001 and 2002, except that in 2002 the concentrations of K were lower in many tissues. The lower concentrations of K were evident in all the canopy tissues (leaves, petioles, canes, fruit) as well as the trunk, and woody roots. It appeared that the vines were pulling more K reserves from the permanent structures in 2002 to supply the canopy, because we had a bigger canopy and crop load in 2002 (**Figure 5**). This probably improved fruit quality, suggesting that vines in this vineyard should have K concentrations similar to 2002, as opposed to the higher values in 2001.

The down side to the greater crop load in 2002 was the effect on vine Phosphorus. P concentrations were significantly lower in the green canes, petioles, fruit, woody roots and woody canes in 2002, as compared to 2001 (**Figure 6**). In a similar fashion as Potassium, the Phosphorus appeared to be mobilized to a greater extent from reserve tissues in 2002 (**Figure 7**). It was interesting that both the fine roots and leaf tissues (organs that do the most work for the plant) did not have reduced P concentrations in 2002. These findings suggest that Phosphorus is already at a critical level in fine roots and leaves. It will be interesting to see if P uptake had occurred to a greater extent in the winter of 2002-2003 (data are not yet available).

The uptake of macroelements (N, P, K, Ca, and Mg) from soil over the course of two seasons is summarized **Figure 8**. Because the rates of whole-plant uptake for each mineral were calculated between 2 destructive samplings, the data are plotted against the median time point between sample dates. Whole-vine N uptake showed three large peaks over the two years of this study. Maximal N uptake occurred in both seasons at the time of bloom, and another peak of N uptake occurred between leaf-fall (2001) and pruning (2002). Whole-vine P uptake also peaked in both years near bloom, but P uptake during the winter was very small compared to N. The maximal uptake of both N and P from soil at bloom coincides with the re-allocation of N and P from reserves. K and Ca uptake peaked in both years between bloom and veraison, while Mg uptake peaked in both years at veraison. All three major cations (K, Ca, Mg) showed significant losses during the winter, when N uptake was occurring. Note that the rates of uptake appear slightly lower in 2002 as compared to 2001, but this is an artifact of our sampling differences between years. Uptake of N, K, and Mg was actually greater in 2002 (see **Table 4**), but appears to be lower in **Figure 8** because the interval between whole vine harvests was longer in 2002. However, P uptake was lower in 2002, even though canopy demand was higher, which we believe is due to the drier soil conditions that occurred in 2002, as compared to 2001.

The total quantity of macronutrients moved to the canopy (defined as canopy demand) and the total vine uptake between budbreak and harvest in 2002 are shown in **Table 4.** Values reported in **Table 4** are pounds of each nutrient per acre. The canopy demand for all macroelements except Ca was higher in 2002, compared to 2001 since we had a larger canopy and greater crop load. Uptake from soil for N, K, and Mg was also higher in 2002, while Ca was similar between years and P was lower in 2002. Note that the quantities of macroelements required to produce a Pinot noir crop of 2.4 tons/acre were still relatively low compared to other crops. Approximately 35 pounds/acre of N and K, and 3.5 pounds/acre of P were required to produce the 2002 crop. The quantities of N, K, and P that left the vineyard system with the fruit were 8, 12, and 1 pounds/acre, respectively.

Table 5 summarizes the relative importance of the trunk and various roots in supplying minerals from stored reserves for 2002. The data are presented from budbreak to harvest. These findings are generally consistent with our findings in 2001. As in 2001, large woody roots were the most important reserve tissue for N and P storage and re-allocation. Fine roots were more important than the trunk for supplying stored K in 2002, which was opposite in 2001. However, as in 2001, the trunk and the fine roots were both the most important tissues in re-allocating K stores. The biggest difference between years was that small woody roots accounted for significant re-allocation of P and K reserves, which was not found in 2001. This difference is most likely due to the greater demand for these elements in 2002 (larger canopy and fruit load in 2002) and the drier soil conditions (which make P and to some extent K less available in soil). Another important difference between the years of this study was that more N, K, and P were re-allocated to the canopy in 2002. 58% of canopy N, 18% of canopy K, and 48% of canopy P came from reserves in 2002. These values were 51% for N, 10.5% for K, and 27% for P in 2001. Finally, Mg uptake from soil in 2002 accounted for all of the canopy needs, while in 2001 17.8% of canopy Mg came from stored reserves. Why we had greater Mg uptake in 2002 is unknown, but may be related to climate differences between years.

Changes in the availability of minerals in soil over the 2002 season are shown in **Table 6.** Only NO_3 and P had significantly changed over the 2002 season. Our findings this year were not consistent with soil analysis in 2001. In 2001, we found significant changes in the soil

availabilities of NO_3, NH_4, Mn, and B, but not P as the season progressed. These differences are once again likely due to the drier soil conditions in 2002.

Uptake of microelements Fe, Mn, B, Zn, and Cu in whole vines could not be accurately determined from our data because their concentrations varied too much within different replicate vines to generate quality content data. There were some important differences in the concentrations of micronutrients that occurred between 2001 and 2002, however. Boron was lower in 2002 as expected, because we chose to delete the foliar B spray in 2002. The lower B concentrations that we saw in the fruit at harvest however, were not apparent in clusters at the time of bloom. Oddly, B concentrations were very high in the petioles in 2002, but lower in most other tissues. Copper concentrations were also very high in the petioles in 2002 as compared to 2001. The fact that we saw lower B in many tissues in the same year that we cut the foliar B applications, shows how important a foliar B spray program is for our soils in Oregon. The micronutrient data for both years will also be made available at the website mentioned above.

Conclusions

A two-year study of nutrient uptake and use in mature Pinot noir vines growing in Jory soil at Woodhall vineyard has shown that the timing of nutrient uptake from soils generally corresponds to the timing of nutrient demand by the developing canopy. Nitrogen uptake was also important in the winter time (between leaf-fall and pruning). The two minerals that vines relied most heavily on stored reserves (N and P), were taken up from soil earlier in the season (peak uptake at bloom) than those minerals that vines were less dependent on stored reserves (K, Ca, and Mg – peak uptake after bloom). For both years of this study, we found that large woody roots were the most important storage organ for N and P. Fine roots and the trunk were the most important storage organs for K. The nutrient requirements of the canopy to produce a Pinot noir crop of 2.4 tons/acre were as follows: 35 pounds/acre of N & K, 3.5 pounds/acre of P, 22 pounds/acre of Ca, and 10 pounds/acre of Mg. However, since significant stores of N and P were re-allocated to the canopy, much less of these nutrients were actually taken up from soil during the growing season. A crop load of 2.4 tons/acre was better than 1.8 tons/acre on these mature vines because the K was in oversupply at the lower crop load resulting in high juice pH. Our data strongly suggest that K supply in this soil is sufficient, but P supply and B supply are limiting in this Pinot noir vineyard.

Table 1. Differences in Plot Management, Research Methods and Climate in Pinot noir grapevines used for this study in 2001 & 2002.

	2001	2002
Management Practices		
Nitrogen Fertilizer	$Ca(NO_3)_2$ @ 15 lb N/ac	none
Foliar Boron	Solubor @ 2 lb B/ac	none
Gypsum	none	CaSO4 @ 9lb/vine (½ of vines)
Shoots/vine	16	20
Crop load	1.8 ton/ac	2.4 ton/ac
Date of Fruit Thinning	September 10	August 7
Research Methods		
Sampling Frequency	~ 1 month intervals	major phonological stages
Selection of Vines Harvested	random	selected for uniform trunk size
Large Root Sampling	4-50 cm^2 soil blocks extracted	Roots tracked from vine base
Fine Root Sampling	4-50 cm^2 soil blocks extracted	6-18cm diam. cores extracted
Climate		
April - Ave. Temp / GDD's °F	47.7 / 45	50.6 / 64
May - Ave. Temp / GDD's °F	56.5 / 218	53.4 / 157
June - Ave. Temp / GDD's °F	58.5 / 264	61.0 / 336
July - Ave. Temp / GDD's °F	65.1 / 475	67.8 / 560
Aug. - Ave. Temp / GDD's °F	66.5 / 519	66.5 / 515
Sept. - Ave. Temp / GDD's °F	62.8 / 391	63.1 / 402
GDD's °F budbreak-harvest	1859	1933
GDD's °F harvest-leaf-fall	135	180
Rainfall (") budbreak-harvest	4.8"	4.0"
Rainfall (") bloom-harvest	2.7"	1.5"
Minimum Soil Moisture (gravimetric)	14.0% - October 6	11.5% - August 20

Table 2. Differences in Vine Growth and Fruit Quality of Pinot noir vines in 2001 & 2002.

Measured Variable	2001	2002	ANOVA sig.
Growth Parameters			
Green Cane Mass at harvest (g)	589	652	N.S.
Leaf Mass at harvest (g)	405	435	N.S.
Fruit Mass at harvest (g)	505	673	<0.001
Date of harvest	9/25	9/26	N.S.
Fruit Quality Parameters			
° Brix	23	25	<0.001
pH	3.8	3.3	<0.001
T.A.	5.8	7.8	0.044
cluster N (%)	0.65	0.67	N.S.
cluster P (%)	0.11	0.08	<0.001
cluster K (%)	1.19	1.01	<0.001
cluster Ca (%)	0.11	0.09	N.S.
cluster Mg (%)	0.07	0.07	N.S.
cluster Fe (ppm)	36.5	36.6	N.S.
cluster B (ppm)	14.7	8.6	<0.001
cluster Zn (ppm)	4.0	4.3	N.S.
cluster Cu (ppm)	4.0	4.8	N.S.
cluster Mn (ppm)	14.3	12.9	N.S.

Table 3. Significance of Sampling Date on Tissue Dry Mass & Nutrient Concentrations in 24-yr-old Pinot noir vines at Woodhall, OR 2002 (n=6). Specific tissue nutrient concentrations throughout the 2001 season are available at www.ars-grin.gov/hcrl/plantphys.htm follow links to Schreiner and 2002 Pinot noir Nutrient Budget.

Plant Tissue	Dry mass	N	P	K	Ca	Mg	Fe	Mn	Cu	B	Zn
Fine Roots	0.003	<0.001	<0.001	<0.001	0.001	0.066	<0.001	N.S.	<0.001	N.S.	<0.001
Sm. Woody Roots	0.002	<0.001	<0.001	<0.001	0.016	<0.001	N.S.	N.S.	0.008	0.019	<0.001
Lg. Woody Roots	N. S.	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.013	N.S.	<0.001	N.S.
Trunk	N.S.	<0.001	<0.001	0.001	N.S.	0.024	N.S.	<0.001	N.S.	<0.001	N.S.
Woody Canes	<0.001	<0.001	<0.001	<0.001	N.S.	<0.001	0.003	<0.001	N.S.	<0.001	<0.001
Green Canes	<0.001	<0.001	<0.001	<0.001	0.018	0.003	<0.001	N.S.	<0.001	<0.001	<0.001
Petioles	<0.001	<0.001	<0.001	<0.001	N.S.	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Leaves	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Clusters	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 4. Summary of Macronutrient Use in 24-yr-old Pinot noir vines at Woodhall, OR 2002. 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 after Harvest	Uptake from soil after Harvest
N	35.8	15.1	7.9	11.0	0
P	3.5	1.8	1.0	0.7	0
K	35.4	28.8	12.0	6.0	0
Ca	22.2	21.5	1.0	0	2.4
Mg	10.4	10.4	0.8	1.3	0

Table 5. Relative Contribution of Root Tissues and Trunk in Supplying Macroelements from Stored Reserves in 2002. Data were calculated from the change in mineral content from budbreak to harvest in each tissue divided by the total content re-allocated to the canopy.

	% of Nutrient Remobilized to Canopy by Harvest for 4 Tissues				% of Total Demand From Reserves
Nutrient	Fine Roots	Sm. Woody Roots	Lg. Woody Roots	Trunk	
N	13.7	17.0	42.6	26.7	58
P	13.0	20.6	41.3	25.2	48
K	35.2	18.9	16.9	29.0	18
Ca	0	20.1	79.9	0	3
Mg	0	0	0	0	0

Table 6. Mean Nutrient Availabilities in Soil (0-50 cm) at Woodhall, OR 2002. Data represent pooled cores from vine rows and alleys (n=6). 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
106 budbreak	1.63	4.63	10.5	179	2.9	0.56	47	13.4	0.53
170 bloom	2.31	3.44	11.6	215	2.1	0.47	109	14.6	0.55
232 veraison	3.61	4.16	14.3	185	3.3	0.62	170	13.7	0.54
269 harvest	5.22	3.77	11.0	207	2.6	0.58	98	14.0	0.56
p-value	0.011	0.105	0.032	0.528	0.162	0.051	0.103	0.754	0.875

Figure 1A. Dry Matter Changes in Green Tissue & Fruit of Pinot noir 2001-2002

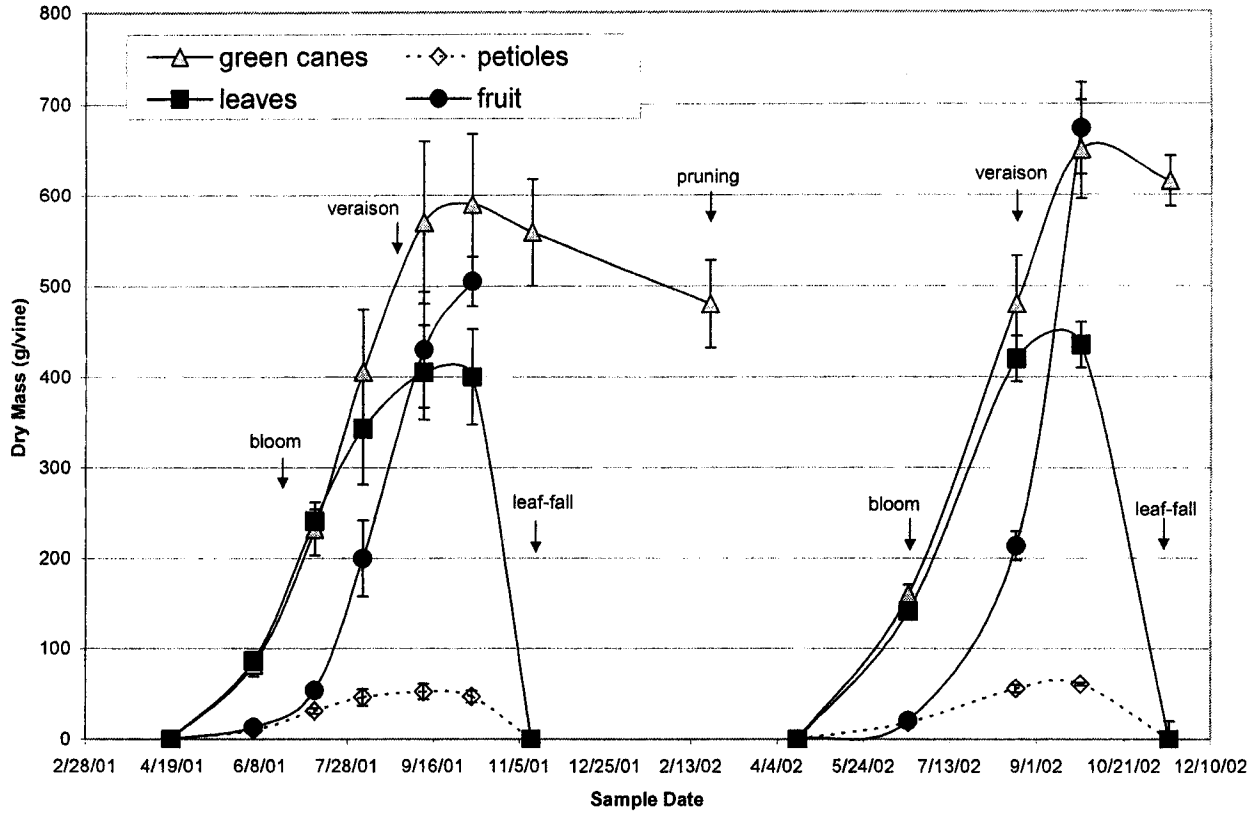

Figure 1B. Dry matter Changes in Roots & Wood of Pinot noir 2001-2002

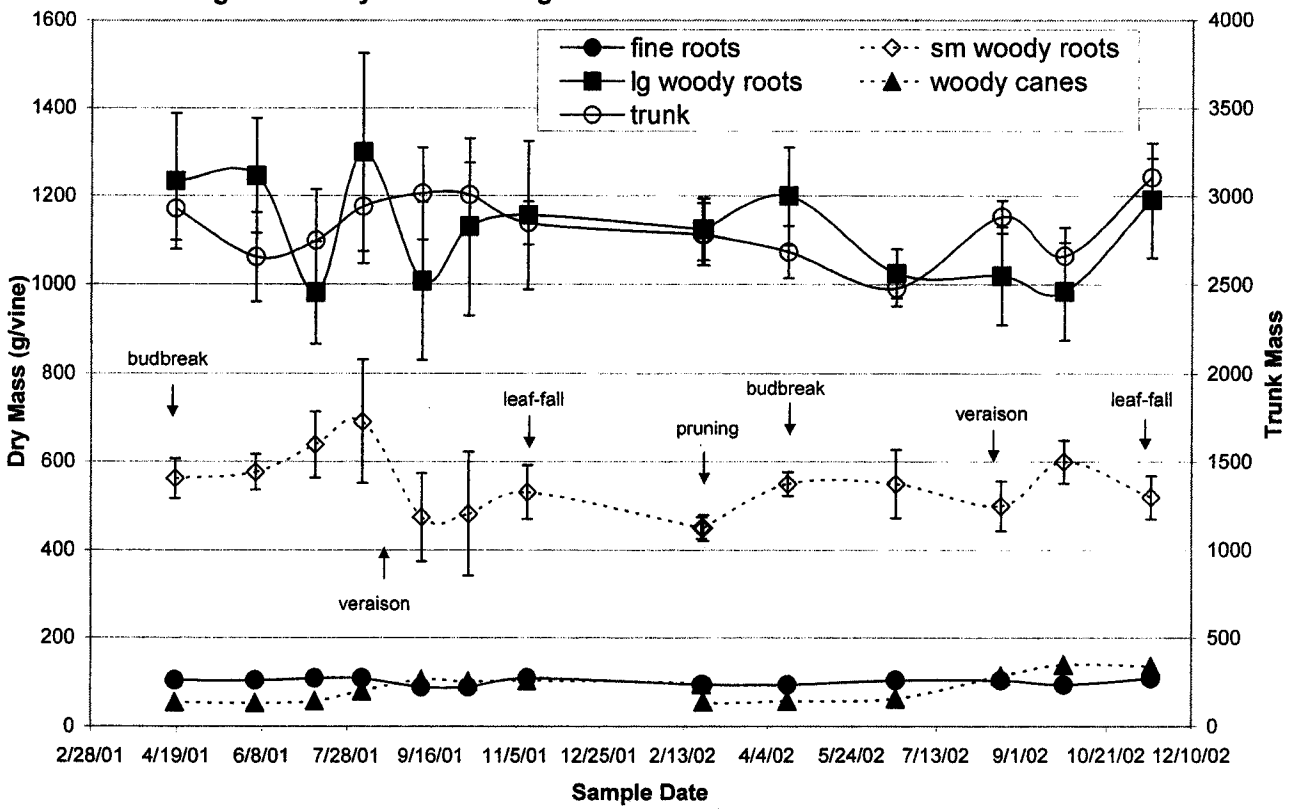

Figure 2A. [N] in Green Tissues & Fruit of Pinot noir 2001-2002

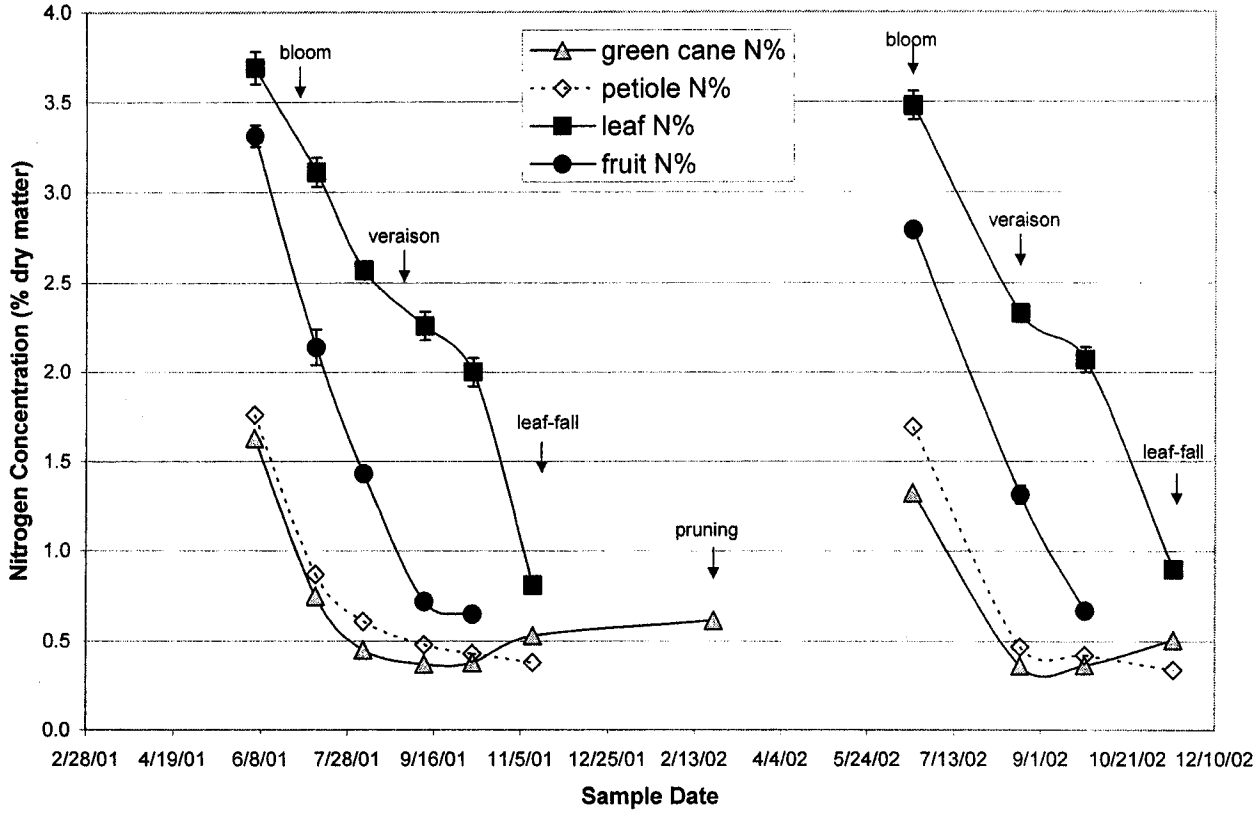

Figure 2B. [N] in Roots, Trunk, & Woody Cane Tissues of Pinot noir 2001-2002

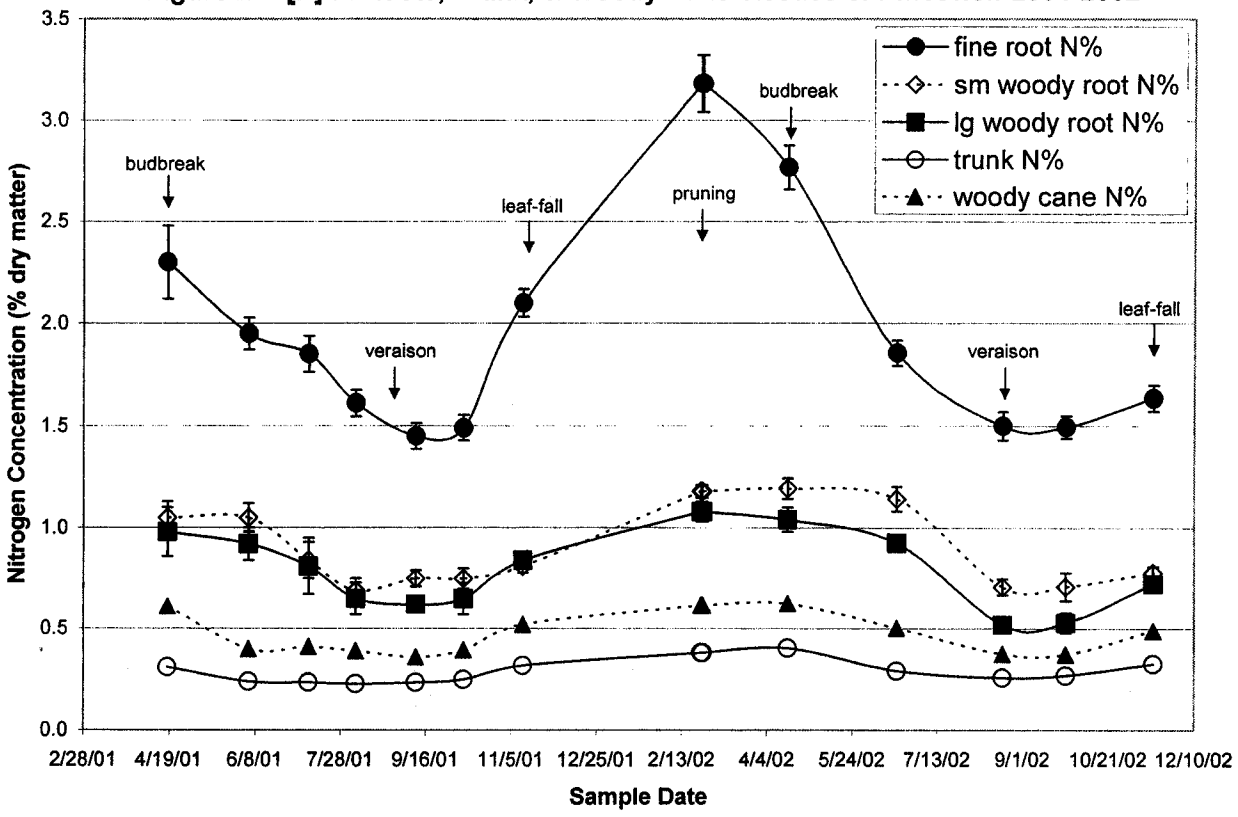

Figure 3A. Total N in Green Tissues & Fruit of Pinot noir 2001-2002

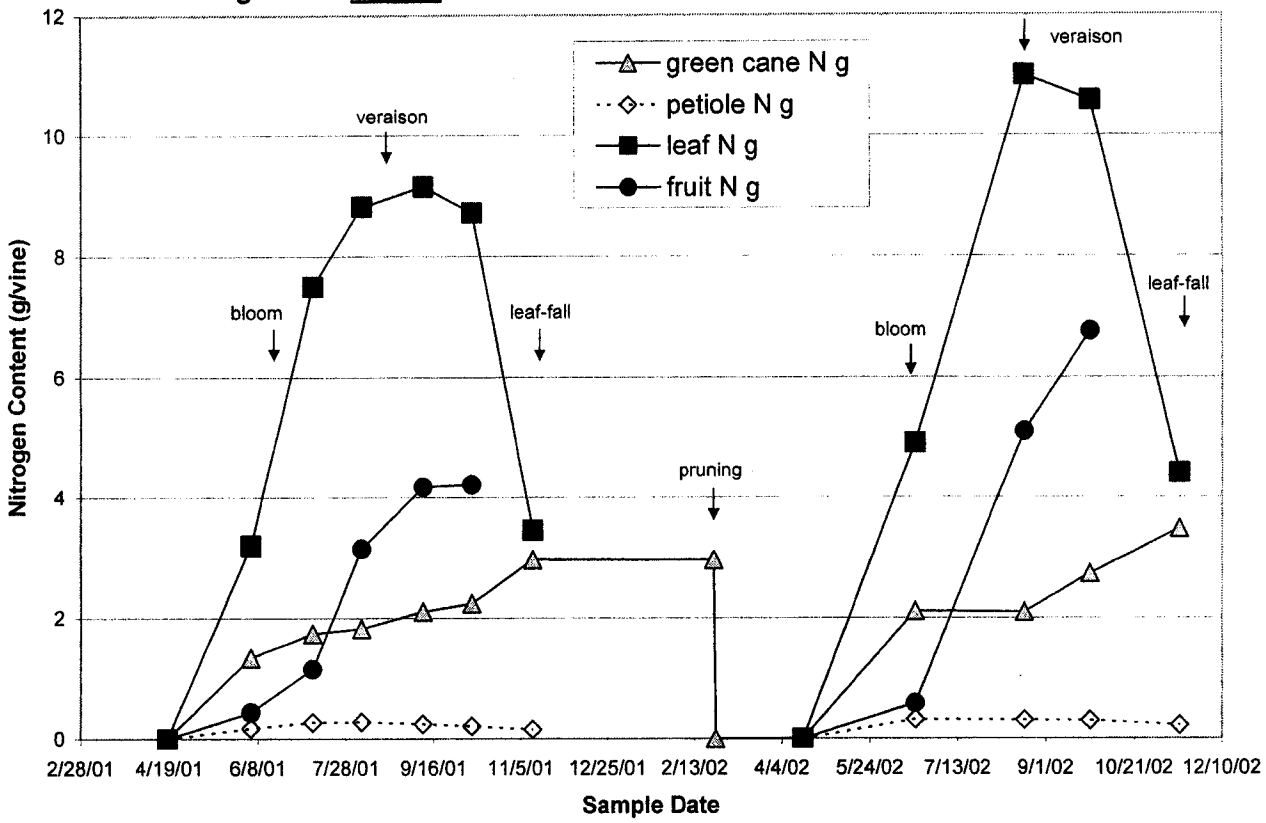

Figure 3B. Total N in Roots, Trunk & Woody Canes of Pinot noir 2001-2002

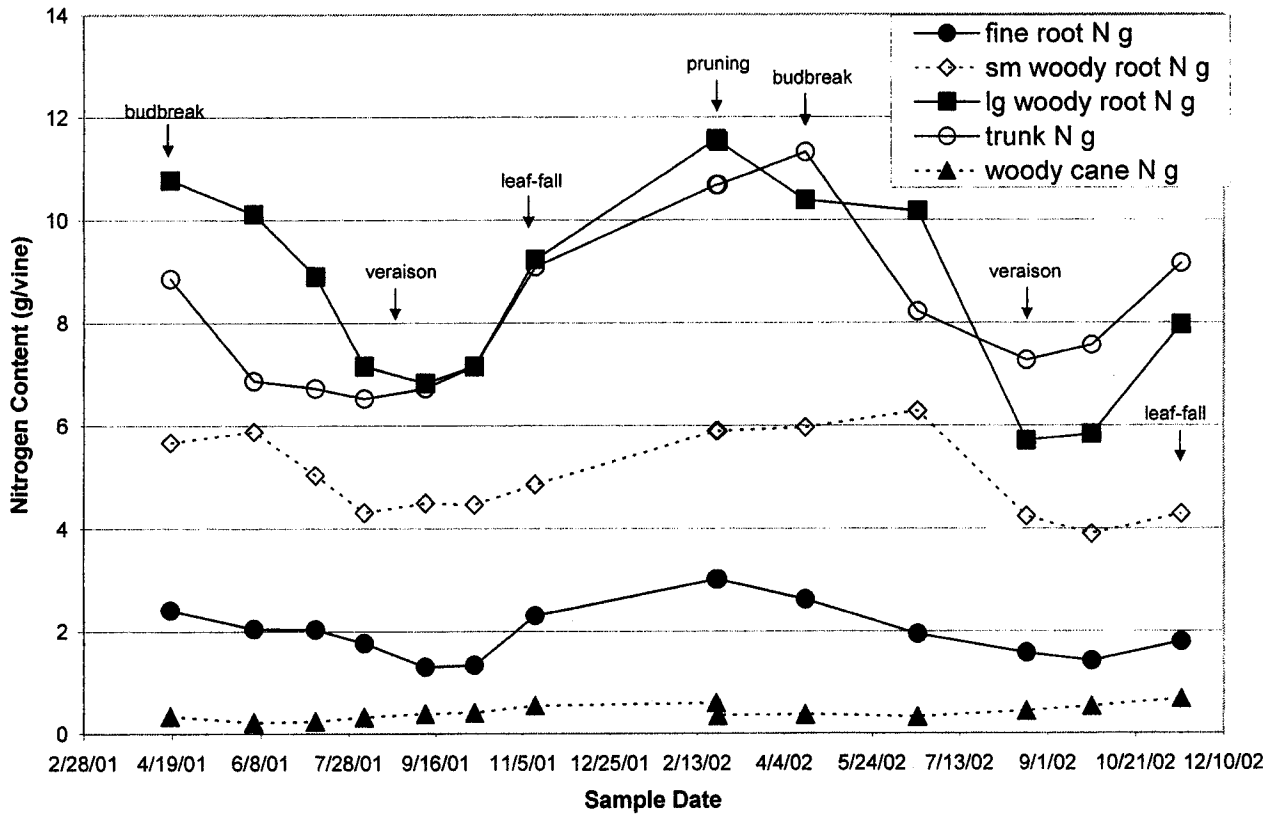

Figure 4A. [K] in Green Tissues & Fruit of Pinot noir 2001-2002

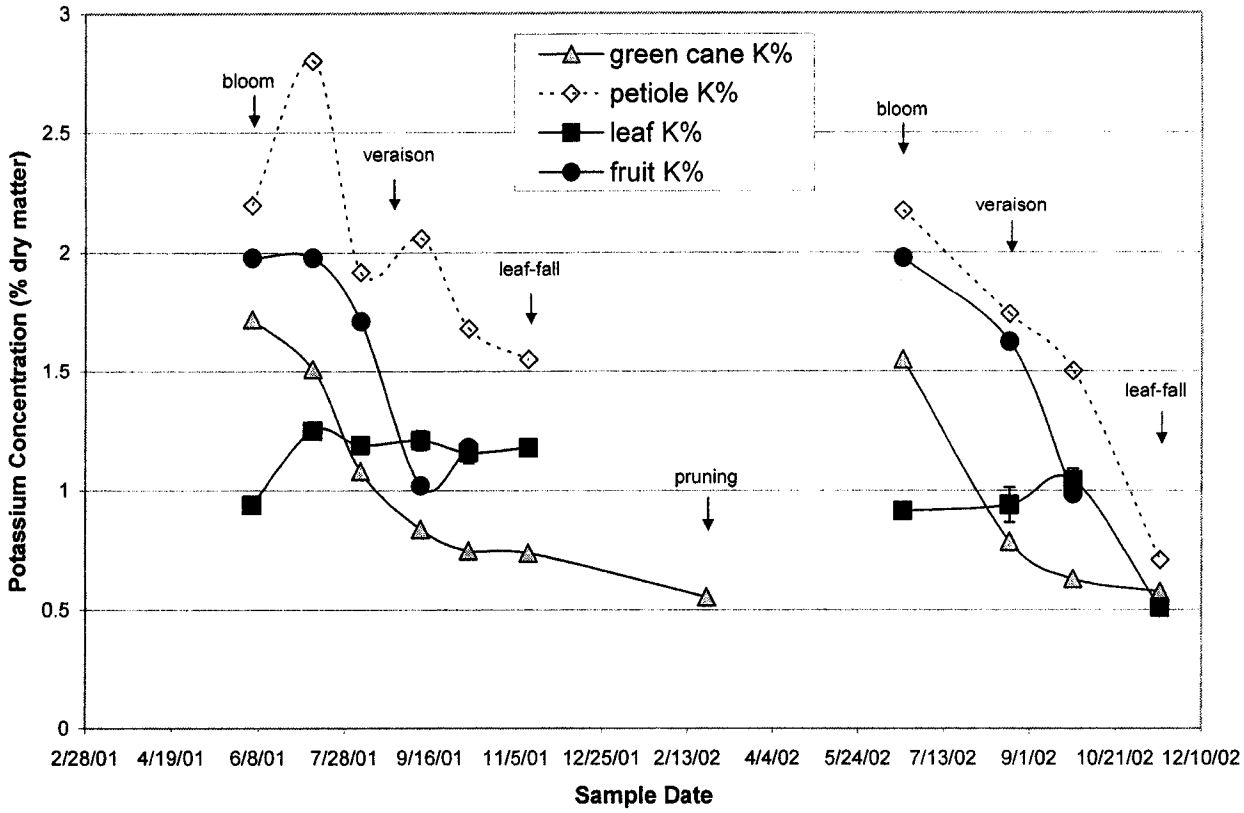

Figure 4B. [K] in Root, Trunk & Woody Cane Tissues of Pinot noir 2001-2002

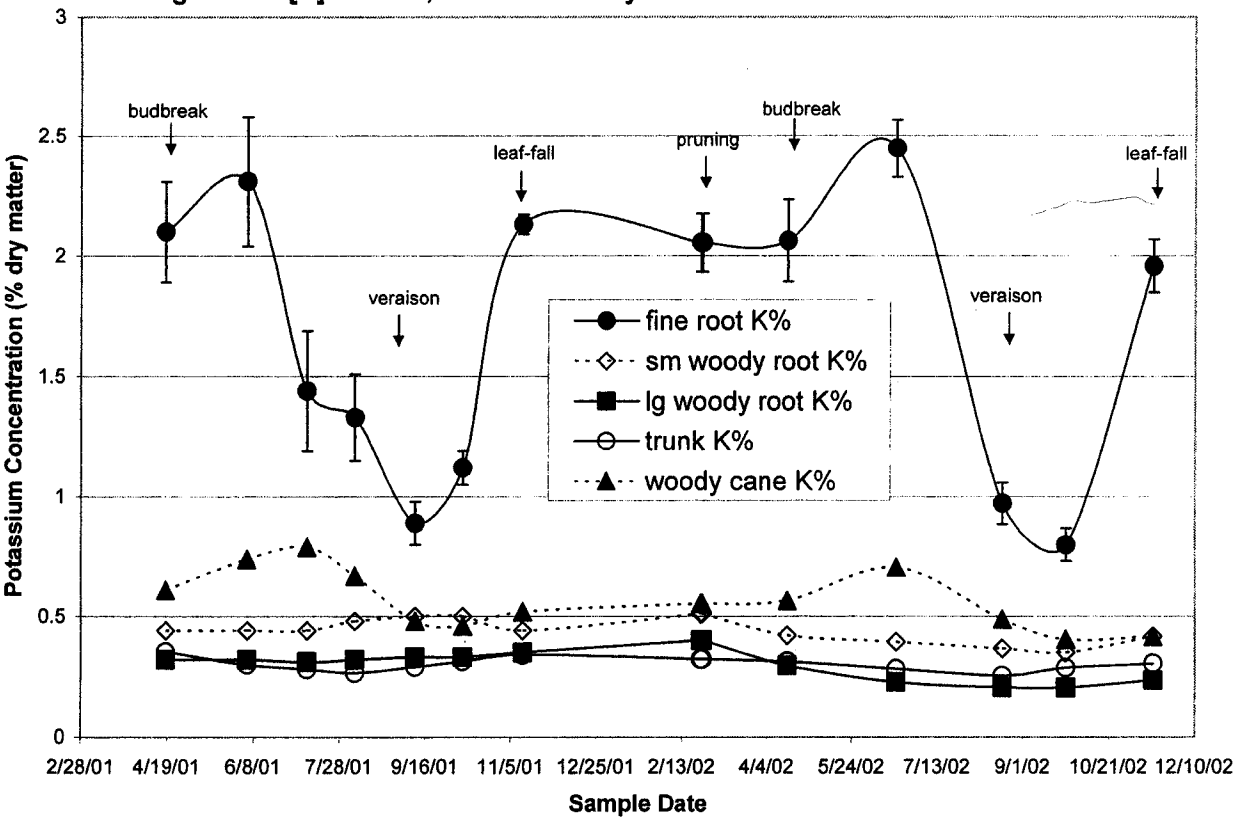

Figure 5A. Total K in Green Tissues & Fruit of Pinot noir 2001-2002

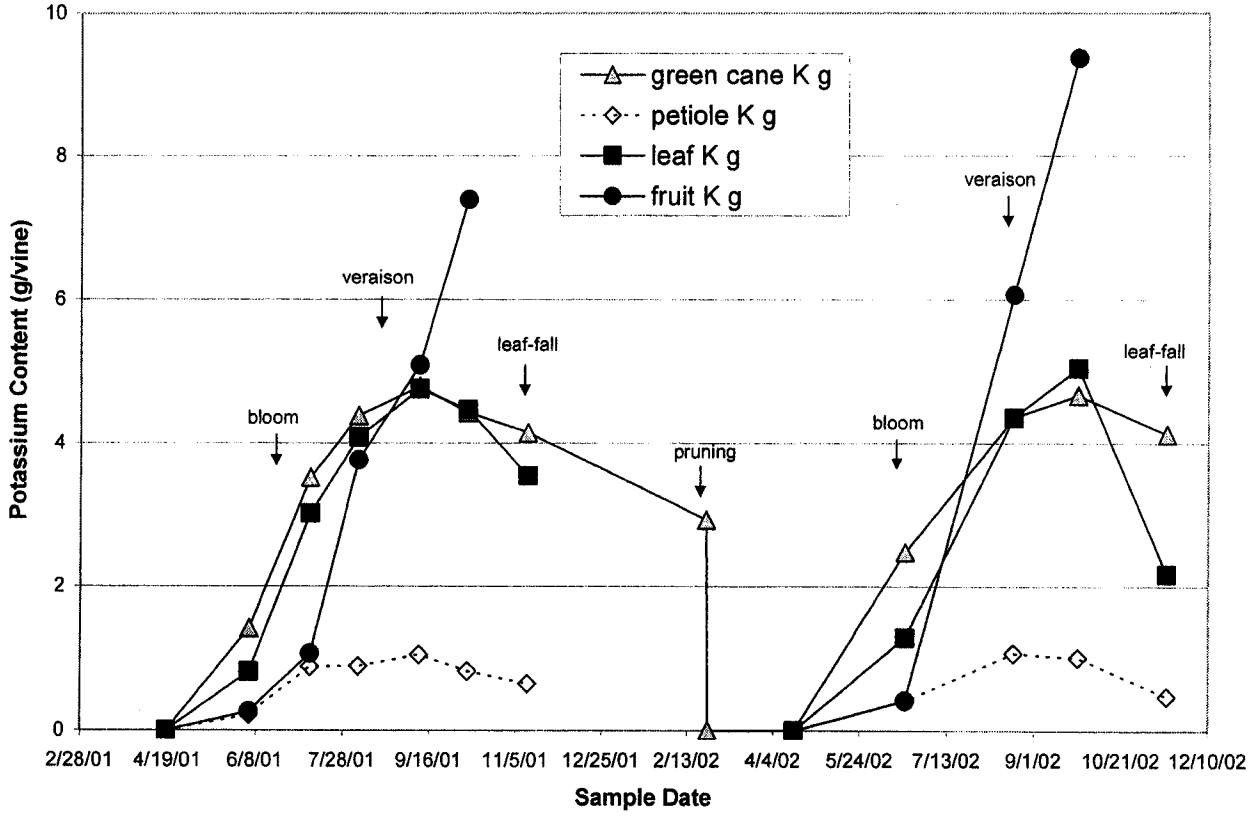

Figure 5B. Total K in Root, Trunk & Woody Cane Tissues of Pinot noir 2001-2002

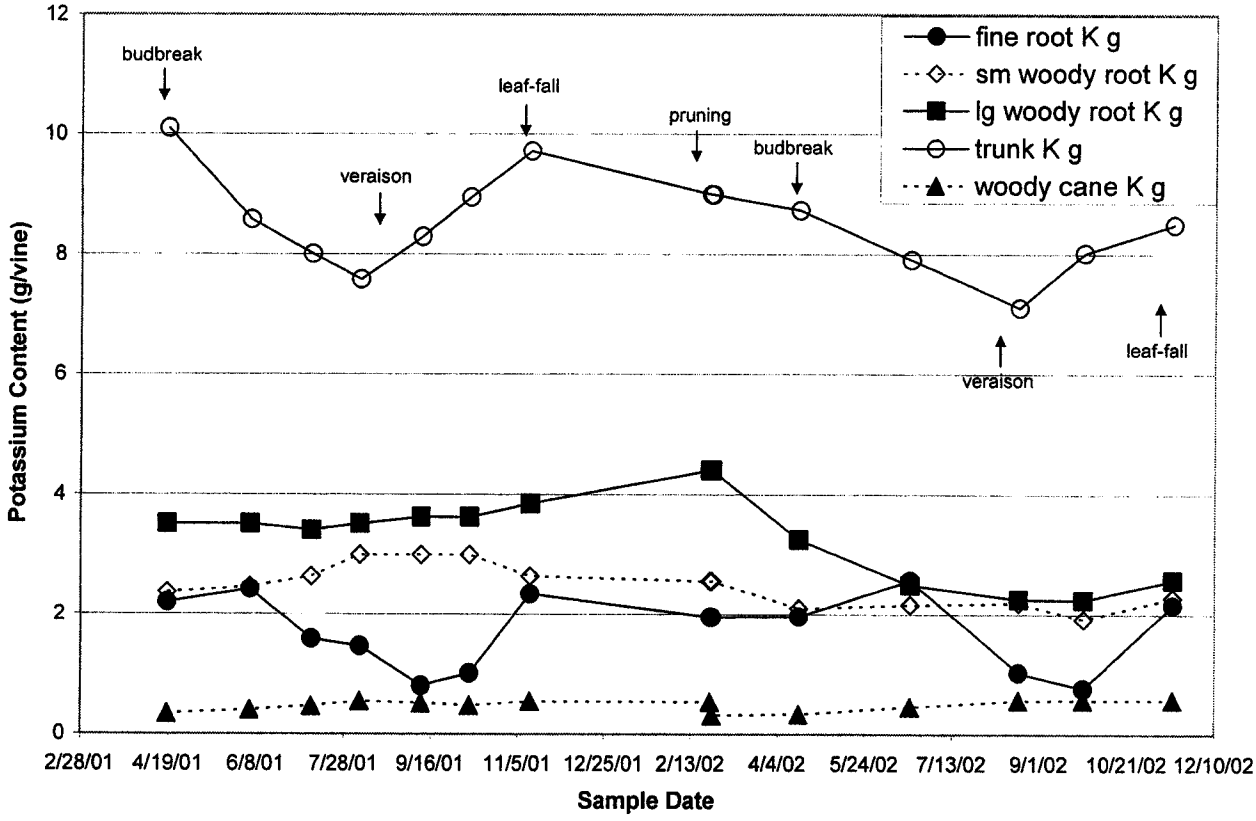

Figure 6A. [P] in Green Tissues & Fruit of Pinot noir 2001-2002

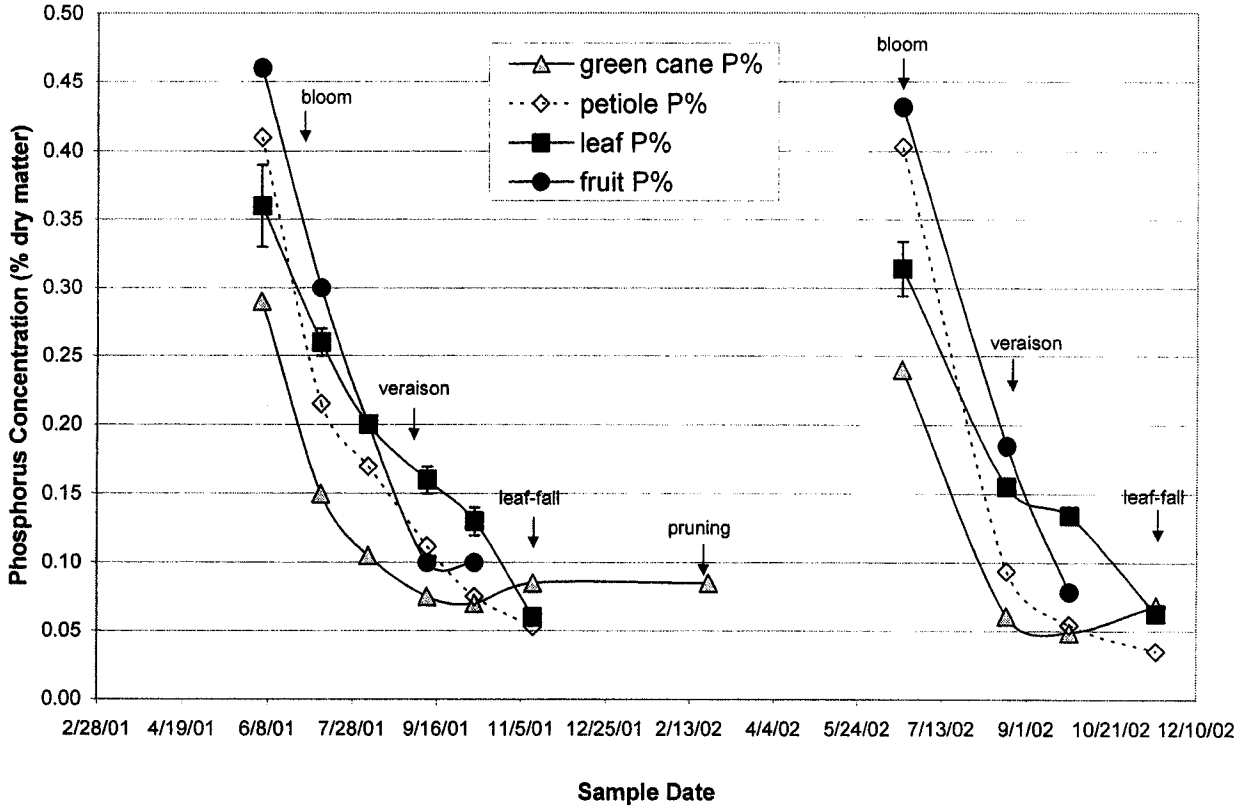

Figure 6B. [P] in Roots, Trunk & Woody Canes of Pinot noir 2001-2002

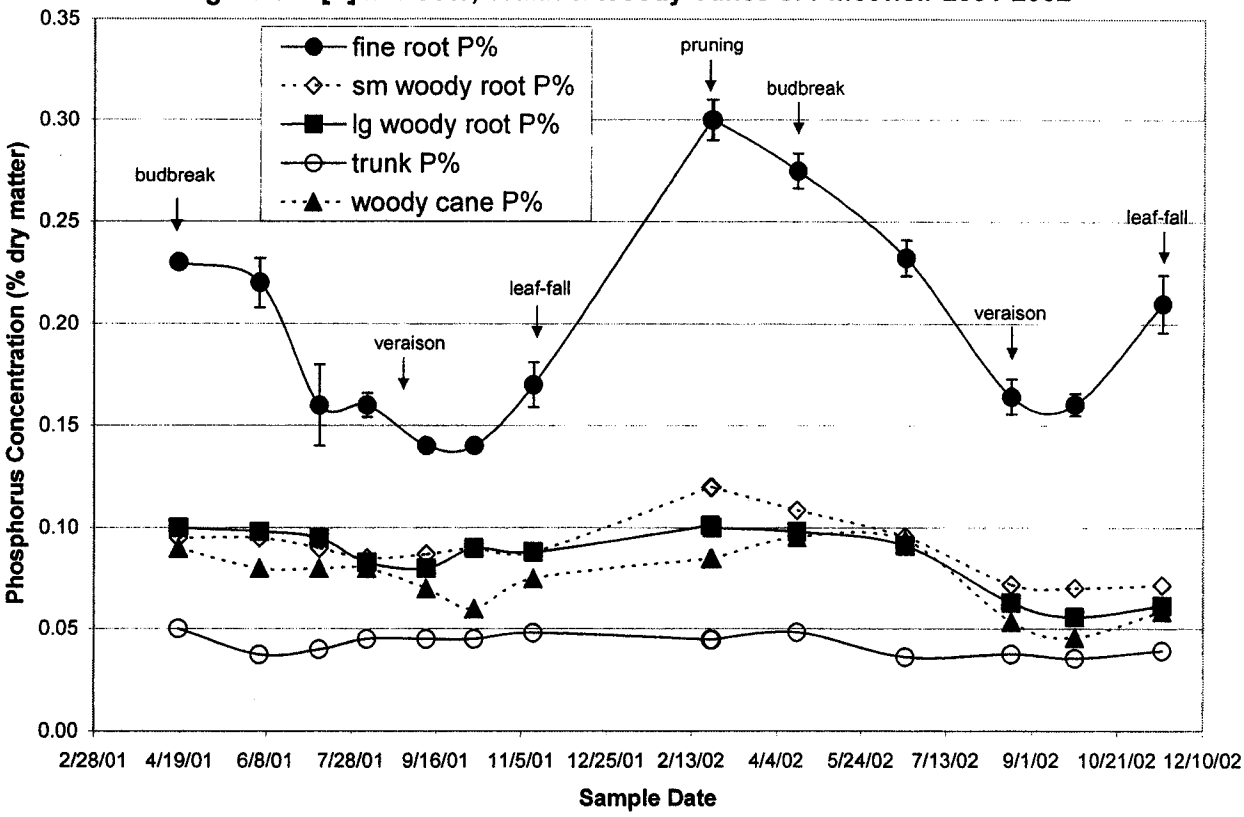

Figure 7A. Total P in Green Tissues & Fruit of Pinot noir 2001-2002

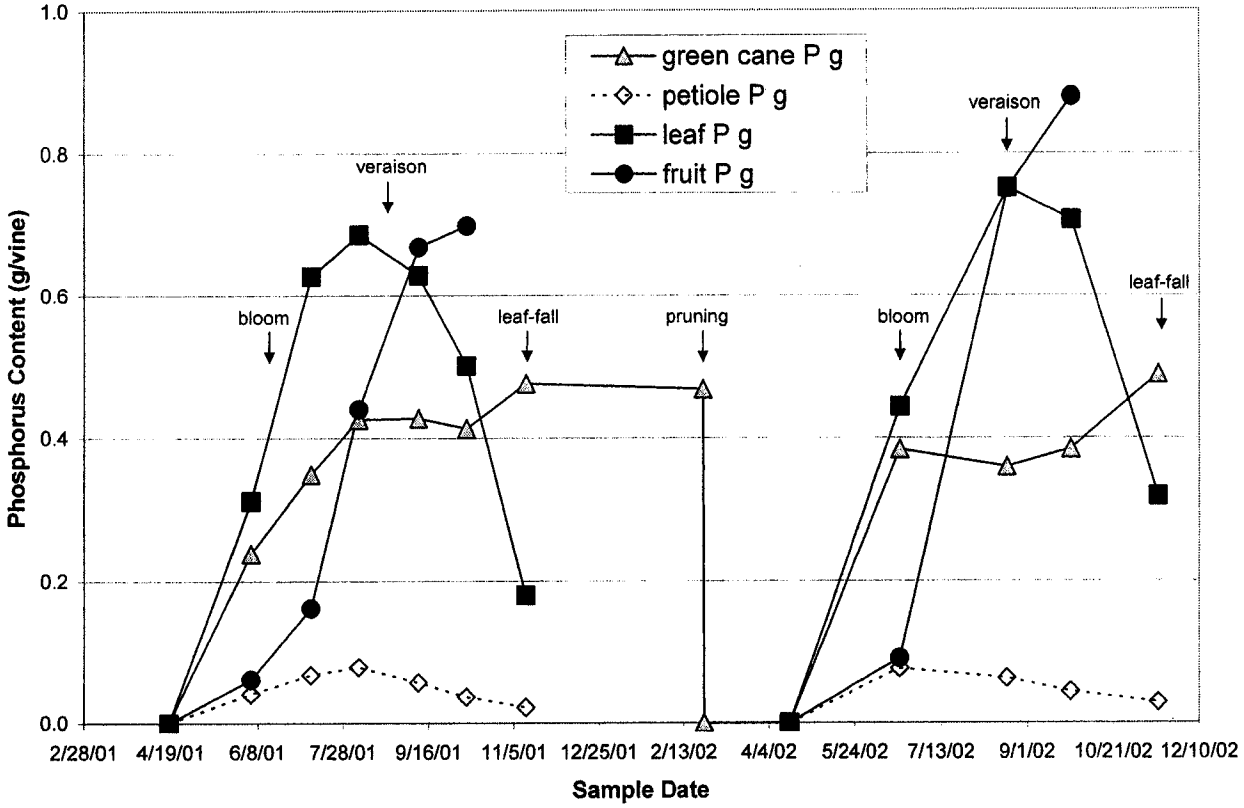

Figure 7B. Total P in Roots, Trunk & Woody Canes of Pinot noir 2001-2002

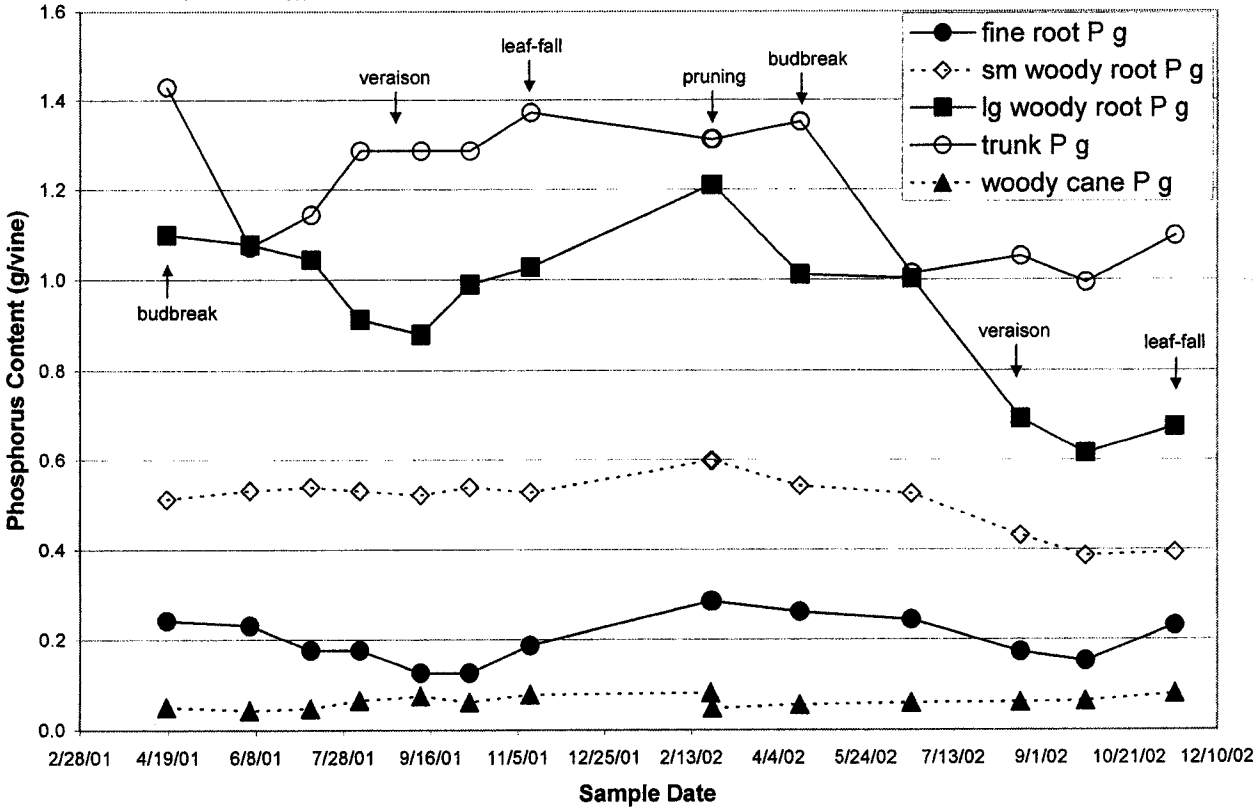

Figure 8. Whole Vine Uptake Rates of MacroElements in Pinot noir 2001-2002