Project Title: Precision Nutrient Management for sweet cherry orchards

Report Type: Final Project Report

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Budget 1
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Item	2023	2024	2025
Salaries			
Benefits			
Wages[1]	7,190	7,478	7,777
Benefits	734	763	793
RCA Room Rental			
Shipping			
Services	56,680	6,680	6,680
Supplies	4,400	4,400	4,400
Travel	1,000	1,000	1,000
Total	70,004	20,321	20,650

Footnotes: [1] Salary for 50% FTE for 4 month per year for Juan Munguia, Research Assistant at Sallato's laboratory for data collecting processing fruit in the laboratory. [2] Services include root monitoring equipment and PNNL services. Supplies include laboratory analysis and processing of samples for nutrient test.

OBJECTIVES

Our main objective was to determine nutrient demand in sweet cherry orchards and to validate a method for extraction-based estimations for young orchards. Specific objectives were:

1. **Demand:** Investigate biomass and nutrient demand in different orchards and rootstocks.

Completed. We determined fruit nutrient extraction for 'Benton' and completed three consecutive seasons (2023–2025) of whole-tree destructive partitioning in two blocks: 'Benton' on Gisela 5 (Gi5), Gisela 12 (Gi12) and MxM14 (6th to 8th leaf), and 'Black Pearl' on Gisela 6 (Gi6), Gi12 and Mazzard at WSU IAREC (1st to 3rd leaf). In 2025, we also excavated two commercial blocks planted the same year as the WSU block: 'Chelan'/Mazzard and 'Black Pearl'/Mazzard. This report emphasizes the final-year (2025) data.

2. **Timing:** Identify strategies to monitor root growth and nutrient availability in sweet cherry.

2.1 Root growth was monitored with root windows, a minirhizotron (CI-600, CID Bio-Science) and electrical resistivity tomography (ERT), the latter conducted by PNNL collaborators. These findings were presented in the 2024 and 2025 reports.

2.2 Nitrogen leaching: In 2024, we evaluated nitrogen leaching in a silt loam soil (Roza farm), as presented in the 2024 report. In 2025–2026, a new trial evaluated the leaching of post-harvest urea in a sandy and a silt loam soil.

3. **Outreach:** Findings have been incorporated into the WSU Tree Fruit soil and nutrition web page (Nutrient Management in Sweet Cherries | WSU Tree Fruit | Washington State University) and the WSU Tree Fruit video (https://treefruit.wsu.edu/videos/optimizing-tree-fruit-nutrition-for-fruit-quality/). Findings will be presented at the 2026 Northwest Cherry Institute meeting, and a summary will be shared in Fruit Matters. Results were also published in two Good Fruit Grower articles (https://www.goodfruit.com/a-window-to-the-roots/ ; https://www.goodfruit.com/research-to-help-growers-schedule-the-sustenance/).

SIGNIFICANT FINDINGS

1. Fruit nutrient removal by 'Benton' was 3.1–4.0 lb N, 0.8–1.0 lb P and 4.0–5.8 lb K per ton of fruit, within the ranges reported for other Washington cultivars. Fruit flesh is about 94% of fruit weight, so analyzing flesh alone is enough to estimate removal.
2. In the mature 'Benton' orchard, whole-tree N did not increase from the 6th to the 8th leaf. Tissues renewed each year (1-year shoots, spurs and fine roots) held only 9% of tree N (24–38 g/tree, 25–40 lb N/acre), and most of this N is recycled in the orchard through fine-root turnover, leaf fall and pruning residues. In mature orchards, annual N demand is therefore driven mainly by fruit yield: about 31–40 lb N/acre at 10 tons/acre.
3. Nutrient demand of new orchards should be estimated from biomass growth. Third-leaf 'Black Pearl' at WSU IAREC accumulated 27–37 g N per tree, or 64–88 lb N/acre at 1,089 trees/acre. Of this, 13–17 lb N/acre was in renewable tissues (leaves, 1-year shoots and fine roots). Total N did not differ among Gi6, Gi12 and Mazzard, although Mazzard allocated half of its biomass to the trunk and rootstock.
4. The N accumulated by the WSU 'Black Pearl' trees in three years (64–88 lb N/acre) was about twice the N applied (about 34 lb N/acre). Nursery reserves and soil and water N supplied a large share of young-tree demand.
5. Trees of the same age in two commercial blocks were 2–3 times larger than those in the WSU experimental orchard. The extra biomass was mostly in the leader, 2- and 1-year wood and leaves, while trunk + rootstock weight was similar. 'Black Pearl'/Mazzard weighed 23.1 kg at the commercial site and 7.9 kg at WSU IAREC.

6. However, N accumulated in the trees per acre did not differ among the five blocks (49–88 lb N/acre; p = 0.33), even though cumulative N inputs over three years ranged from about 34 lb/acre (WSU) to 75 lb/acre ('Black Pearl', commercial) and 300 lb/acre ('Chelan', commercial).
7. Root windows were the most practical method to monitor root growth. New roots formed 3–4 weeks after full bloom, once the minimum soil temperature at 8 inches exceeded 49 °F, and growth was greatest from early June to the end of July.
8. Most of the post-harvest (September) ground-applied urea was not recovered in the sandy soil (Mattawa): ammonium increased only in the top 2 inches and declined by 60% by April, and nitrate did not increase below 6 inches. In the silt loam (Roza), no change was detected in November, but by January the urea had been converted to nitrate, 72–138 ppm above the control in the top 6 inches and reaching 12–18 inches in one replicate. The urea nitrified while trees were dormant, leaving nitrate exposed to leaching with spring irrigation.

METHODS

1. Demand: Investigate biomass and nutrient partitioning in distinct rootstocks and systems.

Biomass and nutrient partitioning were evaluated in the following blocks:

- 'Benton' on MxM14, Gi12 and Gi5 planted in 2018 at the WSU Roza farm (479 trees/acre). Trees were excavated after the 2023, 2024 and 2025 seasons (6^{th} to 8^{th} leaf).
- 'Skeena' and 'Selah' on Gi12 planted in 2012, used only for root monitoring and fruit extraction.
- 'Black Pearl' on Gi6, Gi12 and Mazzard planted in 2023 at the WSU IAREC farm (1,089 trees/acre). Trees were excavated after each season (1^{st} to 3^{rd} leaf). Each tree received 10 g of monoammonium phosphate (MAP) at planting and 10 g of urea in 2024, and the block received 20 lb N/acre in 2025 (about 34 lb N/acre in total).
- Two commercial blocks planted in 2023 (290 trees/acre): 'Chelan'/Mazzard, which received 100 lb N/acre per year since planting, and 'Black Pearl'/Mazzard, which received 25 lb N/acre per year. Trees were excavated after the 2025 season (3^{rd} leaf).

At harvest, all fruit from four replicate trees per rootstock were collected to determine yield and fruit nutrient removal, with fruit separated into flesh, pit and stem. Before leaf fall, nets were placed around the trees to collect all dropped leaves. After leaf drop, three to four trees per rootstock were excavated (Figure 1). Each tree was separated into components (leader, 2-year-old wood, 1-year-old wood, spurs, trunk, rootstock (stump), big roots and fine roots), and each component was weighed fresh. A subsample of each component was weighed fresh and after drying to determine dry matter, and analyzed for total N, P, K, Ca, Mg, S, B, Zn, Fe, Mn and Cu. Whole-tree nutrient content was calculated as the sum, over all components, of fresh weight × dry matter (%) × nutrient concentration (%).



Figure 1. Leaf collection during the fall (left), whole-tree excavation (middle) of 'Benton' trees and dry matter partitioning (right).

Rootstocks within each block were compared with one-way ANOVA, followed by Tukey's HSD test ($p < 0.05$). The three WSU 'Black Pearl' rootstocks and the two commercial blocks, all in the third leaf, were compared together as five groups. For this comparison, the trunk and upper rootstock were combined because they were weighed together at WSU IAREC. The mature 'Benton' block was analyzed separately and was not compared with the young blocks. Per-acre values were calculated with the actual planting density of each block (g/tree × trees per acre ÷ 453.6).

2. Timing: Identify strategies to monitor root growth and nutrient availability.

2.1 Root growth monitoring. The methods and results for root windows, the minirhizotron and ERT were described in the 2024 and 2025 reports and are not repeated here.

2.2 Nitrogen leaching after post-harvest urea application.

During 2023 and 2024, soil samples were collected through the season at the WSU 'Benton', 'Skeena' and 'Black Pearl' sites, but the results were inconclusive. Therefore, in fall 2025, two independent trials were established in soils with contrasting texture. The Mattawa site has a very sandy soil (organic matter 0.7% at 2 inches, decreasing to 0.2% at 24 inches; bulk density 1.5 g/cm^3). The Roza site has a silt loam (organic matter 2.2% to 1.0%; bulk density 1.4 g/cm^3). At each location, four replicate sites received urea at 10 g/tree (Nitrogen) and four sites remained untreated (Control). Urea was applied as granules about 6 inches from the trunk on September 19, 2025, one day after the baseline (pre-treatment) sampling, and was irrigated immediately for 2 hours at Mattawa and 6 hours at Roza. Both sites are drip and sprinkler irrigated. Mattawa then received 2-hour sets daily until mid-October and one 6-hour set at the end of October, while Roza received no further water until the following spring.

Soil samples were collected at 2, 6, 12, 18 and 24 inches one day before application (September 18, 2025) and after application on November 14 and December 13, 2025, and April 8, 2026 (Mattawa), and on November 14, 2025, and January 12, 2026 (Roza). Samples were analyzed for organic matter (OM), total N, nitrate (NO_3-N) and ammonium (NH_4-N). The treatment effect was calculated as the difference between Nitrogen and Control means at each depth, with the standard error of the difference. One core (Roza, January, replicate 4, 6 inches) with 384 ppm NO_3-N and 401 ppm NH_4-N, consistent with a dissolving granule, was excluded from the means.

RESULTS AND DISCUSSION

1. Demand: Investigate biomass and nutrient partitioning in distinct rootstocks and systems.

Fruit nutrient removal

Fruit removal of N, P and Ca did not differ among rootstocks. Fruit K, Mg, S, B and Cu removal was highest on MxM14 (Table 1). The largest difference was 1.8 lb K per ton of fruit between MxM14 and Gi12; all other differences were below 0.1 lb per ton for macronutrients and below 3 g per ton for micronutrients. Removal values were within the ranges reported for 'Chelan', 'Coral Champagne' and 'Skeena' (Sallato et al., 2024). Fruit flesh made up 94% of fruit fresh weight, so analyzing flesh alone provides a reliable estimate of removal.

Table 1. Fruit nutrient removal by 'Benton' on three rootstocks, per US ton of fresh fruit. Different letters within a column indicate significant differences (Tukey's HSD, $p < 0.05$).

Rootstock	N	P	K	Ca	Mg	S	B	Zn	Mn	Cu
			lb/ton					g/ton		
Gi5	3.20	0.94	5.09 ab	0.51	0.31 ab	0.20 b	4.3 b	0.82 a	1.22 a	0.99 ab
Gi12	3.11	0.83	4.00 b	0.57	0.27 b	0.17 b	4.3 b	0.52 b	0.99 b	0.86 b
MxM14	4.00	0.97	5.76 a	0.45	0.33 a	0.26 a	6.7 a	0.57 b	0.84 b	1.21 a
p value	0.081	0.053	**0.014**	0.683	**0.010**	**0.003**	**0.024**	**0.001**	**0.001**	**0.009**

Mature 'Benton' orchard – 6th to 8th leaf

Over three seasons, MxM14 trees were consistently the largest and held the most nutrients, but the differences were significant only in 2024 (Table 2). In 2025 (8th leaf), tree weight did not differ among rootstocks (Table 2). The leader held 36–39% of tree biomass, followed by the trunk (21–29%) and big roots (11–16%), while spurs were below 0.5%. The only difference in partitioning was the rootstock section, which was 14.4% of tree weight on MxM14 compared with 7.4% on Gi5 (Gi12 9.6%, intermediate; $p = 0.017$). Whole-tree nutrient content did not differ among rootstocks in 2025, except Mn (higher on MxM14). Nutrient content per kg of tree was the same for all three rootstocks (3.95–4.06 g N/kg).

Table 2. Tree fresh weight and macronutrient content (woody tissues) of 'Benton' trees by season and rootstock. Different letters within a column and season indicate significant differences (Tukey's HSD, $p < 0.05$).

Season	Rootstock	Tree weight (kg)	N	P	K	Ca	Mg
					(g/tree)		
2023 (6th leaf)	Gi5	67.9	337.2	64.5	126.3	441.5	52.8
	Gi12	66.2	326.1	69.9	120.6	425.6	54.8
	MxM14	87.4	397.0	73.3	160.2	434.3	70.9
	p value	0.179	0.685	0.847	0.169	0.992	0.350
2024 (7th leaf)	Gi5	63 b	256.3 b	48.8	136.2 b	661.0	42.2 b
	Gi12	74 b	336.9 b	68.7	165.8 b	638.6	52.3 ab
	MxM14	126 a	527.0 a	112.5	328.2 a	1,063.9	90.4 a
	p value	0.022	0.019	0.065	0.023	0.232	0.047
2025 (8th leaf)	Gi5	68.5	279.1	51.9	159.9	694.7	50.7
	Gi12	67.9	265.0	46.0	140.2	522.2	42.9
	MxM14	101.6	408.6	77.0	239.1	733.2	70.1
	p value	0.242	0.214	0.187	0.254	0.438	0.282

In the Gisela rootstocks, whole-tree N did not increase between the 6th and 8th leaf (Gi5: 337, 256 and 279 g; Gi12: 326, 337 and 265 g). The mature trees had reached a steady size maintained by pruning,

so little new N was being stored in permanent wood. The N in new tissues (1-year shoots, spurs and fine roots) was estimated at 24–38 g per tree, only 9% of whole-tree N for all three rootstocks, or 25–40 lb N/acre at 479 trees/acre (Table 3). Because total N did not change, most of this N is likely recycled in a mature orchard: fine roots turn over in the soil, leaves resorb part of their N before falling and the rest returns to the orchard floor, and pruned shoots remain in the alley when mulched.

Fruit, in contrast, is exported every year, so annual nutrient demand is driven mainly by fruit yield (Table 3). Additional N is only needed when a deficiency has been diagnosed.

Table 3. Nitrogen in tissues renewed annually by 8th leaf 'Benton' trees, compared with N removed by fruit. Per-acre values at 479 trees/acre.

Rootstock	1-yr shoots g N/tree	Spurs	Fine roots	Renewable	% of tree N	Renewable lb N/acre	Fruit removal[a]
Gi5	5.2	1.3	17.5	23.9	9.2	25.2	32
Gi12	5.4	1.8	16.8	24.0	9.0	25.4	31
MxM14	16.1	1.1	20.6	37.8	9.0	39.9	40
p value	0.312	0.071	0.763	0.329	0.994		

[a]*Fruit N removal (Table 1) × 10 tons/acre.*

Non-bearing sites:
'Black Pearl' (WSU IAREC) – 3rd leaf
In the third leaf, trees weighed 7.7 kg (Gi6), 9.6 kg (Gi12) and 7.9 kg (Mazzard), including leaves, with no differences among rootstocks. Mazzard allocated 50% of its fresh weight to the trunk and rootstock, compared with 34% (Gi6) and 37% (Gi12) ($p < 0.001$; data not shown). As in the first two years, Mazzard invested more of its biomass in the trunk and rootstock, while the Gisela rootstocks invested more in the canopy.

Total N ranged from 26.6 to 36.6 g per tree and did not differ among rootstocks (Table 4). At the actual density of 1,089 trees/acre, this is 64–88 lb N/acre accumulated by the third leaf, compared with 48–59 lb N/acre after the second leaf (2025 report, adjusted to 1,089 trees/acre). Of the total, 13–17 lb N/acre was in tissues that are partially renewed every year (leaves, 1-year shoots and fine roots) and 51–72 lb N/acre was in the permanent structure.



Figure 2. WSU IAREC 'Black Pearl' block planted in 2023 (left) and remaining 3rd leaf trees (right).

Over the three years, this block received about 34 lb N/acre in total: 2.6 lb from MAP at planting, 11 lb from urea in the second year and 20 lb in the third year. The trees, however, held about twice that amount, so N reserves from the nursery, together with soil and water N, supplied a large share of the demand of these young trees.

Table 4. Nitrogen content (g N/tree) by tree component in 3rd leaf 'Black Pearl' (WSU IAREC), and equivalent N per acre at 1,089 trees/acre. Renewable = leaves + 1-year shoots + fine roots.

Rootstock	Leaves	Leader	2-yr	1-yr	Spurs	Trunk + rootst.	Big roots	Fine roots	Total	Total (lb/ac)	Renew. (lb/ac)
Gi6	4.13	8.76	2.33	1.37	0.49	8.23	5.31	1.39	32.0	76.8	16.5
Gi12	4.02	14.24	2.10	1.32	0.61	7.60	5.52	1.18	36.6	87.8	15.7
Mazzard	3.75	6.47	1.16	0.42	0.27	10.85	2.52	1.21	26.6	64.0	12.9
p value	0.926	0.059	0.578	0.061	0.110	0.621	0.082	0.804	0.537		

Commercial blocks compared with WSU IAREC – 3rd leaf

Trees of the same age grown under different conditions differed greatly in total size (Figure 3, Table 5). The commercial 'Black Pearl'/Mazzard (23.1 kg) and 'Chelan'/Mazzard (17.6 kg) trees were 2–3 times heavier than the WSU 'Black Pearl' trees (7.7–9.6 kg). Comparing the same cultivar and rootstock, 'Black Pearl'/Mazzard weighed 23.1 kg at the commercial site and 7.9 kg at WSU IAREC, so site conditions, spacing and nutrient management had a larger effect than rootstock.

The extra biomass of the commercial trees was mostly in the canopy: leader (5.6–7.3 kg vs 1.7–2.9 kg), 2-year wood (1.8–2.1 kg vs 0.2–0.4 kg), 1-year wood (2.5 kg for 'Black Pearl'/Mazzard, the highest of all blocks) and leaves (2.5–4.2 kg vs 0.8–0.9 kg). Trunk + rootstock weight (p = 0.25) and fine-root weight (p = 0.29) did not differ among blocks. 'Chelan'/Mazzard was the only block that produced a measurable crop in the third leaf (4.7 kg of fruit per tree); the 'Black Pearl' blocks were not cropped.

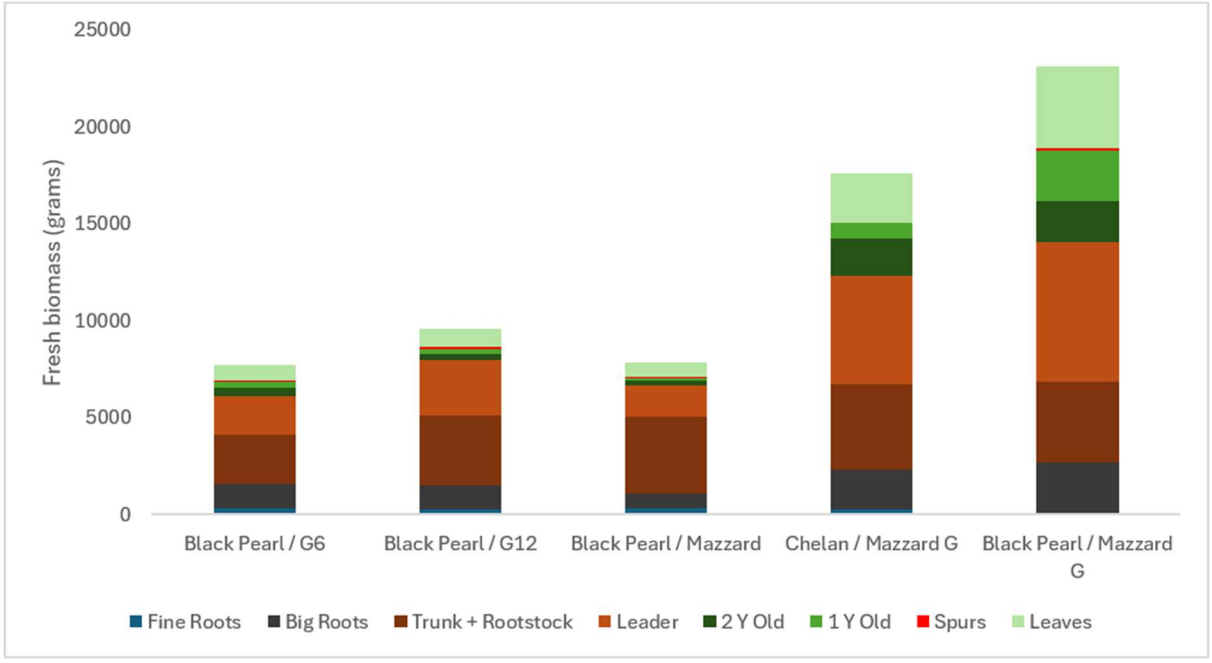


Figure 3. Fresh biomass (g/tree) by tree component in 3rd leaf 'Black Pearl' on Gi6, Gi12 and Mazzard (WSU IAREC, 1,089 trees/acre) and in commercial 'Chelan'/Mazzard and 'Black Pearl'/Mazzard blocks near Pasco (labeled "G"; 290 trees/acre).

Per tree, the commercial trees held two to four times more N, P, K, Ca and Mg than the WSU trees (Table 5). However, the concentration of N in the biomass was similar in all blocks (3.5–4.7 g N per kg of fresh weight; p = 0.06), so the per-tree differences in N were driven by tree size. A similar value (3.95–4.06 g N/kg) was found in the mature 'Benton' trees.

Table 5. Whole-tree fresh weight and macronutrient content of 3rd leaf trees in 'Black Pearl' at WSU IAREC and in two commercial blocks near Pasco. Different letters within a column indicate significant differences (Tukey's HSD, p < 0.05).

Block	Tree weight (kg)	N	P	K	Ca	Mg	N per kg
		(g/tree)					(g/kg)
WSU Black Pearl/Gi6	7.7 c	32.0 bc	9.8 b	13.6 c	60.0 b	5.9 c	4.14
WSU Black Pearl/Gi12	9.6 bc	36.6 bc	8.5 b	16.9 bc	73.0 b	7.2 c	3.77
WSU Black Pearl/Mazzard	7.9 c	26.6 c	6.5 b	16.8 bc	61.1 b	6.1 c	3.48
Commercial Chelan/Mazzard	17.6 ab	77.2 ab	12.2 ab	44.4 ab	80.1 b	13.2 b	4.43
Commercial Black Pearl/Mazzard	23.1 a	110.8 a	17.0 a	57.5 a	155.3 a	21.5 a	4.75
p value	<0.001	<0.001	0.005	0.001	<0.001	<0.001	0.060

On a per-acre basis, the differences change (Table 6). Because the WSU IAREC trees were planted at almost four times the density of the commercial blocks (1,089 vs 290 trees/acre), N accumulated in the trees per acre did not differ among blocks (49–88 lb N/acre; p = 0.33), nor did K, Mg or S. P and Ca per acre were highest at WSU IAREC.

Cumulative N inputs, however, differed widely: about 34 lb/acre at WSU IAREC, and 75 lb/acre for 'Black Pearl' and 300 lb/acre for 'Chelan' at the commercial site. The 'Chelan' block received the most N but stored the least per acre (49 lb N/acre, plus about 5 lb N/acre in fruit). Although direct comparisons with the commercial sites cannot be made, the results show that N applied above young-tree demand was not stored in the trees and was likely exposed to loss.

Table 6. Nutrients accumulated in 3rd leaf trees per acre (lb/acre) at the actual planting density of each block, and cumulative N applied since planting. Different letters within a column indicate significant differences (Tukey's HSD, p < 0.05).

Block	Trees/acre	N applied[a] (lb/acre)	N	P	K	Ca	Mg	S
			(lb/ac)					
WSU Black Pearl/Gi6	1,089	34	76.8	23.5 a	32.6	144.1 ab	14.2	4.1
WSU Black Pearl/Gi12	1,089	34	87.8	20.5 a	40.6	175.1 a	17.3	5.4
WSU Black Pearl/Mazzard	1,089	34	64.0	15.7 ab	40.4	146.6 ab	14.6	4.2
Commercial Chelan/Mazzard	290	300	49.4	7.8 b	28.4	51.3 b	8.4	3.0
Commercial Black Pearl/Mazzard	290	75	70.9	10.9 ab	36.8	99.4 ab	13.7	4.4
p value			0.327	0.012	0.823	0.024	0.083	0.266

[a]*WSU: 10 g MAP/tree at planting + 10 g urea/tree in 2024 + 20 lb N/acre in 2025. Commercial: 100 ('Chelan') and 25 ('Black Pearl') lb N/acre per year for three years.*

For young orchards, these results support estimating N demand from expected biomass growth (about 4 g N per kg of new fresh biomass) at the actual planting density, rather than applying fixed annual rates. N stored in the tree was similar across blocks receiving 34 to 300 lb N/acre, so growth and density, not N rate, determined how much N the trees took up.

2. Timing: Identify strategies to monitor root growth and nutrient availability.

2.1 Root growth monitoring. Root windows, the minirhizotron and ERT were compared over 2023–2025, and detailed results were presented in the 2024 and 2025 reports.

Monitoring methods. Overall, root windows installed between trees provided the most direct and simplest method to monitor the timing of root growth and to compare relative root growth among sites (Figure 4).

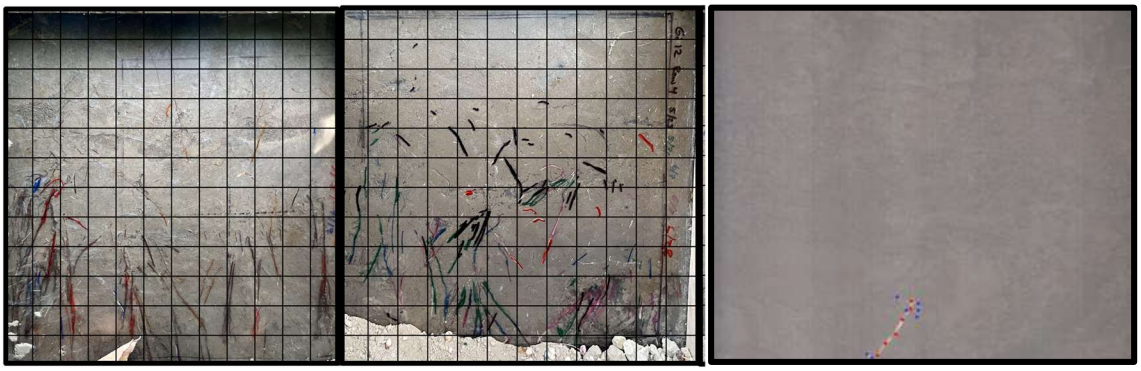


Figure 4. Root growth images collected on June 6, 2023, through root windows for Gisela 5 (left) and Gisela 12 (middle), and with the CID Bio-Science minirhizotron for Gisela 12 (right). Different colors correspond to different monitoring dates.

The minirhizotron did not provide useful information for this study. Although installation and image collection were simple (CI-600, CID Bio-Science), roots were difficult to detect and quantify in the images (Figure 4, right).

Detailed ERT findings were presented in the 2025 report. In summary, time-lapse images of bulk electrical conductivity obtained with ERT were sensitive to root presence, but also to changes in temperature, irrigation, water conductivity and saturation, which made them difficult to interpret without additional soil sensors and controlled environment.

Timing of root growth. Root growth in sweet cherry, regardless of rootstock, began 3 to 4 weeks after full bloom in all years, when the minimum soil temperature at 8 inches exceeded 49 °F. Growth was slow (less than 14 mm per day) during the cell-division period of fruit growth and increased during stage III of fruit growth and after harvest (early June to the end of July; see 2024 report). A few new roots also appeared in late summer (end of September), but they were short-lived.

2.2 Nitrogen leaching after post-harvest urea application.

Before treatment (September), ammonium and nitrate levels were low at both sites (Figure 5). At Roza (silt loam), one replicate had high pre-existing NH_4-N (31–73 ppm from 2 to 18 inches), which explains the positive baseline difference for NH_4-N at that site (Figure 5).

Mattawa (sand). NH_4-N increased at 2 inches after urea application (19.8 ppm above the control in November and 13.1 ppm in December; Figure 5). By April, NH_4-N at 2 inches had declined by 60% (+8.1 ppm), while it increased slightly at 6 inches (+7.4 ppm). Nitrate remained very low, with no change through December (differences ≤0.5 ppm) and background levels at 18 and 24 inches (Figure 5). In April, nitrate increased slightly at 2 and 6 inches (+3.0 and +1.7 ppm), and the NO_3-N share of surface mineral N rose from 8% to 28%, suggesting slow nitrification of the remaining ammonium as the soil warmed in spring. Losses below 24 inches in the weeks immediately after application, before urea hydrolysis, cannot be excluded, because urea moves freely with water until it is converted to ammonium.

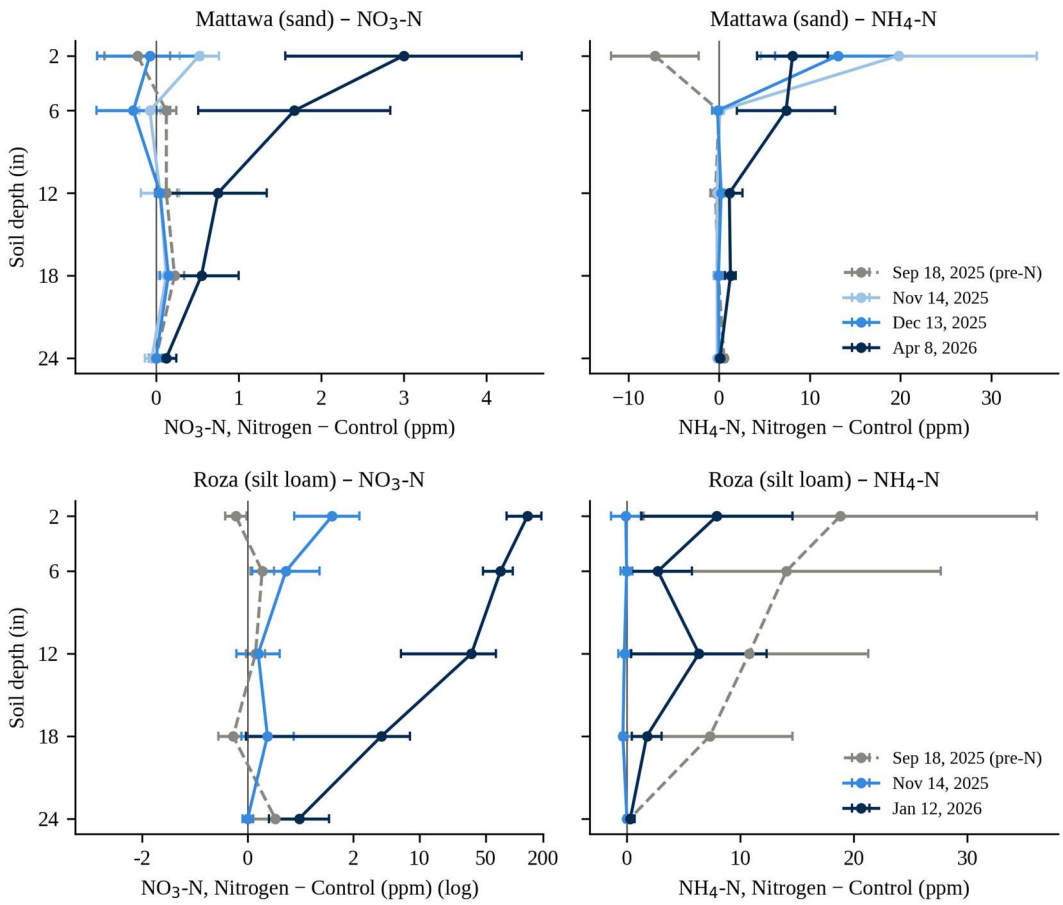


Figure 5. Net effect of urea on soil nitrate (left) and ammonium (right) by depth at Mattawa (sand, top) and Roza (silt loam, bottom). Values are Nitrogen − Control means ± SE of the difference (n = 4). September was sampled one day before application. Roza nitrate is shown on a logarithmic scale.

Roza (silt loam). No increase in NH_4-N or NO_3-N was detected in November, eight weeks after application (Figures 5 and 6). By January, nitrate in the Nitrogen plots was 138 ppm (2 inches) and 72 ppm (6 inches) above the control, making up 95% of surface mineral N. Nitrate was also 35 ppm higher at 12 inches and 4 ppm higher at 18 inches. These deeper increases came mainly from one replicate (123 and 17 ppm), while the other replicates stayed below 14 ppm at 12 inches. Nitrate at 24 inches remained near background (+1.0 ppm). The absence of change in November, followed by a large nitrate increase in January, supports the hypothesis that, with no irrigation after the application set, the urea granules dissolved and hydrolyzed slowly during the fall, and the resulting ammonium was converted to nitrate in early winter, when trees take up little N. Granular placement also created strong spatial variability, reflected in the large standard errors.

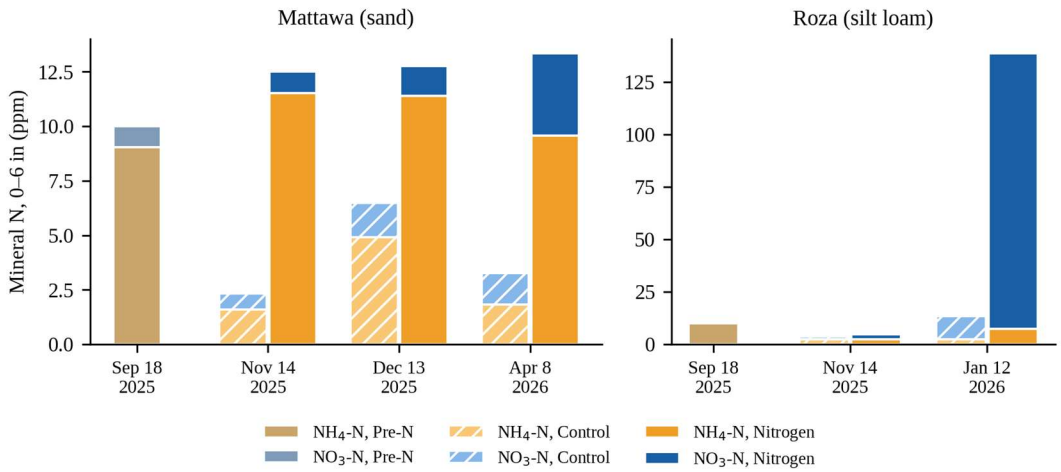


Figure 6. Ammonium (NH_4-N) and nitrate (NO_3-N) in the top 6 inches (mean of 2 and 6 inch samples) at Mattawa and Roza. September values pool Control and Nitrogen plots (pre-treatment, n = 8); other dates n = 4 per treatment.

In the sandy soil, most of the post-harvest urea was not recovered in the 0–24 inch profile during fall and winter. We attribute this to the coarse texture and, probably, to the long irrigation set before dormancy that is commonly applied to refill the soil profile and reduce the risk of frost damage. In the silt loam, mineral N remained in the upper soil and had been converted to nitrate by January; the slower infiltration and greater water-holding capacity of this soil kept the N within the sampled profile.

In both soils, nitrate, whether accumulated over winter (silt loam) or newly formed from ammonium in spring (sand), is mobile and at risk of moving below the root zone with the first spring irrigations or precipitation. Because new roots do not form until 3–4 weeks after full bloom, N applied after leaf fall or early in spring remains exposed to loss before roots can take it up. Applying N during periods of active uptake (from root growth onset in spring through shoot growth, and post-harvest only while leaves are still active), in smaller doses through fertigation, would reduce the time that mineral N remains exposed to leaching.

EXECUTIVE SUMMARY

Project title: Precision Nutrient Management for sweet cherry orchards

Key words: sweet cherry, nutrient demand, biomass partitioning, rootstock, root growth, nitrogen leaching, urea

Nutrient recommendations for sweet cherry are usually based on fruit removal, while there is little information regarding demand prior to full production, during tree establishment. Over three seasons (2023–2025), we quantified biomass and nutrient partitioning by whole-tree excavation in a mature 'Benton' orchard (Gi5, Gi12 and MxM14; 6th–8th leaf) and a young 'Black Pearl' orchard at WSU IAREC (Gi6, Gi12 and Mazzard; 1st–3rd leaf), and in 2026 we compared the young orchard with two commercial blocks of the same age. We also evaluated methods to monitor root growth and evaluated the risk of leaching with post-harvest urea applications in a sandy and a silt loam soil.

Fruit removed 3.1–4.0 lb N, 0.8–1.0 lb P and 4.0–5.8 lb K per ton, with small differences among rootstocks and among cultivars (when compared with our previous project). In sweet cherry, analyzing fruit flesh alone is enough to estimate removal. Whole-tree N in 'Benton' did not increase from the 6th to the 8th leaf, and new growth (1-year shoots, spurs and fine roots) held only 9% of tree N, most of which is recycled within the orchard. Annual N demand of mature orchards is therefore driven by yield: about 31–40 lb N/acre for a 10 tons/acre crop.

In young orchards, nutrient demand is driven by biomass growth. Third-leaf 'Black Pearl' at WSU IAREC accumulated 64–88 lb N/acre (1,089 trees/acre), about twice the N applied over three years (34 lb N/acre). Commercial trees of the same age were 2–3 times larger, yet N stored per acre was similar in all blocks (49–88 lb N/acre) despite cumulative inputs of 34 to 300 lb N/acre. N concentration in tree biomass was consistent (about 4 g N per kg of fresh weight), so the N demand of new orchards can be estimated from expected growth and planting density rather than fixed annual rates.

Root windows were the most practical monitoring tool; minirhizotron images were difficult to quantify, and ERT was confounded by soil moisture and temperature. In our study, new roots formed 3–4 weeks after full bloom, once the soil at 8 inches exceeded 49 °F, with the most growth from early June to the end of July. Scheduling N applications based on root growth should be considered for improving nitrogen use efficiency.

Post-harvest urea applied in September was largely not recovered in the sandy soil profile, while in the silt loam it was converted to nitrate during dormancy (72–138 ppm above the control in the top 6 inches by January), when trees cannot take it up.

Recommendations. Base N rates on expected yield in mature orchards and on expected biomass growth at the actual planting density in young orchards. Apply N while roots and leaves are active, from root growth onset in spring through shoot growth and post-harvest only before leaf senescence, in split fertigation doses, to improve efficiency and reduce leaching.