

Nutrient and Soil Health Management for Sweet Corn (Western Oregon)

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Note: This guide replaces an earlier Oregon State University nutrient management guide for sweet corn grown in western Oregon (EM 9010, 2010). Findings from recent research have been incorporated into this guide and are described in detail in appendices.

In this guide, we present traditional nutrient management concepts with added emphasis on cover cropping practices that promote long-term soil health. We introduce interseeding, an evolving management practice (Appendix C, page 21).

Interseeding is the practice of seeding the fall cover crop when corn plants are small enough to allow sufficient light penetration for cover crop establishment. After corn harvest, the interseeded cover crop is already established and ready to grow.

This publication primarily addresses sweet corn production for full-season hybrids grown with conventional (inorganic) fertilizer inputs. See “Nutrient management in organic sweet corn” (page 13) for nutrient management recommendations for sweet corn produced under organic certification. Cover cropping and soil health management recommendations in this guide apply to both conventional and organic cropping systems.

Generally, sweet corn yields for full-season hybrids in western Oregon are 10–12 ton/acre (“as-harvested”



Photo: ?????

Photo: Ed Peachey

fresh weight). The recommendations in this guide, especially those for N, are adequate to produce yields of 14 ton/acre or more with newer hybrids.

Sweet corn processors want uniform maturity, uniform ear size and a cylindrical (rather than tapered) ear filled to the tip with narrow, deep kernels. Deep kernels give a high%age cut-off or net yield. Many of these traits can be influenced by nutrient management.

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This publication uses the leaf collar method for describing corn growth stages. The leaf collar is the point at which the leaf blade breaks away from the leaf sheath and stalk. Vegetative growth stages in corn are described by the number of visible leaf collars. For example, at V6 growth stage, six leaf collars are visible. Visual guides for growth staging using the leaf collar method are available from Iowa State University (www.ipm.iastate.edu/files/03%20Corn%20Growth%20and%20Development.pdf).

Nutrient recommendations in this guide assume adequate control of pests, including weeds, insects and plant diseases (especially root rot disease). Even excellent nutrient management cannot overcome inadequate pest control.

Many recommendations given in this guide are based on field research conducted with support from the Oregon Processed Vegetable Commission. Annual OPVC reports are available online at agsci.oregonstate.edu/category/veg/oregon-processed-vegetable-commission.

Nutrient management and cover cropping quick facts

With the exception of nitrogen (N), nutrient recommendations in this guide are based on a preplant soil test. Collect the preplant soil sample in the fall or in spring prior to corn seeding.

Recommendations in this guide are valid only when the laboratory employs soil test methods as described for western Oregon in the *Soil Test Interpretation Guide* (EC 1478).

See “Nutrient management in organic sweet corn” (page 13) for recommendations for sweet corn grown under organic certification. Cover cropping benefits both organic and conventional cropping systems.

Nutrient management

Nitrogen (N)	Apply 30 lb N/acre in a starter band at planting. Starter N may not be required when sweet corn follows a legume. Apply sidedress N at the V4 to V6 growth stage based on an in-season pre-sidedress nitrate test (PSNT). See table 3 (page 6) for sidedress N rate recommendations.
Lime	Soil pH above pH 5.8 is recommended for sweet corn production. Apply lime according to table 4 (page 7) if soil pH is below 5.8.
Phosphorus (P)	Apply P according to table 6 (page 9) if soil test P is below 50 ppm.
Potassium (K)	Apply K according to table 5 (page 8) if soil test K is below 200 ppm or 0.5 meq/100 g soil.
Sulfur (S)	Apply 15–20 lb S/acre in the sulfate form at planting time (page 8).
Calcium (Ca)	Apply 1 ton lime/acre if Ca is below 1,000 ppm (5 meq/100 g soil) even if soil pH is adequate (page 8).
Magnesium (Mg)	If soil test Mg is below 120 ppm (1 meq/100 g soil), band 10–15 lb Mg/acre at planting (page 8).
Zinc (Zn)	Apply Zn if soil test Zn (DTPA method) is below 1 ppm (below 1.5 ppm in the Stayton area). Band 3–4 lb Zn/acre at planting or broadcast 10 lb Zn/acre before planting (page 10).

Cover cropping

- To maximize winter cover crop benefits, seed before October 1. In most cases, a legume-cereal cover crop mixture provides more overall benefit than do solo cereal or legume cover crops.
- Cereal cover crops provide ground cover and reduce soil erosion following corn. They also take up nitrate from soil that otherwise would be lost via overwinter leaching. In spring, residue from a legume cover crop releases plant-available N, reducing the amount of N fertilizer required to grow corn.
- Establishing a cover crop following corn may not be feasible in all cases. Consider inter-seeding to increase success in cover crop establishment. See Appendix C (page 21) for details.



Photo: Ed Peachey

Nutrient uptake and removal by sweet corn

Maintaining nutrient balance in the soil over the long term requires consideration of nutrient inputs (from fertilizer and other inputs), as compared with nutrient removal in the harvested portion of the crop (Table 1). Consider nutrient balance for the entire crop rotation, not just the sweet corn crop. For most nutrients, nutrient balance implies that:

- Crop yield is not limited by nutrient supply.
- An excessive amount of one nutrient in the soil does not interfere with crop uptake of other nutrients.
- Nutrient loss to surface or groundwater is minimized.

Aboveground nutrient uptake includes nutrients present in cornstalks and ears (Table 1). Only the ears are removed at harvest. Nutrients present in cornstalks are returned to the soil after harvest. Nutrient uptake and removal values in Table 1 are for full-season varieties grown for processing. Nutrient uptake and

Table 1. Nutrient uptake and removal by sweet corn.

Nutrient	Aboveground nutrient uptake ^a (lb/a)	Nutrient removed in harvested ears ^b (lb/a)
N	150–200	70
P ₂ O ₅	70–90	30
K ₂ O	240–360	60

^aSource: Hart, et al., 2010.

^bSource: Heckman, 2007. Based on 10-ton/acre ear yield.

Sweet corn production in the Willamette Valley

Sweet corn is grown in rotation with agronomic crops (such as winter wheat and grass seed), other vegetable crops and specialty crops (such as hemp). Soils are predominantly medium textured (sandy loam, silt loam, clay loam or silty clay loam) and have access to irrigation water. Sweet corn is typically planted in fields with soils mapped as Amity, Chehalis, Cloquato, Coburg, Concord, Newberg, Salem, Stayton, Willamette and Woodburn series. Rivers or wells that draw from shallow aquifers provide most of the irrigation water.

Winter rainfall in the Willamette Valley is sufficient to leach soluble nutrients such as nitrate-N below the rooting depth of corn. Some fields used for corn production are within the South Willamette Valley Groundwater Management Area designated by the Oregon Department of Environmental Quality due to elevated nitrate-N concentrations.

nutrient removal are approximately 25%–40% lower for early varieties grown for fresh market.

A few farms harvest sweet corn residue and remove it from the field as a substrate for anaerobic digestion or composting. Because the residue is rich in N and K, removing it depletes the reservoir of nutrients stored in the soil. Crop residue removal can also deplete soil organic matter over the long term.

Nitrogen

Nitrogen (N) is the most difficult nutrient to manage in Willamette Valley vegetable production systems. Crops in almost every field respond to N fertilizer or other N inputs. A key part of the N challenge in western Oregon is that much of the nitrate remaining in the soil profile in early September moves below the rooting depth by the following spring and eventually may enter groundwater. The goal of N management is to provide a reliable supply of N for the crop while protecting groundwater quality.

Nitrogen management in conventional production systems

This section addresses N management for cropping systems that employ inorganic fertilizers such as urea and ammonium sulfate to supply N. Most of the same soil health management practices (for example, cover cropping) are used under conventional management and under organic certification. See page 13 for a discussion of N management practices specific to organic farming.

Nitrogen management decisions include:

- How much N to apply (rate).
- When the application should be made (timing).

Maintaining soil health

Soil health can be defined as the “continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans” (see Healthy Soil for Life, nrcs.usda.gov/wps/portal/nrcs/main/soils/health).

Connections between nutrient management and soil health management practices are described in *Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon* (EM 9165). Specifically, maintenance of soil health to support sweet corn production includes:

- Maintaining soil organic matter.
- Maintaining soil pH.
- Maintaining soil biology.
- Maintaining nutrient balance (avoiding excessive depletion or buildup of nutrients in soil).

Winter cover crops grown prior to or following sweet corn can help meet soil health goals. In addition, cover crops can take up some of the N that otherwise would be lost below the root zone via overwinter leaching.

Corn growth and N uptake

This section describes corn growth stages and the timing of dry matter and N accumulation by the crop. See page 5 for N fertilizer recommendations for conventional sweet corn production. For organic production, see “Nutrient management in organic sweet corn” (page 13).

A sweet corn crop takes up 150–200 lb N/acre in aboveground biomass. An ear yield of 10 ton/acre removes about 70 lb N/acre.

Newer sweet corn varieties can produce higher ear yields than older varieties such as ‘Golden Jubilee’. Yields as high as 16 ton/acre have been measured in Oregon State trials. Total aboveground N uptake by the newer varieties is similar to that of ‘Golden Jubilee’.

Sweet corn growth and nutrient accumulation can be divided into three stages, each lasting approximately one month: (1) planting to the five-leaf (V5 or fifth collared leaf) growth stage, (2) V5 to silk emergence and (3) from silk emergence to harvest (Abendroth, et al., 2011). Efficient N management provides adequate, but not excessive, N supply to support crop requirements at all growth stages.

Planting to the five-leaf (V5) growth stage

For the first month, sweet corn grows slowly, and root development is limited. The corn plant takes up only small quantities of nutrients during this period. Although growth and N uptake are minimal, this period sets the stage for future leaf and ear development. When the corn is 12 inches tall, both N uptake (5–15 lb/acre) and biomass production (150–250 lb/acre) are small, but all leaf and ear shoot initiation is complete, and a small tassel is present. The corn plant is ready to grow and reproduce. Sufficient N during this stage is extremely important.

Five-leaf stage (V5) to silk emergence

Leaf number and height begin to increase rapidly after the appearance of six collared leaves (V6 growth stage). After 10 leaves are produced, sweet corn growth accelerates, with new leaves appearing every two or three days until silk emergence, or when the sweet corn is about waist high. When corn is planted at the end of May, silk emergence occurs at the end of July.

At this stage of growth, N uptake is more than 5 lb/acre/day. Although this period of growth and development is short (approximately 30 days), sweet corn takes up most of its N during this time.

Nitrogen accumulation precedes growth (Figure 1). At silk emergence, seasonal accumulation of N is nearly complete, while dry matter production is 50 percent complete.

Silk emergence to harvest

After silk emergence, little additional N is taken up by the plant. Most of the N for the developing ear is translocated within the plant from leaves to ears.

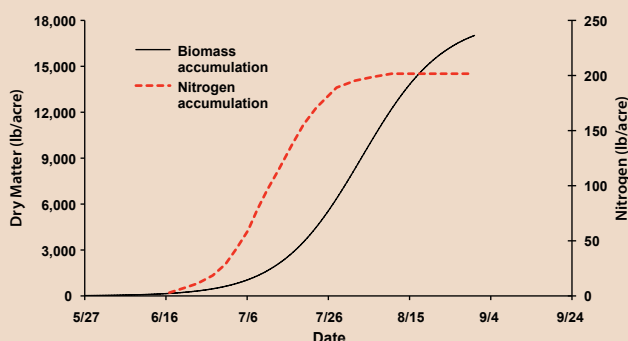


Figure 1. ‘Basin’ sweet corn aboveground biomass (dry matter) and nitrogen accumulation. Corn was planted May 27 in 30-inch rows, and a stand of 26,000 plants/acre was achieved. The V5 to V6 development stage occurred on July 1, and silk emergence was noted July 29. Corn was harvested Aug. 31, 2009.

- Method of application (placement).
- N fertilizer source.

Research conducted in the Willamette Valley has demonstrated that a total N application of 100–180 lb/acre is sufficient for sweet corn production. Applying all of the N fertilizer preplant is not recommended for several reasons. During the first month after seeding, N applied preplant is subject to loss below the rooting depth with irrigation or rainfall, especially on sandy soils such as the Newberg sandy loam. Also, during the first month after seeding, variable amounts of plant-available N (PAN) are mineralized from

soil organic matter and from previous crop residues, depending on field history.

We strongly recommend applying most of the N fertilizer at the V4 to V6 growth stage, with the application rate based on a soil nitrate test (the pre-sidedress nitrate test, or PSNT, page 5). Typically, the N application is split between a starter application of 30–50 lb N/acre and an application of 100–150 lb/acre at sidedress (V4 to V6 growth stage).

Table 2 (page 5) provides an overview of N management decision points for conventional sweet corn production.

Table 2. Overview of N management decision points for conventional sweet corn production.^a

Timing	Goals	Placement options	Fertilizer source comments	N rate
At planting (starter)	Apply enough N to establish the crop. Avoid crop injury.	Broadcast N preplant or band N at planting. Broadcasting is less efficient than banding. Excess fertilizer close to seed can kill or stunt seedlings.	N fertilizers vary in salt and ammonia hazard: Urea is more likely to injure seedlings than are ammonium sulfate or ammonium phosphate fertilizers.	Apply 30–50 lb N/acre. Wait until V4 to V6 growth stage to determine site-specific N rate, based on PSNT soil test.
Sidedress (V4 to V6 growth stage)	Choose N rate based on soil nitrate test (PSNT) results.	Broadcast, fertigate or apply beside the row. Irrigate within a few days to incorporate surface-applied fertilizer	Research shows no advantage to any specific source of N or method of sidedress application. Because of very rapid crop N uptake that follows the V6 growth stage, controlled-release N fertilizers are not recommended.	Apply sidedress N based on PSNT (Table 3, page 6)

^aFor organic cropping systems, see “Nutrient management in organic sweet corn” (page 13).

Starter N fertilizer application at planting

Although corn takes up a small amount of N (5–15 lb/acre) during the first four to six weeks of growth (Figure 1, page 4), the crop cannot recover from N deficiency at this time. Later-season N applications will not compensate for early-season N deficiency.

Starter N fertilizer is most beneficial early in the season (May) when soil is cool and soil test nitrate-N is low. Crops planted after June 1 into soils with preplant NO₃-N above 15 ppm (50 lb/acre) are less likely to benefit from starter N.

Apply 30 lb N/acre in starter fertilizer to meet crop N requirements up to the V6 growth stage. Apply starter fertilizer in a band 2 inches beside and 2 inches below the seed (2 x 2 placement). If banding is not feasible, apply 50 lb N/acre by broadcasting.

Placing starter N fertilizer closer than 2 inches from the seed risks injury to seedlings from excess ammonia (NH₃) or soluble salt. The risk of seedling injury is greatest in sandy soils, such as Newberg sandy loam, that have low water-holding capacities. Application of urea, either as dry, granular urea (46-0-0) or liquid urea-ammonium nitrate (UAN, 32-0-0), is more likely to injure seedlings than is application of ammonium phosphates such as granular MAP (11-52-0) or liquid ammonium polyphosphate (10-34-0). In soil, urea can release ammonia (NH₃).

Sidedress nitrogen fertilizer application based on PSNT

After corn plants have produced six leaf collars (V6 growth stage), plant growth and crop N uptake increase rapidly (Figure 1, page 4). To ensure adequate N during

this critical period, apply sidedress N fertilizer, if needed, when corn is at the V4 to V6 growth stage.

To determine a site-specific sidedress N fertilizer rate, collect a PSNT soil sample for nitrate-N determination when corn is at the V4 to V6 growth stage. Sample between rows to a depth of 12 inches. When collecting the soil sample, avoid starter fertilizer bands adjacent to rows. Put samples on ice after collection and ship to the analytical laboratory for nitrate analysis. See *Soil Nitrate Testing for Willamette Valley Vegetable Production* (EM 9221) for additional sample collection guidance.

Research to calibrate the PSNT-based sidedress N recommendations for sweet corn in western Oregon was performed in the 1990s with ‘Golden Jubilee’. The PSNT was subsequently validated for newer corn varieties (Appendix A, page 15).

Interpretations for the PSNT are given in Table 3 (page 6). These recommendations are based on research performed in more than 20 grower fields and in replicated field trials at the North Willamette Experiment Station (Hemphill and Hart, reports to OVPC, 1995–1998). This research demonstrated that a total of 175 lb N/acre (soil nitrate-N as measured in PSNT + applied sidedress N) is sufficient to meet the corn N requirement.

Other research has demonstrated no yield benefit from sidedress N fertilizer application when nitrate-N measured by the PSNT exceeded 25–30 ppm, or approximately 85–105 lb N/acre (Heckman, et al., 1995; Gale, 2005; Ma, et al., 2007). With current varieties and production practices, a yield response to sidedress N is unlikely when the PSNT test result exceeds 30 ppm (105 lb nitrate-N/acre; see Table 3, page 6).

Besides the soil NO₃-N measured via PSNT, additional PAN mineralizes from soil organic matter after a PSNT sample has been collected. The typical amount of N mineralized from soil organic matter in conventionally managed Willamette Valley silt loams and silty clay loams at summer temperatures (70°F) ranges from 1 to 2 lb N/acre/day (reports to OVPC: Peachey and Sullivan, 2011; Sullivan, et al., 2012). Thus, during the 30 days following PSNT, an additional 30–60 lb of PAN is typically provided via mineralization. Corn will also utilize NO₃-N that is present deeper in the soil profile (not measured by PSNT).

Postharvest soil nitrate testing as an indicator of excess N supply

Excess nitrate accumulates in soil when PAN supplied from all sources, including mineralization from soil organic matter, exceeds crop capacity for N uptake. A postharvest nitrate test measures nitrate-N that remains in the soil at the end of the season and is available for overwinter leaching loss. The postharvest test does not indicate whether N supply was deficient or adequate to achieve optimum ear yield.

Postharvest testing is most useful in systems supplying N via organic inputs, as accurate predictions of the timing and amount of PAN are difficult in organic cropping systems.

Soil samples for a postharvest nitrate test are most meaningful when collected within a few days of ear harvest. Sweet corn residue has a C-to-N ratio of less than 20 to 1, so nitrate-N release accompanies crop residue decomposition, and this additional nitrate confounds the interpretation of the postharvest nitrate test.

An adequate sampling depth for a postharvest test is 0–12 inches. Research demonstrates that soil nitrate-N concentration almost always declines with soil depth, so there is little benefit to deeper soil sampling.

In general, when postharvest nitrate test values are high (above 15 ppm), N supply from all sources (N mineralized from soil organic matter, N from inputs and N in irrigation water) exceeded crop need.

The effect of N fertilizer application rate on postharvest nitrate-N was demonstrated in field trials at the North Willamette Experiment Station on a Willamette silt loam soil (Figure 2). Maximum ear yields occurred with application of 100–150 lb N/acre (as urea). At N fertilizer rates of 0–150 lb N/acre, sweet corn was efficient in N uptake, and postharvest nitrate-N was less than 50 lb N/acre (15 ppm N). At the highest N fertilizer rate (200 lb N/acre), postharvest nitrate-N averaged 75 lb/acre and had the greatest variability (43–123 lb/acre).

Table 3. Sidedress N rate for sweet corn in the Willamette Valley, based on a soil sample (0–12 inches) collected when corn is at the V4 to V6 growth stage.

PSNT soil test value (0–12 inches) ^a		Recommended sidedress N fertilizer rate ^b (lb N/acre)
Soil test NO ₃ -N (ppm)	Soil test NO ₃ -N (lb/acre)	
3	10	165
6	20	155
9	30	145
11	40	135
14	50	125
17	60	115
20	70	105
23	80	95
26	90	85
30+	105+	0 ^c

^aSoil test values given in the same row (ppm and lb/acre) are equivalent. For example, a soil test value of 50 lb N/acre is approximately equivalent to 14 ppm in a 12-inch depth of soil (assumed soil bulk density = 1.3 gram/square centimeter or 81 pounds/cubic foot).

^bRecommendations for fertilizer sidedress rates when PSNT is below 30 ppm NO₃-N are reproduced from Hart, et al., 2010, *Nutrient Management Guide for Sweet Corn (Western Oregon)*, EM 9010.

^cIn most situations, an ear yield response to sidedress N is not expected when PSNT is greater than 30 ppm (105 lb NO₃-N/acre). Some N fertilizer application may be warranted in fields with large spatial variability.

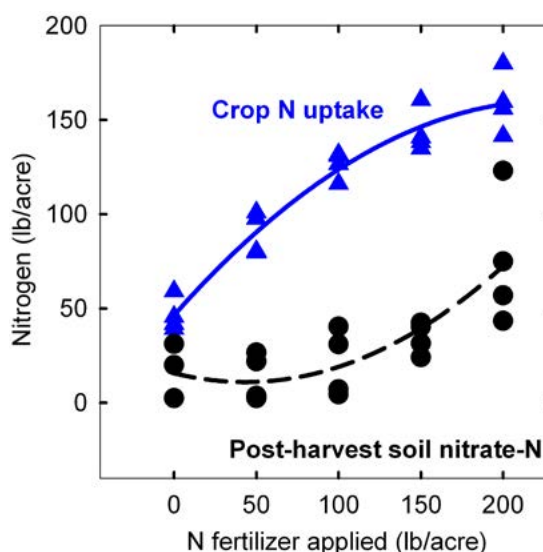


Figure 2. Aboveground crop N uptake (at ear harvest) and postharvest soil nitrate-N for ‘Golden Jubilee’ sweet corn. Combined data from four site-years: Puyallup, Washington, and Aurora, Oregon, in 2003 and 2004. Nitrogen fertilizer (urea) was applied preplant (50 lb N/acre), with the remainder of the N applied via sidedress at PSNT time. Adapted from Gale (2005) and Kusunwiriawong (2005).

Nitrogen fertilizer additives

Oregon State field trials with sweet corn evaluated “enhanced efficiency” additives for urea and ammonium-based fertilizers (Sullivan, et al., OVPC reports, 2013, 2014, 2015). The EEF fertilizers contained proprietary polymer coatings, urease inhibitors or nitrification inhibitors. Major findings:

- Preplant application of EEF fertilizers did not increase sweet corn ear yield when compared to preplant application of urea.
- EEF products prevented the conversion of some of the $\text{NH}_4\text{-N}$ to leachable $\text{NO}_3\text{-N}$ for up to four weeks following preplant application.
- Measured ammonia volatilization loss from surface-applied urea in field trials was insignificant (less than 5% of N applied), so EEF products that reduce ammonia loss from urea (urease inhibitors) did not provide benefit.

Our research did not include all available EEF products, and it did not include all of the possible application scenarios for EEF products.

Nutrient management based on preplant soil testing

Soil test methods

Interpretations provided in this guide are based on soil testing methods described in the *Soil Test Interpretation Guide* (EC 1478) for western Oregon soils. These interpretations are not valid when other soil testing methods are used.

Soil pH and lime

Soil pH between 5.8 and 6.2 is considered adequate for sweet corn production. A substantial yield reduction (1–4 ton/acre) is possible when soil pH is below 5.8.

An example of sweet corn response to soil pH is shown in Figure 3. Lime was applied two and a half years prior to planting sweet corn, resulting in preplant soil pH values of 5.6 to 6.6. Corn total ear yield and ear quality (U.S. No. 1 ears) increased with soil pH. Maximum ear yield and quality occurred at a soil pH of 6.2 or 6.6.

When soil pH is less than 5.8, liming is recommended. Use SMP buffer test results to determine lime application rate (Table 4). Sample and test soil ahead of planting, because lime needs to be incorporated by tillage prior to planting. Recommendations given in Table 4 are based on a plow layer soil sampling depth (approximately 6 inches). A lime application is effective for several years.

Sample soil for pH at the same time each year to avoid confusion from seasonal pH fluctuation. Soil pH fluctuates by 0.3–0.5 unit during the year. It is usually lowest (most acidic) in late August and September, before fall rains begin. It is usually highest in February or March, when the soil is wettest, and N fertilizer has not been applied recently. Because of seasonal soil pH fluctuation, we list a range of pH values that are considered adequate for sweet corn (5.8 to 6.2).

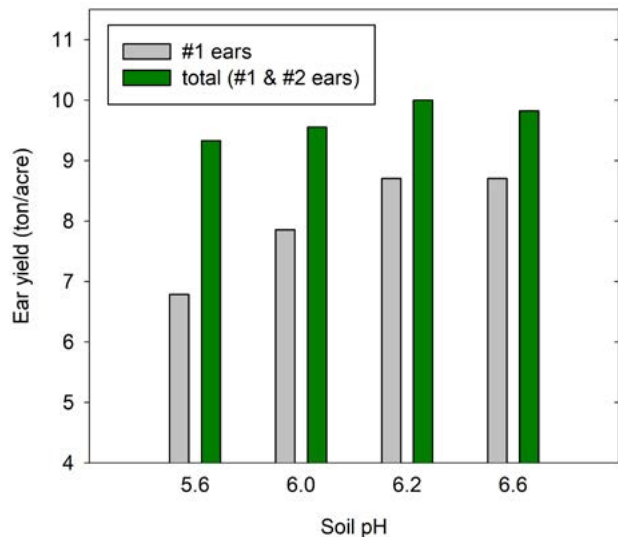


Figure 3. Effect of soil pH on ‘Golden Jubilee’ sweet corn yield. Corn was planted June 3 and harvested Sept. 17, 1981. Lime was applied at 0, 2, 4 or 6 ton/acre in the fall of 1978. Soil pH was measured in 1981 prior to corn planting. Ear yield (No. 1 and total) increased in response to increased soil pH up to a pH of 6.2 (at 5 percent level of probability). Willamette silt loam soil, Aurora, Oregon. Source: McAndrew, 1983, page 65.

Table 4. Lime rate recommendations for western Oregon using the SMP buffer test.^a

Use SMP buffer test when soil pH is below	SMP buffer test for lime ^b	Apply this amount of lime ^c (t/a)
5.8	Below 5.6	5–4
	5.6–5.8	4–3
	5.8–6.0	3–2
	6.0–6.3	2–1
	Over 6.3	None

^aLime recommendations are based on the SMP buffer test only. If other buffer tests are used, recommendations may differ.

^bNote that the SMP buffer test is an index of lime needed and does not equal soil pH.

^cLime rate is based on 100-score lime.

Calcium (Ca), magnesium (Mg) and potassium (K)

These nutrients are cations (positively charged), and their concentrations in soil are determined after extraction at the soil testing laboratory with ammonium acetate. Soil test values are routinely reported in units of meq/100 g for Ca and Mg and in units of ppm for K. The meq/100 g units describe equivalent quantities of cation charge (+), while ppm units describe the equivalent weight of each cation. The conversion from meq/100 g to ppm is as follows: 1 meq/100 g of charge = 200 ppm Ca, 120 ppm Mg or 390 ppm K.

Sandy soil or fields with a soil pH below 5.5 are most likely to have low soil test Ca and Mg values. Soil test K values are usually not related to soil pH.

Calcium and magnesium

Calcium deficiency has not been identified as a problem in sweet corn in the Willamette Valley. If Ca is less than 5 meq/100 g (1,000 ppm), apply 1 ton lime/acre to supply Ca, even if soil pH is adequate. Low soil test Ca is most often observed on sandy river bottom soils such as the Newberg sandy loam.

Magnesium deficiency in sweet corn is uncommon. To ensure sufficient Mg for sweet corn production, apply Mg if soil test Mg is below 1 meq/100 g soil (120 ppm). At planting time, supply Mg as magnesium sulfate, marketed as either Sul-Po-Mag or K-Mag (0-0-22 with 21% S and 11% Mg). A starter band application of 10–15 lb Mg/acre is sufficient for sweet corn production.

Periodic lime applications will maintain soil pH in an acceptable range and will supply calcium or magnesium or both. Calcitic limestone (aglime) supplies Ca, while dolomitic lime supplies both Ca and Mg. Dolomitic lime usually costs more than agricultural lime and reacts more slowly with acidity to increase soil pH.

Potassium

A sweet corn crop takes up 240–360 lb K₂O/acre in aboveground biomass. An ear yield of 10 ton/acre removes about 60 lb K₂O/acre. Potassium in crop residue is readily available to the next crop.

Apply K when soil test K (0–12 inches) is below 200 ppm (Table 5). Potassium chloride (KCl, 0-0-60) is the most common K fertilizer source.

Potassium chloride is a soluble salt, and corn, especially at germination, is sensitive to salt damage from fertilizer. To minimize soluble salt concentration near the seed, band no more than 50 lb K₂O/acre when the band is at least 2 inches from the seed. The sum of

N + K₂O, banded 2 inches from the seed, should not exceed 90 lb/acre. When the fertilizer band is within 1 inch of the seed, the sum of N + K₂O should not exceed 40 lb/acre. If additional K is required, broadcast and incorporate K before planting.

High soil test K (above 500 ppm) occurs when the long-term supply of K from fertilizer or other inputs (for example, compost or manure) exceeds crop removal. When K is present at very high levels in soil, corn plants accumulate K, usually accompanied by a reduction in Ca and Mg uptake, so additional K inputs may be detrimental.

Sulfur (S)

Sulfur cycling in soil and its role in plant nutrition is most similar to N, with some important differences. Sulfate (SO₄²⁻) is the plant-available form of S. Like N, an important source of S for plants is from the mineralization of S present in soil organic matter and organic inputs as soil biota transform organic S into the sulfate-S form. Like nitrate, sulfate is an anion (negatively charged); however, the sulfate anion is much less subject to leaching than nitrate. Some residual sulfate-S present in soils in the fall will carry over to the next year.

Sulfur application rates are based on crop S uptake. A corn crop taking up 150 lb N/acre will contain about 15 lb S/acre. No S fertilization is recommended when soil test S in the top 12 inches of soil is greater than 20 ppm. A test value of 20 ppm is equivalent to about 70 lb of plant-available S in the top 12 inches of soil.

The soil test for sulfate-S is not reliable enough to predict crop need for S when test values are low. If S is below 20 ppm, apply 15–20 lb S/acre in the sulfate form in a preplant broadcast or starter fertilizer application.

Fertilizers that contain immediately available sulfate-S include the solid fertilizers ammonium sulfate (24 % S), potassium sulfate (18% S), gypsum (19% S) and Sul-Po-Mag or K-mag (22% S). Composts, manures and other organic fertilizers also supply sulfur.

Table 5. Fertilizer potassium rate recommendations for western Oregon using the ammonium acetate soil test.

Soil test K ^a (ppm)	Apply this amount of K ₂ O (lb/a)
0–100	100–150
101–200	50–100
Over 200	None

^aAmmonium acetate method.

Phosphorus (P)

A sweet corn crop takes up 70–90 lb P₂O₅/acre in aboveground biomass. An ear yield of 10 ton/acre removes about 30 lb P₂O₅/acre.

Phosphorus deficiency can reduce ear yield and delay ear maturity (Fletcher and Moot, 2006). Sweet corn for processing is harvested at a relatively immature stage of development, when kernel moisture is 70%–75% and dry matter is relatively low. Uniform maturity maximizes kernel removal or “cut-off.”

The ability of sweet corn to obtain P from the soil is influenced by soil temperature, biological activity and root diseases. In contrast to N, P moves very slowly in soil. During a growing season, P may move a distance similar to the thickness of your thumbnail.

Mycorrhizal fungi and P

Mycorrhizal fungi are beneficial fungi that extract immobile nutrients such as P from the soil. They colonize corn roots, effectively increasing root surface area for P uptake. These fungi will be present in soil if the previous crop was a host. Planting corn following fallow provides few mycorrhizal fungi for root colonization, increasing the probability of P deficiency in young corn plants (Bittman, et al., 2006).

The roots of most crops provide habitat for mycorrhizal fungi. Plants in the beet, brassica and buckwheat families (sugar beets, Swiss chard, spinach, cabbage, broccoli, mustard and buckwheat) do not. To increase soil habitat for mycorrhizal fungi, plant corn after a host crop, such as beans or small grains.

Mycorrhizal fungi overwinter on a network of living or dead roots. To increase survival of mycorrhizal fungi, plant a cover crop and reduce tillage.

Early-season P deficiency

Purple coloration of corn plants may indicate P deficiency. Slow-growing, purple-colored corn plants are common with early planting dates; cool, wet spring weather; and in areas with compacted soils, such as field entry and exit areas. Development of purple color is not predictable, as it varies yearly and with corn variety. Contemporary corn hybrids, which have a more vigorous root system, are likely less susceptible to P deficiency than older varieties such as ‘Golden Jubilee’.

Low soil temperatures limit P solubility in soil solution and the ability of seedlings to take up P. Specifically, low soil temperature reduces the mineralization rate of organic soil P to soluble plant-available P and reduces the diffusion rate of soluble P in soil solution. Low soil temperature also reduces the rate of root development, thereby limiting root surface area available for P uptake.

Phosphorus management summary

To increase soil habitat for beneficial mycorrhizal fungi that assist the plant in acquiring P, plant corn after a host crop, such as beans or cereals, and limit tillage.

When Bray soil test P is below 50 ppm, apply P at planting in a starter fertilizer band, at a rate based on table 6.

To avoid excessive accumulation of P in soil, apply P at a rate at or below crop removal (30 lb P₂O₅/acre) when the Bray soil test is above 50 ppm.

Table 6. Fertilizer phosphorus rate recommendations for western Oregon using the Bray soil test.

Soil test P ^a (ppm)	Apply this amount of P ₂ O ₅ (lb/a)
0–15	120–150
16–50	60–120
Over 50	0–30 ^b

^aBray soil test method.

^bRecent research demonstrated no ear yield benefit to P fertilization when Bray soil test P was above 50 ppm (Appendix B, page 18). Corn ear harvest typically removes 30 lb P₂O₅/acre.

Plants suffering from root pruning by soil-borne insects or root disease may also develop nutrient deficiency symptoms such as purple foliage. Additional P will not solve the problem in such cases.

Soil testing and P deficiency

The Bray P soil test is useful for determining the likelihood of P deficiency and for predicting economic response to P fertilization. When the Bray soil test P exceeds 50 ppm, little or no yield benefit is expected from a starter application of P fertilizer (Table 6).

Recent research conducted in the Willamette Valley showed that corn ear yield did not increase in response to starter P fertilization (Appendix B, page 18). This research included fields that were planted in mid-May at low soil temperatures (60°F for the first two to four weeks after planting). High soil test P was likely responsible for the lack of yield response to starter P in these trials. Bray soil test P ranged from 42 to 134 ppm at the research sites.

Consider reducing P fertilizer application rate

Frequent application of P fertilizers to Willamette Valley fields has increased Bray soil test P over time, as phosphorus not removed from the field at harvest remains in the soil, increasing soil test P. Most fields planted to sweet corn exceed the soil test P response threshold of 50 ppm. Increasing soil test P above the

crop response threshold will not harm crops, but it does increase the risk of P loss to surface waters via runoff or soil erosion, and it is a waste of money.

Soil test P concentrations decline slowly. An ear yield of 10 ton/acre removes approximately 30 lb P₂O₅/acre. It typically takes a decade or more with no P fertilizer input for soil test P to decline by 10–30 ppm. If soil test P is 80 ppm today, and no additional P fertilizer is added for the next 10 years, soil test P is still expected to exceed 50 ppm a decade from now.

To reduce P application rate, consider blending N fertilizers with ammonium phosphates to obtain starter fertilizer blends that supply sufficient N (30 lb N/acre) with a higher N-to-P ratio. Never band urea or fertilizer blends that contain urea directly with seed. Instead, broadcast urea or apply it at a low rate (less than 25 lb urea-N/acre) using 2 x 2 inch placement at seeding. In liquid urea-ammonium nitrate (UAN, 32-0-0) or in granular urea-ammonium sulfate (33-0-0) fertilizers, about half of the total N is provided by urea.

Although not recommended here, some growers apply “pop-up” liquid fertilizer close to seed or in contact with seed. The closer the fertilizer is applied to the seed, the greater the risk of seedling death or injury. Therefore, it is important not to apply an excessive rate of fertilizer via pop-up application. Pop-up fertilizer applications of less than 10 gal/acre of 10-34-0 (supplying less than 35 lb P₂O₅/acre) have been used successfully by Willamette Valley farmers for sweet corn. In research trials, pop-up fertilizer application did not increase corn yield on a soil with a Bray test above 50 ppm (Peachey and Sullivan, 2015). More vigorous early growth was sometimes observed with pop-up fertilizer, but it did not improve ear yield, quality or kernel cut-off.

Zinc (Zn)

Corn is among the crops most sensitive to Zn deficiency. Soils testing below 1 ppm Zn (DTPA extraction method) are expected to benefit from Zn application (Table 7).

When corn is grown on soils mapped as Sifton or Salem, or on other dark-colored soils in the Stayton area, Zn application is recommended when soil test Zn

Table 7. Fertilizer zinc rate recommendations for western Oregon using the DTPA soil test.

Soil test Zn ^a (ppm)	Apply this amount of Zn (lb/a)
Less than 1	3–4 banded or 10 broadcast
More than 1	None except Stayton area ^b

^aDTPA soil test method.

^bWhen the Zn soil test is between 0.8 and 1.5 ppm in the Stayton area, a yield increase from Zn application is expected on most fields.

is below 1.5 ppm. The reduced plant availability of Zn in these soils may be due to their volcanic ash content, but the explicit mechanism responsible for reduced Zn availability has not been identified.

If a need for Zn application is identified by the DTPA soil test, broadcast 10 lb Zn/acre and incorporate it before planting. This application will meet crop requirements for two or three years. An alternative method is to band 3–4 lb Zn/acre at planting.

Boron (B)

Interruption of adequate boron (B) supply, even for a short time, can disrupt plant growth. Some have speculated that B deficiency is the cause of incomplete ear fill, especially at the tip of the ear (Figure 4).

Boron is soluble and enters plants with water flow. Thus, if transpiration is slow, B uptake is slow. After entering the plant, B is immobile, so developing plant parts, such as growing points and ears, will exhibit B deficiency despite later fertilization with B.

Soil test B is determined by hot-water extraction. In western Oregon, soil test B in fields that have not received B application for several years is usually 0.25 to 0.35 ppm. At this soil test level, application of 2 lb B/acre from Solubor increased B in corn leaf tissue but did not improve kernel fill or increase yield (McAndrew, 1983).

When soil test B is below 0.25 ppm, a trial application of 2 lb B/acre could be considered. Do not band B fertilizer because it can be toxic to plants. Always broadcast B fertilizer.

Other micronutrients

Research has not demonstrated a crop response to micronutrients other than Zn and B in sweet corn in western Oregon.



Photo: © Oregon State University

Figure 4. Sweet corn with incomplete tip fill.

Cover crops

Winter cover crops following sweet corn benefit soil health, suppress weeds and reduce groundwater contamination. Specifically, cover crops can reduce winter nitrate loss below the root zone, provide habitat for beneficial soil biology (including mycorrhizal fungi), improve soil tilth the following spring and suppress establishment and growth of winter weeds. Mineralization of PAN from leguminous cover crop residues also can reduce the amount of N fertilizer needed for corn.

This section describes various aspects of cover cropping:

- **Preceding corn:** Estimating PAN provided by winter cover crops for corn.
- **In corn:** Interseeding winter cover crops into corn (V6 growth stage).
- **Following corn:** Using cereal cover crops to reduce winter nitrate leaching.

Estimating plant-available N provided by winter cover crops for corn

Winter cover crops generally decrease or do not change N fertilizer requirements for sweet corn. Cereal cover crops have little effect on N fertilizer requirements when killed at tillering or stem elongation growth stages. If allowed to grow to boot stage, cereal cover crop residue may increase N fertilizer requirements for sweet corn. Legume cover crops can contribute up to 100 lb PAN/acre when killed at late vegetative growth stage (late April). Estimates of site-specific N credits based on cover crop species and growth stage usually are not very accurate, especially when more than one cover crop species is present.

Most cover crop decomposition and N mineralization occurs rapidly, within four to six weeks following cover crop termination. Thus, measurement of soil nitrate-N (preplant or when corn is at the V4 to V6 growth stage) can increase site-specific accuracy in forecasting the N fertilizer requirement for corn following a winter cover crop. See Table 3 (page 6) for interpretation of

soil nitrate testing at the V4 to V6 corn growth stage. Interpretations of soil nitrate test values for a preplant nitrate test are given in *Soil Nitrate Testing for Willamette Valley Vegetable Production* (EM 9221).

The effect of a cover crop on site-specific N fertilizer requirements for sweet corn can also be estimated at the time of cover crop incorporation using the OSU Organic Fertilizer & Cover Crop Calculator, hosted by the Oregon State Small Farms website (extension.oregonstate.edu/organic-fertilizer-cover-crop-calculators). The calculator predicts PAN provided by cover crop decomposition at four and 10 weeks following spring cover crop termination. You can find the same PAN predictions for cover crop residues in look-up tables in *OSU Organic Fertilizer & Cover Crop Calculator: Predicting Plant-Available Nitrogen* (EM 9235). Step-by-step instructions for obtaining a cover crop sample for a site-specific PAN estimate are provided in *Estimating Plant-Available Nitrogen Release from Cover Crops* (PNW 636).

Interseeding winter cover crops into corn

Interseeding is the practice of seeding the fall cover crop when corn plants are small enough to allow sufficient light penetration for cover crop establishment. With interseeding, the cover crop is planted into corn in June or July instead of after corn harvest. To be successful, interseeded cover crops must survive until corn is harvested, cornstalks are cut down and sunlight returns. After corn harvest, the interseeded cover crop is already established and ready to grow.

Interseeding offers several potential advantages over traditional fall-seeded cover crop establishment, including: (1) increased cover crop growth and soil cover in early fall and (2) reduced soil erosion from slopes or from low-lying fields that flood seasonally. The greatest advantage from interseeding is expected when corn is harvested after Oct. 1 or when soil remains dry after corn harvest, circumstances that make it difficult to establish a cover crop following harvest.

Read more about interseeding in Appendix C (page 21).

Using cereal cover crops to reduce overwinter nitrate leaching

A long-term field trial at the North Willamette Experiment Station on a Willamette silt loam soil demonstrated the beneficial effect of fall-planted cereal rye or triticale in reducing soil nitrate loss via leaching (Feaga, et al., 2010).

In this study, leachate from the soil profile was collected at a depth of 4 feet below the surface of a Willamette silt loam soil, using passive capillary lysimeters. Sweet corn was grown every other year, followed by a winter cover crop. The cover crop consisted of cereal rye (1992–1998) or a mixture of cereal rye and common vetch (2000–2002). It was seeded in September or early October and killed in late March or early April the following year. Because the cover crop was killed in early spring, N fixation by the vetch was minimal. Results are shown in Figure 5.

Summary

- Nitrate leaching increased with N fertilizer application rate. Only two N fertilizer rates were evaluated: low (50 lb N/acre) and high (200 lb N/acre).
- Winter cereal cover crops removed some of the nitrate from the soil, reducing the amount of nitrate-N leached.
- Nitrate-N concentrations in leachate under sweet corn were above the public health limit for drinking water (10 milligrams/liter) when corn received fertilizer N at 200 lb/acre and a winter cereal cover crop did not follow corn.
- Some nitrate-N (12 lb N/acre/year) was lost in leachate even when the field did not receive N fertilizer for 12 consecutive years and corn was followed with a winter cover crop. This nitrate was produced by mineralization of soil organic matter and crop residues.

- Nitrogen fertilizer trials conducted at the same location (Hemphill, et al., reports to OVPC, 1995–1998) suggest that nitrate leaching at typical N fertilizer rates (100–150 lb N/acre) likely would be comparable to that measured with rates of 50 lb N/acre in this lysimeter trial (Feaga, et al., 2010). Application of 50 lb N/acre was not sufficient to produce maximum corn ear yields.
- The date of corn harvest is a practical limit to cover cropping as a nitrate scavenging strategy. Cover cropping is difficult to implement when corn harvest occurs after Oct. 1. This is one reason to consider interseeding (see Appendix C, page 21) as a method for reliable fall cover crop establishment.

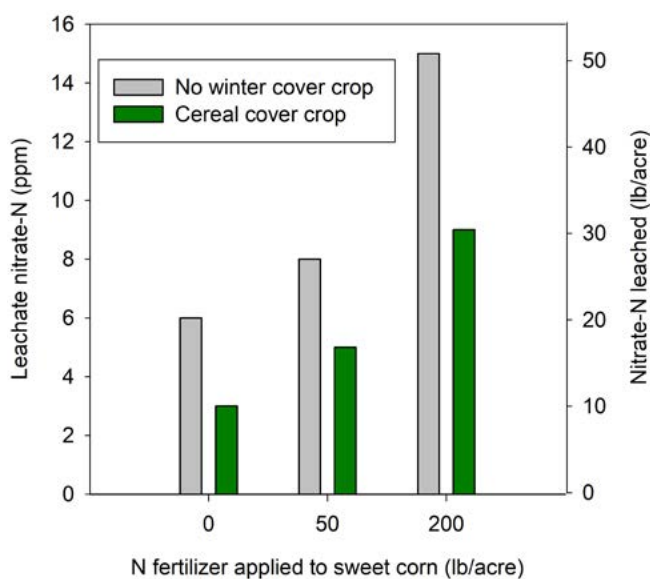


Figure 5. Effect on nitrate-N leached during fall and winter of N fertilizer rate for corn and presence of a winter cereal cover crop established after corn harvest. Leachate was collected below the 4-foot depth in a Willamette silt loam soil. Left axis: concentration of N in leachate (milligrams per liter, or ppm). Right axis: pounds N per acre. The amount of N leached (pounds per acre) was estimated based on a measured leachate volume of approximately 15 inches per year. Source: Feaga, et al., 2010.

Nutrient management in organic sweet corn

Nutrient management in organic cropping systems is more complex than in conventional cropping systems. This section describes some of the challenges and provides general guidance.

Fertilizers and soil amendments used under organic certification must be compliant with the USDA National Organic Program standards. The Organic Materials Review Institute (omri.org), Washington State Department of Agriculture (agr.wa.gov/organic) and California Department of Food and Agriculture (www.cdffa.ca.gov/is/fldrs/pdfs/RegisteredOrganicInputMaterial2019.pdf) review products for NOP compliance and publish brand-name materials lists. Many other products and materials are allowed for use on certified organic farms. If you are unsure whether a product is allowed, ask your organic certifier.

Plant-available N supplied by mineralization

Nitrate is the predominant form of N taken up by corn in both organic and conventional cropping systems. Nitrate is lost from soil by leaching during winter. As a consequence, soils are almost always low in nitrate in early spring in western Oregon.

Nitrogen mineralization is the process whereby organic N is converted to plant-available nitrate-N via the action of soil biota. New inputs (for example, legume cover crop residue or pelleted chicken manure) are mineralized rapidly. Soil nitrate increases rapidly during the first four to six weeks following application of these materials.

Soil also contains a large reservoir of N stored in organic matter that mineralizes slowly. In general, the synchrony of N mineralization from soil organic matter with corn demand for N depends on planting date. Plant-available N release via mineralization may be too slow in spring and too fast in late summer to provide the right amount of PAN at the right time for a sweet corn crop.

Nitrogen management strategy

In organic systems, farmers apply most N inputs (compost, manure or cover crop residues) before seeding. Some solid organic fertilizers can be sidedressed by hand. Equipment for mechanical sidedress fertilizer application is now available from a few suppliers. Liquid organic N fertilizers can be applied via drip irrigation, but they are relatively expensive.

During the first years of organic management, use the OSU Cover Crop & Organic Fertilizer Calculator

(or another PAN estimation method) to supply approximately 100–150 lb PAN/acre from winter cover crops and organic fertilizers. A well-nodulated winter legume cover crop can provide the equivalent of 50–75 lb PAN/acre when allowed to grow to late vegetative growth stage (mid-April).

Gradually reduce N inputs in successive years as you gain confidence that organic inputs are meeting crop N needs. After three to five years of organic management, annual inputs equivalent to 50–75 lb PAN/acre are typically adequate for sweet corn production. Soil nitrate monitoring can confirm whether your application rates are meeting crop requirements. Consult *Soil Nitrate Testing for Willamette Valley Vegetable Production* (EM 9221) for details.

Seeding or transplanting organic sweet corn after June 1 is recommended, so that some nitrate accumulates in soil prior to seeding and so that the warmest part of the summer coincides with the rapid phase of sweet corn uptake (from V6 to silking). When corn is planted before June 1, apply a fast-acting organic N source to supply sufficient N to support early growth (30–50 lb PAN/acre) and incorporate it prior to seeding. Consult *OSU Organic Fertilizer @ Cover Crop Calculator* (EM 9235) for details.

Organically managed soils can mineralize a relatively large amount of PAN, especially after years of compost or manure application. High levels of soil nitrate are possible in late August or September. A corn crop planted on June 1 completes most of its N uptake by Aug. 1 (silking growth stage, page 4), but warm, moist soil continues to mineralize N until harvest. Therefore, it is very important to seed a cereal or cereal/legume cover crop as early as possible following organically managed corn, so that the cover crop takes up some of the soil nitrate remaining in the soil after corn harvest. A cover crop seeded in September can take up to 50 lb N/acre from the soil prior to heavy fall rains. Interseeding a cereal cover crop into corn is one way to reliably establish a cover crop, even in situations where corn is harvested after Oct. 1 (see Appendix C, page 21).

Monitoring soil nitrate

Soil nitrate testing can assist in fine-tuning organic management practices to provide a timely supply of nitrate for a corn crop. See *Soil Nitrate Testing for Willamette Valley Vegetable Production* (EM 9221) for details.

continues on next page

Nutrient management in organic sweet corn — continued

A sufficient level of soil nitrate-N at the V6 growth stage is 25–30 ppm (0- to 12-inch depth). When nitrate-N exceeds 40 ppm at V6, more than enough N is present to grow the crop. Consider reducing N inputs for future corn crops. Specialty organic fertilizers such as feather meal, pelleted chicken manure or fish meal provide PAN within a week or two of application. Thus, they can be useful as a rescue sidedress application in situations where soil nitrate at V6 is low (below 15 ppm).

Managing other nutrients in organic systems

Compost, manure or specialty fertilizer applications provide macro- and micronutrients. You can use soil testing to monitor levels of these nutrients. Soil nutrient tests recommended in this guide for conventional production are also appropriate for organic vegetable production systems.

When composts or manures are applied at a rate that supplies adequate N, more P and K is applied than is required by the crop. As a result, soil test P and K often increase when compost or manure are applied regularly. To avoid building up P and K to

excessive levels in soil, use legume cover crops or low-P organic fertilizers such as feather or blood meal to supply PAN for organically grown sweet corn. A legume cover crop supplies N, but does not supply additional P and K.

Sweet corn requires soil pH above 5.8. Organic matter inputs assist in stabilizing soil pH, but they are not a substitute for liming when soil pH is less than ideal for sweet corn, as the “liming effect” of organic inputs is small compared to that of aglime.

Additional details on how to address nutrient management challenges in organic farming systems are provided in:

- *Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon* (EM 9165).
- *Estimating Plant-Available Nitrogen Release from Cover Crops* (PNW 636).
- *Fertilizing with Manure and Other Organic Amendments* (PNW 533).
- *Soil Nitrate Testing for Willamette Valley Vegetable Production* (EM 9221).
- *OSU Organic Fertilizer & Cover Crop Calculator: Predicting Plant-Available Nitrogen* (EM 9235).

Appendix A. Pre-sidedress nitrate test verification

Situation

Nitrogen fertilizer recommendations for sweet corn in western Oregon were developed based on the pre-sidedress nitrate test (PSNT, see EM 9010). The PSNT soil testing method predicts sidedress N fertilizer requirement based on a soil nitrate-N test collected when corn has four to six collared leaves (V4 to V6 growth stage). Field trials to validate PSNT fertilizer recommendations were conducted in the 1990s on ‘Golden Jubilee’. Since then, ‘Golden Jubilee’ has been replaced by varieties having greater resistance to root rot diseases.

Objectives

1. Verify the accuracy of sidedress N fertilizer recommendations based on PSNT, using contemporary corn varieties.
2. Determine sidedress N fertilizer use efficiency of contemporary sweet corn varieties under Willamette Valley crop management practices.
3. Evaluate the impact of PSNT-recommended N fertilizer rate on residual soil nitrate-N at sweet corn harvest.

Methods

Replicated field experiments were conducted in grower fields in 2010 and 2011 (Table 8). Treatment plots were arranged in a randomized complete block design with four replications. Each treatment plot was 25–30 feet wide by 65–75 feet long. Plots were positioned within the field so that irrigation was uniform across the plot area.

Growers prepared the seedbed with strip tillage (Stayton, 2010, 2011) or with conventional tillage (Mt. Angel, 2010; North Albany, 2011) and reported the rate of N fertilizer broadcast preplant or applied with the planter (Table 8).

Composite soil samples (0- to 12-inch depth, 10 cores per composite sample) were collected from between corn rows at the V4 to V6 growth stage. We used the average soil nitrate-N concentration (ppm, $n = 4$) to choose a range of sidedress N application rates for each field. Sidedress N rates included N rates equal to, above, and below that recommended by PSNT (Table 3, page 6). Urea (46-0-0) was sidedressed at the V5 to V6 growth stage using a hand-push drop spreader calibrated to deliver the urea granules within 6 inches of the corn row.

A few days prior to harvest, the aboveground plant biomass from 10 feet of row within each plot was harvested, weighed and shredded. We analyzed a subsample of this plant biomass for N concentration and then calculated plant N uptake by multiplying crop biomass by N concentration. Sidedress N fertilizer use efficiency (percent) was calculated for each N rate as:

$$[(\text{plant N uptake with N fertilizer} - \text{plant N uptake for zero N rate}) / \text{N fertilizer applied}] \times 100$$

Corn ear yield was determined by harvesting center rows within each treatment plot. The grower’s harvester removed and dropped ears on the ground. The ears were collected by hand and weighed on a platform scale.

At harvest, soils were sampled for nitrate-N in 2011 only. Within a day after harvest, soil samples were collected to determine residual soil nitrate-N at the 0–12- and 12–24-inch depths using a bucket auger or a soil probe. Three soil cores from each treatment plot were composited for nitrate analysis.

Table 8. Site information for PSNT trials in grower fields.

Location	Year	Soil mapping unit	Corn variety	Previous crop	Tillage	Seeding date	N applied by grower ^a (lb/acre)	PSNT soil NO ₃ -N ^b (ppm)	Sidedress N rate based on PSNT (lb/acre)
Stayton	2010	Nekia silty clay loam	Basin	Wheat	Strip	June 14	32	9	150
Mt. Angel	2010	Amity silt loam	Coho	Cauliflower	Conv.	July 3	80	28	70
Stayton	2011	Nekia silty clay loam	Coho	Wheat	Strip	May 14	32	7	150
North Albany	2011	Newberg loam	Basin	Snap bean	Conv.	June 14	51	14	125

^aIncludes N fertilizer applied preplant and at planting.

^bSoil sampled between rows (0- to 12-inch depth) at V4 to V6 growth stage. One ppm NO₃-N is equivalent to approximately 3.5 lb NO₃-N/acre.

Results

The Stayton field sites (2010 and 2011) had low soil PNST values (below 10 ppm NO₃-N), and a strong crop response to sidedress N fertilizer was expected. Factors reducing “background” N supply at these sites included wheat as the previous crop and a low rate of preplant + starter N fertilizer (30 lb N/acre).

As expected, corn grown at these sites responded to sidedress N fertilizer application (Figure 6, at right, and Table 9, page 17). In both years, the PSNT-recommended sidedress N rate (150 lb N/acre) produced near-maximum ear yield. Using best-fit quadratic regression, 95 percent of maximum yield was produced with application of 160 lb N/acre in 2010 and with 115 lb N/acre in 2011 (Figure 6).

The other field sites (Mt. Angel and North Albany) had medium to high soil nitrate-N values at the V4 to V6 growth stage, resulting in lower PSNT-recommended N rates. These sites had cauliflower or snap bean as the previous crop and early-season N fertilizer rates (preplant + starter N) of 50–80 lb/acre (Table 8). Ear yield at the Mt. Angel site was limited by late planting (July 3) and by heavy rains in late October, which flooded parts of the field just prior to harvest on Nov. 1.

At these sites, the PSNT-recommended N rate was sufficient or more than sufficient for near-maximum ear yield (Figure 6 and Table 9). Using best-fit quadratic regression, 95% of maximum yield was produced with sidedress N application of 76 lb N/acre at Mt. Angel and 79 lb N/acre at North Albany (Figure 6).

Sidedress N fertilizer use efficiency (NUE) was high (68%–81%) with the PSNT-recommended N rate at the Stayton sites (Table 9). In contrast, NUE was less than 50% at PSNT-recommended rates at the Mt. Angel and North Albany sites. Greater NUE values typically result in reduced soil nitrate-N concentrations at harvest.

At-harvest soil nitrate-N values remained low (below 10 ppm) when PSNT-recommended N rates were applied (Figure 7, page 17). At the highest N fertilizer application rates (200 lb N/acre at Stayton and 160 lb N/acre at North Albany), soil nitrate-N exceeded 10 ppm at harvest. The high N rates that resulted in elevated postharvest soil nitrate concentrations were 40–50 lb N/acre above the PSNT-recommended N rate.

Summary and recommendations

In-season soil nitrate testing (PSNT) was a reliable tool to adjust sidedress N rates for near-maximum ear yield. The historic PSNT recommendations (EM 9010) were shown to be reasonably accurate for contemporary corn hybrids grown in soils testing below 30 ppm nitrate-N. Therefore, when PSNT is less than 30 ppm, PSNT-based sidedress recommendations in Table 3 (page 6) are the same as historic recommendations.

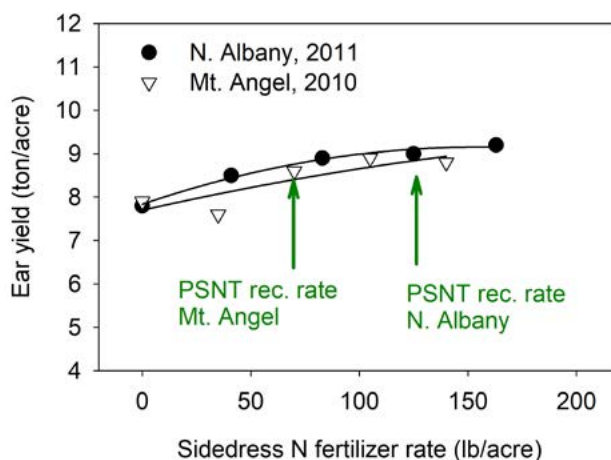
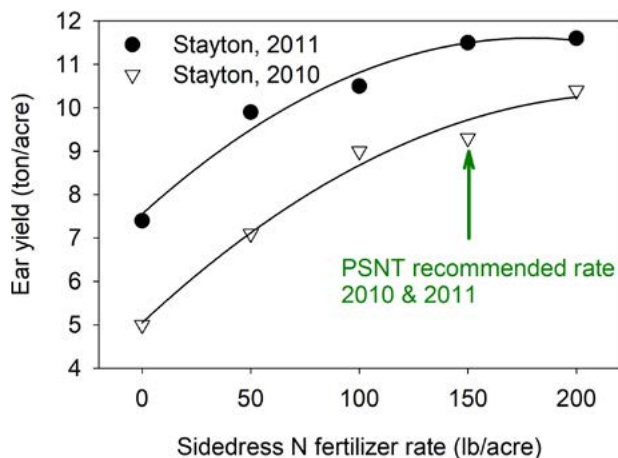


Figure 6. Ear yield response to sidedress N fertilizer in four field experiments. Lines shown are based on best-fit quadratic regression. Sidedress “PSNT recommended rate” was determined based on soil sampling at the V4 to V6 growth stage, using recommendations in EM 9010 (2010). Soil nitrate-N (0–12 inches) measured via PSNT was 7–9 ppm at Stayton, 28 ppm at Mt. Angel and 14 ppm at North Albany when corn was at the V4 to V6 growth stage.

These field trials showed the potential for high ear yields (approximately 10 ton/acre) and high fertilizer N use efficiency (more than 70 percent of sidedress N taken up by the crop) for vigorous contemporary corn hybrids.

When sidedress N fertilizer was applied according to PSNT recommendations, soil nitrate concentrations at harvest were low — less than 10 ppm nitrate-N at 0–12- and 12–24-inch depths.

References (pre-sidedress nitrate test)

Reports to the Oregon Processed Vegetable Commission (agsci.oregonstate.edu/category/veg/oregon-processed-vegetable-commission) provide additional supporting data:

Sullivan, D., A. Heinrich, and E. Peachey. 2012. *Predicting Phosphorus and Nitrogen Needs in Sweet Corn*.

Peachey, E., and D. Sullivan. 2011. *Predicting N Fertilizer Needs in Sweet Corn: Comparing Preplant Nmin and Pre-Sidedress Tests to Improve Predictability*.

Table 9. Sweet corn response to sidedress N fertilizer at four field sites.

Location and year	Sidedress N applied ^a (lb/a)	Ear yield ^b (ton/a)	Plant N uptake at harvest (lb/a)	Fertilizer NUE ^c (% of N applied)
Stayton (2010)	0	5.0	68	NA
	50	7.1	106	75
	100	9.0	156	88
	150*	9.3	170	68
	200	10.4	195	63
	PLSD.05 ^d	0.9	28	—
Stayton (2011)	0	7.4	70	NA
	50	9.9	105	82
	100	10.5	139	75
	150*	11.5	186	81
	200	11.6	215	76
	PLSD.05	0.6	65	—
Mt. Angel (2010)	0	7.9	105	NA
	35	7.6	121	46
	70*	8.6	119	20
	105	8.9	151	44
	140	8.8	155	36
	PLSD.05	1.6	41	—
North Albany (2011)	0	7.8	102	NA
	41	8.5	124	54
	83	8.9	143	49
	125*	9.0	154	42
	163	9.2	141	24
	PLSD.05	0.9	27	—

^aSidedress N rate was determined based on soil NO₃-N at the V4 to V6 growth stage using recommendations in EM 9010 (2010). The sidedress N fertilizer rates recommended by PSNT are marked with “*”.

^bEar yield on a fresh weight basis, including husks.

^cFertilizer N use efficiency (NUE) was determined as: [(plant N uptake with N fertilizer – plant N uptake for zero N rate)/N fertilizer applied] × 100.

^dPLSD.05 = Fisher’s Protected LSD at 5 percent level of probability. This is the minimum difference in treatment values considered to be “real” and not just random variation.

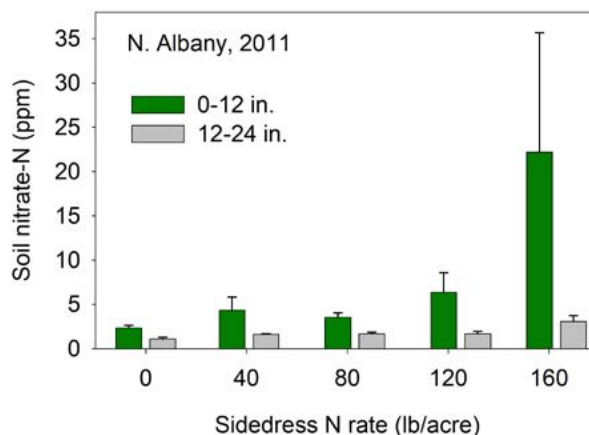
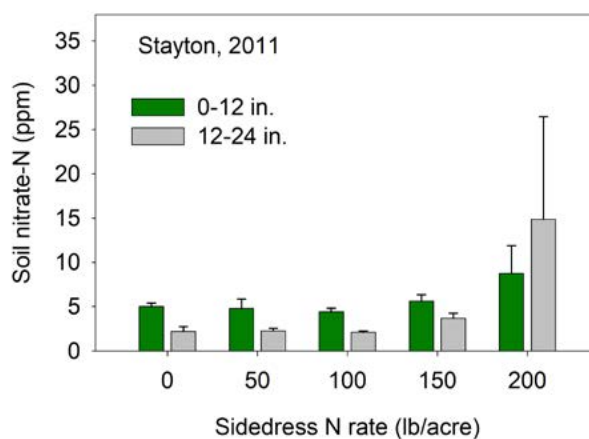


Figure 7. Soil nitrate-N at corn ear harvest (0–12- and 12–24-inches). Error bar is standard error of the mean (n = 4).

Appendix B. Corn response to banded phosphorus

Situation

The previous Oregon State nutrient management guide for sweet corn (EM 9010, 2010) recommended application of banded P fertilizer at planting for fields testing less than 50 ppm P, using the Bray method. Soil test P is above the 50 ppm response threshold in most vegetable production fields in the Willamette Valley. At 15 field sites we sampled in 2012–2013, soil test P (0- to 12-inch depth) ranged from 41 to 189 ppm (median = 127 ppm).

In spite of high soil test P values, many growers routinely apply P in starter fertilizer formulations to sweet corn. The most common starter fertilizer formulations used to supply N (granulated mono-ammonium phosphate [11-52-0] and liquid ammonium polyphosphate [10-34-0]) also supply P. For example, when 10-34-0 is used to supply N at 30 lb/acre, phosphate (P₂O₅) is applied at 102 lb/acre.

Sweet corn varieties grown today are different than those grown when P fertilizer trials with sweet corn were last conducted by Oregon State in the Willamette Valley (McAndrew, 1983). Most current processing corn varieties are higher-yielding and have greater resistance

to root rot diseases compared to ‘Golden Jubilee,’ the variety that dominated production prior to 1998.

Objectives

1. Evaluate corn ear yield and quality response to starter P fertilizer, using contemporary corn varieties and production practices.
2. Evaluate the effect of early versus late planting on plant-available P in soil.
3. Determine whether Oregon State recommendations for starter P application (EM 9010) are supported by recent data.

Methods

In six field experiments, corn was seeded with starter P rates of 0, 15, 30, 60 or 120 lb P₂O₅/acre. Four trials were conducted in 2012, and two trials were conducted in 2013 (Table 10). Treatment plots were arranged in a randomized complete block design with four replications. In grower fields, each treatment plot was 25–30 feet wide by 65–75 feet long, and plots were positioned within the field so that irrigation was uniform across the plot area. Soil textures at field locations were silt loam or silty clay loam.

Table 10. Preplant Bray soil test P, soil temperature and plant-available P determined by Plant-Root Simulator (PRS) probes inserted into soil (3- to 5-inch depth) at six field locations.

Location ^a and corn variety	Seeding date	Bray soil test P (ppm)	Weeks after seeding	Soil temp. at 4 inches (°F)	PRS probes inserted	PRS probes removed	PRS plant-available P ^b (µg/10cm ² /2 wk)
2012 Corvallis I (VF) Variety: Captain	May 11	93	0–2	61	May 11	May 26	3.7
			2–4	62	May 26	June 8	3.4
2012 Gervais (G) Variety: 4927	May 16	108	0–2	60	May 16	May 30	2.2
			2–4	62	May 30	June 14	2.5
2012 Independence (G) Variety: Coho	May 29	81	0–2	60	May 31	June 14	2.4
			2–4	65	June 14	June 28	0.7
2012 Corvallis II (VF) Variety: Captain	June 27	77	0–2	67	June 29	July 13	5.8
			2–4	74	July 13	July 27	6.9
2013 Corvallis I (VF) Variety: Captain	May 14	42	0–2	61	May 14	May 28	4.7
			2–4	69	May 28	June 11	4.9
2013 Corvallis II (G) Variety: Kokanee	June 3	134	0–2	72	June 4	June 18	8.8
			2–4	71	June 18	July 2	25.5

^aField plots: VF = small plots, ear harvest by hand at Oregon State University Vegetable Research Farm, Corvallis. G = Grower field sites with larger, machine-harvested plots.

^bPlant-Root Simulator (PRS) probe values represent the quantity of plant-available P (µg) adsorbed to a flat anion exchange resin (10 square centimeters) over a period of two weeks.

All P fertilizer treatments received the same amount of N fertilizer: 25 lb N/acre in starter fertilizer plus additional N fertilization (broadcast or sidedress) per grower practice. Fertilizer mixtures were prepared for each treatment using dry granular fertilizers (MAP [11-52-0] and urea [46-0-0]). For the zero N treatment, all of the starter N was urea. At the highest rate of P₂O₅ (120 lb/acre), all of the N was supplied by MAP. The starter fertilizer band was placed 2 inches below and 2 inches beside the seed row, using a hand-push fertilizer spreader.

When a soil test indicated a need, K fertilizer (0-0-60) was broadcast and incorporated prior to seeding. All fields received S application of 20+ lb SO₄-S/acre via ammonium sulfate or other sulfate-S source. Soil temperature was monitored continuously in each field experiment at the 4-inch depth using buried temperature probes.

Plant Root Simulator probes (Western Ag Innovations Inc., Saskatoon, Saskatchewan, Canada) were used to measure plant-available P in the absence of P fertilizer at prevailing soil moisture, temperature, physical, biological and pH conditions at each site (Figure 8). PRS probes consisted of an anion exchange membrane mounted on a flat plastic stake. Within each of four replications of the zero P fertilizer treatment in the field, we inserted four PRS probes into the packed soil between corn rows. Every two weeks, probes were removed, washed with clean water to remove adhering soil and sent to a commercial laboratory for P analysis. A new set of PRS probes was installed immediately afterwards.



Figure 8. Plant Root Simulator probes. In our experiments, probes were inserted vertically into the soil between corn rows, on zero P (no fertilizer) plots. PRS probes adsorb cations (left, purple) and anions (right, orange) from soil solution, using a charged resin sheet. When inserted into soil, the window of PRS probes (with exchange resin) was at a soil depth of 3–5 inches.

Photo: Dan Sullivan

Results

Corn ear yield did not increase when P fertilizer was applied (Figure 9); ear yields with and without starter P fertilizer were not statistically different at any of the six field locations. Corn processing quality, including husked ear weight, ear length, ear width and percent tip fill, also did not increase with P fertilization in five of the six field experiments. At a single field site with the lowest soil test P (Corvallis I, 42 ppm soil test P, seeded May 14, 2013), corn grown without P fertilizer showed visual symptoms of P deficiency at the V6 to V7 growth stage. The P-deficient plants were shorter and had lower biomass, although whole-plant P concentration (0.3% P) was similar to that of P-fertilized plants. At harvest, ear

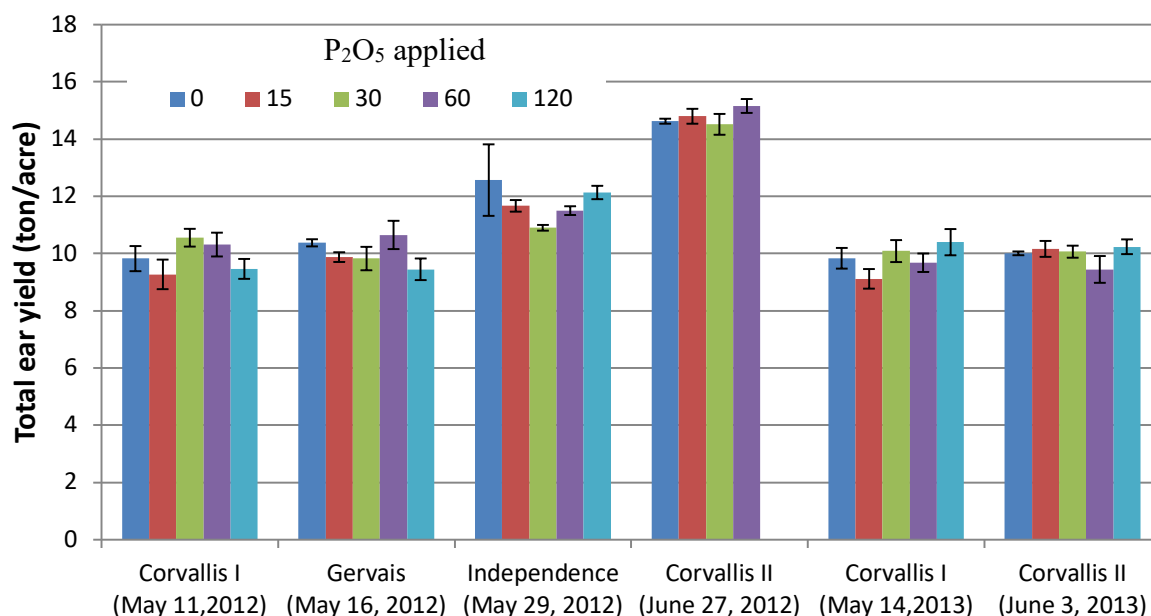


Figure 9. Sweet corn total ear yield response to P fertilizer banded at seeding. Seeding date in parenthesis. Error bar = + standard error of the mean; n = 4. The 120 lb P₂O₅/acre rate was not included in the trial conducted at the Corvallis II field site in 2012.

yields at this site were the same for all P fertilizer treatments, including the zero P control. However, P fertilization at rates of 60 or 120 lb P₂O₅/acre increased ear quality. Husked ear weight increased by 10% and ear diameter by 4% versus the zero P control.

Data from the PRS probes represent adsorbed plant-available P from the 3- to 5-inch soil depth. Units of measurement are quantity of P per surface area per burial time (µg P/10 square centimeters/2 weeks). PRS values showed large differences among field sites. Even in fields with the lowest PRS values (Gervais, 2012; Independence, 2012), corn yield did not increase with P fertilization. Within a field site (Corvallis I and II, 2012, adjacent field experiments), PRS values doubled between an early planting (May 11) and a late planting (June 27).

Summary and recommendations

Corn ear yields did not increase in response to banded P application at any of the field sites. Across the six field sites, corn ear yield averaged 11 ton/acre for all P fertilizer treatments, including the zero P fertilizer control. At the field site with the lowest soil test P (42 ppm), ear quality was improved by starter P application. Across the other five field sites, Bray soil test P ranged from 77 to 134 ppm, and corn ear quality did not respond to P fertilizer application.

This trial supports the 50 ppm P sufficiency threshold for soil test P (Bray method, Table 6, page 9).

In the absence of P fertilization, these trials demonstrated that plant-available P supplied to roots (as estimated by PRS probes) increased about twofold between early May and June plantings. Thus, crop

response to banded P fertilization is even more unlikely for June plantings than for May plantings.

No seedling damage was observed across six field locations when using granular urea (25 lb N/acre at 2 x 2 inch placement) as a starter fertilizer. Consider blending N fertilizers such as urea-ammonium nitrate (liquid 32-0-0) or urea-ammonium sulfate (granular 33-0-0) with ammonium phosphates to obtain starter fertilizer blends that supply sufficient N (30 lb N/acre) with a high N-to-P ratio. Never band urea or fertilizer blends that contain urea with seed. Instead, broadcast urea or apply at a low rate (less than 25 lb N/acre) using 2 x 2 inch placement at seeding.

References (banded P)

- Hart, J., D. Sullivan, J. Myers and R. Peachey. 2010. *Nutrient Management Guide for Sweet Corn: Western Oregon*. EM 9010, Corvallis, OR: Oregon State University Extension Service.
- McAndrew, D. 1983. Soil fertility investigations on soil solution composition and nutrition of sweet corn and onions. Ph.D. thesis, Oregon State University, Corvallis.
- Western Ag Innovations. Plant Root Simulator probes. westernag.ca/innov.
- Reports to Oregon Processed Vegetable Commission**
agsci.oregonstate.edu/category/veg/oregon-processed-vegetable-commission:
- Sullivan, D., E. Peachey, and A. Heinrich. 2013. *Improving Fertilizer P and N Use Efficiency in Sweet Corn*.
- Sullivan, D., A. Heinrich, and E. Peachey. 2012. *Predicting Phosphorus and Nitrogen Needs in Sweet Corn*.

Appendix C. Interseeded cover crops

Background

Interseeding is the practice of seeding the fall cover crop when corn plants are small enough to allow sufficient light penetration for cover crop establishment. An interseeded cover crop is typically planted into corn in June or July instead of after corn harvest.

Grower goals for interseeding include:

- Establishing a cover crop without reducing corn yield,
- Maintaining acceptable weed control and
- Minimizing time and expense required for cover crop establishment.

Here we describe general findings from a series of interseeding trials conducted from 2015 through 2018.

Objectives

1. Evaluate cover crop biomass and N uptake with interseeding versus current practice (fall cover crop seeding).
2. Evaluate the suitability of interseeding in meeting grower goals for weed control and corn yield.
3. Evaluate the effectiveness of interseeding in reducing soil erosion.

Methods

Field trials were established in the fall of 2015–2018 at the OSU Vegetable Research Farm in Corvallis and in grower fields in the Willamette Valley. Cover crop species varied with field location and grower preference.

Cereals were interseeded with a high-clearance drill at the V6 growth stage for corn. Red or crimson clover was broadcast and then lightly cultivated to incorporate seed.

The performance of the interseeded cover crop was compared to alternative cover crop establishment methods: (1) no cover crop, (2) fall cover crop seeded with a drill after tillage to prepare a seedbed and (3) fall cover crop direct-seeded with a no-till drill. Not all of these management strategies were included in each field trial.

Biomass and N uptake of cereal and legume cover crops was measured at corn harvest, in December following corn harvest and in the following spring (prior to killing the cover crop).

Soil erosion within field plots was estimated by collecting soil and runoff water from microplots (Figure 10). Three microplots (11 square feet, 1 square meter) were placed within each cover crop treatment plot (approximately 300 square feet). Microplots were

installed by pushing 6-inch metal strips into soil to a depth of 3 inches around the plot perimeter, leaving an opening on the downhill side to allow runoff to exit. Water was collected using a 1.5-inch diameter plastic pipe connected to a plastic tub. Runoff water volume and sediment weight in the tubs were measured following major precipitation events.



Figure 10. Microplots were used to estimate the effect of cover crop establishment method on soil erosion.

Results

Cover crop biomass with interseeding versus current practice (fall cover crop seeding)

Interseeded cover crops were successfully established in corn at the six-collar growth stage (V6; see figures 11 and 12). Cover crop seeding was also evaluated at the V4 and V8 growth stages at some locations (data not shown). In general, compared to the V6 seeding, the V4 seeding occasionally resulted in too much competition from the cover, while cover crop establishment was less successful with V8 seeding because of shading by the corn canopy. Growers (especially growers producing under organic certification) often preferred to interseed after V6, so that weeds could be controlled just ahead of corn canopy closure.

Fall growth and survival of the interseeded cover crops were strongly affected by October rainfall. Typical October rainfall occurred in 2015 and 2017, allowing the interseeded cover crop to grow successfully (Figure 13, page 23). Interseeded cover crop growth was limited in 2016 because of too much rain in October (13 inches) and in 2018 because of drought in October (less than 0.5 inch of rain).

Nitrogen uptake by interseeded cover crops

At corn harvest in September, interseeded cover crops contained less than 10 lb N/acre. In years with good fall cover crop growth, interseeded cereal cover crops contained 20–50 lb N/acre in aboveground biomass in December. Thus, the interseeded cover crop took up 10–40 lb PAN from the soil that would otherwise be subject to leaching (Donaldson, 2019).



Figure 12. Winter cover crop (mix of triticale and crimson clover) in mid-December 2017. Cover crop was interseeded at the six-collar growth stage (V6, left) or established after corn harvest by conventional tillage and seeding with a drill (right).

Suitability of interseeding in meeting grower goals for weed control and corn yield

In conventional systems, successful in-corn weed control was generally achieved with postemergent herbicides such as Laudis and Impact (Group 27, 4-HPPD inhibitors) without affecting the cover crop stand. These herbicides have very little soil residual activity and allow most cover crops to establish. Broadleaf and grass weed control was good to excellent, but crabgrass was not controlled effectively by these herbicides in one trial. Soil herbicides such as Dual Magnum and Outlook will seriously injure most interseeded cereal cover crops. Atrazine also must be avoided. In organic systems, weed control was acceptable when cover crops were interseeded following



Figure 11. Triticale growth in March 2019 (left) when interseeded at V6 into 'Devotion' sweet corn. Corn yielded 12 ton/acre and was machine harvested.



Figure 13. Growth of interseeded cover crops on April 11, 2016. Top to bottom: spring oats, crimson clover, triticale, Lana vetch. Cover crops were interseeded (Aug. 8, 2015) into organic sweet corn that was planted on July 8 (V8+).

Photos: Ed Peachey

cultivation at the six- to eight-collar growth stage for sweet corn.

Across field locations, corn ear yields with interseeding averaged from the same to about 5 percent lower than conventional yields. This amounts to a loss of 0.5 ton/acre of ear yield, assuming a typical corn yield of 10 ton/acre.

Reducing soil erosion with interseeding

Interseeded cover crops reduced soil erosion that accompanied the first heavy rains in the fall (figure 14). Reduced soil erosion with interseeding was particularly evident in years when fall seeding was delayed due to dry or saturated soil conditions.

Soil disturbance by fall tillage or by the no-till drill coulters (when direct-seeding in the fall) resulted in increased soil erosion (Figure 14). Soil was not disturbed in the fall in the interseeded plots or in the no-cover control plots, thereby limiting soil erosion.

Surface stormwater runoff was also reduced by interseeding. For the scenario shown in Figure 14, cumulative fall runoff (through Nov. 17) with interseeding was 60% of that for the no-cover control. With fall-seeded cover crops, cumulative runoff was 119%–123% of the no-cover control.

Conclusions

Interseeding is a viable method for reliable establishment of a winter cover crop. Interseeding transfers the work of cover crop seeding from fall to June/July. It is a good option to reliably establish a cover crop when corn harvest occurs after Oct. 1.

A high-clearance drill may be needed for interseeding cereals or other large-seeded cover crop species such as common vetch. Red or crimson clover can be successfully interseeded by broadcasting seed and lightly raking to establish seed-to-soil contact.

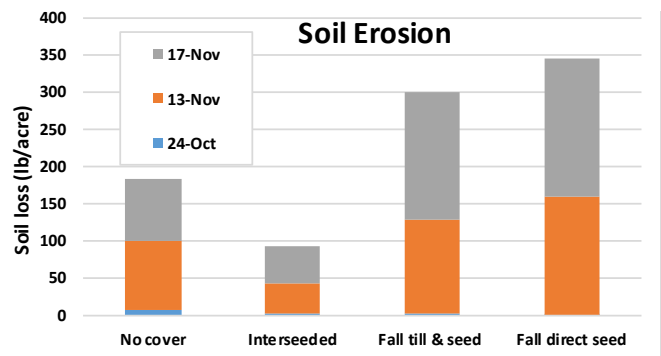


Figure 14. Effect of cereal cover crop establishment method on cumulative soil loss in the fall (through Nov. 17, 2017). Relative soil loss was estimated using microplots (Figure 10). Winter wheat was interseeded into corn at V6, was seeded conventionally (fall tillage and seeding) or was fall seeded with a no-till drill (direct-seeded). Wapato silty clay loam soil (3%–5% slope).

Interseeding reduces soil erosion and captures nitrate-N that otherwise would be lost during winter months to leaching. Cover crop biomass, measured in December, was always greater with interseeding than with fall seeding. Early fall soil cover is critical because severe soil erosion can occur in late October or in November.

Cover crop biomass in early April was often similar with interseeding or fall seeding. With interseeding, no cover crop is planted in the corn row, so only about 75% of the field surface area is planted, limiting production of spring cover crop biomass (Figure 15).

Triticale, winter wheat and oats were the most reliable cover crops for interseeding in this project. Triticale is especially well adapted to interseeding. It produces many tillers, covers soil rapidly and can survive extreme conditions (for example, seasonal flooding or freezing). Use of triticale or wheat as a cover crop may be prohibited by some corn processors due to concerns about allergen contamination of corn products by wheat or triticale by pollen or seed production before corn harvest.

Across field locations, corn ear yields were approximately 5% lower with interseeding than without interseeding. However, corn variety and other site-specific factors had a much greater impact on corn yield than did interseeding.

Successful interseeding requires adaptation of weed control practices. In conventional systems, most preemergence herbicides must be avoided or rates greatly reduced. In these trials, a combination of postemergence herbicides provided adequate weed control. In organic systems, where a final cultivation just before corn canopy closure is needed, consider using interseeding with corn varieties that produce less vegetative growth and less shading of the interseeded cover crop.

Acknowledgments

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M.S. candidate Andrew Donaldson provided technical support.

Reference (interseeded cover crops)

Donaldson, A. 2019. Weeds with a purpose: interseeding cover crops into sweet corn in western Oregon. Master's thesis, Oregon State University, Corvallis. ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/vd66w559b.

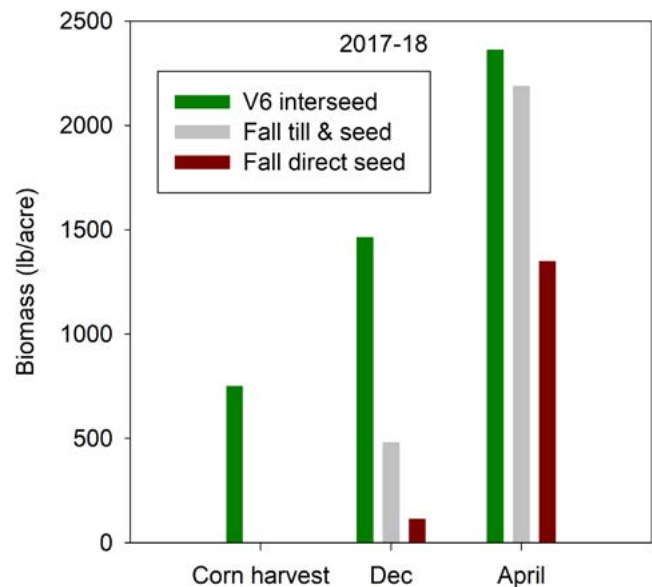


Figure 15. Biomass of cover crops at corn harvest (Sept. 7, 2017), in December and in the following spring (April 2018). The interseeded cover crop (crimson clover and triticale mixture) was drilled into corn at the V6 growth stage. Fall-seeded cover crops were drilled following conventional tillage or were direct seeded with a no-till drill on Sept. 28. OSU Vegetable Research Farm, Corvallis, Oregon, Chehalis silty clay loam soil.

Appendix D. Timeline for nutrient management research on sweet corn

Sullivan, Peachey and Heinrich conducted a series of field experiments from 2010 through 2018, with support from the Oregon Processed Vegetable Commission. Data are summarized in annual reports to OVPC (agsci.oregonstate.edu/category/veg/oregon-processed-vegetable-commission). Reports are also available online at Oregon State Scholar's Archive (ir.library.oregonstate.edu). Selected data from this research are summarized in the appendices in this publication.

Sullivan and Andrews conducted grower and experiment station field trials from 2003 through 2010 to verify the relationship between midseason soil nitrate test values and yield of sweet corn and other vegetable crops. Nitrogen management recommendations, based on these trials, are summarized in EM 9221.

Research was conducted from 2002 through 2005 at the North Willamette Research and Extension Center and at Washington State University-Puyallup to evaluate PAN release from a variety of locally available organic materials (manures, composts, crop residues and specialty products). Results of these trials were published in M.S. theses (Gale, 2005; Kusunwiriawong, 2005) and in Gale, et al. (2006).

The effect of winter cover crops on root rot and fertilizer N requirement for sweet corn was investigated by Miyazoe (2007), working with Alexandra Stone.

Feaga, et al. (2010) summarized a long-term cover crop trial conducted at NWREC (1991–2002), which measured leachate loss of nitrate-N from lysimeter plots. Additional soil and plant data from these trials were published by Richard Dick, John Selker, Del Hemphill and graduate students in EM 8803-E, *Cover Crop Nitrogen for Summer Vegetable Crops* (Burket, et al., 2003). Some of the earlier cover crop research by this group was published as EM 8728-E, *Nitrogen Scavenging:*

Using Cover Crops to Reduce Nitrate Leaching in Western Oregon (Sattell, et al., 1999).

In 2009, corn yield and N uptake response to sidedress N rate were measured by Hart and Peachey for four sweet corn varieties in a small plot trial at the OSU Horticulture Farm. Data were reported to the OPVC in a project report and were briefly summarized in the 2010 update of the sweet corn nutrient management guide (EM 9010).

A series of field experiments at NWREC measured aspects of N management for sweet corn production beginning in 1985 and concluding in 1998. The data are available in annual reports published by NWREC.

Research to calibrate the pre-sidedress soil nitrate test was initiated in 1995 by Hart and Hemphill on large plots in Willamette Valley grower fields. This portion of the research concluded in 1998.

Field experiments evaluating P, Cu, B and lime applications were conducted from 1980 through 1982, and results are reported in David McAndrew's dissertation.

A soil and plant tissue nutrient survey of sweet corn was conducted for the Willamette Valley in 1978. Selected relationships observed in this survey were presented in Hart, et al., 2010 (EM 9010). The original report was by Jackson, Bostdorf and Bissel, *Nutrient Survey: Sweet corn, Willamette Valley, 1978* (publisher not identified).

From 1963 through 1965, the interaction of lime, P and Zn was investigated by James Hay and reported in his thesis.

In 1964, approximately 90 sweet corn fields in Marion and Polk counties were sampled, and Zn in soil and tissue was measured. This work provided recommendations for Zn application when the soil test for Zn is below 2 ppm.

For more information

Extension publications

- Analytical Laboratories Serving Oregon*. EM 8677, catalog.extension.oregonstate.edu/em8677.
- Applying Lime to Raise Soil pH for Crop Production (Western Oregon)*. EM 9057, catalog.extension.oregonstate.edu/em9057.
- Estimating Plant-Available Nitrogen Release from Cover Crops*. PNW 636, catalog.extension.oregonstate.edu/pnw636.
- Fertilizing with Manure and Other Organic Amendments*. PNW 533, catalog.extension.oregonstate.edu/pnw533.
- Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon*. EM 9165, catalog.extension.oregonstate.edu/em9165.
- OSU Organic Fertilizer @ Cover Crop Calculator: Predicting Plant-Available Nitrogen*. EM 9235, catalog.extension.oregonstate.edu/em9235.
- Soil Nitrate Testing for Willamette Valley Vegetable Production*. EM 9221, catalog.extension.oregonstate.edu/em9221.
- Soil Test Interpretation Guide*. EC 1478, catalog.extension.oregonstate.edu/ec1478.

Literature cited

- Abendroth, L., R. Elmore, M. Boyer, and S. Marlay. 2011. *Corn Growth and Development*. PMR 1009, store.extension.iastate.edu/product/6065, Ames, IA: Iowa State University.
- Bittman, S., C. Kowalenko, D. Hunt, T. Forge, and X. Wu. 2006. Starter phosphorus and broadcast nutrients on corn with contrasting colonization by mycorrhizae. *Agron. J.* 98:394–401.
- Feaga, J., J. Selker, R. Dick, and D. Hemphill. 2010. Long-term nitrate leaching under vegetable production with cover crops in the Pacific Northwest. *Soil Sci. Soc. Am. J.* 74:186–195.
- Fletcher, A., and D. Moot. 2006. Phenological development and frost risk of ‘Challenger’ sweet corn (*Zea mays*) in response to phosphorus. *New Zealand J. of Crop and Hort. Sci.* 34(4):393–402.
- Gale, E. 2005. Estimating plant-available nitrogen release from manures, composts, and crop residues. Master’s thesis, Oregon State University, Corvallis.

- Gale, E., D. Sullivan, D. Hemphill, C. Cogger, A. Bary, and E. Myhre. 2006. Estimating plant-available nitrogen release from manures, composts, and specialty products. *J. Envir. Qual.* 35:2321–2332.
- Hart, J., D. Sullivan, J. Myers, and R. Peachey. 2010. *Nutrient Management Guide for Sweet Corn (Western Oregon)*. 2010. EM 9010, Corvallis, OR: Oregon State University.
- Heckman, J., 2007. Sweet corn nutrient uptake and removal. *HortTechnology* 17:82–86.
- Heckman, J., W. Hlubik, D. Prostack, and J. Paterson. 1995. Pre-sidedress soil nitrate test for sweet corn. *HortScience* 30:1033–1036.
- Kusonwiriawong, C. 2005. Nitrogen mineralization from organic amendments during the second year following application. Master’s thesis, Oregon State University, Corvallis.
- Ma, B., K. Subedi, and T. Zhang. 2007. Pre-sidedress nitrate test and other crop-based indicators for fresh market and processing sweet corn. *Agron. J.* 99:174–183.
- McAndrew, D. 1983. Soil fertility investigations on soil solution composition and nutrition of sweet corn and onions. Ph.D. thesis, Oregon State University, Corvallis.
- Peachey, E., and D. Sullivan. 2015. *Effect of Pop-up Fertilizers and Planting Density on Early Season Sweet Corn Growth and Ear Yield*. Report to Oregon Processed Vegetable Commission.

Reports to Oregon Processed Vegetable Commission

- Listed in reverse chronological order. Reports are available online at agsci.oregonstate.edu/category/veg/oregon-processed-vegetable-commission.
- Peachey, E. 2018. Evaluating tolpyralate herbicide and rotational strategies to economize sweet corn production. In *2018–2019 Research Reports for the Oregon Processed Vegetable Commission*.
- Peachey, E. 2017. Interseeding of cover crops to improve cover crop establishment and performance in sweet corn. In *2017–2018 Research Reports for Oregon Processed Vegetable Commission*.
- Heinrich, A., and D. Sullivan. 2016 and 2017. *Providing Organic Nutrient Management Guidance to Processed Vegetable Growers*.
- Heinrich, A., and D. Sullivan. 2015 and 2016. *Increasing Liming Efficiency on Processed Vegetable Farms*.

- Peachey, E., and D. Sullivan. 2015. *Effect of Pop-up Fertilizers and Planting Density on Early Season Sweet Corn Growth and Ear Yield*.
- Peachey, E., and D. Sullivan. 2015. *Interseeding of Cover Crops to Improve Cover Crop Establishment and Performance*.
- Sullivan, D., A. Heinrich, and E. Peachey. 2014 and 2015. *Enhanced Efficiency Fertilizer Technologies for Improved Production in Sweet Corn*.
- Sullivan, D., E. Peachey, and A. Heinrich. 2013. *Improving Fertilizer P and N Use Efficiency in Sweet Corn*.
- Sullivan, D., A. Heinrich, and E. Peachey. 2012. *Predicting Phosphorus and Nitrogen Needs in Sweet Corn*.
- Peachey, E., and D. Sullivan. 2011. *Predicting N fertilizer Needs in Sweet Corn: Comparing Preplant Nmin and Pre-sidedress Tests to Improve Predictability*.
- Peachey, E., and J. Hart. 2009. *Nitrogen Fertilizer Use Efficiency in Sweet Corn: Effect of Variety*.
- Hemphill, D., and J. Hart. 1999. *Nitrogen Management in Sweet Corn*.
- Hemphill, D., and J. Hart. 1998. *Nitrogen Management in Sweet Corn*.
- Hemphill, D., J. Hart, and E. Marx. 1997. *Pre-Sidedress Soil Nitrate Testing in Sweet Corn*.
- Hemphill, D., R. Dick, and J. Hart. 1996. *Nitrogen Management in Vegetable Crops and Their Rotations*.
- Hemphill, D., R. Dick, and J. Hart. 1993. *Nitrogen Rates, Timing, Placement, Catch Crops, and Crop Rotations on Yield and Nitrogen Utilization of Vegetable Crops*.
- Historical Oregon State University research reports and theses**
- Burket, J., J. Sandeno, D. Hemphill, and R. Dick. 2003. *Cover Crop Nitrogen for Summer Vegetable Crops*. EM 8803-E, Corvallis, OR: Oregon State University.
- Donaldson, A. 2019. Weeds with a purpose: interseeding cover crops into sweet corn in western Oregon. Master's thesis, Oregon State University, Corvallis. http://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/vd66w559b.
- Gale, E. 2005. Estimating plant-available nitrogen release from manures, composts, and crop residues. Master's thesis, Oregon State University, Corvallis.
- Hay, J. 1966. The relationships between zinc, iron, and phosphorus in sweet corn. Master's thesis, Oregon State University, Corvallis.
- Hemphill, D. 1981. Sweet corn yield affected by timing of nitrogen application. In *Vegetable Research at the North Willamette Agricultural Experiment Station 1979–1980*. D. Hemphill (ed.). SR 611, Corvallis, OR: Oregon Agricultural Experiment Station.
- Hemphill, D. 1985. Form and timing of applied nitrogen on sweet corn production. In *Vegetable Research at the North Willamette Agricultural Experiment Station 1983–1984*. D. Hemphill (ed.). SR 727, Corvallis, OR: Oregon Agricultural Experiment Station.
- Hemphill, D. 1987. Nitrogen rate, form, and timing on yield of sweet corn. In *Vegetable Research at the North Willamette Agricultural Experiment Station 1985–1986*. D. Hemphill (ed.). SR 798, Corvallis, OR: Oregon Agricultural Experiment Station.
- Hemphill, D. 1995. *A Survey of Vegetable Cropping Practices and Their Effects on Residual Soil Nitrate and Ammonium Concentrations*. DEQ Contract No. 133-94 Final Report, Corvallis, OR: Oregon State University.
- Hemphill, D., and T. Jackson. 1983. Lime-phosphorus interaction on yield and elemental concentrations of vegetable crops. In *Proceedings of the 34th Annual Northwest Fertilizer Conference*, Portland, OR, July 12–13.
- Jackson, T., and J. Hay. 1965. Factors affecting response of sweet corn to Zn in the Willamette Valley. In *Proceedings of the 16th Annual Fertilizer Conference, Pacific Northwest*, Salt Lake City, UT, July 13–15.
- Marx, E. 1995. Evaluation of soil and plant analysis as components of a nitrogen monitoring program for corn. Master's thesis, Oregon State University, Corvallis.
- McAndrew, D. 1983. Soil fertility investigations on soil solution composition and nutrition of sweet corn and onions. Ph.D. thesis, Oregon State University, Corvallis.
- Miyazoe, M. 2007. Cover crop effects on root rot of sweet corn and soil properties. Master's thesis, Oregon State University, Corvallis. <http://hdl.handle.net/1957/6161>.

- Riggert, C. 1978. *The Effect of N-Serve on Sweet Corn Yields*. Oregon State University Extension Service, Lane County.
- Sattell, R., R. Dick, D. Hemphill, J. Selker, F. Brandi-Dohrn, H. Minshew, M. Hess, J. Sandeno, and S. Kaufman. 1999. *Nitrogen Scavenging: Using Cover Crops to Reduce Nitrate Leaching in Western Oregon*. EM 8728-E, Corvallis, OR: Oregon State University.

Acknowledgments

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