REFINING NITROGEN MANAGEMENT FOR ORGANIC BROCCOLI PRODUCTION

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Specialty organic fertilizers used in organic vegetable production are expensive. So, from environmental and economic perspectives, growers want to maximize nitrogen (N) fertilizer use efficiency by the crop. This research was conducted to (1) determine sufficient N fertilizer rates for organic broccoli, (2) evaluate the efficacy of a specialty organic fertilizer (feather meal; 12-0-0), and (3) confirm the effectiveness of midseason soil nitrate analyses (0-30 cm) in determining appropriate sidedress fertilizer rates. Crop and soil response to feather meal application was compared to urea. Fertilizers were applied at rates of 0, 67, 134, and 202 kg N ha^{-1} (0, 60, 120, and 180 lb N $acre^{-1}$) via preplant broadcast or banded sidedress application (6 leaf stage). Two experiments were conducted in successive years in small plots within the same field (Newberg sandy loam; 2.3% SOM in 0-30 cm depth). Soil samples for midseason nitrate analysis were collected between rows at 0-30 and 30-60 cm depth at 39-43 d after seeding. Non-fertilizer N contributions were monitored. During the growing season, irrigation supplied 30-35 kg N ha^{-1}, and nitrate mineralized from SOM (buried bag method) supplied 70-110 kg N ha^{-1}. Broccoli was efficient in taking up N from the soil. With zero N fertilizer applied, aboveground biomass contained 155-185 kg N ha^{-1} at harvest. With fertilization, biomass contained 200-260 kg N ha^{-1} at harvest. Feather meal N mineralized rapidly to nitrate. At midseason, apparent nitrate-N recovery from soil (0-60 cm depth) accounted for 73% of the preplant feather meal N applied. At harvest, all fertilizer treatments were low in residual soil nitrate-N (< 20 kg ha^{-1} in 0-60 cm depth). Because of the high efficiency of crop N uptake from non-fertilizer sources, broccoli yield and N uptake were maximized with fertilizer rates of 67-134 kg N ha^{-1}. Broccoli head yield was maximized without sidedress N application when midseason soil nitrate-N concentrations were > 25-30 ppm (0-30 cm). Based on this research, we recommend applying a modest rate (40 to 70 kg N ha^{-1}) of feather meal or other fast-acting organic fertilizer when preplant NO_3-N is less than 20 ppm (0-30 cm depth). Sidedress N application can be omitted when soil NO_3-N exceeds 30 ppm nitrate-N (0-30 cm) at the 6 leaf stage.

INTRODUCTION

Matching N supply from organic fertilizers to the needs of a broccoli crop is a challenge. Nitrogen uptake by broccoli is limited (< 20 kg N ha^{-1}) during the first month after seeding. During this time, irrigation supplied by overhead sprinklers usually exceeds evapotranspiration and some nitrate leaching occurs from topsoil. From the 6 leaf stage to harvest, broccoli accumulates N rapidly (3 to 5 kg ha^{-1} d^{-1}), taking up 200-300 kg ha^{-1} at harvest, depending on plant population.

Under organic management, the amount of plant-available N mineralized from soil organic matter typically increases. Preplant N mineralization tests have proven ineffective in forecasting the rate of N fertilizer required to meet crop need. Therefore, current N management recommendations for conventional production are to apply a small amount of starter N fertilizer at planting and apply the rest of the N fertilizer based on a soil nitrate test collected just before the onset of rapid crop N uptake.

Feather meal is a specialty N fertilizer that is rapidly converted to nitrate in the soil. At typical summer soil temperatures in western Oregon (70 ºF), approximately 60 % of feather meal N is mineralized to nitrate in 4 weeks, with an additional 15% of total N mineralized between 4 and 10 weeks (OSU EM 9235).

This research was conducted to (1) determine sufficient N fertilizer rates for broccoli, (2) evaluate the efficacy of a specialty organic fertilizer (feather meal; 12-0-0), and (3) confirm the effectiveness of midseason soil nitrate analyses (0-30 cm) in determining appropriate sidedress N fertilizer rates.

MATERIALS AND METHODS

Two experiments were conducted in successive years in separate locations within the same field (Newberg sandy loam; 2.3 % SOM in 0-30 cm depth) at the OSU Vegetable Research Farm near Corvallis, OR. Before our trials, the field was conventionally fertilized for 5+ yr. Subplots were 2.7 x 7.6 m (9 x 25 ft) in a randomized complete block design with 4 replications. *Cascadia*, an exerted head cultivar for mechanical harvest, was seeded and thinned to 52,000 plants ha^{-1} (21,000 $acre^{-1}$).

Fertilizer treatments compared N rate, timing and placement (Table 1). Feather meal was applied at rates of 0, 67, 134, and 202 kg N ha^{-1} via preplant broadcast or banded sidedress application (6 leaf stage), and compared to urea (134 kg N ha^{-1}). Fertilizers were broadcast preplant and immediately incorporated by tillage, or sidedressed at 42 days after planting (DAP) in 2018 and 45 DAP in 2019. Sidedress fertilizer treatments were applied by hand in a furrow 5-8 cm deep and 5-8 cm beside the row. Conventional management was used for weed and insect control.

Broccoli was seeded on 2 Jul 2018 and 3 Jun 2019. Heads were harvested 84-93 DAP in 2018 and 77-85 DAP in 2019. Heads were harvested by hand from 6 m (20 ft) of row.

Soil samples for nitrate analysis were collected between rows at 0-30 and 30-60 cm depth at the 6 leaf stage (39 DAP in 2018, and 43 DAP in 2019) and at final harvest. Three plants per plot were harvested to determine crop N uptake. Soil and plant analyses were performed by Brookside Laboratories, New Bremen, OH. Soil nitrate was determined by colorimetry. Plant N concentration was determined by combustion.

Non-fertilizer N contributions were monitored. During the growing season, sprinkler irrigation water was collected; it supplied 30-35 kg N ha^{-1} during the growing season. Moist soil (0-30 cm) was collected for an in-situ buried bag incubation before preplant fertilizer application. Incubation bags for N mineralization determination were installed in border rows within each replication the day after seeding as described by Sullivan and Moore (2017). We estimated "Unaccounted N" the balance between N supply and N recovery at harvest:

Unaccounted N = N supply - N recovered [Eq.1], where:

N supply = [fertilizer treatment N + soil N mineralization (buried bag; 0-30 cm) + NO_3-N applied in irrigation water + starter N applied with planter at seeding (22 kg ha^{-1})].

N recovered = Crop N uptake + postharvest nitrate-N (0-60 cm)

RESULTS AND DISCUSSION

Crop response to fertilization was more apparent in 2019 than in 2018. In 2019, less N was mineralized from soil organic matter than in 2018 (Figure 1). Crop response to fertilizer treatments is shown only for 2019 (Table 1; Figure 2). Maximum head yields in our trial were lower in 2019 (12 Mg ha^{-1}; Table 1) than in 2018 (20 Mg ha^{-1}; data not shown), even though maximum crop N uptake (200-260 kg ha^{-1}) was similar for both years. We attribute inconsistent yield response across years to interactions of variety x weather. Growers also reported inconsistent head yield for *Cascadia* in 2018-19.

Broccoli was efficient in extracting N from the soil. With only starter N applied at seeding (22 kg ha^{-1}), aboveground biomass at harvest contained 154 kg N ha^{-1} in 2019 (Table 1) and 185 kg N ha^{-1} in 2018 (data not shown). Maximum crop N uptake values measured in this trial are similar to those reported previously for broccoli grown in the Willamette Valley (PNW Extension 513). The amount of N mineralized from soil organic matter in this trial was similar to typical values (80-135 kg N ha^{-1}) measured across 25 conventional sweet corn fields in the Willamette Valley (Figure 5 in OSU EM 9165).

Calculations of apparent balance between total N supply (including non-fertilizer sources) and total N recovered (crop N uptake plus postharvest soil nitrate) demonstrated high efficiency of crop N uptake from non-fertilizer N sources. For the unfertilized control, unaccounted N (the balance between N supply and demand) was negative indicating more than 100% utilization of apparent N supply (Table 1). Unaccounted N was near zero for N fertilizer rates up to 67 kg ha^{-1} in 2018 and for N rates up to 134 kg ha^{-1} in 2019. Unaccounted N increased with feather meal N rate and was high (> 50 kg ha^{-1}) at feather meal N rates > 67 kg ha^{-1} in 2018, and at the highest N rate (202 kg ha-1) in 2019. High levels of unaccounted N are associated with an increased risk of nitrate leaching loss. Research conducted in the Salinas Valley of California also demonstrated high N removal efficiency for broccoli, associated with deep root system development.

Efficacy of feather meal as a fast-acting fertilizer for broccoli. Feather meal N mineralization was rapid following preplant application. Averaged across years, apparent midseason soil nitrate recovery averaged 54% of total N applied in 0-30 cm depth and 73% in 0-60 cm depth (slope of lines in Figure 3). In comparison, soil nitrate recovery from preplant urea treatments at midseason was close to 100% (data not shown). Findings in the present study for nitrate-N recovery from feather meal agree with Extension guidance (OSU EM 9235), which estimates 60% recovery of plant-available N at 4 weeks, and 75% recovery at 10 weeks following feather meal application.

Broccoli head yield with sidedress feather meal application was equivalent to preplant feather meal application in 2018, but yields with sidedress feather meal were lower than for preplant feather meal in 2019 (Figure 2). We attribute this difference in crop response between years to the amount of early season (0-40 DAP) soil nitrate present. When zero preplant N was applied in 2018, nitrate-N (0-30 cm) was 20-22 ppm from 0-40 DAP. In 2019, with zero preplant N, soil nitrate-N (0-30 cm) was 9-10 ppm from 0-40 DAP. Apparently, in 2019, sidedress feather meal application did not provide N early enough, and so crop growth was limited by N deficiency at the 6 leaf stage. Head yields with sidedress urea (faster nitrate release than feather meal) were similar to preplant feather meal or preplant urea at the same N rate (134 kg ha^{-1}; Table 1). In both years, the split feather meal treatment (67 kg N ha^{-1} at seeding plus 67 kg N ha^{-1} at sidedress) and the split urea treatment (67 + 67 kg N ha^{-1}) produced maximum head yields.

The failure of feather meal N to rapidly correct midseason plant N deficiency in 2019 is also seen in the distribution of head yields. With sidedress feather meal, head yield was delayed (fewer heads in the first harvest, more heads in the third harvest), compared to preplant urea or preplant feather meal. Head yields with the highest rate of feather meal were not different than the unfertilized control.

Midseason soil nitrate analyses as an indicator of N sufficiency. Broccoli head yield and biomass N uptake were maximized when soil nitrate (0-30 cm) was 30+ ppm at the 6-leaf growth stage (Figure 3). A considerable amount of nitrate was measured in the 30-60 cm depth. In-season leaching was expected, based on early-season irrigation water application. From 0 to 40 DAP, water supplied by irrigation plus precipitation exceeded cumulative ET by 15-16 cm (6 inches). From 0-40 DAP, irrigation supplied 21-24 cm, while cumulative ET was 6-8 cm during this time. For the rest of the growing season (40 DAP to harvest), the water application rate (17 cm) was approximately equal to cumulative ET (16 cm).

Averaged across all fertilizer treatments, midseason soil NO_3-N concentrations were 26 and 13 ppm in 0-30 and 30-60 cm depths, respectively. The amount of NO_3-N present in the 30-60 cm depth increased with preplant feather meal application rate, indicating that a portion of feather meal N mineralized and was leached to 30-60 cm depth during the first 40 d after seeding. The slopes of linear regression lines for feather meal N rate vs. nitrate-N recovery from soil suggest that about 20% of feather meal N was leached to the 30-60 cm depth (Figure 4).

SUMMARY AND RECOMMENDATIONS

1) Head yield was maximized with an N application rate of 67-134 kg ha^{-1}. The most consistent positive crop growth response was observed with split N application (67 kg ha^{-1} preplant, 67 kg ha^{-1} at midseason). Midseason N application can be omitted when the midseason soil nitrate test (0-30 cm) exceeds 30 ppm nitrate-N.

2) Feather meal N mineralized rapidly, almost as fast as urea. However, feather meal mineralized N too slowly to be effective as a midseason sidedress "rescue treatment" when soil nitrate was low (10 ppm NO_3-N). We advise applying preplant N (40 to 80 kg ha^{-1}) when a preplant nitrate test is low (< 20 ppm NO_3-N; 0-30 cm).

3) Broccoli did not respond to additional sidedress N fertilization when midseason soil nitrate-N exceeded 30 ppm. This finding agrees with current OSU Extension guidance for N management for Willamette Valley vegetable crops (OSU EM 9221).

4) Broccoli was extremely efficient in recovering N from the soil. Biomass N uptake at harvest was roughly equivalent to the sum of N supplied by fertilizer and non-fertilizer N sources (soil N mineralization, irrigation water) when appropriate fertilizer N rates were supplied (67 to 134 kg ha^{-1} in our trials). Because our trials were conducted on a field with low SOM (2.3%) and no history of manuring, we expect even lower N input requirements for commercial organic fields.

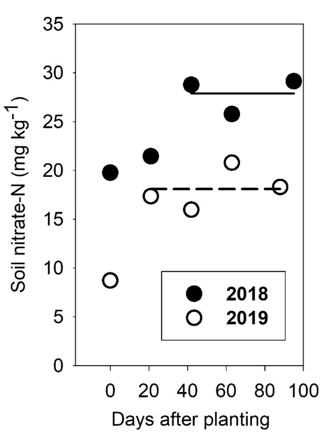
5) At harvest, broccoli plants contained 200-260 kg N ha^{-1}. Of this total N, about a third is removed in harvest, with the remainder returned in crop residues. Planting a cereal cover crop following a summer broccoli crop is strongly recommended to limit nitrate leaching loss over winter.

Table 1. Apparent balance between total N supply (including non-fertilizer sources) and total N recovered (crop N uptake plus postharvest soil nitrate). A positive number for unaccounted N indicates N supply was greater than N recovered[a].

Year	Trt ID[b]	Total N supply	Head yield (fresh wt)	Crop Biomass at harvest	Crop Biomass N conc.	Crop Biomass N uptake	Postharvest soil NO_3-N (0-60 cm)	Unaccounted N[b]
		kg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	%	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
2019	None	126	6.7	6.8	2.3	154	2	-30
2019	F 67/0	193	9.6	7.5	2.6	193	1	-1
2019	F 134/0	260	10.1	9.3	2.6	245	3	12
2019	F 202/0	328	10.8	8.1	2.9	238	6	84
2019	F 0/67	193	9.1	8.5	2.5	213	1	-20
2019	F 0/134	260	9.0	7.6	2.8	210	5	45
2019	F 0/202	328	7.7	6.9	2.8	193	2	134
2019	F 67/67	260	10.8	9.2	2.9	262	4	-6
2019	U 134/0	260	10.6	8.2	3.1	253	4	3
2019	U 0/134	260	10.3	7.1	3.0	213	3	44
2019	U 67/67	260	12.0	8.1	3.2	258	2	1
	PLSD 0.05		*2.5*		*0.4*	*56*		

[a]Unaccounted N = N supply - N recovered [Eq.1].

[b]Trt ID: F = feather meal, U = urea. Numbers indicate preplant/sidedress N applied (kg ha^{-1}). Example: F 67/67 is 67 kg N ha^{-1} preplant, with an additional 67 kg N ha^{-1} sidedressed at 6-leaf stage.



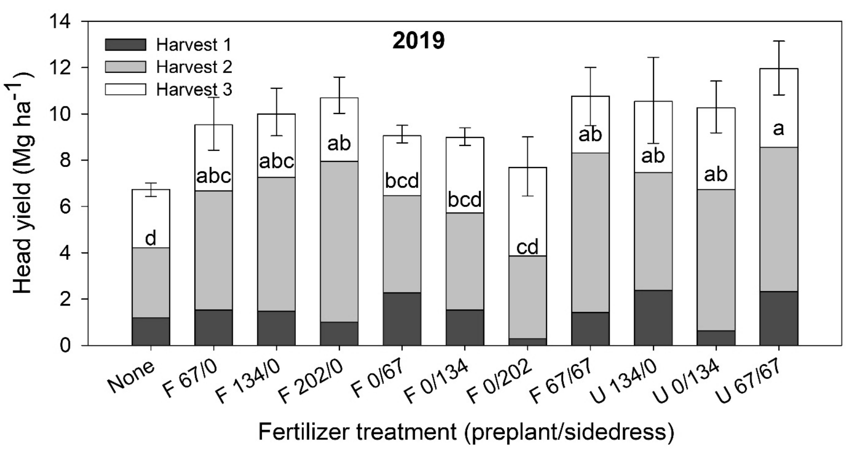


Figure 1 (left). Nitrate recovered from buried soil incubation bags placed in the field at planting time and destructively harvested during the growing season. Soil for the buried bag incubation was collected from 0-30 cm depth prior to preplant fertilizer application. Plateau nitrate-N concentrations were equivalent to 110 kg ha^{-1} in 2018 and 70 kg ha^{-1} in 2019.

Figure 2 (right). Cumulative fresh weight broccoli head yields from three successive harvests in 2019. Letters above bars denote mean separation (PLSD 0.05). Trt ID: F = feather meal, U = urea. Example: F 67/67 is 67 kg N ha^{-1} preplant, with an additional 67 kg N ha^{-1} sidedressed at 6-leaf stage.

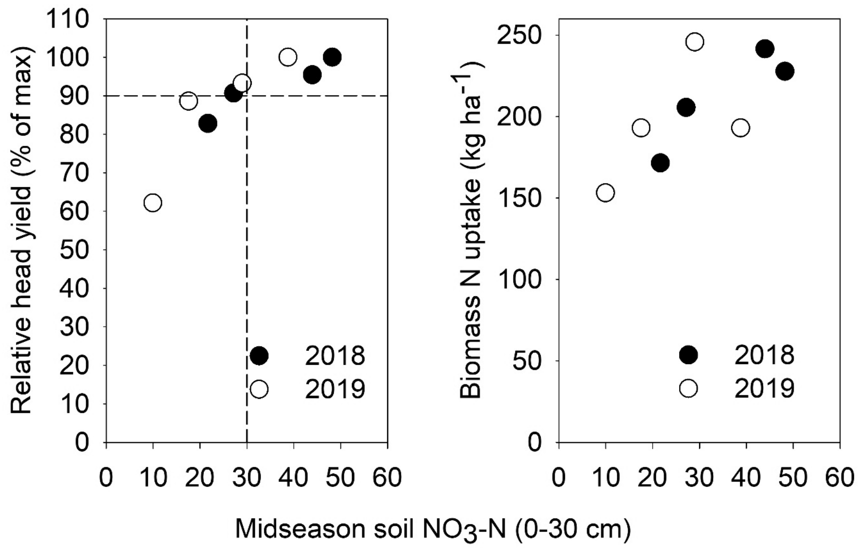


Figure 3. Midseason soil nitrate-N (0-30 cm) for preplant feather meal N treatments (0, 67, 134 and 202 kg ha^{-1}) vs. relative head yield (left), and biomass N uptake at harvest (right). Fertilizer treatments with more than 25-30 mg kg^{-1} nitrate-N in soil at midseason had head yields equivalent to 100% relative yield (P = 0.05; left), and biomass N uptake averaging 230 kg ha^{-1} (right).

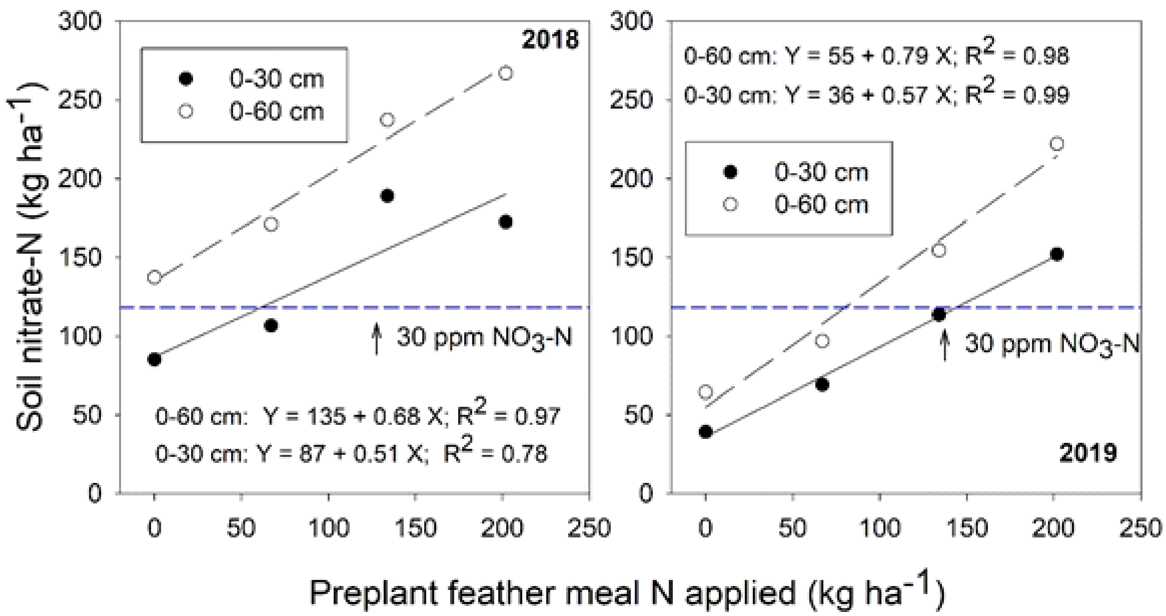


Figure 4. Soil nitrate in 0-30 and 0-60 cm depth at midseason following a preplant feather meal application. The target value for sufficient nitrate-N at midseason is 30 ppm (118 kg N ha^{-1}; OSU EM 9221) in a 0-30 cm depth soil sample (dashed horizontal line). Soil bulk density of 1.3 g cm^{-3} was used in converting ppm to kg ha^{-1}.