

Research Reports

The Feasibility of Organic Nutrient Management in Large-scale Sweet Corn Production for Processing

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SUMMARY. There is significant interest from vegetable processors, growers, and consumers in organic sweet corn (*Zea mays*) production. Organic nitrogen (N) management is particularly challenging in high N consuming crops such as sweet corn because of the low N content and low N to phosphorus (P) ratios of organic soil amendments. Various management programs were compared to determine the optimal combination of soil amendments and green manure crops for organic sweet corn production. Alfalfa (*Medicago sativa*), rye (*Secale cereale*), and field pea (*Pisum sativum*) were used as green manure crops. Composted poultry manure and a high N content organic fertilizer were used as organic amendments. Ammonium nitrate was used in a conventional management program for comparison. Treatments were designed to deliver a full rate of N (150 lb/acre), a half rate of N (75 lb/acre), and to limit the amount of P applied. Phosphorus can become a source of pollution when applied to erodible soils, particularly when soils already contain excessive P. Sweet corn yield in many of the organic programs was highly variable among years while the yield was more consistent in the conventional program. This was attributed to differences in organic N mineralization in both the green manure crops and the amendments. The most stable yield from an organic treatment, among years, was achieved using the commercially available organic N fertilizer. Commercially available amendments were costly, and although organic sweet corn received a premium price in years when organic yields were lower, profit was reduced by the high cost of N management.

Vegetable processors in Wisconsin have expressed interest in producing organic sweet corn. The organic food market has increased in value from \$1 billion in 1990 to \$26.6 billion in 2010 (Organic Trade Association, 2010). Organic vegetable production would provide a new market for Wisconsin vegetable growers and processors. Furthermore, consumers currently

pay a premium price for organically produced food (Oberholtzer et al.,

2005), providing an additional incentive. Large volumes of raw vegetables are needed to designate facilities for organic processing in accordance with U.S. Department of Agriculture National Organic Program rules (USDA, 2007). Therefore, management practices for organic processing vegetables must be practical on a large scale.

Nitrogen management in large-scale production is a challenge to growers, particularly for crops such as sweet corn that require large amounts of N for optimal production (150 lb/acre) (Laboski et al., 2006). Nitrogen can be a costly input for organic growers because of the low N content of many organic fertilizers. Thus, a diversified approach to N management may be a cost effective means of producing sweet corn organically. Animal manure, compost, green manure (GrM) crops, and commercially available soil amendments can be used to meet crop nutrient needs in organic systems (Gaskell and Smith, 2007).

Manure is an important amendment for use in organic production systems. Its relative abundance and role as a waste product make it an inexpensive fertilizer amendment. Manure must be composted before use in organic vegetable production systems because of organic program regulations on using raw manures (USDA, 2007) and to improve the stability of the organic compounds in the manure (Gaskell and Smith, 2007). Composted manure generally contains a low N concentration and a low N to P ratio. Using manure as a sole N source for sweet corn production may cause several complications for the grower. Large quantities must be applied, because of the low N content, creating added expense when transportation and application costs are factored into the overall cost of the amendment (Gaskell and Smith, 2007). Also, application of

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Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
29.574	fl oz	μL	3.3814 × 10 ⁻⁵
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg-ha ⁻¹	0.8922
1	ppm	mg·kg ⁻¹	1
2.2417	ton/acre	Mg-ha ⁻¹	0.4461
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

large quantities of manure may lead to P over-application (Nelson and Janke, 2007; Rosen and Allan, 2007). Applying P in excess of crop need, particularly to soils that already have high P content, can contribute to environmental degradation. Phosphorus adsorbed to soil particles can erode and be deposited in surface water, causing eutrophication and other environmental concerns (Correll, 1998; Sharpley et al., 1994). This is particularly problematic with highly erodible soils. Fertilization with composted manure in combination with other amendments or green manure crops may be a means to optimize N and P simultaneously while minimizing application and input costs.

Commercially available organic amendments can be used as an N fertilizer in organic agriculture. Certified organic producers are limited to amendments that are allowable under the National Organic Program standards. The Organic Materials Review Institute is a nongovernmental, independent organization that reviews amendments and certifies them for organic production under the national standards. These commercially available amendments may contain components such as feather meal, bone meal, and guano. Some of these amendments may resolve complications with using composted animal manure because of a high N content (11% to 14%) and N to P ratios similar to crop need (Hartz and Johnstone, 2006). Some products, made with mostly feather meal, contain minimal P. However, these products can be very costly, ranging from \$4.60 to \$28.00 per kilogram of total N for the least expensive product, feather meal, to the most expensive product, fish powder (Hartz and Johnstone, 2006). To remain cost effective, the amendments would need to consistently provide a significant increase in yield in comparison with other organic N sources. These products in combination with other amendments or GrM crops may provide a means to optimize N while minimizing input costs.

Use of legume GrM crops is a potential means to provide N to subsequent crops at a relatively low cost (Tourte et al., 2003). Hairy vetch (*Vicia villosa*) as a GrM provided all of the N needed for a sweet corn crop (Cline and Silvernail, 2002). Extension recommendations in Wisconsin

suggest that alfalfa can provide up to 100 lb/acre N credit when grown as a GrM for a full year before incorporation (Laboski et al., 2006). However, an alfalfa GrM would result in the loss of a production season in that field for the grower unless it is grown as a forage and organic hay is harvested and marketed during the establishment season. Field pea can be established as a GrM in the spring during optimal cool weather and plowed down just before sweet corn planting. However, extension recommendations suggest that the potential N credit from peas (40 lb/acre) is lower than that from alfalfa (Gerwin and Gelderman, 2005). Furthermore, this credit has not been verified on the sandy soils of the Central Sands region, where the majority of the processing crops are grown in Wisconsin.

Nitrogen is slowly released from organic fertilizer sources over time as they are mineralized by the soil microbial community (Rosen and Allan, 2007). The N mineralization rate from organic amendments may be impacted by several external factors, including soil type. For example, more rapid mineralization of organic residues occurs in sandy soils compared with soils with higher clay and silt content (Jackson, 2000; Ladd et al., 1995). Ideally, to reduce crop N deficiency and potential yield loss, the release of N from organic sources will match the fluctuating crop need throughout the growing season. A mismatch of N availability and crop need could result in either loss of N because of leaching during periods of low crop need or deficient soil N during periods of high crop need. Thus, understanding the mineralization rate of amendments in organic management programs is an important aspect to providing the nutrients required for optimizing crop yield yet minimizing cost to the producer.

The objective of this study was to evaluate a variety of organic N management programs that would be feasible for sweet corn growers in large-scale production. Management programs were selected that provided full (150 lb/acre) and half (75 lb/acre) rates of N for sweet corn, according to current Wisconsin extension recommendations (Laboski et al., 2006), using various combinations of organic amendments. Certain

programs were also designed to limit P application. Phosphorus recommendations in Wisconsin for sweet corn are based on yield goals and soil test levels. When soil tests show high P levels, P applications must be limited to the crop removal rate for a 4-year rotation (sweet corn would be planted twice in a typical 4-year rotation). For a moderate crop yield goal of 15,000 lb/acre, sweet corn removes 10 lb/acre P so in soils high in P we intended to limit application to 20 lb/acre of P.

We evaluated sweet corn ear leaf N and yield response to each of the different management programs to determine which combinations of N amendments were meeting crop N demands. Soil samples were collected in selected programs to determine if the mineralization of organic N from the different organic sources was synchronous with crop need. Economic cost of the various management programs vs. yield response was also quantified to estimate relative net profitability.

Materials and methods

The experiment was conducted at the Hancock Agricultural Research Station, Hancock, WI, in 2006, 2007, and 2008 on an overhead irrigated Plainfield loamy sand soil (mixed, mesic Typic Udipsamment). The specific soil texture was 90% sand, 3% silt, and 7% clay, determined using the hydrometer method (Bouyoucos, 1962). Organic matter was 0.9%, determined by the weight loss-on-ignition method (Shulte and Hopkins, 1996). The pH was 6.2, using a 1:1 soil to water ratio and using a combination reference glass electrode pH meter. Phosphorus and potassium (K) levels were 76 and 87 ppm, respectively. Both P and K were extracted from the soil with the Bray P1 solution, P was determined colorimetrically after reacting with ammonium molybdate, and K was determined via atomic adsorption (Bray and Kurtz, 1945).

The experimental design was a randomized complete block with four replications. Treatments included various combinations of the three different GrM crops and four fertilizer amendments to provide varying levels of N to the sweet corn crop. The GrM crops were rye, alfalfa, and pea. Rye was included as a GrM in the study because it is a standard cover crop to reduce wind erosion in this

region of Wisconsin. The GrM crops were established in blocks within replications to facilitate planting. Block placements were still randomized in each replication. Organic amendments included composted poultry manure [CPM (3N-1.7P-1.7K in 2006, 4N-1.7P-1.7K in 2007, 4N-2.2P-2.5K in 2008; Cashton Farm Supply, Cashton, WI)], a feather-meal-based organic fertilizer, 11N-0P-0K [hereafter referred to as 11-0-0 (Organic Nitrogen Fertilizer; Renaissance Fertilizer Co., Rowley, MA)], and 5N-2.2P-4.2K organic fertilizer [hereafter referred to as 5-5-5 (Organic Garden Fertilizer, Renaissance Fertilizer Co.)]. The organic fertilizers were used as representatives of commercially available organic fertility management products. The conventional fertilizer was ammonium nitrate (34N-0P-0K).

Treatments were given a code name, and specific amendment applications per treatments are given in Table 1. The three GrM crops without any additional amendments were treatments Rye, Alf, and Pea. The Rye1XConv and Rye½XConv treatments consisted of a rye GrM crop with a full and half N rate (150 and 75 lb/acre, respectively) of ammonium nitrate. The Rye1XOrg and Rye½XOrg treatments consisted of a rye GrM crop with a full and half N rate of 11-0-0. The Rye1XCPM and Rye½XCPM treatments consisted of a rye GrM crop with a full and half N rate of CPM. The RyePhosCPM treatment was a rye GrM crop with CPM added to not exceed an application of 20 lb/acre of P. The RyePhosCPMOrg treatment was similar to the previous treatment except 11-0-0 was added to provide a full N rate. The Pea1XOrg and Pea1XCPM treatments were pea GrM crops with 11-0-0 and CPM added, respectively, to a full N rate. The PeaPhosCPM treatment was a pea GrM crop with CPM applied to not exceed an application of 20 lb/acre of P. The PeaPhosCPMOrg treatment was similar to the previous treatment except 11-0-0 was added to provide a full N rate. Alf1XOrg and Alf1XCPM were alfalfa GrM crops with 11-0-0 and CPM added, respectively, to a full N rate.

The alfalfa GrM crop (2.4 million seeds/acre) was planted with a drill in the intended research fields in April the year before conducting the study in 2007 and 2008, allowing

more than 1 year before incorporation. Alfalfa was never harvested from the plots as hay. In 2006, the alfalfa was not established; thus, no alfalfa treatments were included for that year. Pea and rye (122,000 seeds/acre and 1 million seeds/acre, respectively) were planted with a drill in April of the study year. All GrM crops were incorporated ≈ 7 d before planting sweet corn to discourage seed corn maggot (*Delia platura*) infestation. 'Marvel' sweet corn was planted at a rate of 24,000 seeds/acre on 13 June 2006, 19 June 2007, and 18 June 2008. Individual sweet corn plots measured 12 \times 30 ft with 36-inch row spacing, allowing four rows per plot.

In treatments where there was no additional P application, 5-5-5 was applied to provide 10 lb/acre, the minimum P requirement of a sweet corn crop. This initial application of 5-5-5 and the CPM were broadcast-applied by hand 1 week before planting and incorporated with cultivation. Starter fertilizer was applied at planting in the conventional plots using a conventional starter (5N-10.9P-8.3K) and in the organic plots using the 5-5-5. The N content of the CPM varied by year; thus, the amount applied in the various treatments was adjusted accordingly. The remainder of the N required (beyond what was supplied in the starter) in the conventional treatments was side-dressed by hand in split applications when the sweet corn was at the five- and eight-leaf stages. In organic treatments that used 11-0-0, a side-dressed application was hand applied when the sweet corn was at the five-leaf stage. The amount of P in the CPM varied by year, so the amount applied was adjusted accordingly in the P-limited treatments. Nitrogen and P application rates were based on total N and P content of organic amendments, not on an estimate of potential mineralized N and P through the growing season. Potassium chloride was applied as potash annually to the study area in the fall before the study year according to University of Wisconsin extension recommendations for sweet corn production (Laboski et al., 2006).

Soil samples were collected from selected treatments; Rye, Rye1XConv, Rye1XOrg, Rye1XCPM, RyePhosCPM, Alf, and Pea, to measure plant-available N (PAN) under different management programs. Soil

samples were collected every 2 weeks from 1 week before planting until sweet corn harvest. Soil cores were taken from eight random locations in each plot with a 3/4-inch-diameter soil probe and to a depth of 8 inches and composited into one sample. All samples were then dried at 125 °F for 72 h. Ammonium (NH_4^+) and nitrate (NO_3^-) contents were determined for each sample. In 2006, NO_3^- and NH_4^+ contents of the samples were determined by the University of Wisconsin Madison Soil and Plant Analysis Laboratory using injection flow analysis (Ruzicka, 1983). In 2007 and 2008, we determined NO_3^- and NH_4^+ by extracting soils samples with 2 M potassium chloride (KCl) in a 1:10 soil to solution ratio. The extractions were placed on an orbital shaker for 15 min at 200 rpm and then immediately filtered through Whatman no. 2 filter paper into 20-mL glass scintillation vials. A duplicate sample, spiked duplicate, blank, and soil standard were extracted and analyzed every 25 samples for quality assurance. Ammonium and nitrate were analyzed within 24 h of extraction on a microplate spectrophotometer (PowerWaveTM XS; BioTek Instruments, Winooski, VT). The sodium salicylate-nitroprusside method was adapted for microscale analysis to measure ammonium (Keeney and Nelson, 1982). The single reagent method with vanadium chloride as a reductant was used to measure nitrite and nitrate concentrations although nitrite concentrations were considered negligible and were reported as nitrate (Doane and Horwath, 2003). This method was also adapted to use less reagent, 750 μL of reagent for every 15- μL sample extract. The colorimetric reaction occurred in deep-welled (1-mL) microplates before a 250- μL aliquot was transferred to the 300- μL plates used in the spectrophotometer.

Sweet corn ear leaf N at silking is used as a standard predictor of sufficient plant N for optimal ear development. Ten ear leaves were hand-removed from 10 plants in the center two rows of each plot and dried and ground. Ear leaves were analyzed for total N and total carbon (C) by flash combustion (Carlo Erba CN Elemental Analyzer; Thermo Fisher Scientific, Waltham, MA).

Weeds were managed as needed with cultivation and hand-weeding

Table 1. Organic fertility management treatments in sweet corn at Hancock, WI, in 2006, 2007, and 2008.

Treatment code ^z	Target nitrogen rate	Nitrogen contribution of fertility inputs (lb/acre) ^y						Total nitrogen applied (lb/acre)
		Green manure	Conventional starter	Organic starter	Composted poultry manure	5-5-5 organic fertilizer	11-0-0 organic fertilizer	
Rye	0	0						0
Rye½XConv	½X	0						75
Rye1XConv	1X	0	5					150
Rye½XOrg	½X	0		5		20	50	75
Rye1XOrg	1X	0		5		20	125	150
Rye½XCPM	½X	0		5	70			75
Rye1XCPM	1X	0		5	145			150
RyePhosCPM	Phosphorus-limited	0		5	2006: 38 2007: 50 2008: 41			2006: 43 2007: 55 2008: 46
RyePhosCPM Org	Phosphorus-limited	0						
Pea		40		5				45
Pea1XOrg	1X	40		5		20	95	150
Pea1XCPM	1X	40		5	105			150
PeaPhosCPM	Phosphorus-limited	40		5	2006: 38 2007: 50 2008: 41			2006: 93 2007: 107 2008: 97
PeaPhosCPM Org	Phosphorus-limited	40		5	2006: 38 2007: 50 2008: 41			2006: 83 2007: 95 2008: 86
Alf		100		5				105
Alf1XOrg	1X	100		5		20	25	150
Alf1XCPM	1X	100		5	45			150

^zRye, Pea, and Alf = rye, pea, or alfalfa green manure crop, 1X and ¹/₂X = full and half rate of nitrogen (N) for sweet corn (150 and 75 lb/acre, respectively), Org = 11N-0P-0K organic fertilizer was used as primary source of N, CPM = composted poultry manure was used as primary source of N, PhosCPM = composted poultry manure was applied at rate to limit phosphorus application to 10 lb/acre, PhosCPM Org = composted poultry manure was applied at rate to limit phosphorus application to 10 lb/acre and 11-0-0 organic fertilizer was then added to bring N rate up to 150 lb N/acre; 1 lb/acre = 1.1209 kg·ha⁻¹.

^yGreen manure = potential N credit provided in table, conventional starter = 5N-10.9P-8.3K, organic starter = 5-5-5 organic fertilizer applied at planting, 5-5-5 organic fertilizer = 5N-2.2P-4.2K, 11-0-0 organic fertilizer = 11N-0P-0K, composted poultry manure = 3N-1.7P-1.7 K (2006), 4N-1.7P-1.7K (2007), 4N-2.2P-2.5K (2008).

throughout the season to ensure uniformity of weed pressure among plots. Sweet corn yield was evaluated by hand-harvesting the ears in one of the center rows of each plot, recording number of ears and total weight.

Nutrient management cost was estimated for each treatment. Rye seed was \$1.62/lb, pea seed was \$0.58/lb, and alfalfa seed was \$4.50/lb. Composted poultry manure was \$0.05/lb, 5-5-5 was \$0.17/lb, 11-0-0 was \$0.11/lb, and ammonium nitrate was \$0.25/lb. Gross profit was calculated using the average contract price from the 2008 season paid by processors for sweet corn in Wisconsin. Organic and conventional prices were \$0.10/lb and \$0.05/lb, respectively. To calculate the net profit, the cost of nutrient management (cover crop + amendment where applicable) was subtracted from the gross profit for each plot. This would not be a true net profit as only nutrient management is taken into account. Cost of application and transportation of amendments was not included because of variability of cost from farm to farm in proximity to amendment and availability of equipment. Net profits are calculated for the purpose of drawing a comparison among treatments based on the cost of nutrient inputs.

A repeated measures analysis of variance (ANOVA) with a heterogeneous compound symmetry model (Proc Mixed, SAS version 9.2; SAS institute, Cary, NC) was used to compare the PAN content ($\text{NH}_4 + \text{NO}_3$) of the soils under the selected treatments. There was a treatment by date interaction, so each date was analyzed separately and Tukey's honestly significant difference (HSD) test was used to make pairwise comparisons between treatments. Linear and nonlinear regression with a hyperbolic equation was used to relate ear leaf N to sweet corn yields for all treatments. The hyperbolic model fit was: $\text{yield} = \alpha \{1 - \exp[-\exp(\beta)](\text{ear leaf nitrogen} - \gamma)\}$, where α is asymptote (greatest yield), β is the log of the rate constant (the point at which yield will be half of the asymptote), and γ is the value of x when $y = 0$ (ear leaf N when yield = 0). The nonlinear, hyperbolic equation was a better fit for the data than the linear model. The regression lines were not different among the years, so all 3 years of data were combined. ANOVA (Proc Mixed, SAS) was used to compare the sweet corn yield and net profit results

among treatments within years (there was a significant treatment by year interaction), and Tukey's HSD test was used to separate means.

Results and discussion

TEMPERATURE AND PRECIPITATION. There were differences in the accumulation in growing degree days [GDDs (base 50.0 °F)] among the 3 years of the study from planting to harvest (Fig. 1). In 2006, there were over 1600 degree day units accumulated, while 1437 and 1389 were accumulated in 2007 and 2008, respectively. The earlier planting date in 2006 led to the higher GDD accumulation. Planting date decision was made balancing time for GrM crop growth and an adequate growing season for sweet corn development. The reported optimal GDD accumulation for the 'Marvel' hybrid used in the study is 1377. The accumulated GDDs in 2007 and 2008 were close to the optimal number of GDDs required for 'Marvel', but in 2006 there were significantly more heat units. The higher accumulation of GDDs in 2006 possibly led to higher yields. Ears were harvested slightly more mature in 2006 in a failed attempt to coordinate harvest with a processing company to assess quality parameters of the crop.

Heavy rainfall can contribute to the leaching of the nitrate during the growing season and reduce PAN. There was only one heavy (more than 25 mm) rainfall event in 2006, while there were numerous events in 2007 and 2008 (Fig. 1).

PLANT-AVAILABLE NITROGEN CONTENT OF SOILS UNDER SELECTED MANAGEMENT SYSTEMS. Quantifying PAN at consecutive points throughout the growing season allowed evaluation of selected management programs at meeting crop N demand. The plots were simultaneously under crop production, so PAN reflected only the amount not yet absorbed by the plant, leached, volatilized, or lost from soil via other pathways.

Sweet corn uses minimal N until the five-leaf stage when N uptake sharply increases until it reaches a maximum of 5 lb/acre per day at the 12-leaf stage (Doerge et al., 1991). The five-leaf stage in sweet corn corresponds with the first side-dress fertilizer application, and the 12-leaf stage occurs just before silk. Nitrogen uptake by sweet corn drops to ≈ 1.5

lb/acre per day from the 12-leaf stage to silk but steadily increases again from silk to harvest to a rate of 3.5 to 4.0 lb/acre per day.

Soil PAN in the Rye1XConv was greater than in the soil in the Rye treatment on several points during the all three growing seasons, coinciding, perhaps intuitively, with fertilizer side-dressing (Fig. 2). It is likely that this sampling captured the fertilizer in the soil because the conventional fertilizer was in plant-available form at time of application. In 2006 and 2007, PAN in the Rye1XConv treatment decreased following the spike after the second side-dressing, corresponding with the eight-leaf stage of sweet corn and the time of greatest N uptake (Doerge et al., 1991). In 2008, spikes in PAN in the Rye1XConv were never as large as in the previous years. This could be attributed to a large rain event just after the first side-dressing of ammonium nitrate. While side-dressing with conventional fertilizer in sweet corn production aims to reduce leaching by coordinating N application with plant uptake, the nitrate portion of conventional fertilizers can be susceptible to leaching in the time period between application and crop uptake.

Unlike the conventional program, there were no large spikes in PAN in the Rye1XOrg program in any of the study years (Fig. 2). This suggests that the organic fertilizer N mineralization rate through the season closely matched crop need and uptake, that there was insufficient mineralization so that PAN was taken up immediately by the crop, or that heavy rainfall events caused nitrate leaching. Insufficient N mineralization or PAN lost to leaching would result in an N shortage and probable yield reduction relative to the conventional control.

In 2006 and 2008, PAN concentrations were high before the five-leaf stage of sweet corn in the Rye1XCPM treatments compared with the other treatments (Fig. 2). Manure was applied and incorporated 7 d before planting to avoid seed corn maggot damage. Sweet corn does not begin to take up significant amounts of N until the five-leaf stage which occurred ≈ 25 d after planting or 32 d after manure application. Nitrate mineralized during this period in excess of crop need would be vulnerable to leaching. The PAN level decreased to similar levels as found in the other

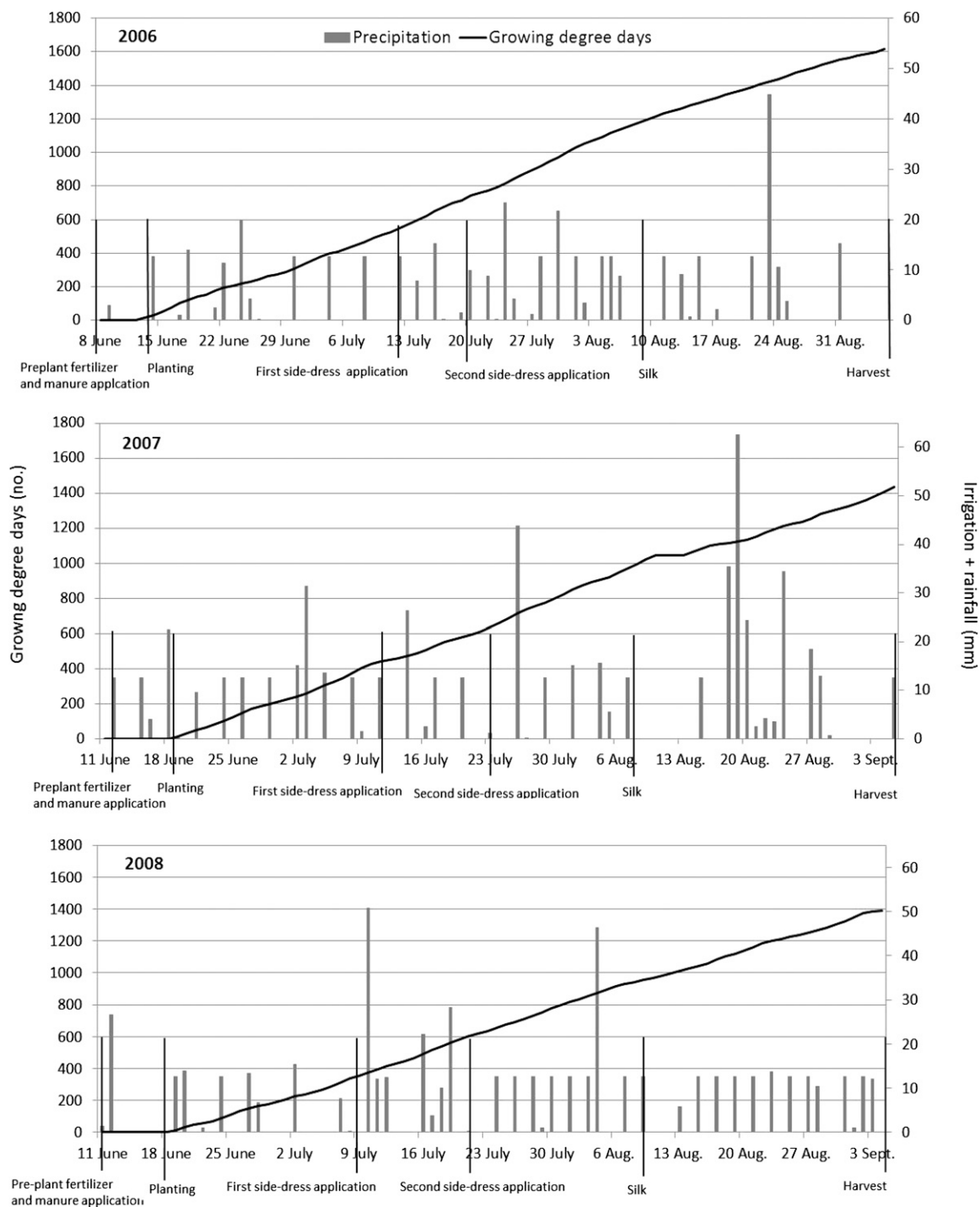


Fig. 1. Accumulated growing degree days [base 50.0 °F (10.00 °C)] and daily precipitation (irrigation + rainfall) in 2006, 2007, and 2008 at Hancock, WI; 1 mm = 0.0394 inch.

treatments by ≈ 32 d after planting in both 2006 and 2008. It was not possible to determine if the PAN was leached or used by the plant. This pattern was not observed in 2007, possibly because of heavy rainfall events. These precipitation events coincided with the apparent mineralization of the organic N in the manure, and nitrate leaching may have reduced PAN

observed in 2007. Pang and Letey (2000) reported that in model simulations based on current literature on poultry manure, the rate of mineralization was highest after application and declined just as corn demand increased. According to this model, poultry manure N mineralization rate was completely asynchronous with the crop demand. Plant-available N

concentrations in the RyePhosCPM treatment (Fig. 2) were never greater than the Rye treatment in any year of the study, at any date, suggesting that either the P-limited treatment did not provide detectable quantities of PAN or the crop used all PAN as it was mineralized.

The PAN concentration in soil over time differed among GrM crops

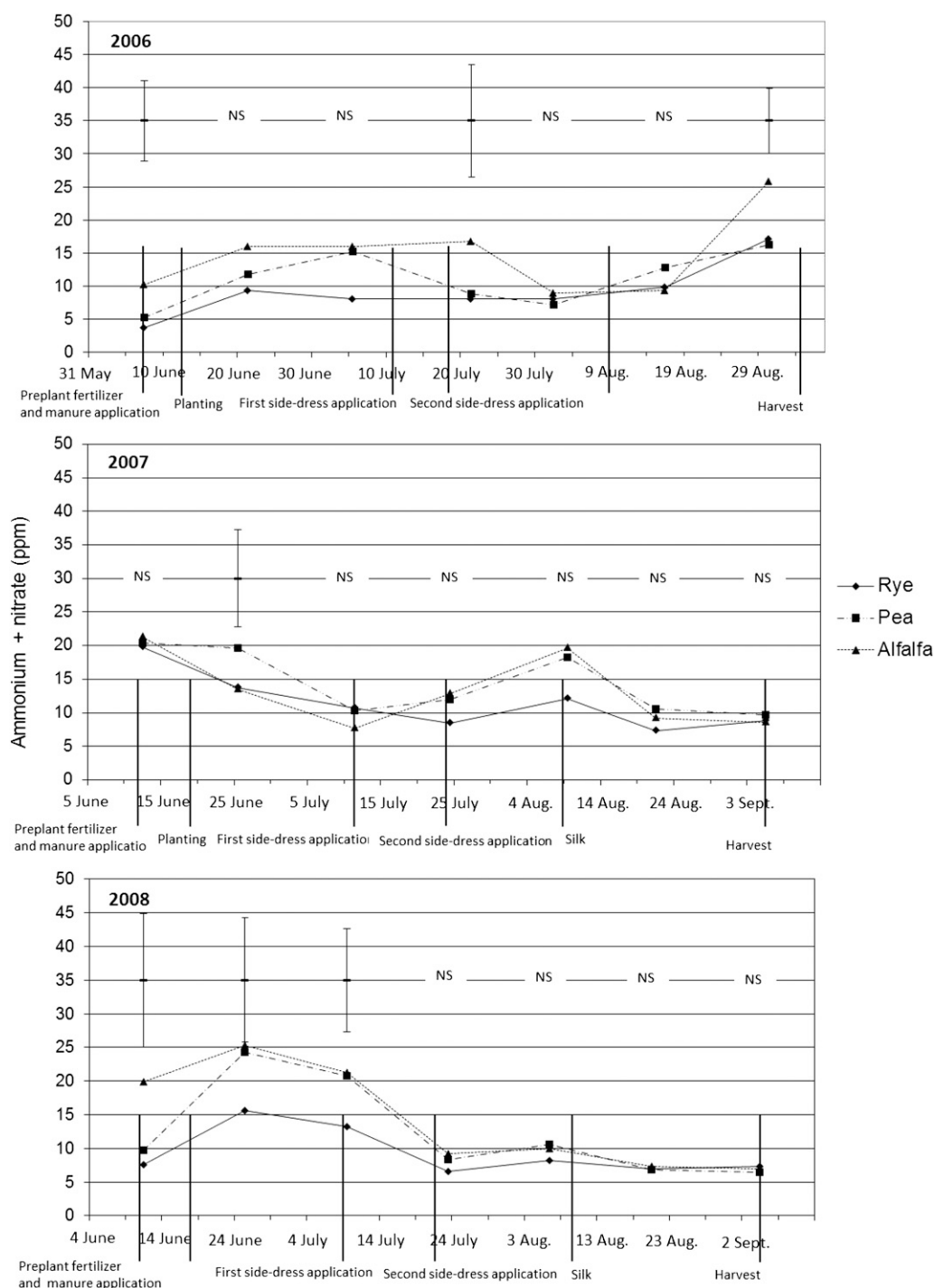


Fig. 2. Plant-available nitrogen (ammonium + nitrate) concentration in the soil of five selected treatments at seven consecutive dates during the growing season in 2006, 2007, and 2008 at Hancock, WI. Rye = rye green manure, Rye1XConv = rye with ammonium nitrate added to supply 150 lb/acre (168.1 kg·ha⁻¹) of nitrogen (1X), Rye1XOrg = rye with 11-0-0 (11N-0P-0K) organic fertilizer at 1X rate, Rye1XCPM = rye with composted poultry manure at 1X rate, RyePhosCPM = rye with composted poultry manure added at rate to limit phosphorus application to 10 lb/acre (11.2 kg·ha⁻¹). The first side-dressing date was for both the organic (11-0-0) and the conventional fertilizers. The second was for just the conventional fertilizer. The first side-dressing coincided with the five-leaf stage of the corn and the second side-dressing coincided with the eight-leaf stage; 1 ppm = 1 mg·kg⁻¹.

(Fig. 3). Plant-available N concentration was greater in soil with an alfalfa GrM crop compared with rye on several dates in 2008. There were no differences in PAN between the alfalfa

and rye crops in 2007. We expected to see higher levels of PAN earlier in the season before crop N uptake, particularly since plant residue incorporated into sandy soils typically

provides an initial flush of PAN (Jackson, 2000).

The pea GrM only increased PAN compared with the rye at 7 d after planting in 2007 (Fig. 3). There were

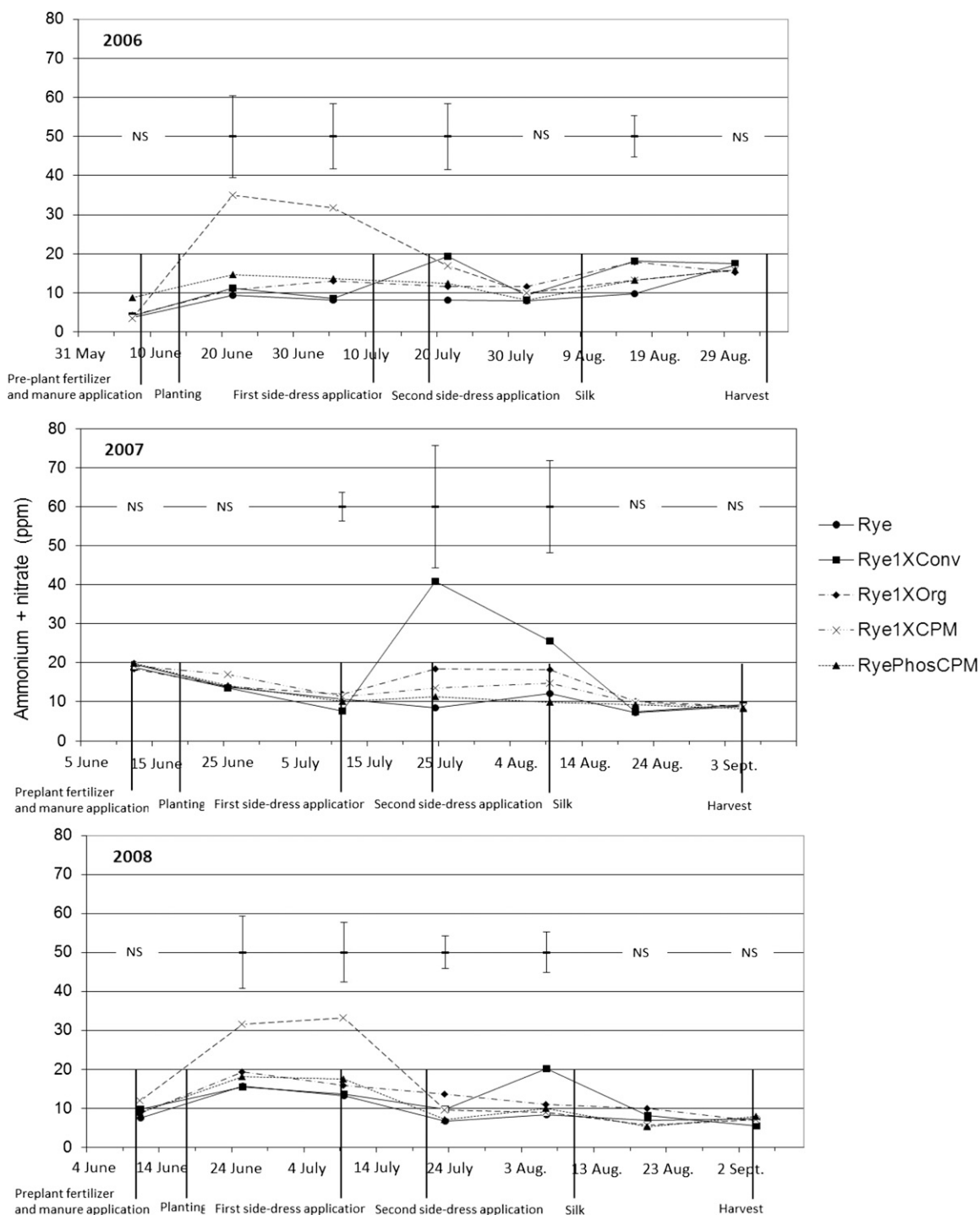


Fig. 3. Plant-available nitrogen (ammonium + nitrate) concentration in the soil of three selected treatments at seven consecutive dates during the growing season in 2006, 2007, and 2008 at Hancock, WI. Rye = rye green manure crop alone, Alfalfa = alfalfa green manure crop alone, Pea = pea green manure crop alone. The five-leaf stage of the corn occurs at 35 d after planting. Error bars are $1.96 \times \text{SE}$; 1 ppm = 1 mg·kg⁻¹.

no other differences in PAN between the rye and pea at any other date or year. Although there was often no difference in PAN between the rye and pea, there was also no difference in PAN between the alfalfa and pea. This suggested that the pea GrM, as hypothesized, should receive some N credit

although lower than alfalfa. The lower N credit was expected because of the limited time for the pea crop in the spring to establish nodulation and begin to fix N between planting and incorporation. We did not analyze the N content of the legume cover crops before incorporation. This

would have helped explain the N contribution of the cover crops. This data should be included in future studies.

SWEET CORN EAR LEAF NITROGEN CONTENT AND YIELD. Sweet corn ear leaf N at silking was related with sweet corn yield in all 3 years of the study

(Fig. 4). In 2006, most treatments, organic and conventional, had ear leaf N and crop yields on the high end of the range of study results. In 2008, only the conventional treatments had high ear leaf N and thus high sweet corn yield, while the organic treatments

had low ear leaf N and poor yield. This suggests that N applied in the organic treatments was not available and consequently resulted in poorer yields. Heavy rainfall events corresponding with organic matter mineralization may have resulted in N leaching,

decreased N uptake, and reduced crop yield. In 2006, there were no significant rainfall events; thus, the ear leaf N and yield in many of the organic treatments were equivalent and sometimes greater than the conventional treatments. 2006 was also the warmest year, which may have contributed to increased mineralization. Increased variability in the relationship between ear leaf N and yield in 2007 suggests limiting factors other than N, such as soil moisture availability impacted yield. Missed irrigation over a week period in Aug. 2007 likely reduced yield potential.

Extension publications have reported an optimum of 2.8% ear leaf N at silking to maximize yield, while levels below 2.8% result in yield loss and above 2.8% are in excess of crop need (Stall et al., 1989). The regression generated from this research predicts that ear leaf N above 2.8% results in higher yields; thus, 2.8% may not be the maximum (Fig. 4). However, variability in yield response to ear leaf N suggests that yields were maximized in this trial between 2.5% and 3.0% ear leaf N. Further research would help elucidate the optimal ear leaf N necessary to maximize yield in sweet corn production on irrigated sandy soils.

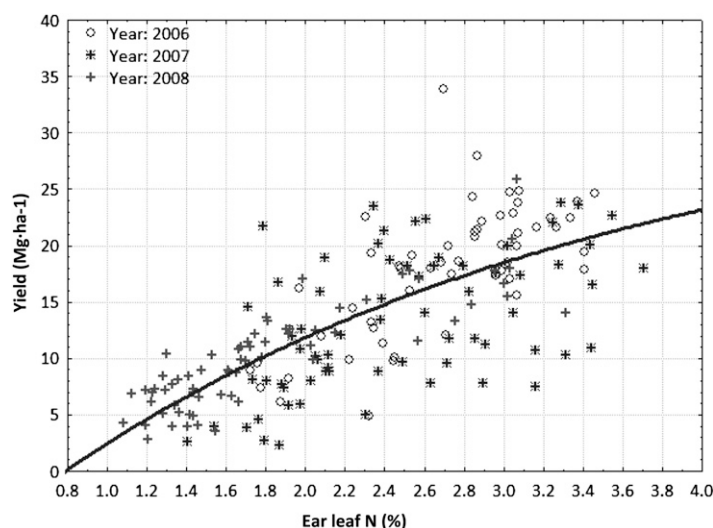


Fig. 4. Sweet corn ear leaf percent nitrogen (N) at silking for all treatments and years. Sweet corn yield was related with ear leaf nitrogen by: $\text{yield} = \alpha \{1 - \exp[-\exp(\beta)](\text{ear leaf nitrogen} - \gamma)\}$, where α is asymptote (greatest yield), β is the log of the rate constant (the point at which yield will be half of the asymptote), and γ is the value of x when $y = 0$ (ear leaf N when yield = 0) with $R^2 = 0.72$; $1 \text{ Mg} \cdot \text{ha}^{-1} = 0.4461 \text{ ton/acre}$.

Table 2. Mean sweet corn yield and net profit (gross profit – cost of nitrogen management) at Hancock, WI, in 2006, 2007, and 2008.

Treatment ^z	Yield ($\text{Mg} \cdot \text{ha}^{-1}$) ^y			Net profit ($\$/\text{ha}$) ^x		
	2006	2007	2008	2006	2007	2008
Rye	7.25 e ^w	7.75 fg	4.72 i	1504 c ^w	1610 ns	973 a-c
Rye½XConv	17.76 a-d	19.44 ab	14.86 bc	1759 bc	1944	1441 c-g
Rye1XConv	21.00 ab	18.16 a-c	20.21 a	1976 a-c	1665	1891 fg
Rye½XOrg	19.73 a-c	15.15 b-d	10.17 d-f	3022 a-c	2114	1068 a-f
Rye1XOrg	22.21 ab	21.92 a	16.06 b	2785 a-c	2742	1512 c-g
Rye½XCPM	16.53 a-d	7.36 g	7.40 gh	3013 a-d	1189	1198 a-f
Rye1XCPM	19.40 cd	14.09 b-e	8.74 fg	3280 a-c	2351	1228 a-g
RyePhosCPM	11.05 de	8.48 fg	5.67 hi	2030 a-c	1484	931 a-e
RyePhosCPM Org	22.94 a	14.80 b-d	15.21 b	3421 ab	1828	1844 e-g
Pea	12.26 c-e	8.24 fg	5.20 i	1975 a-c	1129	493 a
Pea1XOrg	22.52 ab	16.90 a-c	12.67 cd	3197 b-d	2049	1161 a-f
Pea1XCPM	20.81 ab	10.86 d-g	5.43 ih	3648 a-c	1744	604 ab
PeaPhosCPM	14.44 b-e	6.67 g	5.63 ih	2681 b-d	1043	861 a-d
PeaPhosCPM Org	21.32 ab	15.35 b-d	9.23 e-g	3426 a-c	2304	951 a-e
Alf	— ^v	9.19 e-g	11.12 d-f	—	1323	1728 d-g
Alf1XOrg	—	17.22 a-c	10.74 d-f	—	2744	1382 b-g
Alf1XCPM	—	12.75 c-f	11.31 de	—	2336	2032 g

^zRye, Pea, and Alf = rye, pea, or alfalfa green manure crop, 1X and ½X = full and half rate of nitrogen (N) for sweet corn (150 and 75 lb N/acre, respectively), Org = 11N-0P-0K organic fertilizer was used as primary source of N, CPM = composted poultry manure was used as primary source of N, PhosCPM = composted poultry manure was applied at rate to limit phosphorus application to 10 lb/acre, PhosCPM Org = composted poultry manure was applied at rate to limit phosphorus application to 10 lb/acre and 11-0-0 organic fertilizer was then added to bring N rate up to 150 lb/acre N; 1 lb/acre = 1.1209 kg·ha⁻¹.

^y1 $\text{Mg} \cdot \text{ha}^{-1} = 0.4461 \text{ ton/acre}$.

^x\$1.00/ha = \$0.4047/acre.

^wMeans within columns followed by the same letter are not significantly different, $P < 0.05$. Means separated using Tukey's honestly significant different test.

^vTreatments with an alfalfa green manure crop were not included in 2006.

Sweet corn yield was comparable between the Rye1XOrg and Rye $\frac{1}{2}$ Org treatments and their conventional fertilizer counterparts in 2 out of the 3 years of the study (Table 2). However, in 2008, crop yield was lower in both organic fertilizer treatments compared with their conventional fertilizer counterpart treatments. The PAN mineralized from the organic fertilizer in 2006 and 2007 apparently matched crop demand, without requiring split applications like the conventional fertilizer. In 2008, the ear leaf data suggests that PAN mineralized from the organic fertilizer was not available to the sweet corn crop and thus resulted in poor yield. This is potentially due to cool weather through the early part of the 2008 resulting in less mineralization of the organic fertilizer (Fig. 1). Organic N mineralization from feather meal is temperature dependent and correspondingly increases with increasing temperature (Hartz and Johnstone, 2006). Heavy rainfall events in 2008 (Fig. 1) may have also resulted in the leaching of nitrate and loss of PAN compared with 2006 and 2007.

Sweet corn yield in the Rye $\frac{1}{2}$ -Conv treatment was more than twice the yield in the Rye $\frac{1}{2}$ CPM treatment in 2 out of the 3 years of the study. Sweet corn yield in the Rye1XConv was greater than the yield in the Rye1XCPM treatment in 2 out of the 3 years of the study. We based the amount of poultry manure in the treatments on the total percent N of the manure in each year. Other studies have reported that first year availability or mineralization of the N in composted poultry manure ranged from 14% to 60% (Muñoz et al., 2008). Coarse-textured soil is reported to increase the pace of organic N mineralization. Griffin et al. (2002) observed that 99% of sheep manure slurry was mineralized after an accumulated 1400 GDDs when mixed with a sandy loam soil, compared with only 62% mineralized in a silt loam soil. Season-long PAN data suggested mineralization of the poultry manure before crop uptake at five-leaf sweet corn stage in 2006 and 2008 (Fig. 2). In 2008, yield in the Rye1XConv was over twice the yield in the Rye1XCPM treatment, suggesting that the crop was recovering less N from the poultry manure. No spike in PAN was observed during the early part of the

2007 season, suggesting that manure mineralization matched crop need or was leached. Yield between the 1XCPM and 1XConv treatments was similar in this year, but the amount of N mineralized from the CPM within the one cropping season is not known.

Reliance on poultry manure as the sole N source resulted in over-application of P. For example, in 2006 the poultry manure was 3N-1.7P-1.7K, so we applied 4800 lb/acre to obtain the desired rate of N, resulting in the application of 82 lb/acre of P. Sweet corn only uses 10 lb/acre of P (Laboski et al., 2006) in one growing season; thus, the remainder applied is left in the soil. This is particularly problematic in the central sands of Wisconsin where the soil is already excessively high in P and susceptible to wind erosion. This eroded soil could wind up in surface waters and cause environmental degradation. Endale et al. (2008) consistently greater field corn yield using poultry manure as an N source than conventional fertilizer. However, while this study based the manure application rate on full first year availability, they based their poultry litter application rate on 50% availability in the first year, thus requiring 10,000 lb/acre of poultry litter. Although they did not include the P concentration of the litter used in their study, assuming that a P concentration similar to the poultry manure used in this research would result in an application of nearly 197 lb/acre P. Limiting P application in organic systems must be kept in mind to maintain environmental integrity.

Sweet corn yield was comparable in 2 out of the 3 years between the rye treatment and both P-limiting treatments (RyePhosCPM and PeaPhosCPM). Exclusive reliance on CPM did not provide sufficient N for sweet corn when rates were adjusted to match crop P demand. Sweet corn yield was comparable to the Rye1XConv treatment in 2 out of the 3 years when the organic fertilizer was added to P-limiting treatments (RyePhosCPM Org and PeaPhosCPM Org). Poultry manure may be a viable option as part of an integrated nutrient management system but should not be relied on as a sole source of N in organic sweet corn production.

Sweet corn yield in the Alf treatment was nearly half of the yield in the Rye1XConv treatment in both 2007

and 2008. Lower yields were expected because the alfalfa N credit was less than sweet corn need, but such a discrepancy was unexpected. Mean ear leaf N in the Alf was also lower than ear leaf N in the Rye1XConv treatment in 2007 and 2008. Stranger et al. (2008) found a significant increase in yield, not explained by the N credit, when field corn followed alfalfa in rotation in comparison with following corn. There was not a clear indication of a rotational effect in this study.

Comparison of the Alf1XOrg and Alf1XCPM with the Rye1XOrg and Rye1XCPM treatments, respectively, allowed a means to compare alfalfa mineralization to the organic fertilizer and poultry manure, given that the amount of amendments added were equivalent to the alfalfa N credit. Sweet corn yields were comparable in the Alf1XOrg and the Rye1XOrg programs in 2 out of the 3 years of the study. Sweet corn yield was similar between the Rye1XCPM and Alf1XCPM treatments in 2 years, but yield was greater in the Alf1XCPM program in 2008. Variability among years may be symptomatic of amendment/GrM crop mineralization variability from year to year.

Sweet corn yield in the Pea1XCPM was higher than the Rye1XCPM program in 2006, equivalent in 2007 and lower in 2008. As with alfalfa, these results suggested that in certain years N mineralization from the pea residue was similar to the mineralization from the other amendments. However, heavy rainfall events in 2007 and 2008 (Fig. 1) could have contributed to the loss of some of the N mineralized from the pea residue. Given the possibility of loss of N as a result of leaching, the 40 lb/acre N credit given to pea in this study may have been overestimated. Cherr et al. (2007) also reported that green manure crops did not provide any N credit to the following sweet corn crop on a sandy soil.

NET PROFITS. Nitrogen amendment transportation and application costs were not included in the calculation of the cost of N management because of the extreme variability among farms in transporting and applying the various amendments. Proximity to source, cost of diesel, and availability and types of farm equipment greatly influence these costs and

cannot be generalized. These costs could be calculated on a situational basis, added to the cost of the amendment and subtracted from gross profits. Also, the gross profits for the various treatments were calculated using the current organic premium value for the organic treatment and the conventional price for the conventional treatments. These prices are subject to fluctuations in the market. Market saturation or lack of consumer interest could reduce the organic premium and must be kept in mind for the grower to remain sustainable over the long term.

The net value did not differ between the 1XConv and ½XConv in all 3 years of the study because the yield advantage in the 1XConv program was negated by the added expense of the double fertilizer rate. Net profit was similar in all 3 years between the half and full rate organic programs (for the programs in which a half and full N rate is represented). These findings question the advantage to using higher rates of N because of the high cost of N amendments and the lack of a yield advantage large enough to increase net profits.

In 2006, there were few differences among the treatments in net profits. In 2007, there were no differences in net worth among treatments although net profit was variable. In 2008, differences in sweet corn yield were reflected in net profit. Several organic treatments were worth less than the 1XConv treatment, including the RyePhosCPM, Pea, Pea1XCPM, and PeaPhosCPM Org treatments. Although several programs using CPM were equal in worth to the 1XConv program in this comparison, this may not be an accurate representation for some growers for the reasons discussed previously. Also, all of the programs using alfalfa were equal in net profit to the 1XConv, but once again this depends on the profitability and marketability of the organic alfalfa crop in the previous season.

Conclusions

Among organic fertility programs, sweet corn yield in the Rye1XOrg program most consistently matched yield in the Rye1XConv. However, this was also the most costly management program. Alfalfa, as a green manure crop, does merit an N credit, but our credit of 100 lb/acre is most likely too high, especially in years with

reduced mineralization. Alfalfa, with a lower N credit, in combination with the organic fertilizer could maximize sweet corn yield while minimizing N costs. A lucrative market for organic hay in the alfalfa establishment year would help to maximize grower profit in this rotation. Poultry manure alone is not recommended for N management in sweet corn because of variability in mineralization among years and low N:P. Poultry manure could be used in combination with alfalfa and the organic N fertilizer. However, this is a complex management program and may not be ideal for every grower. Pea as a green manure crop gives a minimal N credit and could be used for this small credit if it cost effectively fits within a management program for organic sweet corn.

This research demonstrated the challenge to producing organic processing sweet corn in the central sands of Wisconsin. Estimating N mineralization from organic sources can be difficult because of the dependence on climatic conditions. Continued research on N management for organic sweet corn production may help to resolve some of the challenges presented in this study.

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