Can Manure Replace the Need for Starter Nitrogen Fertilizer?

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ABSTRACT

Current New York land grant university fertility guidelines for corn (*Zea mays* L.) recommend the use of 22 to 34 kg N ha^{-1} of band-applied starter fertilizer. On-farm research was conducted in 2006 and 2007 on a western New York dairy farm with an alfalfa (*Medicago sativa* L.)–corn rotation to evaluate the need for starter N for corn in regularly manured fields. In 2009, the study was expanded to include 21 fields varying in soil type, manure history, and soil N supply potential as expressed by the Illinois soil N test (ISNT). At the western New York farm, there was no increase in corn silage yield or quality with starter N use in first-, second-, or fourth-year corn fields. The results of the statewide assessment also showed that for fields with optimal ISNT-N, manure could replace starter N without a decline in corn silage yield or quality. Starter N fertilizer application was needed for optimal yield in fields deficient or marginal in ISNT-N and without a manure history. For such fields, manure could replace the need for starter N as long as sufficient N was applied with the manure, indicated by corn stalk NO_3 test (CSNT) results between 750 and 2000 mg NO_3–N kg^{-1}. A response of silage yield to starter N was common when CSNT-N was <750 mg NO_3–N kg^{-1}. We conclude that manure can replace the need for starter N, but rates should be adjusted to obtain CSNT values between 750 and 2000 mg kg^{-1}.

Corn is a major agricultural crop in New York, covering a total area of 473,850 ha in 2012, of which 41% was harvested for silage while the remainder was harvested for grain (National Agricultural Statistics Service, 2013). In New York, the greatest N use efficiencies for fertilizer N for corn are typically obtained when the total N application is split into a small starter application at planting followed by sidedress N application when the corn is 15 to 30 cm tall (Lathwell et al., 1966, 1970). Therefore, Cornell University, the land grant university of New York, recommends the application of 22 to 34 kg N ha^{-1} of band-applied starter fertilizer for all corn, followed by a sidedress N application for second- or higher year corn following alfalfa–grass or for corn in other rotations if crop needs are not met with manure application (Ketterings et al., 2003).

In the past, most common starter fertilizers contained N as well as P and K to supply young seedlings with nutrients in the first 2 to 4 wk in the spring. Recent studies in the northeastern United States have shown that for fields testing high or very high in P, elimination of P in the starter band does not impact corn yield or quality (Jokela, 1992; Roth et al., 2003, 2006; Ketterings et al., 2005). A shift in starter blend from a P-containing fertilizer to a P-free fertilizer can result in substantial fertilizer and labor savings as well as a reduction in the farm's environmental footprint (Roth et al., 2006; Ketterings et al., 2011; Ketterings and Czymmek, 2012). It is thus not surprising that New York fertilizer sales records have shown a substantial reduction in the use of starter P fertilizer in the past decade (Ketterings et al., 2011; Ketterings and Czymmek, 2012).

Previous studies in unmanured fields showed that a yield response to starter N was common (Ketterings et al., 2005) but that sidedress N could be eliminated without a yield or quality penalty for soils testing optimal in soil N supply potential as estimated by the ISNT (Klapwyk and Ketterings, 2006; Lawrence et al., 2009). Dairy manure applications add inorganic and readily available N as well as organic N. Such manure applications can increase nutrient cycling and build ISNT-N levels with time (Klapwyk et al., 2006). With a growing interest among farmers in reducing their farm's environmental footprint while also reducing the cost of production, farmers asked whether manure could be used to replace the need for starter N. Eight research station trials and 16 on-farm trials were conducted to evaluate the impact of banded starter N use on corn yield and quality for fields varying in manure history and soil N supply potential.

MATERIALS AND METHODS

Field Trials and Experimental Design

In 2006 and 2007, three on-farm trials were conducted at a western New York dairy farm. The farm implemented three banded starter fertilizer treatments (0, 34, and 68 kg N ha^{-1}) in three replications on three different fields, a second-year corn field after alfalfa in 2006 and first- and fourth-year corn fields in 2007. Fertilizer was applied 5 cm below and 5 cm to the side of the seed at planting. The soils for each of the trials were classified as Langford channery silt loams (fine-loamy, mixed, active, mesic Typic Fragiudepts). Fields were very high in soil test P, K, and Mg, reflecting past manure applications, with pH ranging from

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Abbreviations: CP, crude protein; CSNT, cornstalk nitrate test; ISNT, Illinois Soil Nitrogen Test; NDF, neutral detergent fiber; PSNT, pre-sidedress nitrate test.

6.5 to 7.0 and soil organic matter ranging from 32 to 35 g kg^{-1}. Each plot was 4.6 m wide (12 rows, 38 cm apart) and at least 285 m long. Consistent with practical limitations with the 38-cm row width used for corn at the farm, no sidedress N was applied; the farm aimed to achieve optimal yield with a 34 kg N ha^{-1} starter application (urea) and fall- or spring-applied manure. Dairy manure slurry was spring injected at a rate of 84 m^3 ha^{-1} for the second- and fourth-year fields, supplying an estimated 105 kg plant-available N ha^{-1} while for first-year corn, manure was fall applied at a rate of 39 m^3 ha^{-1} for an estimated 42 kg plant-available N ha^{-1}. Available N estimates assume 35% availability of organic N and 0 vs. 65% availability of inorganic N for fall application and spring injection, respectively (Ketterings et al., 2003, 2013). The manure application rate for second- and fourth-year corn was determined by the farmer-based on soil-derived yield potential, soil N supply potential, and N uptake efficiency. The fall application of manure at a lower rate is a typical practice on dairy farms and takes into account rotation credits for corn following alfalfa–grass sod. Spring application of manure took place 1 to 2 wk before planting, depending on soil moisture.

Soil samples were taken between rows at two depths (0–20 and 0–30 cm, 15 samples per plot) before manure application, when the corn was 15- to 30-cm tall (V4–V6 growth stage), and again at corn silage harvest. Soils were kept cool while sampling in the field. Forage subsamples were taken at harvest (3.78-L subsamples) to determine moisture content and forage quality. End-of-season CSNT samples (15 stalks per plot) were taken at harvest by cutting a 20-cm portion of the stalk between 15 and 35 cm above the ground.

From 2009 through 2011, 21 additional field trials were completed comparing yield and quality of corn as impacted by two banded starter N fertilizer treatments: 0 and 34 kg N ha^{-1}. Fertilizer was applied 5 cm below and 5 cm to the side of the seed at planting. The trials were conducted in 10 agricultural counties of New York, representing different soils, climatic regions, and manure management histories (Table 1). Eight trials were conducted at the Cornell Musgrave Research Farm at Aurora in central New York (2009 and 2010), and 13 trials were conducted on commercial farms in the northern, eastern, western, and southern regions of New York (2009–2011) (Table 1).

At the Musgrave Research Farm, trials (Sites 1–8) consisted of two treatments (0 and 34 kg N ha^{-1} band-applied starter N as urea) with six replications of each treatment in a randomized complete block design. The treatments were imposed on plots varying in manure history and included (i) no manure (fertilizer N only); (ii) surface-applied and unincorporated manure, (iii) manure incorporated using a chisel plow; and (iv) manure incorporated using an aerator, as documented in Lawrence et al. (2008b). Where manure was applied, no sidedress N applications were performed. All plots tested deficient in ISNT-N and those that did not receive manure were sidedressed with 134 kg N ha^{-1} applied as urea–NH_4NO_3 using a four-row sidedress unit (CDS-John Blue Co.) that applies the fertilizer solution to every other interrow. All plots were harvested for corn grain.

At the on-farm sites, trials also consisted of the same two band-applied starter fertilizer treatments (0 and 34 kg N ha^{-1}). The starter N sources varied according to individual farm practice. Urea was applied at one farm; the remainder of the farms applied either urea–NH_4NO_3 or $(NH_4)_2SO_4$. Fields in second- or higher year corn were selected that had no need for the addition of P based on soil test results (Table 2) and had documented manure applications and manure histories (rates and approximate timings of application; Table 1). The corn trials were conducted using 76-cm-wide rows (except for Site 16 which had twin [56/20-cm wide] rows) and replicated four (Sites 10–12, 14–18, 20, and 21) or five times (Site 9) in a randomized complete block design. Plots were 4 to 16 rows wide depending on planter and chopper width (typically two times the chopper width for machine-harvested sites) and 30 to 600 m long, depending on farm equipment and field size. Soils in each plot were sampled at two depths (0–20 and 0–30 cm) when the corn was 15- to 30-cm tall in June and at harvest, consistent with the sampling and sample processing procedures used for the trials at the western New York farm. Stand density was determined midseason or at harvest time by counting two rows of corn plants in 12 m per plot. Where sidedress N applications occurred, N application rates were documented (Table 1). All on-farm sites were harvested for corn silage.

For the starter N trial conducted in 2006 at the western New York dairy farm, corn population density data are not available. In addition, in 2010 at the Musgrave Research Farm, corn population density was measured across treatments at each site so only means are reported. For all other trials, corn population density was determined per treatment and replication by counting all plants in two 12-m rows.

Soil Analyses

Following standard procedures for soil preparation (Greweling and Peech, 1965), all soils were oven dried (50°C) for at least 48 h and ground to pass a 2-mm sieve. General fertility was determined from the 0- to 20-cm-depth soil samples taken midseason, prepared following standard soil preparation procedures at Cornell University, and analyses were performed using methods described in Wolf and Beegle (1995). Briefly, soils were analyzed for pH (1:1 w/v water extract), soil organic matter by loss-on-ignition (Storer, 1984), and Morgan (0.72 mol L^{-1} NaOAc + 0.52 mol L^{-1} CH_3COOH) extractable P, K, Ca, and Mg (Morgan, 1941). For the Morgan extraction, samples were shaken in a 1:5 (v/v) soil/solution ratio for 15 min and filtered through a Whatman no. 2 filter paper. Morgan-extractable PO_4–P was measured colorimetrically (Murphy and Riley, 1962) using an Alpkem automated rapid flow analyzer (RFA/2-320) (OI Corp.). Potassium, Ca, and Mg were analyzed by inductively coupled plasma atomic emission spectroscopy (ICP–AES) using a JY70 Type II ICP–AES (Jobin Yvon). Samples were analyzed for ISNT-N according to Khan et al. (2001) with the enclosed-griddle modification (Klapwyk and Ketterings, 2005) and classified for N supply potential based on the ISNT-N/critical ISNT-N ratio (Table 2). Eleven sites with a ratio <0.93 were classified as “deficient in soil N supply potential,” five sites were “marginal in soil N supply potential” (ratio 0.93–1.07), while the remaining five sites were “optimal in soil N supply potential” (ratio >1.07), where the critical ISNT-N level for a given soil was determined according to Klapwyk and Ketterings (2006) and Lawrence et al. (2009).

Soils were classified as high (14 sites) or very high (six sites) in P with the exception of one location where the soil test results classified the site as medium in P (Site 15; Table 2). A response to

Table 1. Location, soil series, soil taxonomy, crop history, planting and harvest dates, and manure history for 21 starter N trial sites in New York.

		Predominant soil					Manure history†			Trial year	
							Application rate and method				
Site	County	Soil series	Soil taxonomy	Previous crops	Planting date	Harvest date	Trial year	1 yr prior	2 yr prior	Manure N	Side-dress N
							m³ ha⁻¹			kg N ha⁻¹	
1	Cayuga	Lima	fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs	corn, 2005–2008	12 May 2009	13 Nov. 2009	75 spring aerator	75 spring aerator	89 spring aerator	174	0
2	Cayuga	Lima	fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs	corn, 2005–2008	12 May 2009	13 Nov. 2009	75 spring chisel	75 spring chisel	89 spring chisel	174	0
3	Cayuga	Lima	fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs	corn, 2005–2008	12 May 2009	13 Nov. 2009	none	none	none	0	134
4	Cayuga	Lima	fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs	corn, 2005–2008	12 May 2009	13 Nov. 2009	75 spring surface	75 spring surface	89 spring surface	88	0
5	Cayuga	Lima	fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs	corn, 2005–2008	11 May 2010	31 Aug. 2010	75 spring aerator	75 spring aerator	75 spring aerator	122	0
6	Cayuga	Lima	fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs	corn, 2005–2009	11 May 2010	31 Aug. 2010	75 spring chisel	75 spring chisel	75 spring chisel	122	0
7	Cayuga	Lima	fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs	corn, 2005–2009	11 May 2010	31 Aug. 2010	none	none	none	0	90
8	Cayuga	Lima	fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs	corn, 2005–2009	11 May 2010	31 Aug. 2010	75 spring surface	75 spring surface	75 spring surface	35	0
9	Steuben	Howard	loamy-skeletal, mixed, mesic Glossoboric Hapludalfs	alfalfa–grass, 2007; corn, 2008–2009	7 May 2010	26 Aug. 2010	47 spring chisel	47 spring chisel	47 spring chisel	NA‡	0
10	Washington	Vergennes	very fine, illitic, mesic Glossaquic Hapludalfs	corn, 2007–2009	28 May 2010	15 Nov. 2010	112 fall and spring disk >5 d	112 fall and spring disk >5 d	94 fall and spring disk >5 d	82	0
11	Columbia	Occum	coarse-loamy, mixed, mesic Fluventic Dystrochrepts	corn, 2007–2009	11 May 2010	8 Sept. 2010	37 spring chisel	45§ spring chisel	45§ spring chisel	¶	111
12	Albany	Angola	fine-loamy, mixed, mesic Aeric Ochraqualfs	sod, 2007; corn, 2008–2009	27 May 2010	7 Sept. 2010	¶	94 spring incorporated	37 spring incorporated	239	0
13	Washington	Hoosic	sandy-skeletal, mixed, mesic Typic Dystrudepts	corn, 2006–2008	5 May 2009	23 Sept. 2009	56 spring incorporated	none	94 spring surface	¶	0
14	Rensselaer	Occum–Barbour	coarse-loamy/coarse-loamy over sandy or sandy skeletal, mesic Fluventic Dystrochrepts	sod, 2007; corn, 2008–2009	10 May 2010	7 Sept. 2010	75 spring surface	84 spring surface	84 spring surface	77	0
15	Lewis	Croghan	sandy, mixed, frigid Aquic Haplorthods	corn, 2008–2010	25 May 2011	3 Oct. 2011	56 spring chisel 1 d	56 spring chisel 1 d	56 spring chisel 1 d	67	0
16	Tompkins	Hudson	fine, illitic, mesic Glossaquic Hapludalfs	corn, 2008–2010	14 May 2011	26 Sept. 2011	63 fall injection 69 spring injection	80 fall surface	99 fall and spring injection	161	79
17	St. Lawrence	Hogansburg	coarse-loamy, mixed, semiactive, frigid Aquic Eutrudepts	corn, 2008–2010	13 May 2011	21 Sept. 2011	103 spring injection	137 spring injection	59 summer surface	82	28
18	Steuben	Howard	loamy-skeletal, mixed, active, mesic Glossic Hapludalfs	corn, 2008–2010	12 May 2011	23 Sept. 2011	56§ winter 2011 surface	56§ winter 2010 surface	56§ winter 2009 surface	¶	0
19	St. Lawrence	Swanton	coarse-loamy over clayey, mixed, nonacid, frigid Aeric Haplaquepts	alfalfa–grass, 2007–2008; corn, 2009	4 May 2010	24 Sept. 2010	107 spring injection	none	69 fall 2008 surface	143	0
20	St. Lawrence	Malone	coarse-loamy, mixed, nonacid, frigid Aeric Haplaquepts	sod, 2007–2008; corn, 2009	29 May 2010	23 Sept. 2010	19 spring chisel	19 spring chisel	56 summer surface	¶	61
21	Clinton	Malone	coarse-loamy, mixed, nonacid, frigid Aeric Epiaquepts	corn, 2007–2009	10 May 2010	17 Sept. 2010	38§ winter 2009 surface	150 winter 2008 surface	11§ winter 2007 surface	56	80

† Manure applied as a slurry unless otherwise indicated.

‡ NA, not available.

§ Solid application.

¶ Manure probably applied, missing farm records for application rate and/or manure analysis.

Table 2. Initial soil fertility status (0–20-cm depth) for each of the 21 sites (means of plot values) included in the starter N project. All soils were analyzed for pH (water), organic matter (OM) by loss-on-ignition, Morgan-extractable P, K, Mg, Ca, Al, Mn, Zn, and Illinois Soil Nitrogen Test (ISNT). Trials at Sites 1 to 4 and 13 were conducted in 2009, at Sites 5 to 12, 14, and 19 to 21 in 2010, and all others in 2011.

			Morgan-extractable elements†												
			P		K		Mg						ISNT		
Site	pH	OM	Conc.	Class	Conc.	Class	Conc.	Class	Ca	Al	Mn	Zn	Conc.	Ratio‡	Rating§
		g kg^{-1}	mg kg^{-1}		mg kg^{-1}		mg kg^{-1}		mg kg^{-1}				mg kg^{-1}		
1	7.8	35	14	high	108	very high	371	very high	2971	6	14	1	264	0.92	D
2	7.8	33	14	high	105	very high	348	very high	2833	6	14	1	252	0.89	D
3	7.7	31	8	high	64	high	331	very high	2636	6	13	<1	224	0.81	D
4	7.8	33	16	high	112	very high	353	very high	2806	5	15	1	252	0.89	D
5	7.7	37	16	high	134	very high	343	very high	2806	5	20	1	257	0.87	D
6	7.7	35	15	high	122	very high	334	very high	2876	5	20	1	248	0.86	D
7	7.7	33	9	high	58	high	312	very high	2738	5	18	<1	230	0.82	D
8	7.7	35	17	high	132	very high	343	very high	2946	5	19	1	245	0.85	D
9	6.1	33	5	high	99	high	222	very high	1069	17	10	<1	235	0.83	D
10	7.0	41	13	high	122	very high	292	very high	2674	18	20	1	247	0.81	D
11	6.4	28	40	very high	389	very high	192	very high	1491	10	27	2	216	0.81	D
12	6.6	35	36	very high	167	very high	162	very high	2214	9	11	1	290	1.01	M
13	6.4	49	47	very high	480	very high	213	very high	1782	15	17	3	336	1.05	M
14	6.9	40	18	high	305	very high	212	very high	1868	14	17	2	315	1.05	M
15	6.2	52	3	medium	131	high	157	very high	1108	71	3	2	314	0.97	M
16	7.4	41	40	very high	234	very high	274	very high	2733	6	29	1	324	1.07	M
17	6.7	41	6	high	107	very high	256	very high	1851	8	23	1	356	1.17	O
18	6.8	53	82	very high	783	very high	367	very high	1690	11	16	2	439	1.35	O
19	7.0	42	8	high	75	medium	462	very high	2616	8	13	1	334	1.09	O
20	7.0	41	8	high	32	low	312	very high	2298	10	11	1	344	1.13	O
21	6.9	43	25	very high	288	very high	275	very high	1717	12	13	2	344	1.12	O

† Morgan-extractable P, K, and Mg interpretations are defined in Cornell Cooperative Extension (2012). A soil is classified as medium in soil test P when the Morgan-extractable P is between 2 and 4.5 mg kg^{-1}, high in soil test P with a test result between 4.5 and 20 mg kg^{-1}, and very high when the Morgan soil test P exceeds 20 mg kg^{-1}. Soils are very high in Mg when exceeding 100 mg kg^{-1}. Potassium soil test interpretations depend on soil type, as documented in Ketterings et al. (2003).

‡ ISNT-N/critical ISNT-N ratio, where the critical ISNT-N level for a given soil was determined according to Klapwyk and Ketterings (2006) and Lawrence et al. (2009). ISNT-N was measured in 0–20-cm depth samples taken when the corn was 15–30-cm tall (V4–V6 stage). Test results are classified as "deficient in soil N supply potential" when the ratio is <0.93, "marginal in soil N supply potential" when the ratio is between 0.93 and 1.07, and "optimal in soil N supply potential" with a ratio >1.07.

§ O, optimal; M, marginal; D, deficient.

P was not expected at this location because manure was applied (Table 1). Similarly, all sites were high or very high in soil test K with the exception of Site 19 (medium) and Site 20 (low). At both locations, manure was applied and plants did not display any K deficiencies during the growing season, so both sites were retained for the overall study.

Soil samples taken at the western New York farm, the 0- to 20-cm soil samples (both timings), and the 0- to 30-cm depth samples taken midseason for the statewide project were analyzed for NO_3–N using the Morgan extraction (Morgan, 1941). Morgan-extractable NO_3–N for 0- to 30-cm-depth samples taken midseason is the standard pre-sidedress NO_3 test (PSNT) for New York (Klausner et al., 1993).

Harvest, Silage Quality Analyses, and the End of Season Stalk Nitrate Test

At the Musgrave Research Farm, corn was machine harvested for grain at a targeted grain moisture of 160 to 200 g kg^{-1}. Plots were harvested using a Case IH 2144 combine and grain was transferred to an Unverferth 275 gravity wagon situated on four Intercomp PT300DW-5 wheel load scales. For each plot, a grain subsample was taken and dried for 10 d at 65°C to determine moisture content.

For all other trials, corn was harvested as silage at a targeted whole-plant moisture of 600 to 700 mg kg^{-1}. Trials at the western New York dairy farm and 17 of the statewide sites were machine harvested, while five statewide trials (Sites 9, 11, 12, 18, and 20) were hand harvested. For the machine-harvested trials, choppers harvested the inner six to eight rows of individual plots in one pass (minimum plot length of 83 m), with loads weighed on farm or mobile truck (axle) scales before and after each pass through a plot to determine harvest weight. A calibrated yield monitor was used at two sites (Sites 17 and 19). For the hand-harvested trials, two 10- to 12-m-long rows of corn silage were hand harvested 15 cm above the ground (Sites 9, 11, 12, 18, and 20).

At harvest, a 20-cm portion of stalk (between 15 and 35 cm above the ground according to Binford et al., 1990) was collected from 15 plants per plot. Stalk portions were quartered lengthwise. One of four quarters was retained, dried at 60°C in a forced-air oven for a minimum of 48 h, ground to pass a 2-mm screen, and analyzed for extractable NO_3 using a 0.025 mol L^{-1} $Al_2(SO_4)_3$ solution, an extraction ratio of 1:100 (w/v), and a shaking time of 15 min. Extractable NO_3–N was determined using a VWR SympHony NO_3 ion electrode following Miller (1998).

Except for the 2006 trial at the western New York farm, a subsample of approximately 3.78-L volume of the harvested silage per plot was collected at the bunk for all machine-harvested

Table 3. Corn silage dry matter (DM) yield expressed at 650 g kg^{-1} moisture, moisture content at harvest (MC), corn population, and silage quality response to banded starter N applications at a western New York dairy farm, expressed in terms of milk production estimates per megagram DM and per hectare, crude protein (CP), soluble protein (SP), neutral detergent fiber (NDF), digestible neutral detergent fiber at 48 h (dNDF 48h), lignin, and starch contents. Fields received manure injected in the spring at a rate of 85 m^3 ha^{-1}.

Starter N rate	DM yield	MC	Corn population	Milk production†		CP	SP	NDF	dNDF 48h	Lignin	Starch
kg N ha^{-1}	Mg ha^{-1}	g kg^{-1}	plants ha^{-1}	kg Mg^{-1}	kg ha^{-1}	g kg^{-1} DM			g kg^{-1} NDF	g kg^{-1} DM	
Second-year corn after alfalfa (2006)											
0	59 a‡	638 a	–								
34	58 a	652 a	–								
67	58 a	629 a	–								
First-year corn after alfalfa (2007)											
0	61 a	595 a	81,400 a	1730 a	37,000 a	62 b	15 a	438 a	701 a	29 a	356 a
34	61 a	597 a	79,600 a	1690 a	36,200 a	67 ab	15 a	460 a	691 a	33 a	329 a
67	62 a	581 a	78,900 a	1680 a	36,500 a	71 a	17 a	463 a	698 a	32 a	325 a
Fourth-year corn after alfalfa (2007)											
0	40 a	628 a	79,600 a	1690 a	25,000 a	77 a	21 a	448 a	690 a	32 a	337 a
34	42 a	631 a	78,200 a	1700 a	24,200 a	75 a	20 a	444 a	692 a	31 a	337 a
67	41 a	640 a	80,300 a	1730 a	37,000 a	62 b	15 a	438 a	701 a	29 a	356 a

† Milk per megagram and milk per hectare are indicators of overall forage quality estimated using Milk2006 (Shaver, 2006).

‡ Means for starter N rates within a field that are followed by different letters showed a significant change in quality indicators with the use of starter N ($P \leq 0.05$).

silage trials. Per plot, seven to 10 grab samples were collected at varying depths to get a representative sample for moisture and forage quality. For hand-harvested trials, a five-plant subsample from each plot was chopped in the field using a Model 120312 Mighty Mac, a gas-powered chipper-shredder (Mackissic Inc.). The shredded corn was well mixed, subsampled to fill a 3.78-L plastic bag, sealed, and kept in a cooler during transport to the laboratory, where the samples were dried in a 60°C forced-air oven for a minimum of 48 h.

Forage subsamples were analyzed at Cumberland Valley Analytical Services in Hagerstown, MD. The oven-dried samples were ground to pass a 1-mm screen, subsampled, and analyzed for in vitro neutral detergent fiber (NDF) 48-h digestibility (Goering and Van Soest, 1970). Near-infrared reflectance spectroscopy was used to determine crude protein (CP), soluble protein, acid detergent insoluble CP, neutral detergent insoluble CP, acid detergent fiber, NDF, lignin, sugar, starch, crude fat, ash, Ca, P, Mg, and K contents. Milk2006, a model developed at the University of Wisconsin, was used to estimate yields in milk per megagram of silage and per hectare (Shaver, 2006).

Statistical Analysis

Given the large variability in field characteristics and manure histories across sites, yield, forage quality, and soil and stalk data were analyzed for each site independently using PROC MIXED (Littell et al., 1996, p. 87–134), with N treatment as a fixed effect and block as a random effect using SAS (SAS Institute). Mean separations were done using the LSMEANS procedure with TUKEY adjustment at $P \leq 0.05$.

RESULTS AND DISCUSSION

Western New York On-Farm Trials

Starter N application did not increase corn silage yield or impact moisture at harvest for any of the three trials conducted at the western New York farm (Table 3). Eliminating starter N did not impact silage quality parameters in the fourth-year corn site in 2007. For the first-year corn field, adding 67 kg N ha^{-1} did significantly increase CP; however, the increase in CP did not impact the overall silage quality expressed in estimated milk per megagram of silage or milk per hectare (Table 3).

Soil PSNT levels exceeded 21 mg kg^{-1}, the critical value for corn responsiveness (Klausner et al., 1993), at all three sites including the first-year corn site, suggesting a sufficient N supply through the manure applications, mineralization of organic matter, and sod decomposition (Table 4). Soil ISNT levels were classified as optimal for the second- and fourth-year corn sites, while the first-year corn site was classified as marginal, suggesting that manure can replace the need for starter N for sites at or above the critical ISNT-N level determined by Klapwyk and Ketterings (2006) and validated for corn by Lawrence et al. (2009). Corn stalk NO_3 test results and end-of-season soil NO_3 data (Table 4) both reflected the higher soil NO_3 and ISNT-N levels at the second- and fourth-year corn sites than at the first-year corn site, consistent with a larger number of years of annual manure applications for those two sites. Corn stalk N levels for the first-year corn site were classified as marginal, while no yield response to starter N was measured. This is consistent with previous work that indicated lower threshold levels for PSNT (Morris et al., 1993; Yost et al., 2013a) and for CSNT (Lawrence et al., 2008a; Yost et al., 2012, 2013a, 2013b) for corn following sod in the rotation, and is consistent with the lower manure N application rate and fall application of manure at this site. These results suggest that starter N fertilizer can be eliminated without impacting yield or silage quality for regularly manured fields at or above the critical ISNT-N level for the field.

Statewide Assessment

Similar to the findings for the western New York sites, at sites with an optimal soil N supply potential as determined by the ISNT-N/critical ISNT-N ratio (Sites 17, 18, 19, 20, and 21), the manure application alone was sufficient to meet the N needs of the crop; none of these five sites showed a yield increase with starter N use, and moisture at harvest was not impacted (Table 5). The CSNT-N, PSNT-N, and end-of-season soil NO_3 data

Table 4. Pre-sidedress NO_3 test N (PSNT-N), end-of-season soil NO_3–N, both measured in 0- to 30-cm depth samples, Illinois soil N test N (ISNT-N), measured in 0- to 20-cm depth samples taken when the corn was 15- to 30-cm tall (V4–V6 stage), and cornstalk NO_3 test N (CSNT-N) following three rates of banded starter N applications to silage corn at a western New York dairy farm. Manure was injected in the spring at a rate of 85 m^3 ha^{-1} for an estimated available N application of 105 kg N ha^{-1} for second- and fourth-year corn, and fall-applied at a rate of 39 m^3 ha^{-1} for an estimated 42 kg plant-available N ha^{-1}. Available N estimates assume 35% availability of organic N and 0 and 65% availability of inorganic N for fall application and spring injection, respectively (Ketterings et al., 2003, 2013).

Starter N rate	ISNT-N	PSNT-N	CSNT-N	End-of-season soil NO_3–N
kg N ha^{-1}	mg kg^{-1}			
Second-year corn after alfalfa (2006)				
0	322 a†	103 a	9774 a	29 a
34	344 a	98 a	9759 a	27 a
67	340 a	105 a	9857 a	33 a
First-year corn after alfalfa (2007)				
0	271 a	24 a	302 a	6 a
34	283 a	22 a	391 a	4 a
67	274 a	24 a	308 a	7 a
Fourth-year corn after alfalfa (2007)				
0	302 a	37 a	3073 a	12 a
34	291 a	33 a	4119 a	8 a
67	329 a	43 a	2530 a	14 a

† Means for starter N rates within a field that are followed by the same letter are not statistically different ($P \leq 0.05$).

(Table 6) confirmed that N was not limiting yield at any of these sites. The CSNT-N, PSNT-N, and end-of-season NO_3 data also suggest that for the two locations that were sidedressed (Sites 20 and 21), the sidedress application could have been eliminated without impacting yield.

Of the five sites that were classified by ISNT-N levels as marginal in soil N supply potential (Table 2), all received manure and only one (Site 15) showed a yield response to starter N use. The PSNT-N results suggested sufficient N for four of the six sites, while two sites (Sites 15 and 16) indicated a potential deficiency in N. Site 16 was sidedressed to meet N needs (optimal CSNT-N), while at Site 15, the marginal CSNT-N classification was consistent with the yield response to starter N under N-deficient conditions. The additional sites were classified as optimal (Site 12) or excessive (Sites 13 and 14) in N availability based on CSNT-N results (Table 6). We conclude based on these data that manure application can replace starter N for soils with a marginal soil N supply potential as long as sufficient N is added with the manure as confirmed by a CSNT-N >750 mg kg^{-1}.

The sites classified as deficient in soil N supply potential (i.e., soil N alone is not expected to supply sufficient N for the corn crop that year) included two unmanured sites at the Musgrave Research Farm (Sites 3 and 7) and sites with a limited manure history (Sites 1, 2, and 4 in 2009 and 5, 6, and 8 in 2010 at the Musgrave Research Farm) as well as three on-farm sites (Sites 9, 10, and 11). The results at Sites 3 and 7 (significantly higher yield in 2010 with starter N application and a similar trend in 2009 [$P = 0.063$], a year with below-average precipitation in April and July) suggest that starter N is needed for unmanured fields that are deficient in ISNT-N. The results at Site 7 also suggest that a response to N could have been expected if CSNT values were <750 mg kg^{-1} (high-producing year on deficient ISNT soil). Sites 3 and 7 represent scenarios typically seen at cash grain operations where corn is grown without manure. In these scenarios, the best management practice remains to use starter N (22–34 kg N ha^{-1}) and sidedress N where needed, consistent with the response to starter N use documented for unmanured sites in Ketterings et al. (2005).

At Sites 1, 2, and 4 in 2009 and 5, 6, and 8 in 2010, liquid manure had been applied at a rate of ~75 m^3 ha^{-1} yr^{-1} during the past 5 to 6 yr. Manure application can increase ISNT-N with time (Klapwyk et al., 2006), but after 5 to 6 yr of liquid manure application at this location, the ISNT-N levels of these sites were still classified as deficient, reflecting low solid contents of the manure, consistent with findings documented by Klapwyk et al. (2006). Of these six sites, three showed a significant ($P < 0.05$) yield increase with starter N fertilizer addition, while a similar trend was seen for two other sites ($P = 0.116$ and 0.071 for Sites 4 and 6, respectively) (Table 5). The corn grown on these sites exhibited deficient CSNT-N levels as well (Table 6), suggesting that the current-year spring application was insufficient to supply the N needed by the crop, consistent with a yield response to starter N fertilizer. Of the remaining three on-farm sites with low soil N supply potential, two sites had optimal CSNT-N levels (without starter) and one had excessive CSNT-N (Site 11, sidedressed). The latter site also showed the highest PSNT-N and end-of-season soil NO_3 levels, consistent with excessive CSNT-N results and suggesting that the sidedress N application that took place at this site was not needed for optimal yield. The lack of a corn yield response to starter N at Sites 9, 10, and 11 illustrated that for these three locations, the current-year manure supplied sufficient N.

The impact of starter N use on corn silage quality was infrequent and inconsistent. Of the 13 silage trials, two locations showed a significant increase in CP with starter N addition (Sites 13 and 21), while at one site, CP declined with starter N addition (Site 17) (Table 5). Soluble protein increased with starter N application at two locations, although the difference was small (an increase of 1 and 3 g kg^{-1} at Sites 10 and 13, respectively), and decreased at one site (Site 17). Only one site showed a change in NDF (decrease, Site 21). At Site 18, NDF digestibility increased with starter N addition, while at two additional sites, NDF decreased with starter N addition (Sites 15 and 16). Lignin and starch were not impacted by starter N fertilizer use at any of the silage trials. Elimination of starter N did not result in significant differences in milk per megagram of silage estimates except for one site where starter use decreased the estimated milk production (Site 17). Milk per hectare estimates were only impacted at one site (an increase with starter N addition at Site 15), consistent with the yield increase with starter N use at this location.

CONCLUSIONS

Starter N should be used for corn fields with no manure history and no current-year manure applications (sites deficient in ISNT-N). If the ISNT-N is classified as optimal, manure can be used to replace starter N without a yield or quality penalty. Manure can replace starter N for sites deficient or marginal in ISNT-N as well, but only if sufficient N from the manure and other sources is available (CSNT-N between 750 and

Table 5. Corn dry matter (DM) yield expressed at 150 g kg^{-1} moisture for grain yields (Sites 1-8) or 650 g kg^{-1} moisture for corn silage harvests (all other sites), moisture content at harvest (MC), corn population, and silage quality expressed in terms of milk production estimates per megagram DM and per hectare, crude protein (CP), soluble protein (SP), neutral detergent fiber (NDF), digestible neutral detergent fiber (dNDF), lignin, and starch contents as influenced by starter N applications of 34 kg N ha^{-1} at planting in 2009 (Sites 1– 8 and 13), 2010 (Sites 5–12, 14, and 19–21), and 2011 (Sites 15–18). Sites 1 to 8 were harvested for grain. All other sites were harvested for corn silage.

Site	Treatment	Yield	MC	Corn population	Milk production		CP	SP	NDF	dNDF	Lignin	Starch
		Mg ha^{-1}	g kg^{-1}	plants ha^{-1}	kg Mg^{-1} DM	kg ha^{-1}	——— g kg^{-1} DM ———			g kg^{-1} NDF	— g kg^{-1} DM —	
Sites deficient in ISNT-N												
1	starter	7.01 a†	182 a	70,600‡	–	–	–	–	–	–	–	–
	no starter	6.77 a	174 a	70,600‡	–	–	–	–	–	–	–	–
2	starter	7.40 a	183 a	72,900‡	–	–	–	–	–	–	–	–
	no starter	6.54 b	176 a	72,900‡	–	–	–	–	–	–	–	–
3	starter	8.96 a	181 a	72,600‡	–	–	–	–	–	–	–	–
	no starter	7.89 a	190 a	72,600‡	–	–	–	–	–	–	–	–
4	starter	6.43 a	185 a	71,300‡	–	–	–	–	–	–	–	–
	no starter	5.69 a	182 a	71,300‡	–	–	–	–	–	–	–	–
5	starter	9.36 a	166 b	68,900 a	–	–	–	–	–	–	–	–
	no starter	8.61 b	172 a	60,900 b	–	–	–	–	–	–	–	–
6	starter	10.00 a	166 a	71,900 a	–	–	–	–	–	–	–	–
	no starter	9.42 a	169 a	68,800 a	–	–	–	–	–	–	–	–
7	starter	10.77 a	169 b	68,100 a	–	–	–	–	–	–	–	–
	no starter	9.14 b	173 a	59,500 b	–	–	–	–	–	–	–	–
8	starter	8.78 a	167 a	68,400 a	–	–	–	–	–	–	–	–
	no starter	7.80 b	170 a	64,700 a	–	–	–	–	–	–	–	–
9	starter	43.0 a	671 a	63,500 a	1720 a	25,900 a	80 a	16 a	464 a	676 a	35 a	293 a
	no starter	44.8 a	670 a	63,300 a	1760 a	27,600 a	79 a	16 a	438 a	665 a	33 a	314 a
10	starter	40.3 a	683 a	72,700 a	1800 a	25,300 a	83 a	20 a	393 a	702 a	28 a	345 a
	no starter	42.8 a	677 a	72,100 a	1830 a	27,500 a	78 a	19 b	375 a	702 a	27 a	372 a
11	starter	55.3 a	601 a	93,600 a	1680 a	32,500 a	83 a	22 a	470 a	612 a	36 a	287 a
	no starter	55.9 a	612 a	92,800 a	1670 a	32,800 a	83 a	24 a	461 a	606 a	35 a	300 a
Sites marginal in ISNT-N												
12	starter	42.8 a	650 a	80,000 a	1780 a	26,600 a	78 a	18 a	405 a	698 a	28 a	346 a
	no starter	44.8 a	658 a	76,800 a	1780 a	28,000 a	79 a	20 a	396 a	673 a	27 a	356 a
13	starter	56.9 a	673 a	62,100 a	1730 a	34,500 a	83 a	24 a	422 a	652 a	32 a	336 a
	no starter	55.8 a	656 a	61,800 a	1710 a	33,400 a	73 b	21 b	425 a	641 a	30 a	347 a
14	starter	47.5 a	596 a	93,700 a	1790 a	29,700 a	78 a	21 a	400 a	643 a	31 a	404 a
	no starter	46.1 a	579 a	93,700 a	1760 a	28,500 a	77 a	22 a	411 a	647 a	31 a	386 a
15	starter	47.5 a	585 a	78,300 a	1650 a	27,300 a	63 a	13 a	426 a	608 b	31 a	380 a
	no starter	38.5 b	589 a	77,200 a	1640 a	22,100 b	58 a	11 a	444 a	632 a	29 a	362 a
16	starter	39.2 a	590 a	77,400 a	1670 a	22,900 a	91 a	22 a	414 a	795 b	23 a	349 a
	no starter	38.1 a	595 a	77,500 a	1690 a	22,500 a	89 a	22 a	416 a	806 a	23 a	348 a
Sites optimal in ISNT-N												
17	starter	56.2 a	494 a	81,600 a	1690 b	33,100 a	77 b	19 b	401 a	567 a	32 a	398 a
	no starter	54.9 a	587 a	81,500 a	1730 a	33,200 a	80 a	20 a	388 a	582 a	31 a	409 a
18	starter	51.1 a	653 a	77,300 b	1690 a	30,100 a	88 a	24 a	413 a	638 a	32 a	317 a
	no starter	54.0 a	659 a	79,800 a	1660 a	31,400 a	90 a	24 a	413 a	625 b	33 a	314 a
19	starter	50.9 a	498 a	75,300 a	1850 a	43,900 a	81 a	17 a	364 a	748 a	24 a	436 a
	no starter	49.7 a	501 a	76,500 a	1860 a	43,100 a	81 a	18 a	342 a	721 a	24 a	461 a
20	starter	44.8 a	679 a	75,500 a	1710 a	26,800 a	79 a	21 a	461 a	646 a	35 a	308 a
	no starter	47.3 a	665 a	81,700 a	1700 a	28,000 a	76 a	20 a	460 a	631 a	33 a	317 a
21	starter	53.3 a	679 a	78,800 a	1860 a	34,600 a	92 a	25 a	359 b	775 a	24 a	379 a
	no starter	52.9 a	689 a	78,000 a	1780 a	33,000 a	89 b	25 a	396 a	770 a	25 a	341 a

† Sites with treatment means followed by different letters showed a significant change in quality indicators with the use of starter N ($P \leq 0.05$).
‡ Only one stand density (mean of replications) available for combined starter/no starter at this site.

2000 mg kg^{-1}). A yield response to starter N is likely if the ISNT-N is deficient and the additional N applied with manure is insufficient. Corn grown in manured fields and with CSNT-N levels between 750 and 2000 mg kg^{-1}, using 20-cm stalks taken between 15 and 36 cm above the ground, did not respond to starter N use. We recommend that producers analyze second- or higher year corn fields for both ISNT-N and CSNT-N to evaluate past-season N management and identify sites where a starter N application can be omitted without impacting yield or silage quality.

Table 6. Illinois soil N test (ISNT) ratio and rating, soil NO_3–N (0–20- and 0–30-cm depths), pre-sidedress NO_3 test (PSNT), and corn stalk NO_3 test (CSNT) as influenced by starter N fertilizer (0 vs. 34 kg N ha^{-1}) in corn trials in 2009 (Sites 1–4 and 13), 2010 (Sites 5–12, 14, and 19–21), and 2011 (Sites 15–18).

				At sidedress time			At harvest			
	ISNT			NO_3–N	PSNT, 0–30 cm§		NO_3–N		CSNT¶	
Site	Ratio†	Rating‡	Treatment	0–20 cm	Conc.	Class	0–20 cm	0–30 cm	Conc.	Class
				mg kg^{-1}			mg kg^{-1}			
Sites deficient in ISNT-N										
1	0.91	D	starter	6 b#	7 a	Class	12 b	5 a	94 a	deficient
			no starter	9 a	8 a	deficient	14 a	7 a	90 a	deficient
2	0.90	D	starter	9 a	12 a	deficient	11 b	6 a	94 a	deficient
			no starter	11 a	9 a	deficient	14 a	7 a	105 a	deficient
3	0.88	D	starter	2 b	6 a	deficient	8 a	4 a	160 a	deficient††
			no starter	6 a	4 a	deficient	9 a	5 a	208 a	deficient††
4	0.90	D	starter	7 a	9 a	deficient	10 a	5 a	104 a	deficient
			no starter	7 a	7 b	deficient	13 a	6 a	94 a	deficient
5	0.88	D	starter	34 a	28 a	sufficient	11 a	15 a	182 a	deficient
			no starter	37 a	28 a	sufficient	10 a	17 a	99 a	deficient
6	0.86	D	starter	32 a	31 a	sufficient	11 a	18 a	80 a	deficient
			no starter	34 a	26 a	sufficient	11 a	15 a	89 a	deficient
7	0.82	D	starter	18 a	14 a	deficient	9 a	16 a	827 a	optimal††
			no starter	18 a	13 a	deficient	9 a	14 a	669 a	marginal††
8	0.85	D	starter	29 a	24 a	marginal	11 a	15 a	129 a	deficient
			no starter	32 a	25 a	sufficient	11 a	15 a	83 a	deficient
9	0.84	D	starter	42 a	57 a	sufficient	7 a	7 a	1661 a	optimal
			no starter	40 a	54 a	sufficient	5 a	5 b	463 b	marginal
10	0.81	D	starter	33 a	33 a	sufficient	20 a	33 a	2552 a	excess
			no starter	33 a	31 a	sufficient	16 a	25 a	1174 a	optimal
11	0.81	D	starter	65 a	52 a	sufficient	79 a	44 a	7838 a	excess††
			no starter	71 a	45 a	sufficient	66 a	53 a	5938 a	excess††
Sites marginal in ISNT-N										
12	1.01	M	starter	48 a	31 a	sufficient	10 a	10 a	1225 a	optimal
			no starter	38 a	33 a	sufficient	12 a	9 a	818 a	optimal
13	1.07	M	starter	30 a	34 a	sufficient	32 a	27 a	5154 a	excess
			no starter	26 a	30 a	sufficient	24 a	27 a	5017 a	excess
14	1.05	M	starter	62 a	55 a	sufficient	21 a	18 a	10135 a	excess
			no starter	59 a	53 a	sufficient	13 b	11 a	9164 a	excess
15	0.97	M	starter	–	19 a	deficient	–	–	704 a	marginal
			no starter	–	20 a	deficient	–	–	762 a	optimal
16	1.07	M	starter	–	21 a	marginal	–	–	2129 a	excess††
			no starter	–	19 a	deficient	–	–	1308 a	optimal††
Sites optimal in ISNT-N										
17	1.17	O	starter	–	20 a	deficient	–	–	2970 a	excess††
			no starter	–	21 a	marginal	–	–	1353 b	optimal††
18	1.35	O	starter	–	48 a	sufficient	–	–	3449 a	excess
			no starter	–	44 a	sufficient	–	–	5872 a	excess
19	1.10	O	starter	40 a	29 a	sufficient	15 a	14 a	4817 a	excess
			no starter	41 a	33 a	sufficient	16 a	16 a	4164 a	excess
20	1.13	O	starter	27 a	25 a	sufficient	19 a	16 a	4484 a	excess††
			no starter	29 a	27 a	sufficient	19 a	16 a	4599 a	excess††
21	1.12	O	starter	21 a	24 a	marginal	34 a	24 a	9326 a	excess††
			no starter	25 a	23 a	marginal	45 a	33 a	10051 a	excess††

† ISNT-N/critical ISNT-N ratio, where the critical ISNT-N level for a given soil was determined according to Klapwyk and Ketterings (2006) and Lawrence et al. (2009). ISNT-N was measured in 0–20-cm depth samples taken when the corn was 15–30-cm tall (V4–V6 stage). Test results are classified as "deficient in soil N supply potential" when the ratio is <0.93, "marginal in soil N supply potential" when the ratio is between 0.93 and 1.07, and "optimal in soil N supply potential" with a ratio >1.07.

‡ O, optimal; M, marginal; D, deficient.

§ PSNT-N interpretation: <21 mg kg^{-1} is deficient; 21–24 mg kg^{-1} is marginal; >24 mg kg^{-1} is sufficient (Ketterings et al., 2012).

¶ CSNT-N interpretation: <250 mg kg^{-1} is deficient; 250–750 mg kg^{-1} is marginal; 750–2000 mg kg^{-1} is optimal; >2000 mg kg^{-1} is excessive (Lawrence et al., 2012).

Sites with treatment means followed by different letters showed a significant change ($P \leq 0.05$) in N indicators with the use of starter N.

†† Sidedressed in addition to receiving manure (Sites 11, 16, 17, 20, and 21) or sidedressed with no manure history (Sites 3 and 7).

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