Minnesota Department of Agriculture
Pesticide & Fertilizer Management
FINAL REPORT
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PROJECT DESCRIPTION: Advancing Intensive Management of Continuous Corn on Irrigated Sands

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1) GOALS AND OBJECTIVES OBTAINED

a) ***Establish treatments and manage plots.*** Plots were established. Weeds were controlled using pre- and post-emergence herbicides. Plots were end-trimmed and staked, and corn stand counts were taken. In-season nitrogen (N) fertilizer applications were made at the appropriate times for the respective treatments.

b) ***Collect and analyze in-season plant samples***. Corn plant samples were collected at the V10 stage, processed, and analyzed for nutrients.

c) ***Harvest plots for grain, cob, and stover, and analyze plant samples collected at harvest***. Plots were harvested in mid-October. Corn grain, cob, and stover samples were processed and analyzed for nutrients.

d) ***Collect soil samples after harvest and analyze***. Plots were soil sampled after harvest in early November to a depth of 40 inches and samples were analyzed for bulk density and nutrients.

e) ***Manage plots in the fall***. Corn stalks were chopped during harvest with a chopping corn head on the combine. Following soil sampling, the trial area was disk-ripped.

f) ***Present research results to farmers and agricultural professionals and Extension meetings***. Results from this research were presented to farmers and agricultural professionals at Extension meetings across Minnesota.

2) ACTIVITIES PERFORMED

a) The goal/objective "*establish treatments and manage plots*" was accomplished through the activities described in this section.

This experiment was located at Becker, MN on irrigated sand in a different field than the previous year's experiment. The previous crop was corn, and the corn stalks were chopped during harvest with a chopping corn head on the combine. The field was disk-ripped in the fall of 2018.

The soil was a Hubbard-Mosford loamy sand complex. Baseline soil samples were collected from the 0- to 6-inch depth in the spring of 2019 and analyzed. Soil-test values averaged 2.3% organic matter, 6.5 pH (1:1 soil:water), 18 ppm Bray-1 phosphorus (P), 99 ppm potassium (K), 9 ppm sulfate, and 2.58 ppm zinc (DTPA).

This project compared two levels of agronomic management: 1) farmer-practice agronomics and 2) a high-yield system that is also environmentally responsible, referred to as sustainable intensification. For both of these, standard fertilizer management in line with university guidelines was compared to advanced fertilizer management. Within these four main-plot treatments, split plots were with and without N fertilizer for evaluation of N use efficiency parameters.

Treatment details are in Table 1. Compared to farmer-practice agronomics, sustainable intensification included a longer-season corn hybrid and a greater planting rate. Compared to standard fertilizer management, the advanced fertilizer management treatment included P application based on grain removal and in-season N applications that more closely aligned with corn N uptake.

Sulfur, P, and K fertilizers were broadcast according to Table 1 prior to pre-plant tillage. Corn was planted in 30-inch rows on May 3, 2019 with starter fertilizer (4 gal/ac of 10-34-0 placed in the seed furrow) using a custom built 4-row John Deere 7300 MaxEmerge II planter. Pioneer P9608AMXT [96 comparative relative maturity (CRM)] was planted in the farmer-practice treatment and Pioneer P0306AMXT (103 CRM) was planted in the sustainable intensification treatment. Planting rates for target corn populations and starter fertilizers were applied according to Table 1.

Weeds were controlled using pre- and post-emergence herbicides. Corn stand counts were taken at the V3 corn stage. Final corn populations were 34,000 plants/acre for the farmer-practice treatment and 39,000 plants/acre for the sustainable intensification treatment. In-season N applications were made at the appropriate corn stages for the respective treatments. Irrigation water samples were collected at times of irrigation to determine the amount of N supplied through irrigation water.

b) To accomplish the goal/objective "*Collect and analyze plant samples,*" whole-plant samples were collected from each plot at the V10 corn stage for determination of dry matter yield and nutrient uptake. Eight whole plants were collected from the non-harvest rows of each plot, weighed wet, ground, and subsampled for determination of plant moisture content and calculation of whole-plant dry matter yield. A dry subsample of ground plant material from each plot was analyzed for total N, phosphorus, potassium, calcium, sulfur, magnesium, boron, manganese, iron, zinc, copper, and aluminum. Corn nutrient uptake at the V10 corn stage was calculated as the product of plant dry matter yield and nutrient concentration and is shown in Table 2.

For N-fertilized treatments, corn dry matter yield at the V10 stage was greatest with advanced fertilizer management + farmer practice agronomics (Table 2). Corn dry matter yield with this treatment averaged 35% greater than that with standard fertilization + farmer practice agronomics or sustainable intensification with either level of fertilizer management. The non-N-fertilized control treatments were included in this study for calculation of N use efficiency parameters.

Corn uptake of most nutrients at the V10 stage was related to corn dry matter yield. For N-fertilized treatments, uptake of all nutrients at the V10 stage was maximized with advanced fertilization + farmer practice agronomics (Table 2). However, corn uptake of aluminum at the V10 stage was not affected by fertilizer or agronomic management.

Table 1. Agronomic and fertilizer management components of the treatments at Becker, MN in 2019.

	Treatment							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Agronomic management	**Farmer practice**	**Farmer practice**	**Farmer practice**	**Farmer practice**	**Sustainable intensification**	**Sustainable intensification**	**Sustainable intensification**	**Sustainable intensification**
Fertilizer management	**Standard**	**Standard**	**Advanced**	**Advanced**	**Standard**	**Standard**	**Advanced**	**Advanced**
N fertilization beyond 10-34-0	**No (control)**	**Yes**	**No (control)**	**Yes**	**No (control)**	**Yes**	**No (control)**	**Yes**
Corn hybrid RM	96	96	96	96	103	103	103	103
Final stand (plants/ac)	34,000	34,000	34,000	34,000	39,000	39,000	39,000	39,000
S fertilization	25 lb/ac sulfate-S (sul-po-mag)	25 lb/ac sulfate-S (sul-po-mag)	25 lb/ac sulfate-S (sul-po-mag)	25 lb/ac sulfate-S (sul-po-mag)	25 lb/ac sulfate-S (sul-po-mag)	25 lb/ac sulfate-S (sul-po-mag)	25 lb/ac sulfate-S (sul-po-mag)	25 lb/ac sulfate-S (sul-po-mag)
P fertilization strategy	U of M guidelines	U of M guidelines	50% of grain removal	50% of grain removal	U of M guidelines	U of M guidelines	50% of grain removal	50% of grain removal
Broadcast P_2O_5 + K_2O (lb/ac)	0 + 100	0 + 100	47 + 100	47 + 100	0 + 100	0 + 100	47 + 100	47 + 100
Total lb N/ac	5	230	5	230	5	230	5	230
10-34-0 in seed furrow at planting	4 gal/ac: 5 lb N/ac + 16 lb P_2O_5/ac	4 gal/ac: 5 lb N/ac + 16 lb P_2O_5/ac	4 gal/ac: 5 lb N/ac + 16 lb P_2O_5/ac	4 gal/ac: 5 lb N/ac + 16 lb P_2O_5/ac	4 gal/ac: 5 lb N/ac + 16 lb P_2O_5/ac	4 gal/ac: 5 lb N/ac + 16 lb P_2O_5/ac	4 gal/ac: 5 lb N/ac + 16 lb P_2O_5/ac	4 gal/ac: 5 lb N/ac + 16 lb P_2O_5/ac
Sidedressed urea at V2 (lb N/ac)	0	40	0	40	0	40	0	40
Sidedressed urea at V6 (lb N/ac)	0	185	0	70	0	185	0	70
Sidedressed urea at V12 (lb N/ac)	0	0	0	70	0	0	0	70
Sidedressed urea at VT (lb N/ac)	0	0	0	45	0	0	0	45

Table 2. Corn dry matter yield and nutrient uptake at the V10 stage as affected by the agronomic and fertilizer management treatments at Becker, MN in 2019. Treatments are described in detail in Table 1.[1]

	Treatment							
	1	2	3	4	5	6	7	8
Agronomic mgt.[2]	**FP**	**FP**	**FP**	**FP**	**SI**	**SI**	**SI**	**SI**
Fertilizer mgt.	**Standard**	**Standard**	**Advanced**	**Advanced**	**Standard**	**Standard**	**Advanced**	**Advanced**
N fertilization	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
Dry matter yield at V10 (lb/acre)	2,079 c[3]	3,019 b	2,105 c	3,961 a	1822 c	2,730 b	2,003 c	3,068 b
N uptake at V10 (lb N/acre)	39 d	109 ab	40 d	118 a	37 d	88 c	42 d	101 b
P uptake at V10 (lb P/acre)	6.5 d	7.6 bc	7.4 bc	11.2 a	5.7 d	7.4 bc	7.4 bc	8.6 b
K uptake at V10 (lb K/acre)	80 cd	125 b	87 c	153 a	73 d	123 b	85 cd	118 b
Ca uptake at V10 (lb Ca/acre)	4.7 c	7.5b	4.9 c	10.3 a	4.0 c	6.9 b	4.6 c	7.6 b
S uptake at V10 (lb S/acre)	3.3 d	5.7 bc	3.6 d	7.0 a	3.4 d	5.3 c	3.8 d	6.0 b
Mg uptake at V10 (lb Mg/acre)	4.9 c	7.2 b	4.8 c	9.7 a	4.2 c	7.4 b	4.8 c	8.0 b
B uptake at V10 (lb B/acre)	0.8 c	1.2 b	0.9 c	1.6 a	0.7 c	1.3 b	0.8 c	1.3 b
Mn uptake at V10 (lb Mn/acre)	9.8 c	13.0 b	10.2 c	16.2 a	9.9 c	13.0 b	10.5 c	13.1 b
Fe uptake at V10 (lb Fe/acre)	36.2 b	50.4 b	42.0 b	70.1 a	36.4 b	42.5 b	38.4 b	42.7 b
Zn uptake at V10 (lb Zn/acre)	6.4 c	11.9 b	7.0 c	13.8 a	5.8 c	10.7 b	7.1 c	10.3 b
Cu uptake at V10 (lb Cu/acre)	1.0 d	2.5 b	1.0 d	2.8 a	1.0 d	2.2 c	1.1 d	2.4 bc
Al uptake at V10 (lb Al/acre)	25.6 a	22.6 a	25.4 a	23.3 a	23.0 a	22.3 a	27.3 a	22.5 a

[1] N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; S = sulfur; Mg = magnesium; B = boron; Mn = manganese; Fe = iron; Zn = zinc; Cu = copper; Al = aluminum.

[2] FP = farmer practice; SI = sustainable intensification.

[3] Within a row, values followed by the same letter are not statistically different at the 10% probability level.

c) To accomplish the goal/objective "*harvest plots for grain, cob, and stover, and analyze plant samples collected at harvest*," whole-plant corn samples were collected from each plot at the R6 growth stage (physiological maturity). Ears were separated from the rest of the plant (stover). Ears were dried, weighed, and shelled, after which grain and cobs were weighed separately. Stover was weighed, chipped, and sub-sampled in the field, with sub-samples weighed wet and again after drying. These data were used to calculate corn silage yield at 65% moisture content. In mid-October, plots were end-trimmed and harvested using a plot combine. Grain yield was adjusted 15.5% moisture content. A dry subsample of ground grain, cobs, and stover from each plot was analyzed for total N, P, K, calcium, magnesium, sulfur, boron, copper, iron, manganese, and zinc. Corn nutrient uptake was calculated as the product of plant dry matter yield and nutrient concentration and is shown in Tables 3-4.

Parameters of corn N uptake and N use efficiency were calculated as:

i) Apparent N fertilizer uptake efficiency = [(aboveground N uptake in treatment with N fertilization – aboveground N uptake in corresponding treatment without N fertilization) / (N fertilizer rate in treatment with N fertilization – N fertilizer rate in corresponding treatment without N fertilization)]

ii) Physiological N use efficiency = [(grain yield in treatment with N fertilization – grain yield in corresponding treatment without N fertilization) / (aboveground N uptake in treatment with N fertilization – aboveground N uptake in corresponding treatment without N fertilization)]

iii) Agronomic N use efficiency = [(grain yield in treatment with N fertilization – grain yield in corresponding treatment without N fertilization) / (N fertilizer rate in treatment with N fertilization – N fertilizer rate in corresponding treatment without N fertilization)]

With N fertilization, corn silage yield was greatest with sustainable intensification and either level of fertilizer management (28.0 tons of silage/acre), while corn grain yield was greatest with sustainable intensification and either level of fertilizer management, and with advanced fertilizer management applied to farmer-practice agronomics (average = 204 bushels of grain/acre) (Table 3). With N fertilization, silage and grain yields averaged 1.9 and 2.7 times greater, respectively, compared to when no N fertilizer was applied.

When N fertilizer was applied, grain moisture at harvest averaged 3.5 percentage points greater with sustainable intensification than farmer-practice agronomics (Table 3). This is attributed to the later-maturity hybrid (103-day) with sustainable intensification compared to farmer-practice agronomics (96-day).

Apparent fertilizer N uptake efficiency, or the increase in corn N uptake per pound of N fertilizer applied, was greatest with advanced fertilization and either level of agronomic management, and with standard fertilization + sustainable intensification (Table 3). These treatments also maximized grain yield. However, physiological N use efficiency (bushels gained per one-pound increase in corn N uptake when N fertilizer was applied) and agronomic N use efficiency (bushels gained per pound of N applied) were not significantly different among the treatments.

Corn nutrient uptake in grain, cobs, and stover at maturity was affected by agronomic management, fertilizer management, and N fertilization. Aboveground corn nutrient uptake averaged 0.6- to 4.4-fold greater with N fertilization compared to without N fertilization for all nutrients measured in this study except aluminum, which was not significantly affected by N fertilization (Tables 3 and 4). These increases in corn nutrient uptake were associated with greater grain and silage yields.

The non-N-fertilized treatments were included in this study for calculation of N use efficiency parameters. Therefore, this paragraph only refers to treatments where N fertilizer was applied. Sustainable intensification + standard fertilization maximized corn uptake of each nutrient measured in this study (Tables 3 and 4). Similarly, sustainable intensification + advanced fertilization maximized corn uptake of all nutrients except N and potassium. Corn uptake of N was greater with farmer-practice agronomics + advanced fertilization and sustainable intensification + standard fertilization compared to farmer-practice agronomics + standard fertilization and sustainable intensification + advanced fertilization. Greatest corn uptake of phosphorus occurred with advanced fertilization + either level of agronomics and standard fertilizer management + sustainable intensification. Corn uptake of potassium was greatest with sustainable intensification + standard fertilizer management, followed by sustainable intensification + advanced fertilizer management, and was least with farmer-practice agronomics and either level of fertilizer management. For sulfur, magnesium, boron, zinc, and copper, greatest uptake of these nutrients by corn occurred with sustainable intensification and either level of fertilizer management (and with farmer-practice agronomics + standard fertilization for zinc). For calcium, manganese, iron, and aluminum, uptake of these nutrients by corn was not significantly affected by the level of agronomics or fertilizer management.

Table 3. Corn yield, grain moisture at harvest, N uptake at R6 (maturity), N use efficiency parameters, and residual soil nitrate-N in the 0-40 inch depth as affected by the agronomic and fertilizer management treatments at Becker, MN in 2019. Treatment details are in Table 1.

	Treatment							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Agronomic mgt.[1]	**FP**	**FP**	**FP**	**FP**	**SI**	**SI**	**SI**	**SI**
Fertilizer mgt.	**Standard**	**Standard**	**Advanced**	**Advanced**	**Standard**	**Standard**	**Advanced**	**Advanced**
N fertilization	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
Silage yield (ton/acre at 65%)	9.2 d [2]	25.3 c	9.6 d	26.6 b	9.1 d	28.2 a	9.0 d	27.7 ab
Grain yield (bu/acre at 15.5%)	56 cd	192 b	65 c	206 a	50 d	204 ab	47 d	203 ab
Grain moisture at harvest (%)	20.5 d	20.5 d	22.8 c	20.5 d	26.5 a	23.6 c	25.1 b	23.2 c
Corn N uptake in grain, cobs, and stover at R6 (lb N/acre)	40 c	165 b	42 c	179 ab	36 c	196 a	35 c	174 b
Apparent fertilizer N uptake efficiency (lb increase in corn N uptake in grain, cobs, and stover at R6 per lb N applied)	---	0.55 a	---	0.61 ab	---	0.71 a	---	0.62 ab
Physiological N use efficiency (bushels gained per 1-lb increase in corn N uptake in grain, cobs, and stover at R6 when N was applied)	---	1.09 a	---	1.04 a	---	0.97 a	---	1.14 a
Agronomic N use efficiency (bushels gained per lb N applied)	---	0.60 a	---	0.63 a	---	0.68 a	---	0.70 a
Residual soil nitrate-N after harvest in the 0-40 inch depth (lb nitrate-N/acre)	29 b	38 ab	32 b	50 a	27 b	38 ab	26 b	40 ab

[1] FP = farmer practice; SI = sustainable intensification.

[2] Within a row, values followed by the same letter are not statistically different at the 10% probability level.

d) To accomplish the goal/objective "*collect soil samples after harvest and analyze*," soil samples were collected after harvest in early November to a depth of 40 inches and were processed and analyzed for bulk density and nutrients. When N fertilizer was applied, residual soil nitrate-N in the 0- to 40-cm depth was not significantly different among the four combinations of agronomics and fertilizer management and ranged from 38 to 50 lb/acre (Table 3).

Soil-test levels from the fall of 2019 show that the treatments in this study did not affect soil pH, organic matter, cation exchange capacity, electrical conductivity, potassium, calcium, sulfur, magnesium, boron, manganese, iron, zinc, copper, or sodium for any depth increment within the 0- to 40-inch soil profile (Tables 5-8).

Table 4. Corn uptake of nutrients other than N in grain, cobs, and stover at R6 (maturity) as affected by the agronomic and fertilizer management treatments at Becker, MN in 2019. Treatment details are in Table 1.[1]

	Treatment							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Agronomic mgt.[2]	**FP**	**FP**	**FP**	**FP**	**SI**	**SI**	**SI**	**SI**
Fertilizer mgt.	**Standard**	**Standard**	**Advanced**	**Advanced**	**Standard**	**Standard**	**Advanced**	**Advanced**
N fertilization	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
Corn P uptake in grain, cobs, and stover at R6 (lb P/acre)	15 c [3]	22 b	16 c	25 ab	14 c	26 a	17 c	24 ab
Corn K uptake in grain, cobs, and stover at R6 (lb K/acre)	57 d	131 c	51 d	127 c	58 d	171 a	62 d	149 b
Corn Ca uptake in grain, cobs, and stover at R6 (lb Ca/acre)	6 b	19 a	6 b	18 a	6 b	21 a	7 b	20 a
Corn S uptake in grain, cobs, and stover at R6 (lb S/acre)	6 c	14 b	6 c	14 b	6 c	16 a	6 c	16 a
Corn Mg uptake in grain, cobs, and stover at R6 (lb Mg/acre)	10 c	22 b	10 c	20 b	12 c	26 a	12 c	25 a
Corn B uptake in grain, cobs, and stover at R6 (lb B/acre)	1.2 c	2.8 b	1.2 c	2.8 b	1.0 c	3.5 a	1.1 c	3.4 a
Corn Mn uptake in grain, cobs, and stover at R6 (lb Mn/acre)	20 bc	37 a	16 c	40 a	23 b	39 a	22 bc	41 a
Corn Fe uptake in grain, cobs, and stover at R6 (lb Fe/acre)	89 b	128 a	60 c	125 a	71 bc	129 a	86 b	128 a
Corn Zn uptake in grain, cobs, and stover at R6 (lb Zn/acre)	16 c	31 a	17 c	28 b	17 c	33 a	17 c	32 a
Corn Cu uptake in grain, cobs, and stover at R6 (lb Cu/acre)	1.3 d	6.8 b	1.2 d	6.0 c	1.3 d	7.5 a	1.4 d	8.0 a
Corn Al uptake in grain, cobs, and stover at R6 (lb Al/acre)	95 a	81 a	51a	80 a	72 a	70 a	88 a	74 a

[1] N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; S = sulfur; Mg = magnesium; B = boron; Mn = manganese; Fe = iron; Zn = zinc; Cu = copper; Al = aluminum.

[2] FP = farmer practice; SI = sustainable intensification.

[3] Within a row, values followed by the same letter are not statistically different at the 10% probability level.

Table 5. Soil-test pH, organic matter, cation exchange capacity, and electrical conductivity by depth in the fall of 2019 for the agronomic and fertilizer management treatments at Becker, MN. Treatment details are in Table 1.

		Treatment							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Agronomic mgt.[1]	**FP**	**FP**	**FP**	**FP**	**SI**	**SI**	**SI**	**SI**
	Fertilizer mgt.	**Standard**	**Standard**	**Advanced**	**Advanced**	**Standard**	**Standard**	**Advanced**	**Advanced**
Soil test	**N fertilizer**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
	Depth (inches)								
pH	0-2	6.8 a [2]	6.5 a	6.6 a	6.3 a	6.6 a	6.3 a	6.6 a	6.5 a
	2-4	6.6 a	6.6 a	6.6 a	6.5 a	6.5 a	6.5 a	6.9 a	6.5 a
	4-8	6.4 a	6.4 a	6.5 a	6.2 a	6.1 a	6.2 a	6.5 a	6.2 a
	8-12	5.7 a	5.7 a	5.7 a	5.4 a	5.6 a	5.6 a	6.0 a	5.7 a
	12-24	6.1 a	5.7 a	5.9 a	5.6 a	5.9 a	5.7 a	6.1 a	5.9 a
	24-40	6.9 a	6.9 a	6.1 a	6.1 a	6.4 a	6.1 a	7.3 a	6.8 a
Organic matter (%)	0-2	2.6 a	2.7 a	2.6 a	2.8 a	2.9 a	2.9 a	2.3 a	2.4 a
	2-4	2.4 a	2.6 a	2.5 a	2.8 a	2.8 a	2.8 a	2.2 a	2.4 a
	4-8	2.5 a	2.4 a	2.2 a	3.0 a	2.6 a	2.5 a	2.2 a	2.2 a
	8-12	2.1 a	2.1 a	2.6 a	2.7 a	3.0 a	2.8 a	2.0 a	1.9 a
	12-24	1.0 a	0.9 a	1.7 a	1.0 a	1.5 a	1.5 a	1.0 a	0.8 a
	24-40	0.3 a	0.3 a	0.6 a	0.4 a	0.6 a	0.5 a	0.3 a	0.3 a
Cation exchange capacity by summation (meq/100 g)	0-2	9.5 a	11.5 a	8.6 a	12.8 a	13.2 a	12.2 a	9.7 a	8.5 a
	2-4	10.0 a	10.2 a	9.7 a	11.2 a	10.3 a	9.1 a	7.3 a	10.4 a
	4-8	12.7 a	11.2 a	10.5 a	13.1 a	12.5 a	11.7 a	10.6 a	11.8 a
	8-12	12.8 a	13.4 a	12.6 a	13.4 a	13.5 a	12.5 a	13.2 a	12.3 a
	12-24	7.1 a	8.0 a	12.8 a	8.0 a	10.9 a	10.2 a	8.3 a	6.2 a
	24-40	4.1 a	3.8 a	4.3 a	3.4 a	4.2 a	3.4 a	4.0 a	3.6 a
Electrical conductivity (mmhos/cm)	0-2	0.123 a	0.123 a	0.145 a	0.145 a	0.118 a	0.123 a	0.128 a	0.135 a
	2-4	0.160 a	0.125 a	0.158 a	0.153 a	0.130 a	0.120 a	0.128 a	0.128 a
	4-8	0.123 a	0.115 a	0.113 a	0.135 a	0.113 a	0.115 a	0.150 a	0.113 a
	8-12	0.115 a	0.115 a	0.105 a	0.155 a	0.145 a	0.125 a	0.115 a	0.115 a
	12-24	0.105 a	0.123 a	0.123 a	0.148 a	0.103 a	0.100 a	0.118 a	0.113 a
	24-40	0.113 a	0.115 a	0.133 a	0.135 a	0.113 a	0.135 a	0.118 a	0.128 a

[1] FP = farmer practice; SI = sustainable intensification.

[2] Within a depth for a given soil test, values followed by the same letter are not statistically different at the 10% probability level.

Table 6. Soil-test Bray-1 phosphorus, Olsen phosphorus, potassium, and calcium by depth in the fall of 2019 for the agronomic and fertilizer management treatments at Becker, MN. Treatment details are in Table 1.

		Treatment							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Agronomic mgt.[1]	**FP**	**FP**	**FP**	**FP**	**SI**	**SI**	**SI**	**SI**
	Fertilizer mgt.	**Standard**	**Standard**	**Advanced**	**Advanced**	**Standard**	**Standard**	**Advanced**	**Advanced**
Soil test	**N fertilizer**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
	Depth (inches)								
Bray-1 phosphorus (ppm)	0-2	10 c [2]	11 c	21 a	16 b	12 c	12 c	13 bc	13 bc
	2-4	9 bc	8 c	17 a	11 bc	10 bc	10 bc	11 bc	12 b
	4-8	7 b	9 ab	10 ab	10 ab	9 ab	12 a	8 b	8 b
	8-12	7 a	6 a	7 a	6 a	6 a	7 a	6 a	8 a
	12-24	7 a	6 a	7 a	6 a	6 a	6 a	6 a	6 a
	24-40	7 a	6 a	9 a	7 a	7 a	8 a	7 a	6 a
Olsen phosphorus (ppm)	0-2	7.2 c	7.5 c	11.0 a	9.7 ab	7.7 c	7.5 c	9.1 b	7.7 c
	2-4	6.8 b	6.8 b	8.8 a	7.6 b	6.5 b	6.6 b	8.1 a	7.4 b
	4-8	6.2 a	7.4 a	6.7 a	7.5 a	6.7 a	6.7 a	6.3 a	6.9 a
	8-12	6.5 a	6.4 a	6.6 a	6.7 a	6.9 a	7.0 a	6.3 a	6.7 a
	12-24	6.7 a	6.5 a	5.7 a	5.5 a	5.9 a	6.4 a	6.2 a	5.6 a
	24-40	6.8 ab	6.1 ab	6.7 ab	6.3 ab	7.3 ab	6.8 ab	5.9 b	6.3 ab
Potassium (ppm)	0-2	142 a	151 a	137 a	161 a	143 a	192 a	135 a	115 a
	2-4	122 a	94 a	121 a	104 a	126 a	93 a	114 a	92 a
	4-8	78 a	59 a	79 a	73 a	70 a	64 a	71 a	51 a
	8-12	35 a	36 a	43 a	38 a	41 a	42 a	36 a	36 a
	12-24	26 a	25 a	27 a	25 a	29 a	33 a	24 a	37 a
	24-40	17 a	19 a	19 a	20 a	24 a	20 a	17 a	16 a
Calcium (ppm)	0-2	1134 a	1101 a	1025 a	1094 a	1155 a	1126 a	1106 a	1007 a
	2-4	1127 a	1125 a	1117 a	1174 a	1113 a	1146 a	1028 a	1070 a
	4-8	1106 a	1097 a	1042 a	1150 a	1008 a	1132 a	1051 a	917 a
	8-12	720 a	754 a	777 a	769 a	932 a	886 a	790 a	671 a
	12-24	511 a	549 a	831 a	565 a	834 a	726 a	561 a	441 a
	24-40	561 a	522 a	403 a	354 a	483 a	345 a	547 a	425 a

[1] FP = farmer practice; SI = sustainable intensification.

[2] Within a depth for a given soil test, values followed by the same letter are not statistically different at the 10% probability level.

Table 7. Soil-test sulfur, magnesium, boron, and manganese by depth in the fall of 2019 for the agronomic and fertilizer management treatments at Becker, MN. Treatment details are in Table 1.

		Treatment							
		1	2	3	4	5	6	7	8
	Agronomic mgt.[1]	**FP**	**FP**	**FP**	**FP**	**SI**	**SI**	**SI**	**SI**
	Fertilizer mgt.	**Standard**	**Standard**	**Advanced**	**Advanced**	**Standard**	**Standard**	**Advanced**	**Advanced**
Soil test	**N fertilizer**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
	Depth (inches)								
Sulfur (ppm)	0-2	36.5 a [2]	36.7 a	34.0 a	38.7 a	42.2 a	41.2 a	34.8 a	37.3 a
	2-4	36.6 a	40.2 a	37.9 a	40.7 a	40.7 a	38.6 a	37.8 a	39.4 a
	4-8	43.8 a	47.1 a	38.7 a	47.4 a	45.8 a	44.7 a	43.3 a	45.9 a
	8-12	52.1 a	56.0 a	53.1 a	56.8 a	52.6 a	51.4 a	56.6 a	49.3 a
	12-24	27.7 a	32.0 a	37.9 a	38.0 a	34.4 a	35.7 a	35.7 a	26.5 a
	24-40	7.0 a	7.6 a	15.8 a	12.1 a	11.3 a	9.4 a	7.6 a	6.8 a
Magnesium (ppm)	0-2	244 a	226 a	219 a	222 a	246 a	225 a	231 a	199 a
	2-4	248 a	244 a	247 a	255 a	243 a	245 a	214 a	217 a
	4-8	264 a	271 a	251 a	284 a	246 a	268 a	245 a	216 a
	8-12	206 a	224 a	220 a	208 a	227 a	227 a	206 a	192 a
	12-24	105 a	104 a	145 a	94 a	134 a	148 a	104 a	96 a
	24-40	56 a	53 a	53 a	43 a	58 a	48 a	58 a	52 a
Boron (ppm)	0-2	0.38 a	0.39 a	0.36 a	0.44 a	0.36 a	0.39 a	0.33 a	0.35 a
	2-4	0.41 a	0.39 a	0.35 a	0.44 a	0.38 a	0.37 a	0.32 a	0.38 a
	4-8	0.40 a	0.37 a	0.40 a	0.41 a	0.40 a	0.41 a	0.33 a	0.39 a
	8-12	0.36 a	0.40 a	0.42 a	0.42 a	0.44 a	0.36 a	0.31 a	0.36 a
	12-24	0.23 a	0.24 a	0.30 a	0.25 a	0.31 a	0.26 a	0.23 a	0.25 a
	24-40	0.16 a	0.14 a	0.18 a	0.17 a	0.19 a	0.17 a	0.15 a	0.17 a
Manganese (ppm)	0-2	12.5 a	17.7 a	13.1 a	20.9 a	17.7 a	19.0 a	11.8 a	15.5 a
	2-4	14.9 a	14.9 a	15.1 a	18.1 a	15.9 a	15.5 a	11.1 a	13.5 a
	4-8	13.2 a	12.8 a	10.6 a	16.2 a	18.1 a	12.0 a	9.7 a	11.4 a
	8-12	19.8 a	25.9 a	37.2 a	34.2 a	42.7 a	28.6 a	20.4 a	20.7 a
	12-24	7.4 a	9.3 a	8.8 a	10.1 a	7.9 a	12.0 a	10.9 a	6.3 a
	24-40	5.8 a	7.2 a	5.8 a	6.3 a	6.1 a	5.7 a	6.3 a	5.4 a

[1] FP = farmer practice; SI = sustainable intensification.

[2] Within a depth for a given soil test, values followed by the same letter are not statistically different at the 10% probability level.

Table 8. Soil-test iron, zinc, copper, and sodium by depth in the fall of 2019 for the agronomic and fertilizer management treatments at Becker, MN. Treatment details are in Table 1.

		Treatment							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Agronomic mgt.[1]	**FP**	**FP**	**FP**	**FP**	**SI**	**SI**	**SI**	**SI**
	Fertilizer mgt.	**Standard**	**Standard**	**Advanced**	**Advanced**	**Standard**	**Standard**	**Advanced**	**Advanced**
Soil test	**N fertilizer**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
	Depth (inches)								
Iron (ppm)	0-2	38 a [2]	43 a	37 a	51 a	48 a	48 a	35 a	42 a
	2-4	47 a	45 a	47 a	54 a	51 a	48 a	35 a	44 a
	4-8	50 a	52 a	49 a	60 a	66 a	53 a	43 a	52 a
	8-12	61 a	103 a	89 a	95 a	120 a	81 a	60 a	68 a
	12-24	35 a	37 a	43 a	40 a	44 a	48 a	34 a	31 a
	24-40	25 a	25 a	27 a	26 a	29 a	26 a	26 a	25 a
Zinc (ppm)	0-2	3.25 a	3.25 a	3.18 a	3.93 a	3.60 a	3.70 a	3.47 a	3.07 a
	2-4	3.29 a	3.23 a	3.23 a	3.59 a	3.51 a	3.72 a	3.37 a	2.94 a
	4-8	2.25 a	2.19 a	2.37 a	2.72 a	2.90 a	2.55 a	2.01 a	1.92 a
	8-12	1.56 a	1.43 a	2.65 a	1.82 a	2.71 a	2.12 a	1.27 a	1.48 a
	12-24	0.33 a	0.21 a	0.62 a	0.33 a	0.46 a	0.57 a	0.45 a	0.17 a
	24-40	0.20 a	0.39 a	0.36 a	0.43 a	0.31 a	0.21 a	0.26 a	0.22 a
Copper (ppm)	0-2	0.56 a	0.70 a	0.52 a	0.68 a	0.71 a	0.75 a	0.54 a	0.55 a
	2-4	0.70 a	0.70 a	0.59 a	0.64 a	0.81 a	0.74 a	0.54 a	0.59 a
	4-8	0.65 a	0.65 a	0.63 a	0.75 a	0.89 a	0.74 a	0.65 a	0.61 a
	8-12	0.63 a	0.62 a	0.82 a	0.76 a	0.91 a	0.89 a	0.68 a	0.58 a
	12-24	0.30 a	0.29 a	0.47 a	0.31 a	0.54 a	0.64 a	0.34 a	0.28 a
	24-40	0.07 a	0.06 a	0.11 a	0.04 a	0.17 a	0.14 a	0.09 a	0.11 a
Sodium (ppm)	0-2	11.3 a	11.0 a	11.0 a	11.8 a	13.3 a	12.3 a	12.7 a	11.8 a
	2-4	12.0 a	12.3 a	12.5 a	13.3 a	11.8 a	11.8 a	13.3 a	11.5 a
	4-8	12.5 a	12.8 a	11.5 a	13.3 a	12.0 a	12.8 a	14.5 a	11.5 a
	8-12	14.5 a	12.8 a	12.8 a	12.5 a	13.0 a	14.8 a	13.3 a	12.5 a
	12-24	14.0 a	11.5 a	13.0 a	11.3 a	12.0 a	12.8 a	12.3 a	11.3 a
	24-40	10.5 a	10.8 a	11.5 a	11.0 a	11.8 a	10.5 a	11.8 a	10.3 a

[1] FP = farmer practice; SI = sustainable intensification.

[2] Within a depth for a given soil test, values followed by the same letter are not statistically different at the 10% probability level.

Within the 0- to 2- and 2- to 4-inch soil depths, Bray-1 phosphorus averaged 40 and 38% greater, respectively, and Olsen phosphorus averaged 25 and 19% greater, respectively, with advanced fertilizer management compared to standard fertilizer management (Table 6). In deeper soil layers, differences in Bray-1 and Olsen phosphorus among the treatments were not significantly different or were relatively inconsequential from an agronomic standpoint.

e) To accomplish the goal/objective "*manage plots in the fall*," plots were managed as appropriate. This involved chopping corn stalks during harvest with a chopping corn head on the combine. Following soil sampling, the trial area was disk-ripped.

f) To accomplish the goal/objective "*research results to farmers and agricultural professionals and Extension meetings*," results from this research were presented to farmers and agricultural professionals at Extension meetings across Minnesota.

3) MULTI-YEAR SUMMARY FOR KEY METRICS OF CROPPING SYSTEM PERFORMANCE

Table 9. Corn grain yield for treatments with N fertilization at Becker, MN. Treatment details are in Table 1.

Agronomic mgt. [1]	**Fertilizer mgt.**	**Total N applied**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**6-year avg.**
		lb N/acre	bu/acre						
FP	Standard	210-230	159 c [2]	163 d	190 c	169 c	169 c	192 b	174 c
FP	Advanced	210-230	192 ab	183 c	189 c	192 b	207 a	206 a	195 b
SI	Standard	210-230	180 b	197 b	209 b	171 c	190 b	204 ab	192 b
SI	Advanced	210-230	205 a	222 a	229 a	224 a	190 b	203 ab	212 a

[1] FP = farmer practice; SI = sustainable intensification.

[2] Within a column, values followed by the same letter are not statistically different at the 10% probability level.

<u>Key findings for grain yield</u>:

1) There was a yield gap of 14 to 59 bu/acre between treatments with highest and lowest yields. Averaged across years, this yield gap was 39 bu/acre or 22%.
2) Greatest 6-year average yield occurred with advanced fertilizer management + sustainable intensification.
3) Intermediate 6-year average yield occurred with either advanced fertilizer management + farmer-practice agronomics or standard fertilizer management + sustainable intensification.

Table 10. Net economic net for treatments with N fertilization at Becker, MN. Treatment details are in Table 1.

Agronomic mgt. [1]	Fertilizer mgt.	Added inputs	2014	2015	2016	2017	2018	2019	6-year avg.
		$/acre	------- change in net return after drying + inputs, $/acre -------						
FP	Standard	-	-	-	-	-	-	-	-
FP	Advanced	38-52	44	16	-54	12	73	8	17
SI	Standard	18	28	84	31	-6	19	-7	25
SI	Advanced	56-70	36	101	42	17	-17	-44	17

[1] FP = farmer practice; SI = ecological intensification.

Key findings for net economic return:

1) When compared to farmer-practice agronomics + standard fertilizer management, net economic return was significantly greater with either farmer-practice agronomics + advanced fertilizer management or sustainable intensification + standard fertilizer management in 3 of 6 years and on average.
2) When compared to farmer-practice agronomics + standard fertilizer management, net economic return was significantly greater with advanced fertilizer management + sustainable intensification in 4 of 6 years and on average.
3) Across years, net economic return was greatest with standard fertilizer management + sustainable intensification, but this was only $8/acre greater than that with advanced fertilizer management and either level of agronomic management.

Table 11. Agronomic N use efficiency at Becker, MN. Treatment details are in Table 1.

Agronomic mgt. [1]	Fertilizer mgt.	Total N applied	2014	2015	2016	2017	2018	2019	6-year avg.
		lb N/acre	------------ increase in yield (bu/acre) per lb N applied ------------						
FP	Standard	210-230	0.61 c [2]	0.65 c	0.77 c	0.70 c	0.58 b	0.60 a	0.65 c
FP	Advanced	210-230	0.77 a	0.79 b	0.78 bc	0.82 b	0.73 a	0.63 a	0.75 ab
SI	Standard	210-230	0.69 b	0.82 b	0.84 ab	0.68 c	0.69 a	0.68 a	0.73 b
SI	Advanced	210-230	0.77 a	0.91 a	0.88 a	0.91 a	0.71 a	0.70 a	0.81 a

[1] FP = farmer practice; SI = sustainable intensification.

[2] Within a column, values followed by the same letter are not statistically different at the 10% probability level.

Key findings for agronomic N use efficiency:

1) In 4 of 6 years and on average with farmer-practice agronomics, greater agronomic N use efficiency occurred with advanced compared to standard fertilizer management.
2) In 3 of 6 years and on average with sustainable intensification, greater agronomic N use efficiency occurred with advanced compared to standard fertilizer management.

3) In all years and on average, agronomic N use efficiency was maximized with advanced fertilizer management + sustainable intensification.

Table 12. Corn N recovery efficiency at Becker, MN. Treatment details are in Table 1.

Agronomic mgt. [1]	Fertilizer mgt.	Total N applied	2014	2015	2016	2017	2018	2019	6-year avg.
		lb N/acre	----------- increase in N uptake (lb N/acre) per lb N applied -----------						
FP	Standard	210-230	0.36 b [2]	0.48 b	0.56 b	0.53 c	0.38 c	0.55 b	0.48 c
FP	Advanced	210-230	0.60 a	0.56 a	0.59 b	0.65 b	0.59 a	0.61 ab	0.60 a
SI	Standard	210-230	0.44 b	0.56 a	0.54 b	0.49 c	0.48 b	0.71 a	0.54 b
SI	Advanced	210-230	0.57 a	0.60 a	0.67 a	0.72 a	0.50 a	0.62 ab	0.61 a

[1] FP = farmer practice; SI = sustainable intensification.

[2] Within a column, values followed by the same letter are not statistically different at the 10% probability level.

<u>Key findings for corn N recovery efficiency</u>:

1) In all years and on average, corn N recovery efficiency was maximized with advanced fertilizer management + sustainable intensification. Advanced fertilizer management + farmer-practice agronomics had comparable corn N recovery efficiency in 4 of 6 years and on average.

Table 13. Residual soil nitrate-N after harvest in the 0- to 40-inch depth for treatments with N fertilization at Becker, MN. Treatment details are in Table 1.

Agronomic mgt. [1]	Fertilizer mgt.	Total N applied	2014	2015	2016	2017	2018	2019	6-year avg.
		lb N/acre	lb nitrate-N/acre						
FP	Standard	210-230	16 b [2]	26 a	19 a	19 a	16 b	38 ab	22 a
FP	Advanced	210-230	14 b	30 a	22 a	13 b	20 a	50 a	25 a
SI	Standard	210-230	12 b	30 a	19 a	13 b	18 ab	38 ab	22 a
SI	Advanced	210-230	25 a	30 a	22 a	12 b	12 c	40 ab	24 a

[1] FP = farmer practice; SI = sustainable intensification.

[2] Within a column, values followed by the same letter are not statistically different at the 10% probability level.

<u>Key findings for residual soil nitrate-N after harvest in the 0- to 40-inch depth</u>:

1) In 3 of 6 years and on average, residual soil nitrate-N after harvest in the 0- to 40-inch depth was not significantly different among the four treatments that received N fertilization.

2) In 1 of 6 years (2014), residual soil nitrate-N after harvest in the 0- to 40-inch depth was greater with advanced fertilizer management + sustainable intensification compared to the other treatments.

3) In 1 of 6 years (2017), residual soil nitrate-N after harvest in the 0- to 40-inch depth was greater with standard fertilizer management + farmer-practice agronomics compared to the other treatments