Integrating 4R Nutrient Management and Soil Health to Optimize Michigan Corn Production
FINAL Report 2015

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Location: South Campus Research Farm	**Tillage**: Conventional
Planting Date: May 01, 2015; 30 in. rows	**N Timing, Rate, and Source**: See below
Soil Type: Capac Loam; 3.4 OM, 13.1 CEC; 36 ppm P; 91 ppm K; 6.5 pH	**Population**: 34,000 seeds/ acre
Variety: DKC48-12RIB	**Replicated**: 4 replications

Location: South Campus Research Farm	**Tillage**: Conventional
Planting Date: Cover Crops: August 14, 2014; 7.5 in. rows Corn: May 01, 2015; 30 in. rows	**Cover Crops, N Timing, Rate, and Source**: See below
Soil Type: Capac Loam; 2.5 OM, 6.1 CEC; 57 ppm P; 101 ppm K; 6.1 pH	**Population**: Covers: See below Corn: 34,000 seeds/ acre
Variety: DKC48-12RIB	**Replicated**: 4 replications

Location: Saginaw Valley Research and Extension Center	**Tillage**: Conventional
Planting Date: April 28, 2015; 30 in. rows	**N Timing, Rate, and Source**: See below
Soil Type: Tappan Londo Loam; 2.7 OM, 13.3 CEC; 19 ppm P; 138 ppm K; 7.6 pH	**Population**: 34,000 seeds/ acre
Variety: DKC48-12RIB	**Replicated**: 4 replications

Introduction: Increased variability in spring and summer weather, volatile pricing, and continued degradation of Great Lakes Basin surface- and ground-water quality all continue to emphasize improved nitrogen (N) management strategies in relation to corn N response. In an attempt to address economic, social, and environmental concerns over nutrient management, the world fertilizer industry has adopted *4R Nutrient Stewardship*. This concept emphasizes applying the right source of N, at the right rate, at the right time, and in the right place. However implementation of the 4R practices are both state and site-specific and require further investigation as to best management practices for the state of Michigan.

Although N fertilizer recommendations are a straightforward calculation based on crop demand minus N contributions from soil, N placement and timing are key factors in more closely synchronizing N availability with peak corn N demand. The greatest potential for N loss occurs 1) during wet, warm conditions, and 2) when soil nitrate is present without active crop growth. Applying N closer to the time of corn N uptake minimizes these two factors and improves efficiency from both a yield and environmental risk perspective. With advances in application technology including pre-tassel coulter N injection, there is a critical need to identify corn response and efficiency to new N fertilization strategies that demonstrate Michigan corn producers' commitment to both economic returns and environmental stewardship.

Plants, soils, and soil microbes all function simultaneously to manipulate and influence each other and plant productivity. Healthy soils are more productive due to the increased ability to tolerate stress thus requiring fewer inputs, retaining more soil moisture, and improving soil physical properties. Growing two crops to harvest one may be warranted with the first crop being microbial activity and the second being the cash crop of interest. There is very little information available regarding how to support or promote diverse populations of soil microbes. The question that remains unanswered is to identify to what extent management and cultural factors influence microbial activity and soil health which in turn may impact the ability of the soil to produce a healthy plant.

Objective 1: Develop a series of N management strategies based on 4R Nutrient Stewardship that take into account N placement and N timing to increase corn nitrogen use efficiency.

Objective 2: Determine the effects of cover crops individually and in combination with 4R Nutrient Stewardship on temporal changes in soil health including soil and rhizosphere microbial community composition (soil biology) and corn yield. Our *working hypothesis* is that specific categories of cover crop (N scavenger, biomass producer, or none) will differentially affect soil health, and different approaches to 4R nutrient management may have different results when practiced in combination with a specific cover crop. Early season increases in soil microbial activity through a mix of carbon substrates in the form of readily decomposable cover crop residues, organic fertility, and inorganic fertility will positively affect corn yield in a manner not achieved through conventional N, P, K fertilization.

To achieve objective #1:

Methods and Procedures: Trial was planted in Lansing and Richville, MI under non-irrigated conditions following soybean. Nitrogen rates were equalized at each site based on MRTN recommendations to 140 lbs N/A in Lansing and 180 lbs N/A in Richville. Ammonium polyphosphate (10-34-0) was used as the N source for in-furrow applications while UAN was used for V4-6 sidedress injected treatments and V10-12 applications. Herbrucks dried poultry litter was used as an organic N source while Environmentally Smart Nitrogen (ESN®) was used as the PCU N source. To maintain soil P and K levels, monoammonium phosphate was applied pre-plant incorporated at 30 and 80 lbs P_2O_5/A at Lansing and Richville, respectively, while muriate of potash was applied at 80 and 60 lbs K_2O/A at Lansing and Richville, respectively.

Treatments:

1) Lansing, MI

Trt #	N Rate (lb. N/A)	N Placement and Timing
1	0	Untreated Control
2	140	Pop-up (7 lbs N), Sidedress injected (V4)
3	140	Pop-up (7 lbs N), Pre-tassel (V10-11)
4	140	Pop-up (7 lbs N), 50% Sidedress injected (V4), 50% Pre-tassel (V10-11)
5	140	Pre-plant Incorporated
6	140	Pre-plant Incorporated with a 75:25 split of PCU/Urea
7	140	1 T/A poultry manure PPI, Pre-tassel (V10-11)
8	140	2x2 (40 lbs N), Sidedress injected (V4)
9	140	2x2 (40 lbs N), Pre-tassel (V10-11)
10	140	2x2 (40 lbs N), 50% Sidedress injected (V4), 50% Pre-tassel (V10-11)

-A starter fertilizer was applied at planting, pre-plant incorporated, of 30 lbs P_2O_5 and 80 lbs K_2O.
-Pop-up (10-34-0) provided 23.9 lbs P_2O_5 / A.
-Pop-up, pre-plant incorporated, and 2x2 occurred at planting 5/01/2015.
-V4-6 Sidedress injection occurred on 6/02/2015. V10-12 Sidedress occurred on 6/29/2015.
-Trial was harvested 10/14/2015.

2) Richville, MI (Saginaw Valley Research and Extension Center)

Trt #	N Rate (lb. N/A)	N Placement and Timing
1	0	Untreated Control
2	180	Pop-up (7 lbs N), Sidedress injected (V4)
3	180	Pop-up (7 lbs N), Pre-tassel (V10)
4	180	Pop-up (7 lbs N), 50% Sidedress injected (V4), 50% Pre-tassel (V10)
5	180	Pre-plant Incorporated
6	180	Pre-plant Incorporated with a 75:25 split of PCU/Urea
7	180	1 T/A poultry manure PPI, Pre-tassel (V10)
8	180	2x2 (40 lbs N), Sidedress injected (V4)
9	180	2x2 (40 lbs N), Pre-tassel (V10)
10	180	2x2 (40 lbs N), 50% Sidedress injected (V4), 50% Pre-tassel (V10)

-A starter fertilizer was applied at planting, pre-plant incorporated, of 80 lbs P_2O_5 and 60 lbs K_2O.
-Pop-up (10-34-0) provided 23.9 lbs P_2O_5 / A.
-Pop-up, pre-plant incorporated, and 2x2 occurred at planting 4/28/2015.
-V4-6 Sidedress injection occurred on 5/28/2015. V10-12 Sidedress occurred on 6/25/2015.
-Trial was harvested 10/19/2015.

Results and Discussion:

Lansing:

Corn N strategy utilizing either pop-up, 2x2, PPI N applications resulted in similar grain yields (Table 1). Monthly rainfall was variable from April to October with April 69% below the

30-yr mean resulting in dry soil conditions at planting on May 1st (Fig. 1). A lack of early-season heavy rainfall events may have prevented some degree of N loss in pre-plant incorporated applications and hindered the effectiveness of substituting urea with ESN. When poultry litter was followed with a V10-11 sidedress application a 31 bu/a yield increase was observed vs. the remaining PPI treatments (i.e., treatments 5 and 6) (Table 2). Cumulative June rainfall was 116% above the 30-yr monthly average and may have influenced N loss conditions with 6 events in excess of 0.5 in. (Fig. 1). Fewer growing degree days (GDD) during grain fill may have reduced test weight across all N strategies as July 1 to August 31 GDD's were 42 units behind the 30-yr mean.

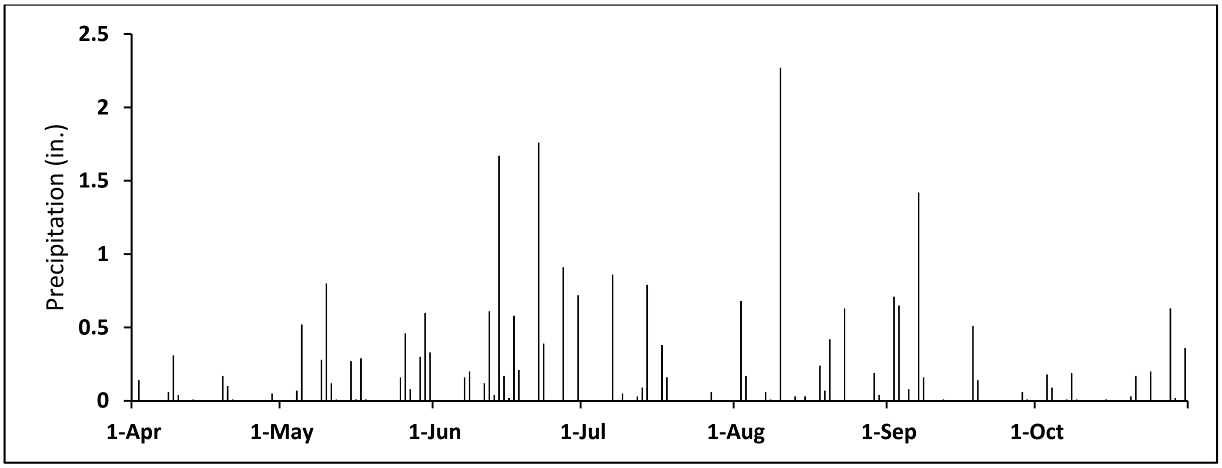

Figure 1. 2015 Lansing precipitation

Precipitation Summary:

- Total rainfall between At-Plant applications and 7/13/15: 12.9 inches.
- Total rainfall between At-Plant applications and V4 sidedress: 4.3 inches.
- Total rainfall between At-Plant applications and V10-11 sidedress: 11.2 inches.
- Apr (0.89 in.), May (4.31 in.), June (7.56 in.), July (2.42 in.), Aug (4.84 in.), Sept (3.75 in.), Oct (1.90 in.), and Nov (1.22 in.)

Table 1. Lansing: Effects of N strategy on grain yield, moisture, and test weight.

Trt No.	Method	Treatment	Yield —— bu/A ——	Moisture —— % ——	Test weight —— lbs/bu ——
2	Pop-up	popup+V4	201.8	16.8 c†	52.4 a
3		popup+V11			
4		popup+V4+V11			
5	PPI's	PPI	200.3	17.4 b	51.6 b
6		PPI ESN/Urea			
7		PPI+V11			
8	2x2	2x2+V4	205.0	19.1 a	51.4 b
9		2x2+V11			
10		2x2+V4+V11			
LSD			NS	0.6	0.5
Pr > F			0.7104	<.0001	0.0028
Unfertilized Control Means			94.0	16.7	51.4

† Means in the same column followed by the same letter are not significantly different (F-test, α=0.10).

Synchronizing N availability with active crop N uptake may increase the efficiency of N use by reducing the number of opportunities for N loss. Data from the 2015 Lansing site suggest when utilizing pop-up and 2x2 starter N strategies, delaying the majority of corn N application until V10-11 may have reduced opportunities for N loss, but did not significantly increase the opportunity for positive yield gains as compared to early season V4 applications (Table 2). When pop-ups were followed with a split N application at SD V4/V10 a non-significant 8 bu/A yield gain was observed compared to the V10 SD application indicating that some yield potential may be lost when N applications are delayed until V10 (Table 2). However, data in Table 2 demonstrate that growers missing the opportunity to apply early-season N can still attain similar corn yields with late season rescue N applications where early-season rainfall is conducive to N loss opportunities.

Table 2. Lansing: Within N strategy, effects of N timing on grain yield, moisture, and test weight.

Trt No.	Treatment	Yield	Moisture	Test weight
		—— bu/A ——	—— % ——	—— lbs/bu ——
2	popup+V4	193.8	16.4	52.5
3	popup+V11	201.9	16.7	52.4
4	popup+V4+V11	209.6	17.3	52.3
	LSD (*p* < 0.10)	NS	NS	NS
	Pr* > *F	0.2424	0.5501	0.8062
5	PPI	189.6 b†	17.3	51.8
6	PPI ESN/Urea	190.5 b	17.1	51.3
7	PPI+V11	220.9 a	18.0	51.7
	LSD	22.1	NS	NS
	Pr* > *F	0.0545	0.2850	0.3294
8	2x2+V4	204.2	18.8	51.9
9	2x2+V11	209.3	19.1	51.7
10	2x2+V4+V11	201.6	19.5	50.6
	LSD	NS	NS	NS
	Pr* > *F	0.2718	0.5548	0.1901

† Means in the same column followed by the same letter are not significantly different (F-test, α=0.10).

Richville:

Unlike the Lansing location where spring rainfall increased opportunities for N loss, a rainfall deficit of 3.93 in was observed Apr 1 to Sep 30. (Fig. 2) at the Richville location. Corn N strategies utilizing either pop-up or 2x2 starter applications increased mean grain yield 10 bu/a as compared to pre-plant incorporated applications (Table 3). This was probably influenced by dry early season soil conditions limiting N movement to the plant. Similar to the Lansing location, when poultry litter was followed with a V10-11 SD N application grain yields were increased 13 bu/a relative to a single PPI urea application. Pop-up and 2x2 strategies resulted in similar yield levels. Low test weights (<56 lbs/bu) were also an issue at Richville regardless of N strategy. Fewer growing degree days (GDD) during grain fill may have reduced test weights across all N strategies as July 1 to Aug 31 GDD's were 75 units behind the 30-yr mean.

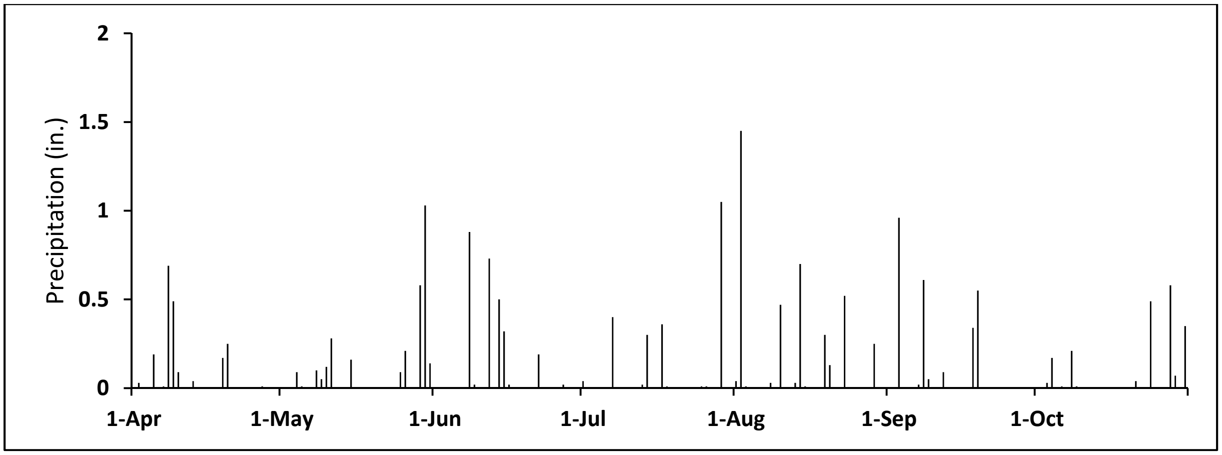

Figure 2. 2015 Richville precipitation

Precipitation Summary:

- Total rainfall between At-Plant applications and 7/13/15: 6.00 inches.
- Total rainfall between At-Plant applications and V4 sidedress: 1.11 inches.
- Total rainfall between At-Plant applications and V10-11 sidedress: 5.52 inches.
- Apr (1.97 in.), May (2.86 in.), June (2.68 in.), July (2.20 in.), Aug (3.94 in.), Sept (2.62 in.), Oct (2.00 in.), and Nov (1.26 in).

Table 3. Richville: Effects of N strategy on grain yield, moisture, and test weight.

Trt No.	Method	Treatment	Yield	Moisture	Test weight
			bu/A	%	lbs/bu
2	Pop-up	popup+V4	193.1 a†	16.0 a	54.5
3		popup+V11			
4		popup+V4+V11			
5	PPI's	PPI	183.7 b	15.2 b	54.9
6		PPI ESN/Urea			
7		PPI+V11			
8	2x2	2x2+V4	195.5 a	16.3 a	54.7
9		2x2+V11			
10		2x2+V4+V11			
LSD			8.6	0.5	NS
Pr > F			0.0637	0.0020	0.6370
Unfertilized Control Means			114.4	13.4	53.1

† Means in the same column followed by the same letter are not significantly different (F-test, α=0.10).

Similar to the Lansing location, delaying N application until V10-11 in order to synchronize N availability with corn N uptake did not significantly increase corn grain yield in pop-up or 2x2 application strategies (Table 4). Furthermore, a single V10-11 late N application reduced mean grain yield 18 bu/a when utilized with the pop-up strategy, similar to 2014. This indicates the 7 lbs N/A supplied by the pop-up may not have been sufficient to maintain yield potential until a single V10-11 SD timing under reduced N loss conditions. However, data in Table 4 indicate that growers missing the opportunity to apply early-season N can utilize a late-season N application and achieve >181 bu/a corn when fertilizing based on MRTN. Less variation was observed among grain yield SD timings within the 2x2 strategy as compared to the popup strategy indicating that the 2x2 strategy can offer a more consistent response.

Table 4. Richville: Within N strategy, effects of N timing on grain yield, moisture, and test weight.

Trt No.	Treatment	Yield	Moisture	Test weight
		—— bu/A ——	—— % ——	—— lbs/bu ——
2	popup+V4	201.6 a†	16.5	54.4
3	popup+V11	181.0 b	15.6	55.3
4	popup+V4+V11	196.7 a	15.7	54.0
	LSD (*p* < 0.10)	11.3	NS	NS
	Pr* > *F	0.0280	0.2905	0.1801
5	PPI	177.8 b	14.6 b	54.6
6	PPI ESN/Urea	182.4 ab	14.9 b	54.6
7	PPI+V11	190.8 a	16.1 a	55.4
	LSD	9.9	1.1	NS
	Pr* > *F	0.1044	0.0755	0.3921
8	2x2+V4	189.4	16.4	54.4
9	2x2+V11	201.2	16.7	55.0
10	2x2+V4+V11	196.0	15.9	54.8
	LSD	NS	NS	NS
	Pr* > *F	0.5822	0.4213	0.4702

† Means in the same column followed by the same letter are not significantly different (F-test, α=0.10).

To achieve objective #2:

Methods and Procedures: This trial was planted in Lansing, MI on a loam-textured, non-irrigated field. The location was previously cropped to soft red winter wheat. Cover crops were seeded with conventional tillage following wheat harvest. Cover treatments consisted of a no cover treatment, 'Magnum' forage oats seeded at 25 lbs/A, and 'The Buster' daikon radish seeded at 10 lbs/A. Covers were allowed to grow until chemical termination on Nov. 5th with glyphosate to aid in volunteer wheat control. The trial was lightly disked in the spring prior to establishing subplots (see treatment list below). Nitrogen rates were equalized based on MRTN recommendations for corn following small grains not interseeded with leguminous cover crops to 160 lbs N/A. Urea ammonium nitrate (UAN) was used for 2x2 and V4 sidedress injected treatments and mixed with Agrotain® Ultra (urease inhibitor) for banded V10-11 applications. Herbrucks dried poultry litter was used as an organic N source. NutraLime® pelletized limestone (97% CCE) was used to adjust soil pH prior to spring tillage. Muriate of potash was applied pre-plant incorporated prior to corn planting.

Treatments:

3) Lansing, MI

Trt #	Cover Crop	N Rate (lb. N/A)	N Placement and Timing
1	No Cover	0	Untreated Control
2	No Cover	160	Pre-plant Incorporated
3	No Cover	160	1 T/A poultry manure PPI, Pre-tassel (V10-11)
4	No Cover	160	2x2 (40 lbs N), Sidedress injected (V4)
5	No Cover	160	2x2 (40 lbs N), Pre-tassel (V10-11)
6	No Cover	160	2x2 (40 lbs N), 50% Sidedress injected (V4), 50% Pre-tassel (V10-11)
7	'The Buster' Radish	0	Untreated Control
8	'The Buster' Radish	160	Pre-plant Incorporated
9	'The Buster' Radish	160	1 T/A poultry manure PPI, Pre-tassel (V10-11)
10	'The Buster' Radish	160	2x2 (40 lbs N), Sidedress injected (V4)
11	'The Buster' Radish	160	2x2 (40 lbs N), Pre-tassel (V10-11)
12	'The Buster' Radish	160	2x2 (40 lbs N), 50% Sidedress injected (V4), 50% Pre-tassel (V10-11)
13	'Magnum' Oats	0	Untreated Control
14	'Magnum' Oats	160	Pre-plant Incorporated
15	'Magnum' Oats	160	1 T/A poultry manure PPI, Pre-tassel (V10-11)
16	'Magnum' Oats	160	2x2 (40 lbs N), Sidedress injected (V4)
17	'Magnum' Oats	160	2x2 (40 lbs N), Pre-tassel (V10-11)
18	'Magnum' Oats	160	2x2 (40 lbs N), 50% Sidedress injected (V4), 50% Pre-tassel (V10-11)

-Pelletized limestone was applied 3/24/15 at 1.0 tons/ac.
-A starter fertilizer was applied at planting, pre-plant incorporated, of 55 lbs K_2O
-Pre-plant incorporated, and 2x2 occurred at planting 5/01/2015.
-V4-6 Sidedress injection occurred on 6/02/2015. V10-12 Sidedress occurred on 6/29/2015.
-Trial was harvested 10/14/2015.

Results and Discussion:

Lansing:

When N strategy subplots were imposed on whole plots receiving cover treatments, a significant effect of cover x N strategy on corn grain yields was observed (*P*=0.0285; data not shown). The interaction was due to the impact of cover treatment on unfertilized plots within each cover (*P*<.0001). Grain yields per treatment were contrasted to the 'true' control consisting of a 'no cover' x 'no N' treatment to which yields of all other treatments were significantly different (*Pr*>F; Table 5). Grain yield was reduced 10.8% and 17.8% following an unfertilized oat and radish cover crop, respectively, relative to the control (Table 5). This was likely due to a lack of plant available nutrients as grain yields increased 14-22% relative to the control upon addition of N. When grain yields were normalized to the control treatment only the main effect of N strategy significantly affected grain yield indicating that N strategies did not have to be catered to specific cover treatments (Table 6). Unfertilized radish and oat cover treatments reduced yield potential to 85% of the control treatment. The organic + inorganic fertility approach (i.e. poultry litter+SD) increased yield 4.2% and 35.4% more than urea PPI and unfertilized strategies, respectively. Delaying the majority of N application until V10-11 SD to synchronize N uptake with plant availability did not provide opportunities for positive yield gains, but did offer an alternative strategy to growers missing an early SD timing.

Table 5. Lansing: Summary of single degree of freedom contrasts comparing corn grain yields from the 'true' control to cover x N strategy treatments and subsequent ANOVA on % yield change relative to control.

Contrast	vs.	Cover	N Strategy	P_r>*F**	% change relative to control
Control	vs.	No Cover	Urea PPI	0.0003	18.7
(no N, no cover)	vs.	No Cover	PM+V10 SD	0.0008	18.0
	vs.	No Cover	2x2+V4 SD	0.0005	18.3
	vs.	No Cover	2x2+V10 SD	<.0001	22.0
	vs.	No Cover	2x2+V4/V10 SD	0.0004	18.6
	vs.	Radish	Control (No N)	0.0003	-17.8§
	vs.	Radish	Urea PPI	0.0017	16.6
	vs.	Radish	PM+V10 SD	<.0001	21.8
	vs.	Radish	2x2+V4 SD	0.0005	18.2
	vs.	Radish	2x2+V10 SD	0.0002	19.2
	vs.	Radish	2x2+V4/V10 SD	0.0003	19.1
	vs.	Oat	Control (No N)	0.0510	-10.8
	vs.	Oat	Urea PPI	0.0112	14.0
	vs.	Oat	PM+V10 SD	<.0001	21.9
	vs.	Oat	2x2+V4 SD	0.0005	17.9
	vs.	Oat	2x2+V10 SD	0.0006	18.0
	vs.	Oat	2x2+V4/V10 SD	<.0001	20.5

*Results of Dunnett's test to control Type I error rate vs. control (no cover + no N).
§Negative numbers indicate yield was decreased relative to control

Table 6. Lansing: Main effects of cover and N strategy on grain yield, % moisture, and test weight.

Treatment	**Rate** --lbs acre^{-1}--	**Grain Yield** -% of control-	**Moisture** ---%---	**Test Weight** ---lbs/bu---
Cover Crop	*seed*	--	--	--
No Cover	--	113.6 a†	22.2 a	51.7 b
Radish	10	112.9 a	20.4 b	52.3 a
Oat	25	113.6 a	20.3 b	52.4 a
N Strategy	*nitrogen*	--	--	--
Unfertilized	0	85.2 c*	20.5 b	51.7 a
Urea PPI	160	116.4 b	20.6 b	52.2 a
Poultry Litter (1 ton/a)+V10 SD	160	120.6 a	20.2 b	52.5 a
2x2 starter + V4 SD	160	118.1 ab	20.6 b	52.3 a
2x2 starter + V10 SD	160	119.7 ab	21.8 a	52.0 a
2x2 starter + V4/V10 SD	160	119.4 ab	21.9 a	52.0 a
Source of Variation (*Pr*>F)	df			
Cover Treatment (C)	2	0.8697	0.0067	0.0216
N Strategy (N)	5	<.0001	0.0200	0.1197
C x N	10	<.6223	0.1583	0.6346

† Means in the same column followed by the same letter are not significantly different (F-test, α=0.10).
*Values for 'unfertilized' grain yield column is mean of unfertilized plots across radish and oat covers only.

Summary:

Synchronizing N application timing with plant N uptake may increase efficiency of N use by reducing the number of opportunities for N loss. Under variable N loss conditions in 2015 positive yield gains were not achieved with the use of a single late-season N application combined with either the popup or 2x2 strategy when compared to a V4 SD timing. Yield at the Richville site was reduced when the popup strategy was combined with a single sidedress N application at V10-11. Similar to 2014 results, this may illustrate that some yield potential can be sacrificed when waiting to apply the majority of N at V10-11 SD time,. However growers missing the opportunity to apply PPI or early-season sidedress N may still benefit from a late season rescue N application (but not as a standard practice) as yields in excess of 200 and 180 bu/A were obtained at the Lansing and Richville sites, respectively.

A grower's N strategy may be influenced by the level of risk involved. Even with minimal N losses, popup strategies were not able to supply sufficient N until the V10 application timing as evidenced by both plant chlorosis and yield reductions. Large rainfall events could make the above scenario worse but rescue applications to protect yield losses are still a viable option. A more consistent yield response was noted with the 2x2 strategy where less variation in yield was observed between sidedress timings as compared to the popup applications. The 2x2 strategy may allow sufficient above- and below-ground plant growth for the plant to better capitalize on environmental conditions encountered after planting. Poultry litter applied PPI combined with a single late-season N SD timing provides a slowly-mineralizable natural-organic N component that increased yields relative to the urea PPI strategy at all three study sites.

Investigations on the impact of organic/inorganic fertility on microbial community diversity and composition are currently underway and will determine if living ground covers in combination with the 4R management approach influences microbial community populations and subsequently affects the ability of the soil to produce a healthy plant. Grain yield was reduced 10.8% and 17.8% following an unfertilized oat and radish cover crop, respectively, relative to the control. Unfertilized radish and oat cover treatments reduced yield potential to 85% of the control treatment. Corn yield data from the 2015 soil health study suggests that when N is applied management does not have to be catered to specific living ground covers.