Section 4: Nitrogen Management Practices

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Nitrogen (N) is the most common nutrient that limits corn growth and yield. The management practices that lead to the highest chance of N utilization by the corn crop and the lowest chance of loss to the environment are often referred to as the 4Rs of nutrient management—Right: source, rate, timing, and placement. In this chapter, we will evaluate the results from the 2019 nutrient management survey to help us better understand the local factors that influence the use of various N management practices. The local factors evaluated include geographic location within South Dakota (SD), tillage type, and farm size. Understanding these factors on farmers' decisions regarding N management practices can give guidance to government agencies, extension, and other professionals regarding needed research, educational resources, and trainings that can help farmers adopt appropriate 4R nutrient management practices.

Nitrogen Sources

Nitrogen fertilizer sources used by farmers were not related to location, tillage, or farm size regardless of application timing. This result suggests that fertilizer sources are similarly available to farmers regardless of their location in SD and the associated precipitation amounts along with tillage type did not affect the fertilizer-N source decision. Urea was the primary N source regardless of application timing (49%) followed by manure (24%) and urea ammonium nitrate (UAN-28) (19%) and lastly UAN-32 and anhydrous ammonia (3-5%) (Table 1). Urea and UAN-28 were similarly used (8-19%) when N applications were done during the growing season.

Table 1. Percentage of surveyed farmers who used various N fertilizer sources at different application timings along with percentage use across N fertilizer sources and application timings.

Application timing	Nitrogen fertilizer source[a]					Across products
	Urea	UAN 28%	UAN 32%	AA 82%	Manure	
	---------- % ----------					
Fall	11	0	0	4	33	24
Spring	57	18	5	1	13	47
Early Season	19	12	3	1	1	17
Mid/Late Season	12	8	2	0	2	12
Across timings	49	19	5	3	24	–

Note: Percentages may not add up to 100 as individuals could input data in multiple categories.
[a] UAN, Urea ammonium nitrate; AA, Anhydrous ammonia

Urea N Use and Management

Appropriate management of urea fertilizer is important to avoid N losses from volatilization that occurs when urea is converted by enzymes to ammonia gas (Francis et al., 2008; Kissel et al., 2008; Fernández et al., 2016; Vetsch et al., 2019; Thies et al., 2020). Ammonia volatilization can be reduced by incorporating urea into the soil through tillage or injection, applying it before a precipitation or irrigation event of at least one inch, or use of a urease inhibitor (Bouwmeester et al., 1985; Clay et al., 1990; Upadhyay, 2012; Rochette et al., 2013; Silva et al., 2017). To minimize ammonia volatilization loss from urea, farmers in central SD were most likely to apply urea with a urease inhibitor (39%) or time the application before a precipitation event (42%) and least likely to use tillage (≤ 12%) (Table 2). This result is likely because no-till practices are most frequently used in central SD (79%) (Table 2 in chapter 1) that removes the ability to incorporate urea with tillage. Conversely, farmers in eastern SD relied primarily on tillage within 24 hours (47%) compared to using a urease inhibitor (24%) or timing the urea application before a precipitation event (24%). In eastern SD, conventional- and reduced-tillage practices are most used (71%). Eastern SD also normally has greater annual precipitation than central SD. This greater annual precipitation may influence farmers to use tillage more often to help dry their fields and prepare them for planting. Tillage also gives them an added tool to minimize ammonia volatilization losses by incorporating the urea fertilizer concurrent with seedbed preparation.

Farm size was also a factor in whether urea fertilizer was incorporated to minimize N volatilization losses. Larger farms typically relied upon using a urease inhibitor (33 to 45%) or trying to time the application before a precipitation event (33 to 38%) and lastly using tillage to incorporate the urea fertilizer (23%) (Table 2). These results likely occurred because larger farms (>1,000 ac) are located in the central part of SD, and mostly used no-till practices (74%) that did not allow them to use tillage to incorporate urea fertilizer and avoid N volatilization losses (Table 2 in chapter 1). Conversely, smaller farms (<1,000 ac) primarily relied on tillage to incorporate urea fertilizer (38 to 52%) to minimize N volatilization losses and infrequently used a urease inhibitor (19 to 24%) or tried to time urea application before a precipitation event (19 to 38%) (Table 2). These results likely occurred because smaller farms were more likely to till their fields (47 to 56%). The use of tillage and incorporating fertilizer enabled them to minimize N volatilization losses without needing to invest in a more expensive fertilizer containing a urease inhibitor or time fertilizer application before a precipitation event.

Another potential reason larger farms more frequently use a urease inhibitor or rely on precipitation to incorporate urea may be due to the time, energy, and labor savings. Fertilizer can be broadcast on the soil surface faster and requires less equipment power (and use of energy) compared to banding urea (or UAN solution) or broadcasting it on the surface and then using tillage to incorporate the fertilizer. These savings for larger (>1,000 ac) compared to smaller farms (<1,000 ac) are more likely to be sufficient to pay for the added price of purchasing fertilizers with a urease inhibitor. Whereas it may be more cost-effective for smaller farms to incorporate urea fertilizers with tillage compared to relying on precipitation or urease inhibitors to minimize ammonia volatilization losses. Further, smaller farms may not have application equipment to time fertilizer application or choose what fertilizer sources (e.g., urease inhibitor) are applied and must rely on the co-op's equipment, timing, and urease inhibitor availability.

Table 2. Percentage of surveyed farmers who used various spring urea fertilizer application management practices in relation to location, tillage system, and farm size.

Variables	Incorporation timing			Other practice		
	< 24 hr.	> 24 hr. and < a week	> a week	None	Apply before rain	Use of urease inhibitor
	---------------------- % ----------------------					
Overall	34	11	3	28	31	30
Location						
Central	12b[a]	5b	0b	50b	42a	39a
East	47a	16a	6a	15a	24b	24b
Tillage						
No-till	10b	7b	2	49a	45a	43a
Reduced	48a	28a	12	24b	24ab	28ab
Conventional	67a	12ab	2	0c	16b	16b
Farm size (ac)						
>2000	23	4	2	44a	38	33
1,000-1,999	31	17	2	31ab	33	45
500-1,999	38	22	8	16b	38	24
1-499	52	10	5	14b	19	19

[a] Percentages with different letters within each column are statistically different (P ≤ 0.05). If no letters are present, there are no significant differences.

Liquid N Product Use

The use of liquid-N fertilizer (common products are UAN 28 and 32%) as an N source is becoming more common and similar to urea use after the corn crop is planted (Table 1). In this survey, farmers were polled to determine the percentage of their land where liquid-N fertilizer was applied. The percentage of land where liquid-N was applied was related to location, tillage type, but not farm size ($\alpha = 0.05$). Farmers in eastern compared to central SD applied liquid-N to a larger percentage of their acres (43 vs 25% of their land) (Table 1). This may be due to farms in eastern SD receiving more seasonal precipitation and worrying more about N losses to leaching and denitrification, which would result in farmers being more likely to use an in-season N application with a liquid-N source. The larger in-season precipitation may also allow farmers to time their N application closer to when corn is beginning rapid N uptake at the V6 development stage (Abendroth et al., 2011).

In contrast to the fertilizer-N rate pattern, the percentage of land where liquid-N was applied was greatest for reduced- and conventional-tillage farms (40-46% of their land) and lowest for no-till farms (32% of their land) (Table 4). This result might be an indicator that reduced-and conventional-tillage farms compared to no-till farmers were more likely to apply N during the growing season. However, more detailed questions would be needed to better understand this correlation.

One hypothesis is that larger farms generally have more access to equipment and capital needed to apply a higher-priced liquid-N fertilizer and potentially spread the workload of fertilizer application. However, our results indicate that small and large farms applied liquid-N to a similar percentage of their acres (31-41% of their land).

Enhanced Efficiency Fertilizer Use

Enhanced efficiency fertilizers–fertilizers with urease or nitrification inhibitors or a slow-release fertilizer–were minimally used by farmers in SD (≤ 15%) (Table 3). Because of the low use of these EEFs an analysis related to the influence of location, tillage, and farm size was not completed. Therefore, we examined the use of EEFs across all surveyed farmers. Urease inhibitors delay the conversion of urea to ammonia to lengthen the time urea can be on the soil surface before it is incorporated with precipitation. Using a urease inhibitor lowers the probability of N loss through ammonia volatilization and was the most used EEF by SD farmers (15%). Slow-release fertilizers were the second most used EEFs (10%). These fertilizers are encapsulated or coated with a material that delays the release of N throughout the growing season. Nitrification inhibitors were used 9% of the time. These inhibitors interfere with the bacteria that converts ammonium into nitrite and then nitrate. These N forms are highly mobile in the soil and susceptible to loss through leaching and denitrification.

When EEFs were used by SD farmers they were most used in the spring (55%) and in-season (35%) with minimal use in the fall (10%) (Table 3). These results coincide with our other fertilizer application timing results where synthetic N fertilizers were most applied in the spring and in-season (Table 2). The low use of these EEFs may be due to the effectiveness of nitrification inhibitors being greatest when applied in the fall (Randall et al., 2003; Randall and Vetsch, 2005; Burzaco et al., 2014). However, most N applications in SD occur in the spring and in-season. Additionally, in a synthesis of the literature, Burzaco et al. (2014) determined that corn grain yields had a greater response 56% of the time when nitrapyrin (a nitrification inhibitor) was used compared to when it was not added to the fertilizer-N. This 56% chance is due to nitrification inhibitors working best when potential losses of nitrate can be significant–sandy soils, poorly drained soils, or when ammonia based fertilizers are applied in the fall (Norton, 2008). The precipitation and soil dependent nature of the effectiveness of these EEFs is likely one of the reasons for minimal adoption by SD farmers.

Table 3. Percentage of surveyed farmers who used various enhanced efficiency fertilizers and their application timings across all enhanced efficiency fertilizers.

Variables	Percentage use (%)
Enhanced Efficiency Fertilizer categories	
Urease inhibitors	15
Nitrification inhibitors	9
Both urease and nitrification inhibitors	6
Yes inhibitor, unsure of category	7
Slow-release fertilizer	10
Enhanced Efficiency Fertilizer application timing	
Fall	10
Spring	55
In-season	35

Nitrogen Rates

Fertilizer-N rates used in corn production were influenced by location, tillage type, but not farm size (α = 0.05). Farmers in eastern compared to central SD applied more N to their corn crop (147 vs 139 lbs N ac-1) (Table 4). This difference in fertilizer-N rate applied may be due to the often lower yield levels in central SD (USDA-NASS, 2021). Following the university recommended yield goal system to determine fertilizer-N rates, these lower yield potentials in central SD would require lower fertilizer-N rates. This result suggests that farmers are likely following the university recommendation system. Regarding tillage, no-till farmers applied the least amount of N to their corn crop (137 lbs N ac-1) while conventional- and reduced-till farmers applied the most (146-155 lbs N ac-1). These results indicate that in general no-till farmers apply lower amounts of fertilizer-N to corn. This lower application rate may be due to improved soil properties from switching to no-till from conventional tillage (Veum et al., 2014). This does contradict the SD university recommendation system that recommends an additional 30 lb N ac-1 in no-till fields compared to a conventional tillage system (Clark et al., 2019). However, it is in accordance with research from North Dakota where after five or six years of no-till, fertilizer recommendations are less with no-till than conventional tillage (Franzen, 2018). These results indicate that further research is needed regarding the effect of long-term no-till on corn N fertilizer needs in SD to see if adjustments to the current recommendation system is needed. The fact that farm size was not related to fertilizer-N rates among farmers indicates that the rates applied are not likely being changed based on number of acres operated, equipment availability, or ability to absorb financial risk.

Table 4. Total fertilizer-N rate and proportion of land liquid-N was used as the primary N source in relation to location, tillage system, and farm size.

Variable category	Variables	Fertilizer-N rate	Liquid-N use
		lbs N ac^{-1}	% of land
Location	East	147a	43a
	Central	139b	25b
Tillage	No-till	137b	32b
	Reduced	155a	46a
	Conventional	146ab	40ab
Farm size (ac)	>2000	147	31
	1,000-1,999	141	38
	500-1,999	142	40
	1-499	141	41

[a] Mean values with different letters within each column for each variable category (i.e. location, tillage, and farm size) are statistically different ($P \leq 0.05$). If no letters are present, then there are no significant differences.

Nitrogen Application Time

Minimal fertilizer-N applications were applied in the fall except for manure (Table 1). This is important because N fertilizer applied in the fall has a large window where loss can occur before corn the following season can utilize it. This is reassuring as many states have moved to regulating N fertilizer application timings and prohibited them in the fall. This result is important as it shows farmers in SD are generally choosing to apply N closer to crop use by applying it in the spring or during the season. These types of voluntary actions will minimize the likelihood of policies being created to enforce best management practices for N fertilizers. Across N sources and among the four synthetic N sources (not including manure), spring N fertilizer applications were the most common (47%) followed by early and mid/late growing season applications (12-17%). These results suggest that the primary time for synthetic N fertilizer application is the spring, and that in-season applications are less used.

Some studies have suggested that splitting N fertilizer applications and moving most of the N fertilizer application to in-season can reduce N loss potential (Dinnes et al., 2002). The use of split applications by SD farmers was 55% and 45% for single and split-N applications, respectively (Table 5). Farm location was related to the use of single- and split-N applications, whereas tillage and farm size were not. Single-N applications were used more on farms in central (53%) compared to eastern SD (47%). Whereas split-N applications were used more in eastern (63%) compared to central SD (37%). The more frequent use of single- compared to split-N applications in central SD and the opposite occurring in eastern SD was likely due to the differences in annual precipitation. As previously stated, central SD receives less annual precipitation than eastern SD. This is important as recent research throughout the US Midwest has shown that reliable precipitation around the timing of a split application is strongly related to the split-N management strategy increasing crop yields over single-N applications (Spackman et al., 2019; Clark et al., 2020). The lower likelihood in central SD of receiving precipitation to incorporate fertilizer-N and make them available to the crop during the growing season is likely the reason single- compared to split-N applications were used more frequently. Whereas the greater annual precipitation in eastern SD increases the chance of receiving needed precipitation at the time of split applications to make fertilizer available to plants and is likely the reason split- compared to single-N applications were more frequently used in eastern SD. More research is needed evaluating single- and split-N applications in the various precipitation zones in SD and using different placement methods (e.g., surface broadcast vs. injected side-dress) before educational training and demonstrations can be created.

Table 5. Percentage of surveyed farmers who used single- and split-N application strategies in relation to location, tillage system, and farm size.

Variables	Single-N application	Split-N application
	----------- % -----------	
Overall	55	45
Location		
Central	53a[a]	37b
East	47b	63a
Tillage		
No-till	65	35
Reduced	50	50
Conventional	48	52
Farm size (ac)		
>2000	49	51
1,000-1,999	67	33
500-1,999	44	56
1-499	73	27

[a] Percentages with different letters within each column are statistically different (P ≤ .05). If no letters are present, there are no significant differences.

Nitrogen Placement

Placing nutrients on or below the soil surface can influence the availability of N to crops and its susceptibility to loss. For example, urea left on the soil surface can lead to ammonia volatilization loss, reducing the total N available to the crop. In this survey, we evaluated various placement methods, both when N was single or split applied. For single-N applications, broadcast application of N in the spring was by far the most common placement method (Table 6). It was evenly split between broadcasting fertilizer with and without incorporation after application (26 vs. 39%; Table 6). This result is likely due to approximately 50% of SD farmers using no-till practices that would inhibit them from using tillage to incorporate a broadcast application of N fertilizer (USDA-NRCS, 2019; Wang, 2019). All other fertilizer placement methods and application timing combinations were minimally used (≤ 10%).

For farmers that split up their N applications, broadcast placement and spring timing compared to the other options were still the dominant placement by timing combinations (28-50% vs 1-23%) (Table 6). However, likely due to the nature of splitting up the applications, the percent use of early and mid/late season applications increased from 1-6% to 1-23%. Additionally, when split applying N compared to single-N applications, application methods that place the fertilizer below the soil surface during in-season applications was also more frequently used (1-5% vs. 1%). This greater use of below the surface application with in-season applications is likely due to the lower likelihood of precipitation events occurring after in-season applications to move the fertilizer from the soil surface to the roots. Therefore, farmers use a placement method that increases the likelihood of the fertilizer being able to move with soil moisture to the roots and taken up by the crop. However, the use of placement methods that place fertilizer below the surface are still minimally used (≤ 5%). This low usage is likely due to the specialized equipment that is often needed to place fertilizer below the soil surface. These types of applications also frequently require the use of liquid-N sources that are commonly more expensive than dry-N sources. Additionally, many farmers hire co-ops to apply fertilizer for them. These co-ops most frequently broadcast fertilizer on the soil surface as this method can be used to apply N to more acres each day compared to methods that place fertilizer below the soil surface. To change any of these practices it will take research results and educational programs geared to farmers and fertilizer applicators, showing a combination of improved yields and profits with the use of placement methods that place fertilizer below the soil surface or applications completed in-season.

Table 6. Percentage of surveyed farmers who used various N fertilizer application timing by placement methods along with percentage use across application timings and placement methods.

Placement Method	N fertilizer application timing				Across timings
	Fall	Spring, preplant	Early Season	Mid/late season	
	-------------------- % --------------------				
Using single-N applications					
Broadcast: incorporated	10	39	4	0	53
Broadcast: not-incorporated	2	26	6	0	32
Banding: with strip till	3	1	0	0	4
Banding: under the row	1	1	0	0	1
Sub-surface banding: next to row	1	1	1	0	3
Sub-surface banding: mid row	2	1	0	0	3
Surface banding: next to row	0	0	1	0	1
Surface banding: mid row	0	0	1	0	1
Top dress: foliar feed	0	0	1	1	2
With irrigation	0	0	0	0	0
Across placement methods	18	67	14	1	
Using split-N applications					
Broadcast: incorporated	9	50	6	4	29
Broadcast: not-incorporated	8	28	23	13	29
Banding: with strip till	13	2	2	1	7
Banding: under the row	0	4	2	0	3
Sub-surface banding: next to row	1	3	2	2	3
Sub-surface banding: mid row	2	1	5	3	4
Surface banding: next to row	0	3	2	7	5
Surface banding: mid row	1	2	4	3	4
Top dress: foliar feed	2	4	6	17	12
With irrigation	0	0	4	6	4
Across placement methods	15	40	22	23	

Note: Percentages may not add up to 100 as individuals could input data in multiple categories.

Nitrogen Placement with Split-N Applications

For those farmers who split up their total N application among two or more application times, we wanted to understand what percent of their total N rate they applied at each timing and placement method combination. Before planting, the mean percent of fertilizer applied ranged from 5-61% of the total N application (Table 7). After planting, the mean percent of the total N application had a smaller range of 19-59% with no major difference between the early and mid to late season application timings. Banding next to or under the row had the lowest mean percent of total application at 5-6% while broadcast methods had the highest mean range between 37-61%. Analyzing across placement methods, mean percent of total N application applied at each timing ranged from 31-38%. This result indicates that regardless of placement method(s) used when SD farmers split up their N fertilizer applications, they generally do so evenly throughout the growing season.

Table 7. For split N applications, the mean percentage ± standard deviation of total fertilizer-N rate for each application timing and placement method combination.

Placement method	N fertilizer application timing				Across timings
	Fall	Spring, preplant	Early season	Mid to lateseason	
	% of total N rate ± standard deviation				
Broadcast: incorporated	41 ± 21	61 ± 16	59 ± 17	37 ± 15	54 ± 17
Broadcast: not-incorporated	39 ± 25	57 ± 18	45 ± 20	37 ± 25	47 ± 22
Banding: with strip till	38 ± 22	33 ± n/aa	50 ± n/a	n/a	40 ± 6
Banding: under the row	n/a	6 ± 1	n/a	n/a	6 ± n/a
Sub-surface banding: next to row	5 ± 1	26 ± 8	50 ± n/a	33 ± 7	27 ± 4
Sub-surface banding: mid row	55 ± n/a	n/a	27 ± 20	39 ± 15	40 ± 9
Surface banding: next to row	n/a	38 ± 26	25 ± 8	33 ± 17	31 ± 13
Surface banding: mid row	33 ± n/a	n/a	30 ± 15	44 ± n/a	32 ± 4
Top dress: foliar feed	25 ± n/a	26 ± 7	19 ± 17	28 ± 11	23 ± 9
With irrigation	n/a	n/a	38 ± 15	26 ± 10	32 ± 6
Across placement methods	34 ± 17	31 ± 13	38 ± 16	34 ± 13	–

[a] "n/a" indicates that no response was recorded from the survey for that placement and timing combination. If "n/a" is in the place of the standard deviation, it indicates only 1 response was recorded from the survey for that placement and timing combination so no standard deviation could be calculated.

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