5-2009

Best Management Practices for Corn Production in South Dakota: Soil Fertility

David E. Clay
South Dakota State University

Kurtis D. Reitsma
South Dakota State University

CHAPTER 7
Soil Fertility

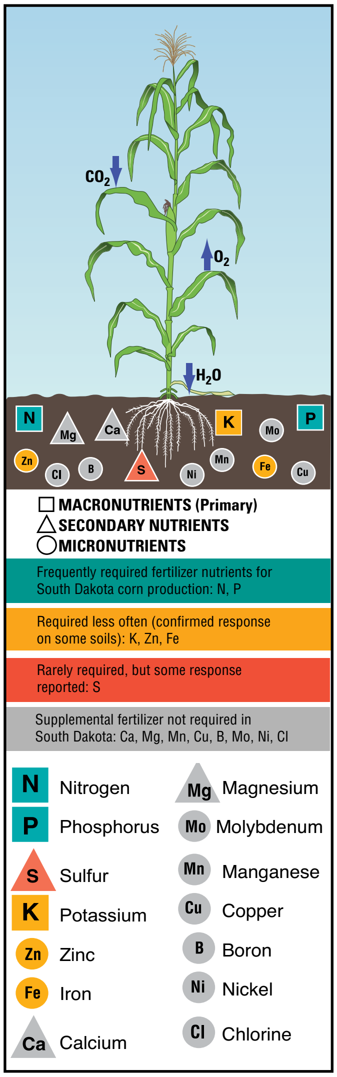
Corn requires sufficient amounts of at least 14 nutrients for optimal production (fig. 7.1). Soil fertility strategies should consider soil residual plant nutrients, cost of fertilizer relative to the value of corn, and management techniques that increase efficiency.

Different fertilizers have different concentrations of plant nutrients reflected in the grade or percent of each nutrient (%N, %P_2O_5, %K_2O). Commonly used fertilizers in South Dakota and their grades are listed in Table 7.1.

Table 7.1. Common fertilizers used in South Dakota

	----Percent----			
Dry fertilizers	N	P_2O_5	K_2O	
Ammonium nitrate	33	0	0	
Urea	46	0	0	
Diammonium phosphate (DAP)	18	46	0	
Mono-ammonium phosphate (MAP)	11	52	0	
Ammonium sulfate (21-0-0-24 S)	21	0	0	
Potassium chloride	0	0	60	
Potassium nitrate	13	0	44	
Liquid fertilizers	N	P_2O_5	K_2O	lb/gal.
Urea-ammonium-nitrate (UAN)	28-32	0	0	10.8
Ammonium polyphosphate	10	34	0	10.5
Multigrade (7-21-7)	7	21	7	10.7
Multigrade (9-18-9)	9	18	9	11.0
Gaseous fertilizers	N	P_2O_5	K_2O	
Anhydrous ammonia	82	0	0	

Figure 7.1. Nutrients required for corn growth and development



(Modified from Colorado State University)

Corn Yield Expectations

Fertilizer recommendations for nitrogen (N), phosphorus (P), and potassium (K) are based on expected yield or "yield goal." Calculating yield goals is complicated by improved genetics, which are gradually increasing crop yields. Further complications are introduced by rotations, which reduce the amount of available information for specific crops.

General guidelines for calculating yield goals include the following:

- It is not recommended to consider more than 10 years in yield goal calculations (Table 7.2).
- Abnormally high or low yield values should not be included in the calculation.
- To account for increasing yield potentials, some attempt should be made to standardize the data (Table 7.3). For example, a field with a yield of 140 bu/acre 10 years ago may now produce a yield of 160 bu/acre.
- Corn yields in South Dakota have been increasing at an annual rate of ≈2.0 bu/acre over the past 20 years.
- Managing for an optimistic, yet realistic, yield goal is important. Underestimating yield goal can lead to a gradual yield decline.
- Achieving full yield potential depends on management, climate, and soil, and will likely vary from field to field.

Additional information regarding yield goals is available in Reitsma et al. (2008).

Table 7.2. Estimating a yield goal from multiple years of data

Field records

Year	#Standardized yield (bu/A)	Conditions
1	136	Average
2	133	Average
3	126	Average
4	128	Average
5	126	Average
6	145	Average
~~7~~	~~*171~~	Excellent
8	163	Excellent
~~9~~	~~*112~~	Poor
10	129	Average

Base yield goal = 136

#Standardized yield considering average annual increase of 2 bu/A/yr.
*Outliers were removed to calculate average yield.
The yield goal + 10% recommendation:
136 • 1.10 = 150 bushel
Yield goal + moisture recommendation:
Full soil profile at planting
136 • 1.10 = 150 bushels
Average soil profile at planting
136 bushels
Poor moisture conditions at planting
136 – (0.10 • 136) = 123 bushels
Producers should be prepared to apply additional fertilizer N as an in-season side-dress if needed when using the soil moisture approach.

Table 7.3. Methods for estimating yield potential

- Remote sensing
- Field history (field)
    - Yield goal + 10% -- Add 10% to a multiple-year average where the maximum and minimum values have been removed.
    - Yield goal + moisture -- Adjust a multiple-year yield, after outliers have been removed, based on plant available water at planting.
    - County average
    - Productivity index

Soil Sampling

Soil samples are collected both to estimate nutrient levels in a field and to estimate the amount of residual nutrients in the soil. For accurate estimates, representative soil samples must be collected. Accuracy improves both by increasing the number of subsamples composited into a bulk sample and by avoiding areas of the field that do not represent the majority of the field (e.g., old feedlots, farmsteads, and fence lines). Details on soil sampling and sample handling are available in Clay et al. (2002) and Gelderman et al. (2005). "Rules of thumb" for soil sampling are provided in Table 7.4.

Table 7.4. "Rules of thumb" for soil sampling

- DO NOT sample dead furrows, turn-rows, waterways, terraces, old fence lines, farmsteads, feedlots, or any other areas that do not represent the field.
- Remove crop residue and debris before sampling.
- Sample when moisture conditions are suitable for tillage.
- Take enough samples to minimize error.
- Sample to represent old fertilizer bands in relation to the whole field.
- Nitrogen and sulfur recommendations are based on a 0-to-24-inch sample and may require an additional 24-to-48-inch depth increment.
- Analysis for phosphorus (P), potassium (K), and micronutrients are based on 0-to-6-inch samples.

Grid or management-zone soil sampling can be used to develop site-specific recommendations that can be used to generate field maps. These maps, in turn, can be used as a basis for precision fertilizer placement. In grid sampling, a composite sample from each point or cell is collected and analyzed. Grid or management-zone sample results can be compared with yield monitor data to make more precise decisions. Further details on precision nutrient management are available in Clay et al. (1997).

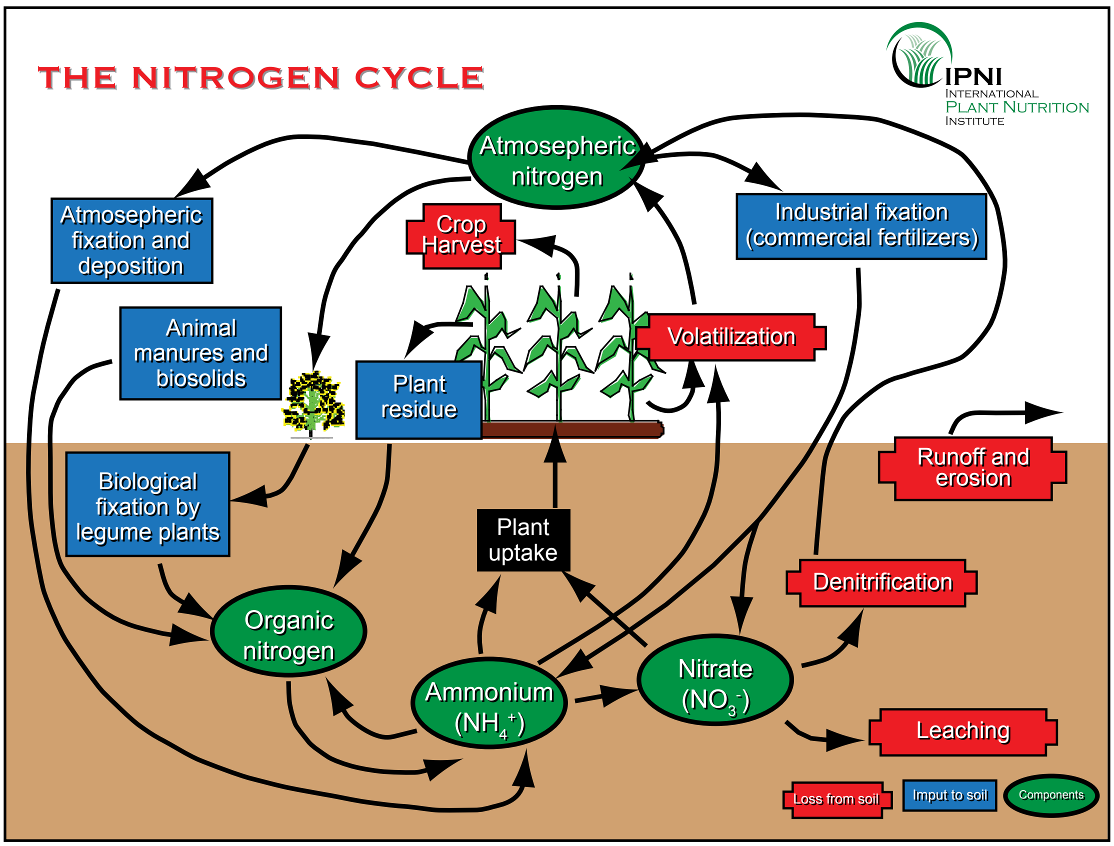
Nitrogen Recommendations

N applied to soil undergoes many transformations (fig. 7.2). In some situations, N can even be lost from the system before the plant can use it. N is mobile in the plant and will move from older growth to newer growth (translocation), resulting in a yellowing of older leaves (fig. 7.3).

The N recommendations for corn that is to be harvested for grain or silage are different (Table 7.5). For both corn and silage, though, the N-fertilizer recommendation is the difference between crop need and N credits. Credits that should be considered include residual soil test N, manure N, legumes (if grown within the previous 2 years), and irrigation water (see Tables 7.6 and 7.7 for additional information).

Residual soil N is estimated by analyzing a 0-to-24-inch sample collected in the spring. If a soil sample is not available, residual-soil N can be estimated using the long-term soil test average of 55 lbs. N/acre.

Figure 7.2. Important N transformations in agricultural soils



(Courtesy of International Plant Nutrition Institute)

Definition of Key Terms

Volatilization – loss of N from the profile as ammonia (NH_3) gas
Denitrification – loss of N from the soil as N_2 gas
Leaching – movement and loss of $N0_3$- from the root zone
Immobilization – microbial conversion of inorganic N (available) to organic N (unavailable)
Fixation – conversion of N_2 from the atmosphere to ammonia form N
Mineralization – microbial conversion of organic N (unavailable) to inorganic N (available)

The importance of measured residual-N value increases with the potential for the soil to contain a significant amount of NO_3^--N (fig. 7.4).

In sensitive areas, such as folds over shallow aquifers, an additional sample from the 24-to-48-inch depth should be collected. If soil test N exceeds 30 lbs. NO_3^--N/A in the 24-to-48-inch depth, 80% of that soil test N is included in the residual N credit (Gerwing and Gelderman 2005).

The manure N credit is best determined by sampling the manure. The sample should be representative of the source and should be taken after the material has been well mixed. If the manure is not sampled, N content can be estimated using values in Table 7.6.

Legume plants that form symbiotic relationships with *Rhizobium* sp. bacteria can provide a significant amount of N to the crop that follows. In situations where corn follows soybeans, a credit of 40 lbs. N/acre is recommended. Credits for other legume crops are provided in Table 7.7.

Additional information on N management is available in Reitsma et al. (2008).

Figure 7.3. Nitrogen deficiency in corn

Note the V-shaped chlorosis in older leaves and that the lowest leaves (the oldest leaves on the plant) are dead. *(Photo courtesy of Iowa State University)*

Table 7.5. Nitrogen fertilizer recommendation

Corn for grain

N = (1.2xRYG(grain)) - Credits

Corn for silage

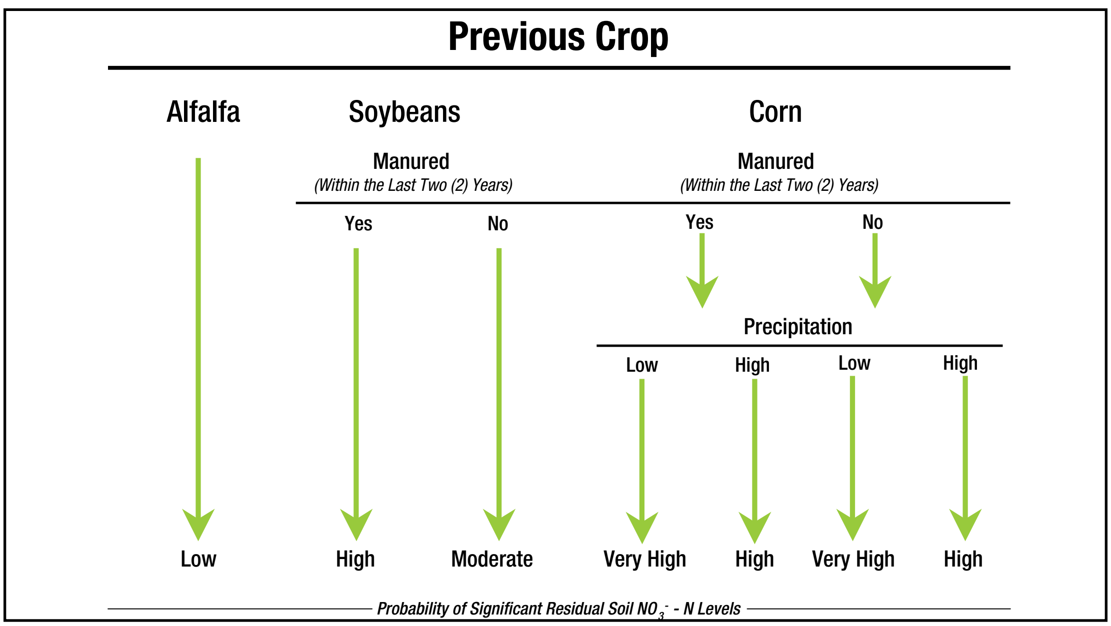
N = (10.4xRYG(silage)) - Credits

Where:

- N = estimate of nitrogen need (lbs/Acre)
- RYG(grain) = Realistic Yield Goal (bu/Acre)
- RYG(silage) = Realistic Yield Goal (tons/Acre)

(Adapted from Gerwing and Gelderman 2005)

Figure 7.4. Probability of significant soil NO_3^- – N level



(Courtesy of Reitsma et. al. 2008)

Table 7.6. Estimated nitrogen content of manure

Type of Livestock	Liquid Manure Nitrogen (N) lbs/1000 gal		Solid Manure Nitrogen (N) lbs/ton	
	$N_{ORGANIC}$	$N_{INORGANIC}$	$N_{ORGANIC}$	$N_{INORGANIC}$
Swine				
Farrowing	7	8	11	3
Nursery	11	14	8	5
Grow-Finish	-	-	10	6
Grow-Finish(deep pit)	17	33	-	-
Grow-Finish(wet/dry feeder)	21	39	-	-
Grow-Finish(earthen pit)	8	24	-	-
Breeding-Gestation	13	12	4	5
Farrow-Finish	12	16	8	6
Farrow-Feeder	10	11	5	5
Dairy				
Cow	25	6	8	2
Heifer	26	6	8	2
Calf	22	5	8	2
Veal calf	26	21	4	5
Herd	25	6	7	2
Beef				
Beef cows	13	7	4	3
Feeder calves	19	8	6	3
Finishing cattle	21	8	7	4
Poultry				
Broilers	50	13	34	12
Pullets	48	12	39	9
Layers	20	37	22	12
Tom turkeys	37	16	32	8
Hen turkeys	40	20	32	8
Ducks	17	5	13	4

(Adapted from Lorimor and Powers 2004)
These values should not be used in place of a regular manure analysis, as true nutrient content varies drastically depending on feeding and manure storage and handling practices. Use only for planning purposes.

Table 7.7. Nitrogen credits from previous legume crop

Crop	Population (Plants/ft^2)	[1,2]N Credit (lbs N/Acre)
Alfalfa or [3]Legume Green Manure	<1	0
	1–2	50
	3–5	100
	>5	150
Soybeans, edible beans, peas, lentils, and other annual legumes		40

[1]No-till corn into alfalfa or green manure crop: use half credit first year. Other tillage systems: use full credit.
[2]For second year following alfalfa and green manure crops: use half credit.
[3]Includes sweet clover, red clover, and other similar legumes.
(Adapted from Gerwing and Gelderman 2005)

Phosphorus

P-deficiency symptoms in corn appear as "purpling" of leaves and are most commonly seen during early growth stages (fig. 7.5). Symptoms may appear even though soil test P levels are high. Deficiency symptoms can result from either cool or dry soil conditions. For soils that test high for P, banding 30 lbs. P_2O_5 at planting may increase early growth but may not increase yield. In low to medium soil test P levels, a band application at planting will usually increase yields. A bushel of corn removes about 0.38 lbs. of P_2O_5. Based on this estimate, a 150 bu/acre corn crop removes 57 lbs. of P_2O_5.

P exists in solution, mineral, and organic forms (fig. 7.6). About 1% of P is in solution (plant available), whereas 85% is in mineral form and 14% is in organic form. Because P is constantly being transformed among the soil pools, P can be difficult to manage.

The optimal pH range for P availability is between 6.0 and 7.0. As soil pH values increase or decrease from the optimum, P becomes less available. Clay soils in the western part of the state often have high soil calcium (Ca^{2+}) levels, reducing soil test P levels. Irrespective of the soil test P values, these soils may not respond to P fertilizer.

Band applications of P, applied at planting, generally have higher efficiency than other approaches. Concentrating fertilizer P in a small area improves P availability, as there is less opportunity for the fertilizer P to be fixed. Rates can sometimes be reduced by one-third or more for band-applied P. However, reducing rates can result in a decline of soil test P over time. Equations for current recommendations are available at http://plantsci.sdstate.edu/soiltest/.

P recommendations are based on yield goal and laboratory results from a 0-to-6-inch soil sample. In South Dakota, P-fertilizer recommendations can be calculated from either the Bray-1 or Olson P methods. The Bray-1 (B1-P) method is used for acid soils (pH < 7), while the Olsen (O-P) method is used for basic soils (pH >7). Results from Mehlich III (MIII) soil tests, which are sometimes reported by soil testing labs in neighboring states, are similar to those obtained from the Bray-1 method.

The soil test results represent index values that coincide with a recommended P fertilizer rate. The rate of fertilizer P increases with yield goal and/or with declining soil test P values. As soil test P values increase, the probability that the crop will show a positive yield response from applied fertilizer P decreases. Corn grown in areas where soil test values are very low (B1-P and MIII-P, 0–5 ppm; O-P, 0–3 ppm) has an 80% chance of showing a yield response. Fertilizer P recommendations are calculated using the equations in Table 7.8.

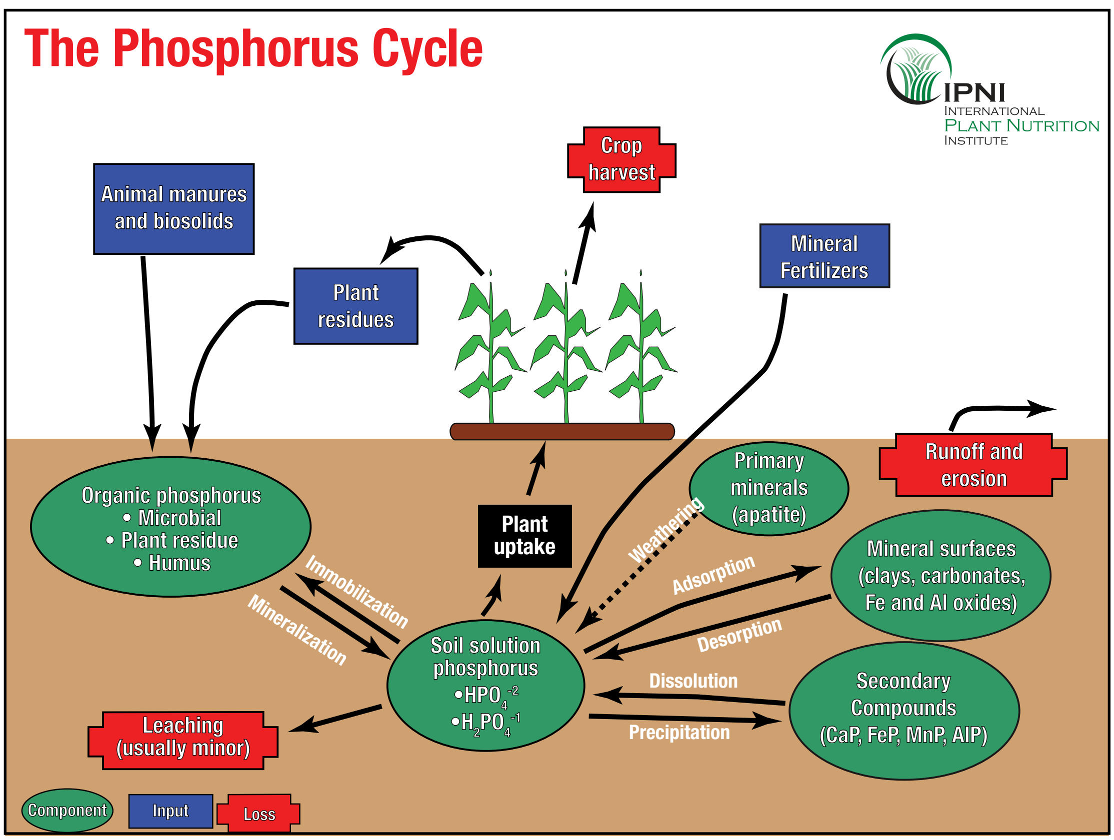
If manure is applied, the recommendation should be adjusted based on the amount of P contained in the manure. If an analysis of the manure is available, assume 90% of total P is available. If an analysis is not available, calculate P from data in Table 7.9.

Figure 7.5. P-deficient Corn

Deficiency symptoms appear as leaf "purpling" along leaf edges and slow and stunted growth. Symptoms most often appear early in the season, especially in low areas with high water tables.

(Photo courtesy of Howard J. Woodard, South Dakota State University)

Figure 7.6. The phosphorus cycle



(Courtesy of International Plant Nutrition Institute)

Table 7.8. Equations used to calculate P recommendation

Bray-1 P & Mehlich III

FPR = (0.7 – 0.035 x STP) x RYG

Olson P

FPR = (0.7 – 0.044 x STP) x RYG

Where:

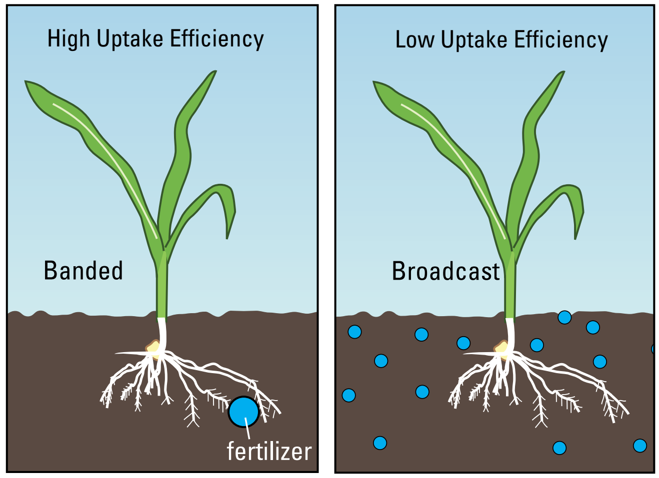
FPR = Fertilizer P Rate (lbs P_2O_5/A)

STP = Soil Test P Value (ppm)

RYG = Realistic Yield Goal (Bu/A)

(Gerwing and Gelderman 2005)

Figure 7.7. Band vs. broadcast P application



(Illustrations courtesy of Colorado State University)

Phosphorus in the Environment

Off-site movement of P generally occurs with runoff and erosion because P is strongly attached to soil. The transport of P from production fields to streams and lakes can result in algal blooms. Transport is minimized by adopting conservation tillage and other management practices designed to reduce or contain runoff and erosion. Concentrations of P in runoff waters can be reduced by minimizing the exposure of manure and fertilizer to runoff water (Table 7.10). Adopting these and other management practices has the potential to improve the quality of surface water.

Table 7.10. Phosphorus management techniques to improve water quality

- Place P sources below soil surface:
  - incorporate
  - inject
  - band apply
- Divide large variable fields into small management units – fertilize according to crop need and soil test.
- Maintain a buffer between "fertilized" and surface water or drainage.
- Consider developing and maintaining "grassed" or "wooded" buffers or filter strips in fields near surface waters or drainages.
- Avoid application of manure on frozen or snow-covered ground.
- Maintain surface residue levels above 30% to reduce erosion and runoff.

Table 7.9. *Estimated phosphorus content of manure

Type of Livestock	P_2O_5	
	Liquid (Lbs/1,000 gal.)	Solid (Lbs/ton)
Swine		
Farrowing	12	6
Nursery	19	8
Grow-Finish(deep pit or solid)	42	9
Grow-Finish(wet/dry feeder)	44	-
Grow-Finish(earthen pit)	22	-
Breeding-Gestation	25	7
Farrow-Finish	24	8
Farrow-Feeder	18	7
Dairy		
Cow	15	3
Heifer	14	3
Calf	14	3
Veal calf	22	3
Herd	15	4
Beef		
Beef cows	16	4
Feeder calves	18	4
Finishing cattle	18	7
Poultry		
Broilers	40	53
Pullets	35	35
Layers	52	51
Tom turkeys	40	50
Hen turkeys	38	50
Ducks	15	21

(Adapted from Lorimor and Powers 2004)

* These values vary drastically depending on feeding and manure storage and handling practices and are not likely representative of actual nutrient content of the manure. Use only for planning purposes. These values should not be used in place of a regular manure analysis.

Potassium

Potassium-deficiency symptoms appear as leaf yellowing and burning that begins at the tip of older leaves (fig. 7.8). Commonly, these symptoms are observed in sandy soils with low organic matter and in fields that were previously harvested for silage. About 0.27 lbs. of K_2O are removed by each bushel of corn grain, while K_2O removed with silage averages about 7.3 lbs./ton. Silage's high potassium (K) removal occurs 1) because K levels in plant material are nearly three times greater those that found in grain and 2) because K is soluble and can be washed out of dead leaves (so when the entire live plant is harvested, most K is removed from the field). Based on these estimates, a 150 bu/acre corn crop removes 40.5 lbs. of K_2O with the grain.

Most agricultural soils in South Dakota have relatively high K levels. However, in some situations there may be a positive response to K fertilizer applied as starter or broadcast. In South Dakota, K fertilizer recommendations are based on the amount of K extracted from a 0-to-6-inch soil sample using the equations in Table 7.11.

If manure is applied, K fertilizer may not be needed (manure contains high amounts of K). K fertilizer can be applied in contact with the seed in small amounts. However, seed germination can be reduced from salt damage if the N plus K_2O in the fertilizer exceeds 10 lbs./acre.

Figure 7.8. Potassium-deficient corn

Potassium-deficiency symptoms appear as burning of leaf edges.
(Photo courtesy of University of Georgia–Athens)

Table 7.11. Calculating a K recommendation

Corn for Grain

FKR = (1.1660 – 0.0073 x STK) x RYG

Corn for Silage

FKR= (9.50 – 0.06 x STK) x RYG

Where:
FKR = Fertilizer K Rate (lbs K_2O/A)
STK = Soil Test K Value (ppm)
RYG = Realistic Yield Goal (Bu/A)
A minimum of 60 lbs K_2O/A is recommended.
(Gerwing & Gelderman 2005)

Secondary and Micronutrients

In most situations, the secondary nutrients (Ca, Mg, S) and micronutrients (B, Zn, Fe, Cu Mo, Mn) do not limit yields in South Dakota. Zinc (Zn) deficiencies can be observed in coarse-textured soils, eroded soils, organic soils, or soils with high levels of P. Seasonal climate conditions may also affect Zn availability, as Zn-deficiency symptoms are often observed in cool, wet soils. Corn suffering from Zn deficiency can be seen in fig. 7.9.

Iron (Fe) deficiencies may be observed in leveled or eroded sites when calcareous subsoils have been exposed and pH levels are above 7. Fe-deficiency symptoms in corn are observed as yellowing with interveinal striping of younger leaves (fig. 7.10). Correcting for Fe deficiency can be difficult; the best approach is to incorporate manure or biosolids in problem areas.

Micronutrient deficiencies usually result from environmental conditions and may be temporary or have little effect on yield. If micronutrient deficiencies

Figure 7.9. Zinc deficiency in corn

Zinc-deficiency symptoms are shown on the youngest leaves and appear as feathering and striping.
(Photo courtesy of University of Georgia)

Figure 7.10. Iron deficiency in corn

Iron deficiency appears first in youngest leaves.
(Photo courtesy of University of Georgia)

are suspected, soil testing is recommended. Recommendations for Zn and Fe can be found in Table 17.12.

Considerations for No-Till

No-tillage can result in slower early season growth. Starter fertilizer applied with or near the seed can be used to enhance early season growth. If N or K is applied with the seed, the total amount added should not exceed 10 lbs. of N + K_2O. If possible, N fertilizer should be subsurface band applied. In no-tillage systems, it is recommended that the N rate be increased 30 lbs./acre. Broadcasting urea onto residue-covered fields in the fall can result in a substantial amount of N loss. To increase N-use efficiency, it is recommended that the N be spring-applied.

Table 7.12. Zinc and iron recommendations

Zinc soil test interpretation (ppm)	Zinc recommendations (lb/acre[1])
0.0–0.25 Very low	10
0.26–0.50 Low	10
0.51–0.75 Medium	5
0.76–1.00 High	0
1.01+ Very high	0

[1]Based on inorganic products as source of zinc, such as zinc sulfate.

Iron soil test ppm	Interpretation	Iron recommendations lb/acre
0–2.5	Low	0.15
2.6–4.5	Medium	0.15
>4.5	High	0

(Gerwing and Gelderman 2005)

Additional Information and References

Clay, D.E., C.G. Carlson, K. Brix Davis, J. Oolman, and B. Berg. 1997. Soil sampling strategies for estimating residual nitrogen. J. Production Agriculture. 10: 446-51.

Clay, D.E., N. Kitchen, C.G. Carlson, J.C. Kleinjan and W.A. Tjentland. 2002. Collecting representative soil samples for N and P fertilizer recommendations. Crop Management. http://www.plantmanagementnetwork.org/cm/.

Gelderman, R., Gerwing J. and K. Reitsma. 2005. Recommended soil sampling methods for South Dakota. FS935. South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Department of Agriculture. Brookings, SD. http://agbiopubs.sdstate.edu.

Gerwing, J. and R. Gelderman. 2005. Fertilizer recommendations guide. EC750. South Dakota State University, South Dakota Cooperative Extension Service, United States Department of Agriculture. Brookings, SD. http://agbiopubs.sdstate.edu/articles/EC750.pdf.

Lorimor, J. and W. Powers. 2004. Manure characteristics–manure management systems series. Midwest Plan Service – 18, Sec. 1, 2nd ed. Ames, IA.

Reitsma, K.D., R.H. Gelderman, P. Skiles, K. Alverson, J. Hemenway, H.J. Woodard, T.E. Schumacher, D.D. Malo and D.E. Clay. 2008. Nitrogen Best Management Practices for Corn in South Dakota. FS941. South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Department of Agriculture. Brookings, SD. http://agbiopubs.sdstate.edu.

Rehm, G., G. Randall, J. Lamb, and R. Eliason. 2006. Fertilizing corn in Minnesota. FO-3790-C. U. of Minn. Ext. Service, St. Paul, MN. http://www.soils.umn.edu.

Clay, D.E., and K.D. Reitsma. 2009. "Soil fertility." Pp. 39-48. In Clay, D.E., K.D. Reitsma, and S.A, Clay (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.