Chapter 5

Using the Nitrogen Balance Approach for Agricultural Systems

The Nitrogen Balance Approach (Chapter 3) includes three variables for calculating a biosolids application rate—the amount of N required by plants and soil (N requirement), the amount of N available from biosolids (net plant-available N, or PAN), and the amount of N available from other sources (N credits):

$$B_{app} = (N_{req} - N_{credits})/PAN \tag{3.1}$$

This chapter presents a method for calculating the net N requirement for agricultural systems ($N_{req} - N_{credits}$), gives a range of acceptable application rates, and discusses the uncertainties that accompany the calculation of such rates. (The method for estimating the PAN from biosolids is given in Chapter 4.) The calculation method presented can be used for a number of purposes:

- To screen potential sites for their capacity to use N inputs from biosolids
- To assess the possible causes of excess available N at a site
- To fine-tune net N requirements taken from university fertilizer guides
- To develop net N requirements for crops without a published university fertilizer guide

The method is designed for large sites that receive annual biosolids applications. We do not recommend its use for small sites or for sites that receive only occasional biosolids applications. Moreover, use of this calculation method requires regular soil and plant tissue testing and the involvement of a professional agronomist. A simpler calculation method using university fertilizer guides (Cogger and Sullivan, 1999) is sufficient for most sites.

Acceptable agronomic rate ranges

Crops respond to N by the “law of diminishing returns” (Figure 5.1a). The shape of N response curves for chemical fertilizers and for biosolids are generally similar. However, calculations of PAN for biosolids assume that biosolids total N is less available than is chemical fertilizer N. In Figure 5.1a, the total N supplied by biosolids is about 30 percent as available as N supplied by a chemical fertilizer. Without added N, some crop yield is produced from N supplied by soil organic matter, residual inorganic N in the soil, and other non-fertilizer N sources. If N is deficient (limiting yield), the first application of N fertilizer (chemical or biosolids) increases yield the most. Successive increments of applied N continue to increase yield up to a maximum yield imposed by climate, crop genetics, and other factors. As the maximum yield is approached with increasing N rates, less of the applied N is used by the crop.

In the example in Figure 5.1a, biosolids applied at 184 lb/ac N or fertilizer applied at 55 lb/ac N result in 95 percent of maximum yield. But maximum crop N uptake (Figure 5.2a) usually occurs at a higher N application rate than 95 percent of maximum yield, and additional crop N uptake near the maximum yield increases crop N concentration (Figure 5.2b). To reach maximum yield, however, applied N rates would have to increase substantially (over 50 percent) (Figure 5.1b). (Note that this example does not account for unplanned variability due to soil type, weather, and so forth.). To address this difficulty, a range of rates near maximum yield are used (Johnson and Raun, 1995; Raun and Johnson, 1995). It is important to monitor crop and soil N to fine-tune estimated agronomic rates. At N rates above the agronomic rate range shown in Figures 5.2 a & b, the additional applied N is not used by the crop and accumulates as excess soil N. The “excess range” is characterized by high soil nitrate (Figure 5.2a) and very high crop N concentrations (Figure 5.2b).

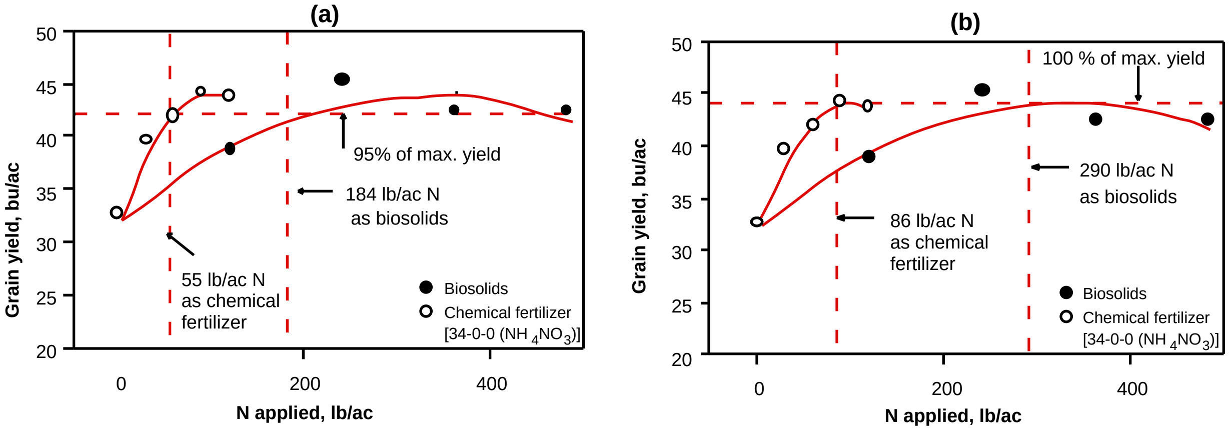

Figure 5.1. Nitrogen application rates required to reach 95 percent of maximum yield (a) or 100 percent of maximum yield (b). Nitrogen response plotted as a quadratic function. Dryland soft white winter wheat, Ellensburg, WA, 1992.

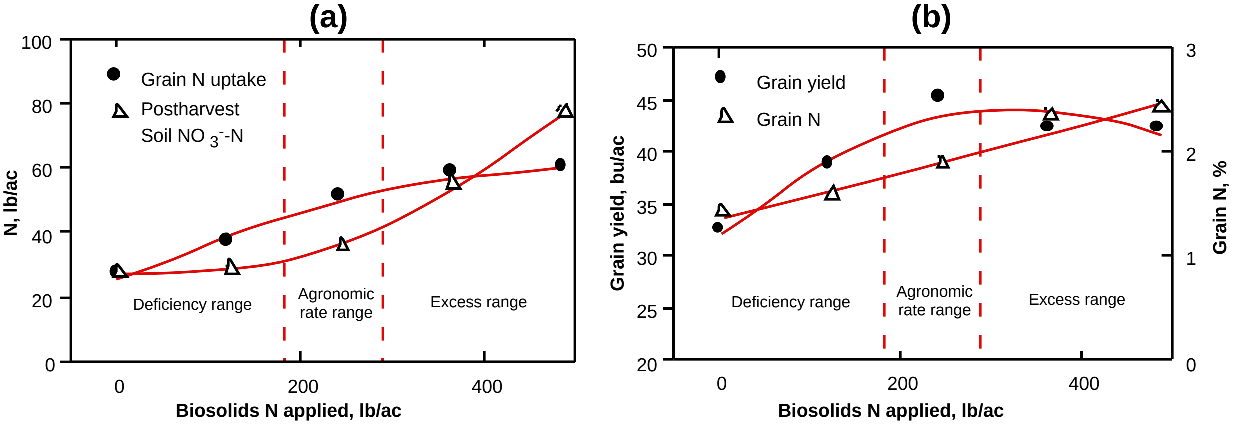

Figure 5.2. Example of nitrogen deficiency, agronomic rate, and excess N ranges as demonstrated by grain N uptake and soil nitrate-N (a) and grain yield and grain N concentration (b). Dryland soft white winter wheat, Ellensburg, WA, 1992.

Estimating plant-soil (crop) nitrogen requirement (N_{req})

Estimates of crop N requirement must consider the N uptake and N uptake efficiency factor for the crop (Bock and Hergert, 1991). The N uptake must be estimated for both the harvested and unharvested portions of the crop. The following is a simplified equation for estimating crop N requirement:

$$N_{req} = N_{uptot}/e_f \qquad (5.1a)$$

where

N_{uptot} = Total above-ground crop N uptake, lb/ac
e_f = Crop N uptake efficiency factor, decimal fraction (see following discussion)

A more detailed equation is used for calculating crop N requirement:

$$N_{req} = [(Y_h \times N_{upunit}) + (Y_{res} \times N_{upunit})]/e_f \qquad (5.1b)$$

where

Y_h = Unit yield goal of harvested above-ground portion of crop (tons, bushels, and so forth)
N_{upunit} = N uptake by harvested or unharvested portions of crop, lb/unit yield
Y_{res} = Unit yield of unharvested above-ground crop residues
e_f = Crop N uptake efficiency factor

Example: For soft white winter wheat in a dryland cropping system, the estimated grain yield is 60 bu/ac, grain N uptake is 0.95 lb/bu, straw yield is 3 t/ac, straw N uptake is 10 lb/t, and crop N uptake efficiency factor is 0.60.

Variables:

Y_h = 60 bu/ac
N_{upunit} for grain = 0.95 lb/bu
Y_{res} = 3 t/ac
N_{upunit} for straw = 10 lb/t
e_f = 0.60

Result: $N_{req} = [(60 \times 0.95) + (3 \times 10)]/0.60 = 145$ lb/ac

N removal from grazed pastures is lower than for forages harvested for hay or silage at the same yield level. With grazing, a portion of the N is returned to the field in the form of animal feces and urine. Estimates of crop N requirements under grazing management should be made by a professional agronomist.

Harvested crop yield goal (Y_h)

A reasonable method for determining a yield goal is to calculate a 5-year average of yields and then to add 5 to 10 percent to that average. Field-by-field records are the best source for crop yields. Proven yields for most grain farms can be obtained from the local U.S. Department of Agriculture Farm Service Agency (FSA) office. For most other crops, grower records are the only available source. A site used repeatedly for biosolids application should have yield data collected each year. This accumulated data can be used for determining crop N requirement. If crop yield data is not kept, additional crop and soil N monitoring may be appropriate.

For high-yielding grain crops, the upper limit on crop N requirement should be used. For example, research in western Oregon has demonstrated that winter wheat has the same crop N requirement (approximately 260 lb/ac) for a 100 bu/ac yield as for a 150 bu/ac yield (Karow, 1995). This amount of N is needed to maximize crop yield potential; actual yields reflect limiting factors other than N (such as plant disease).

Nitrogen uptake per unit of harvested yield (N_{upunit})

The N uptake per unit of harvested yield (N_{upunit}) for common grain, forage, and other crops are shown in Table 5.1. These N uptake values were derived from the crop N concentrations, moisture contents, and unit weights listed in Table 5.1 and then applied to the following equation:

$$N_{upunit} = [N_{conc}/100 \times (100 - Y_m)/100] \times Y_{lbac} \qquad (5.2)$$

where

N_{conc} = Crop N concentration, dry weight basis, %
Y_m = Crop moisture content, %
Y_{lbac} = Crop yield unit, lb/ac

Example: For N uptake per ton of grass silage harvested at the late vegetative stage of growth, the moisture content is 75 percent, the usual dry weight N concentration for this stage of growth is 2.50 percent, and the crop yield unit is 2,000 lb/ac.

Variables:

N_{conc} = 2.50 percent
Y_m = 75 percent
Y_{lbac} = 2,000 lb/ac

Result: $N_{upunit} = [2.5/100 \times (100 - 75)/100] \times 2{,}000 = 12.5$ lb/ac grass silage

For moisture contents other than the "typical" values given in Table 5.1, the N_{upunit} can be calculated by applying the N concentrations for each crop listed in Table 5.1 to equation 5.1. The crop N concentrations listed in Table 5.1 are averages for crops fertilized to near-maximum yield. Crops supplied with excessive N or crops stressed by disease, lack of water, or other factors may have substantially higher N concentrations (over 115 percent of the values in Table 5.1). For forage crops, the stage of maturity has a major effect on harvested N concentrations. N concentrations are highest in young, leafy forages, declining with crop maturity. Matching the projected yield with the appropriate growth stage is critical for accurate estimates of forage crop N removal. Crop N concentrations substantially different than the typical values listed in Table 5.1 should be documented by plant tissue testing.

Crop residue yield (Y_{res})

For some crops, only a portion of the above-ground biomass is harvested. The crop residue per unit of grain production is not listed in Table 5.1 because of the wide range in straw yields for different cereal varieties. If straw is routinely baled after grain harvest, crop residue yield can be estimated from grower records. Otherwise, estimates can be obtained from a professional agronomist.

Nitrogen uptake per unit of crop residue yield (N_{upunit})

Typical crop residue N concentrations are listed in Table 5.1. The N_{upunit} for crop residue can be calculated using Equation 5.2.

Crop N uptake efficiency factor (e_f)

Not all of the PAN present in the root zone is recovered as above-ground crop N uptake. The crop N uptake efficiency factor accounts for the following:

- Available N taken up by roots
- Available N (ammonium and nitrate) that is lost via leaching, immobilization, and denitrification with good crop, fertilizer, and irrigation management
- Available N present as soil ammonium or nitrate at the end of the growing season

Assuming recovery of fertilizer N by above-ground crops under good management practices, we recommend using a crop N uptake efficiency factor of 0.60 to 0.75 (0.60 for annual crops and 0.75 for forage crops with perennial root systems). Perennial forage crops are generally more efficient than are annual crops, because perennial forage crops have deeper root systems that have greater surface area for absorption and that actively take up N for a longer period each year. Bock and Hergert (1991) discuss in more detail the factors involved in estimating crop N uptake efficiency factors.

Table 5.1. Estimated Nitrogen uptake per unit of above-ground harvested biomass for crops used for biosolids application.

Crop	Plant Part	"As-is" (wet weight basis)				Data Source[b] (growing region)
		Moisture Content (Y_m) (%)	Unit Weight	N_{Conc}[a] (% of dry weight)	N Uptake Per Unit (N_{upunit}) (lb/ac)	
Grain crops						
Barley	Grain	12	bu (48 lb)	2.10	0.9	U.S.
Oats	Grain	12	bu (32 lb)	2.20	0.6	U.S.
Spring wheat, soft white	Grain	12	bu (60 lb)	1.80	1.0	W. OR
Winter wheat, hard red	Grain	12	bu (60 lb)	2.10	1.1	U.S.
Winter wheat, soft white	Grain	12	bu (60 lb)	1.80	1.0	W. OR
Barley, oats or wheat	Straw	12	ton	0.55	9.7	U.S.
Grass seed	Seed	12	ton	2.40	42.2	W. OR
Grass seed	Straw	12	ton	0.95	16.7	W. OR
Forage crops						
Alfalfa, late vegetative	Hay	12	ton	3.30	58.1	U.S.
Alfalfa, early/mid bloom	Hay	12	ton	2.90	51.0	U.S.
Alfalfa, full bloom	Hay	12	ton	2.50	44.0	U.S.
Clover, late vegetative	Hay	12	ton	3.40	59.8	U.S.
Clover, full bloom	Hay	12	ton	2.40	42.2	U.S.
Corn	Silage	70	ton	1.35	8.1	W. OR
Grass, late vegetative	Hay	12	ton	2.50	44.0	W. WA
Grass, late vegetative	Silage	75	ton	2.50	12.5	W. WA
Grass, mid-bloom	Hay	12	ton	1.75	30.8	W. OR
Grass, mature	Hay	12	ton	1.10	19.4	W. OR
Specialty crops						
Hops	Cones	5	bale	2.30	4.6	W. OR
Hops	Residue	5	per bale		7.6	W. OR

[a] Typical range in plant N concentration is ± 15 % of the "common value" given. Actual crop N concentrations will vary depending on climate and crop maturity, variety, and general nutritional status.

[b] Data sources for typical U.S. crops: Meisinger and Randall (1991) and the National Research Council (1996). Data sources for Oregon and Washington: published and unpublished data from Oregon State and Washington State Universities.

Estimating nitrogen from other sources ($N_{credits}$)

N from other sources contributes to the total quantity of N available for plant uptake. These sources are credited in calculating an agronomic biosolids application rate. Other N sources are as follows:

- Expected N additions
  —Fertilizer N applications
  —Irrigation water
  —Atmospheric deposition
- Available inorganic N present in the soil
- Estimated soil organic N mineralized
- Adjustments to estimated soil organic N mineralization:
  —N mineralized from plowdown of a legume or a cover crop
  —N mineralized from previous biosolids or manure applications

Expected N additions

The following paragraphs describe methods for calculating the credit for expected N additions.

Fertilizer N applications. A small amount of a phosphorus (P) starter fertilizer may be needed for maximum yield of some row crops. Starter P fertilizers are usually ammonium phosphates that contain 10 to 20 percent N (weight basis). Sulfur also may be supplied as ammonium sulfate (21 percent N) or ammonium thiosulfate (12 percent N). N supplied from these sources should be credited.

Irrigation water. Irrigation water is a significant N source when groundwater or reuse water with a high nitrate concentration (over 10 mg/L), such as wastewater effluent, is applied. Irrigation water can be a highly effective N source. Research with irrigated corn in Nebraska showed that the efficiency of N from irrigation water was similar to side-dress N fertilizer (Francis and Schepers, 1994; Ferguson et al., 1991). The N supplied by irrigation water is the product of water applied (inches) and the nitrate concentration of the water (lb/in.). For example, irrigated pasture in the Hermiston area (Oregon) has an annual irrigation requirement of 35 in./yr (Cuenca, 1992). Irrigation water containing 10 mg/L (2.3 lb/ac-in.) of N would supply about 80 lb/ac/yr of N.

Atmospheric deposition. In most areas of the Northwest, the quantity of N supplied by atmospheric deposition is very low (less than 10 lb/ac/yr) and can be ignored as N addition. Zero can be entered for this credit unless site-specific monitoring data show significant deposition.

Available inorganic N present in the soil

Both soil nitrate (NO_3^-) and soil ammonium (NH_4^+) are considered in calculating the credit for inorganic N in the soil.

Soil nitrate. Soil testing is a reliable measure of the current soil NO_3^-. Testing must be conducted before biosolids application. Credits for pre-application soil NO_3^- are widely used in low-precipitation cropping zones (less than 18 in./yr). Early spring NO_3^- testing (February through April) usually is **not** useful in higher precipitation areas (over 18 in./yr) because NO_3^- remaining from the previous year has leached and little spring mineralization has occurred. Pre-application testing later in the year (May through August) is useful in all precipitation zones.

Appropriate sampling depths for soil nitrate-N (NO_3-N) vary with cropping system, soil depth, and other factors. Sampling to a 24-in. depth is suggested for most crops. Soil samples should be composited in 12-in. depth increments. An initial deep sampling (48 to 60 in.) should be considered at new biosolids application sites to document accumulations of NO_3-N below the root zone.

In most soils, a small amount of the NO_3-N (1 to 3 mg /kg) is unavailable to plants because of limited root access. This amount of NO_3-N (about 4 to 12 lb/ac-ft) is insignificant in most cropping systems but becomes important when NO_3-N is credited on the basis of a deep (36- to 72-in.) sampling depth. Soils with higher clay contents have more NO_3-N that is inaccessible for root extraction. A suggested formula for adjusting measured soil NO_3-N for unavailable NO_3^- is based on soil clay content (Schepers and Mosier, 1991):

$$\text{Unavailable } NO_3\text{-N (mg/kg)} = \text{percent clay x } 0.1 \tag{5.3}$$

Using this formula, a soil with 30 percent clay would have 3 mg/kg NO_3-N that is not available for plant uptake. So, a soil test of 10 mg/kg NO_3-N would be adjusted to 7 mg/kg NO_3-N.

Soil ammonium. Soil NH_4^+ is sometimes included as N credit, particularly for samples collected from the surface soil (12-in. depth). In agricultural soils, NH_4^+ levels are usually low because nitrification (conversion of NH_4^+ to NO_3^-) generally proceeds more rapidly than mineralization (conversion of organic N to NH_4^+). Soil NH_4^+ levels are more difficult to interpret than NO_3^- levels for the following reasons:

- Chemical extraction with 2M KCl (the recommended extractant) displaces some NH_4^+ bound by clay minerals that is not plant-available.
- Drying soils increases extractable NH_4^+ content.

We suggest that soil NH_4^+ (0- to 12-in. depth) be included in N credits **only when** fertilizer or organic N sources have been recently applied (within the last 60 days). Soil samples for NH_4^+ analysis should be air dried at room temperature (approximately 68 to 77°F).

Estimated soil organic N mineralized

Soils contain a large reserve of organic N (ON). For most situations, N mineralized from soil ON ranges from 40 to 200 lb/ac/yr. Annual mineralization rates for soil ON are calculated using the following equation:

$$SON_{yr} = TKN_{soil} \times N_{soilmin}/100 \times BD \times c_{bd} \qquad (5.4)$$

where

SON_{yr} = Soil organic N mineralized per year, lb/ac/yr
TKN_{soil} = Soil total N, mg/kg, 0- to 12-in. depth
$N_{soilmin}$ = Estimated annual soil organic N mineralized, %
BD = Soil bulk density at the site, g/cm^3
c_{bd} = 2.72, conversion factor for standard soil bulk density (1 g/cm^3) and standard soil depth (12 in.)

Example:

Variables:

TKN_{soil} = 3,000 mg/kg
$N_{soilmin}$ = 1% of soil organic N mineralized/yr
BD = 1.3 g/cm^3

Result: $SON_{yr} = 3{,}000 \times 1/100 \times 1.3 \times 2.72 = 106$ lb/ac/yr

For purposes of this estimation, the $TKN_{soil,}$ (total Kjeldahl N content of soils) is considered equivalent to total ON, because over 99 percent of total N in soil is present in an organic form. A soil with 3 percent (0 to 12 in. depth) organic matter contains approximately 5,000 lb/ac N.

Estimating the $N_{soilmin}$ in agricultural soils depends on depth of soil, season, and other conditions at the site. Usually only the surface soil (12-in.depth) and only the period from March through October are considered in calculating annual mineralization rates. The small amount of soil ON mineralized during winter months (November through February) is usually ignored in calculating annual mineralization rates. Most soil ON mineralization takes place from March through October, which corresponds roughly with the growing season for perennial grasses. The quantity of soil ON mineralized per acre increases as the following conditions increase:

- Soil ON concentrations
- Tillage
- Soil moisture content (unless soil is saturated)
- Soil temperature
- Artificial (tile) drainage

- Length of cropping cycle (for example, a higher N mineralization for a wheat-fallow cropping system than for an annual cropping system)

Typical $N_{soilmin}$ values range from 1 to 4 percent of the ON present in the surface horizon. Desert soils recently brought under irrigation often have high N mineralization rates (over 4 percent of ON per year). In these soils, a larger proportion of soil organic matter is of recent origin (easier to decompose) and temperature and moisture conditions are near optimum for soil N mineralization. Soils with high organic matter contents (over 5 percent) west of the Cascade mountains often have low N mineralization rates (approximately 1 percent of ON per year), because the organic matter is older (more resistant to mineralization), soil temperatures are lower, and poor drainage often limits oxygen availability.

Adjustments to estimated soil organic N mineralization

Previous ON mineralized from plowdown of a legume or a cover crop and from previous biosolids or manure applications must be factored into the calculation of N from other sources, and the soil N mineralization rates must be adjusted accordingly.

$N_{credits}$ for legume or cover crops. The following information is needed to estimate N contributions from legumes or cover crops:

- Legume or cover crop biomass
- ON content biomass
- Estimated N mineralization rate of the biomass

Mineralization rates usually increase as crop residue N concentrations increase (Vigil and Kissel, 1991). For green residues with high N concentrations (over 2.5 percent N, dry weight), first-year N mineralization rates are usually 20 to 50 percent of N plowed down. For cover crops with low N concentrations (less than 1 percent N), first-year N mineralization rates are usually less than 10 percent of N plowed down. Recommended N fertilizer rates for most crops decrease by about 30 to 100 lb/acre for the year following plowdown of an alfalfa or a legume cover crop.

$N_{credits}$ for previous biosolids or manure applications. Sites with a history of continuous biosolids or manure application have elevated soil ON mineralization rates. Soil testing for organic matter content alone will not detect differences in mineralization rates resulting from previous biosolids or manure applications. The appropriate credit for a site depends on the following factors:

- Previous biosolids/manure application rate
- Biosolids/manure ON content
- Quantity of remaining ON
- Mineralization rate of remaining ON
- Residual effects of previous applications on soil pH and microbial activity

Application records can be used to calculate historical ON inputs. Estimates of residual ON quantity and mineralization rates vary widely. For sites with a history of frequent biosolids or manure applications, N credits for previous applications usually range from 40 to 100 lb/ac/yr. Repeated biosolids or manure applications at a site increase the need for soil and crop N monitoring. The longer the history of biosolids or manure N application, the more uncertain is the proper credit for previous applications. (Chapter 4 gives methods for calculating N credits for previous biosolids applications.)

Example net crop nitrogen requirement calculation

Table 5.2 shows all of the steps described so far in this chapter for calculating the crop N requirement (N_{req}) and credits for N from other sources ($N_{credits}$). The table uses two examples: grass silage and winter wheat.

Uncertainties in estimating net crop nitrogen requirements in agricultural systems

This chapter provides a step-by-step procedure using the Nitrogen Balance Approach for estimating net N requirements for agricultural biosolids applications. In describing the process, we have attempted to point out some major limitations in the approach and to caution that agronomic rates for biosolids application should be regarded with a level of uncertainty (a range of application rates for near-maximum yield).

Monitoring soils and crops and following good crop management practices are essential. Soil and crop N monitoring are valuable tools in biosolids N management. These tools are currently the best available technology for determining if biosolids application rates are appropriate. Protocols for N monitoring are well developed for the major agronomic crops and for some high-value crops. The design and implementation of a high quality crop and soil N monitoring program will require the involvement of a professional agronomist.

A number of agricultural N management models have been developed recently to increase the accuracy of the Nitrogen Balance Approach. These models continue to be adapted and will undoubtedly become a larger part of routine N management in the future. They provide a time scale (daily, weekly, or monthly) that is more meaningful for most cropping systems, where most of the annual crop N uptake takes place over a short 4- to 12-week period. They also can provide site-specific estimates of soil organic N mineralization if soil moisture and temperature data are available. Soil temperature and moisture measurements can now be routinely taken via automated systems, with the data retrieved electronically. We anticipate a merging of our knowledge of N availability from biosolids with models for N cycling and soil water balance. Managing biosolids in the context of such models will be a major step forward.

Critical variables

In general, the most powerful variables affecting net N requirements (N_{req}- $N_{credits}$) in agricultural systems are as follows:

- Crop N uptake efficiency factor (e_f), which needs further research on N losses (leaching, immobilization, denitrification, volatilization) for specific cropping systems
- Estimated soil ON mineralized (SON_{yr}), especially for soils that have a history of manure, biosolids, or cover crop inputs

Unfortunately, regional estimates for these variables are usually not very accurate. This problem is not exclusive to biosolids management. It is a challenge for all organic waste management plans. However, we have a higher confidence in our ability to estimate the available N supplied by biosolids. This is the result of recent research on biosolids in the Northwest (Appendixes C, D and E).

Table 5.2. Worksheet for estimating net crop N requirement for grass silage and winter wheat crops.

	Symbol	Units	Examples			
			Grass Silage [a] (tons)		Winter Wheat [b] (bushels)	
Crop N Requirement						
$N_{req} = N_{uptot}/e_f$	$N_{uptot} = (Y_h * N_{upunit}) + (Y_{res} * N_{upunit})$		$N_{upunit} = [N_{conc}/100 * (100 - Y_m)/100] * Y_{lbac}$			
Harvested portion						
Yield goal	Y_h		25		60	
Moisture content	Y_m	%	75		12	
N concentration	N_{conc}	% of dry wt.	2.5		1.8	
Unit N uptake	N_{upunit}	lb/unit yield	12.5		1.0	
N uptake (harvested)		lb/ac		313		57
Unharvested portion						
Yield	Y_{res}	tons			3	
Unit N uptake	N_{upunit}	lb/unit yield			10	
N uptake (unharvested)		lb/ac		0		30
Combined N uptake	N_{uptot}	lb/ac		313		87
N uptake efficiency factor	E_f	Fraction, 0-1	0.75		0.60	
Total crop N requirement	N_{req}	**lb/ac**		**417**		**145**
N from Other Sources						
Expected N additions						
Fertilizer N		lb/ac	0		0	
Irrigation water		lb/ac	10		0	
Atmospheric deposition		lb/ac	0		0	
Total N additions				10		
Residual soil nitrate		lb/ac		80		**60**
Annual soil organic N mineralized ($SON_{yr} = TKN_{soil} * N_{soilmin}/100 * BD * c_{bd}$)						
Soil organic N (0-12 in.)	TKN_{soil}	mg/kg	1900		400	
Soil bulk density (0-12 in.)	BD	g/cm^3	1.30		1.30	
Estimated annual N mineralization rate	$N_{soilmin}$	% of TKN_{soil}	2.00		2.00	
Total annual N mineralized	SON_{yr}	lb/ac		134		**28**
Mineralization adjustments						
Legume or cover crop		lb/ac	0			0
Previous biosolids application		lb/ac	0			0
Previous manure application		lb/ac	0			0
Total mineralization adjustments				0		
Total N from other sources	$N_{credits}$	**lb/ac**		**224**		**88**
Net N requirement ($N_{req} - N_{credits}$)				**193**		**57**

Note: The numbers in the black boxes were derived from research studies on grass silage and winter wheat.

[a] Reflects the usual values for tall fescue grown on a sandy loam soil in western Washington.

[b] Reflects the usual values for soft white winter wheat grown on a silt loam soil in a wheat/fallow rotation in central Washington (10 to 14 inches of annual precipitation).

Keeping the following cautions in mind can help refine these estimates:

- The net N requirement (N_{req}- $N_{credits}$) calculated in this chapter is roughly comparable to a N fertilizer recommendation from a university fertilizer guide. It is critical to remember that university fertilizer recommendations will not be comparable to the N requirement (N_{req}) as calculated in this chapter.
- Credits for soil organic matter mineralization must be included for **all sites.** Failure to do so will result in an excessive net N requirement.
- Crop N uptake and crop N requirement do not mean the same thing, nor are they interchangeable. Crop N requirement is always greater than crop uptake because it includes an efficiency factor that accounts for N not taken up by the plant or stored in plant roots.
- The suggested values given here for N from other sources ($N_{credits}$) may seem high to those accustomed to reviewing N budgets. This is because our N credits represent the available N supplied by an N source (for example, soil organic matter), not the net N uptake by the crop. For example, if soil organic matter supplies 100 lb/ac N and a crop N uptake efficiency factor (e_f) of 60 percent is used for calculating crop N requirement (N_{req}), then net crop N uptake from soil organic matter mineralization is estimated at 60 lb/ac.

The importance of timing in matching nitrogen supply with crop demand

The method for calculating net N requirement presented in this chapter implicitly assumes that N can be accurately managed with the Nitrogen Balance Approach. This is a big assumption, because it assumes that N supply from a variety of sources will match crop N needs throughout the growing season, ensuring the desired yield without accumulating excess N that can be leached as nitrate. Timing, crop management practices, and monitoring are vital. Table 5.3 shows a sample estimate of the PAN from biosolids and other sources throughout the growing season for a silage corn crop. Figure 5.3 plots this PAN against the plant uptake for the same crop.

Table 5.3. Plant-available nitrogen throughout the growing season (May-September) for a silage corn crop planted May 15 with biosolids applied on April 15 at a rate of 400 lb/ac total nitrogen.

N Sources	Unavailable N	Available N
From other sources		Soil nitrate 60 lb/ac N, as tested April 15 Soil organic N mineralized at 1 lb/ac/day
From biosolids		
Inorganic N	10 percent of total N (40 lb/ac) in ammonium form lost by volatilization	10 percent of total N (40 lb/ac) in ammonium form
Organic N	60 percent of total N (240 lb/ac)	20 percent of total N (80 lb/ac) mineralizes: · 10 percent is fast-pool organic N that mineralizes at a rate of 2 lb/ac/day in the first 20 days (40 lb/ac total) · 10 percent is slow-pool organic N that mineralizes at a rate of 0.6 to 0.3 lb/ac/day during the remainder of the growing season (approximately 90 days at an average of 0.45 lb/ac/day = 40 lb/ac)
Total plant-available N from biosolids		30 percent of 400 lb/ac, or 120 lb/ac

Note: The crop has no cultural problems such as disease, insects, or irrigation failure.

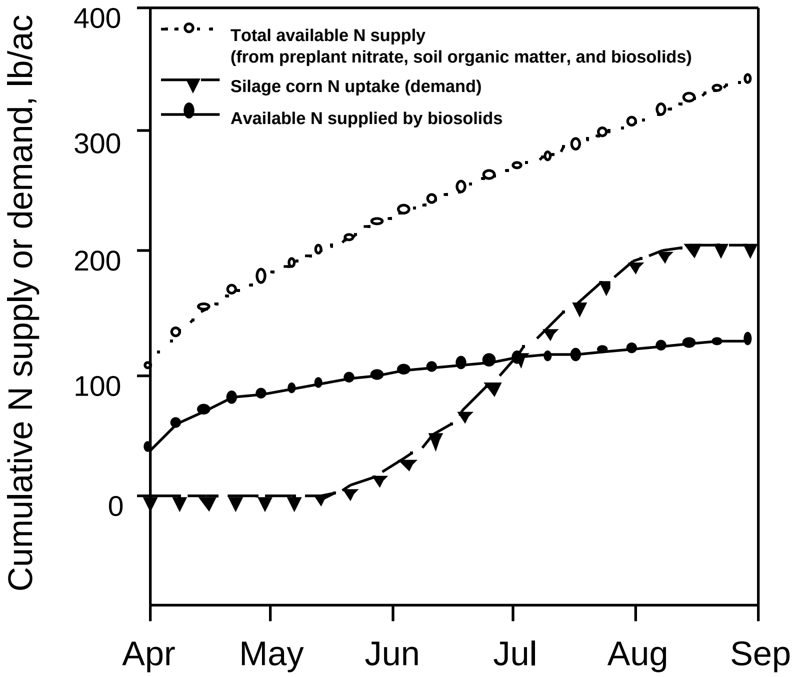

Figure 5.3. Plant-available nitrogen supplied by biosolids and other available nitrogen sources compared with nitrogen uptake by a silage corn crop. The difference between total nitrogen supply and crop nitrogen uptake represents a nitrogen use efficiency of 60 percent.

As can be seen in Figure 5.3, the total soil inorganic N supply is much greater than crop demand early in the growing season, which provides an opportunity for nitrate leaching. The total soil inorganic N supply is large (180 lb/ac) at planting; an additional 160 lb/ac is predicted from biosolids organic N mineralization and soil organic matter mineralization during the growing season. Cumulative crop N uptake (demand) follows an s-shaped curve over the course of the growing season. Uptake is minimal (less than 30 lb/ac) until mid-June, when the corn begins rapid growth (stem elongation). For the next 8 weeks (mid-June to mid-August), the crop N uptake rate is nearly linear (2 to 3 lb/ac/day). After mid-August there is little additional crop N uptake. Thus, an adequate PAN supply is critical for crop performance during the rapid growth period (mid-June to mid-August).

The key N management practice in this example is irrigation management (proper scheduling and application methods to minimize leaching). The inorganic N present in the root zone in May could be leached out before the crop is capable of taking it up. N mineralized from biosolids and soil organic matter after early August will not be taken up by the plants and will be susceptible to leaching by winter precipitation. Fall cover crops planted after corn harvest would reduce fall nitrate leaching.

To reduce risk, the total PAN could be determined in early June by soil testing, prior to the period of high N demand by the corn crop. If N supply is inadequate in June, additional fertilizer N could be applied. If N supply in June is excessive, lower biosolids application rates could be applied next year.

Other examples of the timing and quantity of N uptake for a variety of Pacific Northwest crops are provided in Sullivan et al. (1999), and additional references are included in Appendix G.

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