Predicting Nitrogen Release from Cover Crops:

THE COVER CROP NITROGEN AVAILABILITY CALCULATOR

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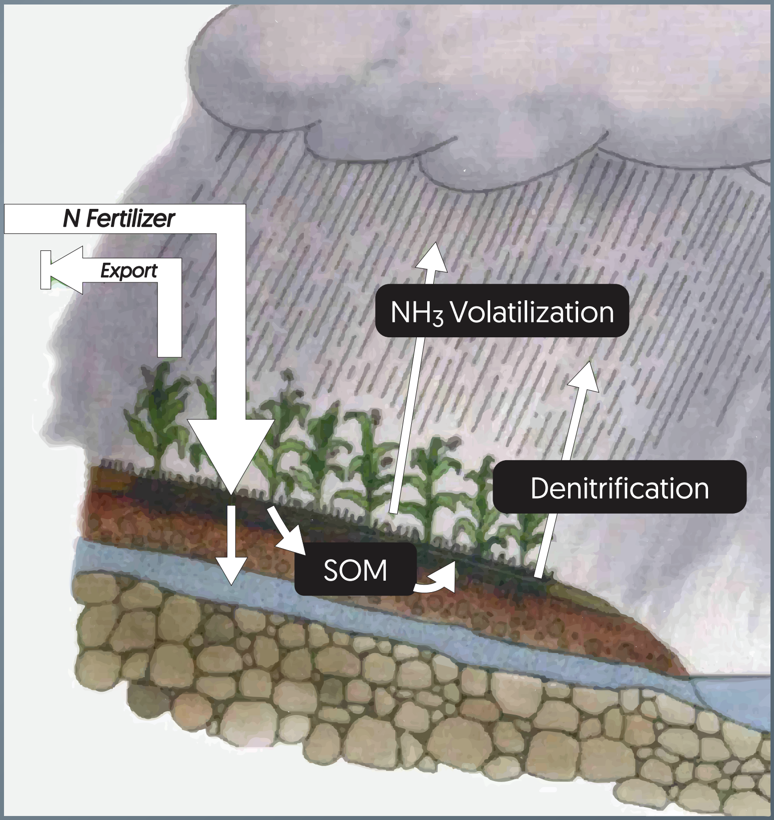
THE NITROGEN CYCLE



Nitrogen is the nutrient needed in the greatest amount by plants. It has a complex cycle. About half of the nitrogen fertilizer applied is used by the growing cash crop. If the entire crop is removed from the field, this nitrogen is effectively removed from the system. The other half of the nitrogen fertilizer applied can be lost through a variety of pathways. Some nitrogen is lost as a gas through ammonia volatilization and denitrification. Nitrogen can also be lost through leaching through the soil below the root zone to groundwater. A portion of nitrogen fertilizer is incorporated into soil organic matter (SOM) and will not be immediately available to the growing cash crop. The SOM will decompose over time and re-release a portion of this nitrogen.

Figure from Nutrient Cycles in the Southern Piedmont.

Including cover crops in a crop rotation has many benefits, such as erosion control, weed suppression, compaction reduction, and habitat for beneficial insects as well as pollinators. The carbon supplied by cover crops feeds the base of the soil food web and helps support a diverse, robust soil microbial community. This community recycles nutrients and improves soil structure. Some microorganisms release chemicals that are plant growth promoters or that can help suppress soil diseases. Cover crops play a direct role in fertility by scavenging nutrients from the subsoil that would otherwise be lost below the root zone, and legume cover crops fix nitrogen (N) from the atmosphere.

One of the challenges facing farmers who use cover crops is quantifying the available nitrogen supplied to the following cash crop by the decomposing cover crop residues, and how they might change their fertilizer management to account for this. In this publication, we describe a new tool to help farmers better manage cover crop nitrogen, but first, we need a better understanding of cover crops and the nitrogen cycle.

UGA extension

Cover Crops and Nitrogen

Cover crops scavenge nitrogen from the soil and prevent it from being lost to leaching or volatilization. Cereal rye (*Secale cereale*) and daikon radishes (*Raphanus sativus*) are two winter cover crops that are known to be good nitrogen scavengers. Cereal rye is reported to take up from 20 to 100 lb N per acre due to its fast-growing roots, and radishes are reported to scavenge from 50 to 200 lb N per acre.

Other small grains like oats (*Avena sativa*), black oats (*Avena strigosa*), wheat (*Triticum* spp.), and barley (*Hordeum vulgare*) are also fairly good nitrogen scavengers. The best summer cover crop for nitrogen scavenging is sorghum-Sudangrass hybrids (*Sorghum bicolor* x *S. bicolor* var. *Sudanese*). None of these cover crops create new nitrogen. Their deep roots pull up residual nitrogen that has moved below the cash crop's root zone and incorporate it into leaves, stems, and eventually, seeds. Nitrogen becomes available to cash crops as the cover crops die and decompose.

Legume cover crops can form symbiotic relationships with rhizobia bacteria that can convert N_2 gas in the atmosphere into ammonia (NH_3) and then to ammonium (NH_4) that can be used by the plant. Some legume cover crops are able to fix greater amounts of nitrogen than others (Figure 1). Winter legumes that perform well in Georgia typically fix from 70 to 200 lb N per acre. Crimson clover (*Trifolium incarnatum*) is a commonly used cover crop that typically fixes 50 to 100 lb N per acre in the Southeastern United States. Hairy vetch (*Vicia villosa*) is generally thought of as a high nitrogen-fixer and typically produces from 80 to 150 lb N per acre with over 200 lb N per acre reported in a few studies. However, it can become a weed in some situations, particularly for organic growers. Austrian winter peas (*Pisum sativum* subsp. *arvense*) produce 70 to 110 lb N per acre. This winter legume may grow better than crimson clover when planted later in the fall, but is susceptible to a plant pathogen—*Sclerotinia*—if there are cool, moist conditions in the spring.

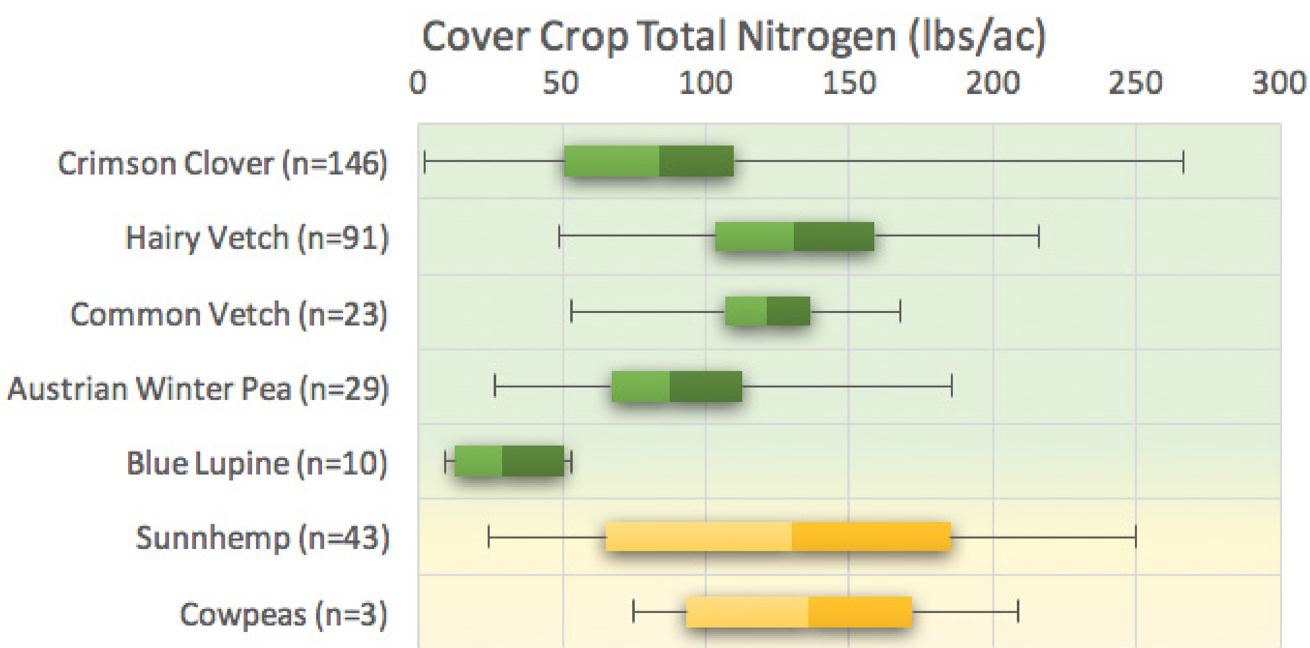


Figure 1. The total amount of nitrogen in legume cover crop biomass based on an unpublished review of research articles on cover crops in the Southeastern United States by J. Gaskin. The vertical bar indicates the average value. The box represents the range in typical values (25th to 75th quartiles). The long lines indicate the total range of reported values. The numbers in parentheses by the cover crop species are the number of data sets for that species identified in the review. Shades of green indicate winter legumes, and shades of yellow indicate summer legumes.

There are also summer cover crops that will fix high amounts of nitrogen. Cowpeas (*Vigna unguiculata*) reportedly fix from 90 to 150 lb N per acre. In our trials in the Piedmont of Georgia, we have seen as much as 170 lb N per acre. Sunn hemp (*Crotalaria juncea*) is a fast-growing tropical legume that reportedly fixes from about 65 to 185 lb N per acre. Our trials in Piedmont Georgia showed that sunn hemp could produce 200 lb N per acre in 60 days. A special note: this species of *Crotalaria* is different from the noxious weed *Crotalaria* species. Because sunn hemp is a tropical legume, short-day varieties do not produce fertile seed.

The amount of nitrogen fixed depends not only on the species, but on plant growth, as well. Timely planting, a soil pH around 6.0 to 6.5, proper fertilization (including moderately high available phosphorus in the soil), and inoculation with the appropriate rhizobial strains will maximize plant growth and biomass. This, in turn, will maximize nitrogen production. For example, crimson clover that produced a biomass of 1,000 lb per acre and has a 3 percent nitrogen concentration will only contain 30 lb N per acre. If the crimson clover has produced 5,000 lb per acre of biomass at the same 3 percent nitrogen concentration, there will be 150 lb N per acre. Any conditions that stress plants will also limit growth and nitrogen production. Soil temperature also affects the nitrogen fixation. Some studies indicate that the greatest nitrogen fixation occurs between 55 to 80 degrees Fahrenheit. In addition, most nitrogen fixation occurs when a legume is beginning its reproductive stage (when it's beginning to flower). Waiting to kill the legume cover crop until mid-bloom will maximize the total nitrogen in the cover crop.

Figure 2. A crimson clover cover crop in Tifton, Georgia with biomass of 5,000 lb per acre.

Nitrogen Mineralization from Cover Crops

Although legumes fix nitrogen, and other cover crops contain nitrogen in the plant tissue, nitrogen is not available to other plants until the cover crop decomposes. As the cover crop residue decomposes, the organic nitrogen in its tissue is converted to ammonium (NH_4) and then to nitrate (NO_3), which are the dominant forms of nitrogen plants use in an agricultural system. Predicting the amount of nitrogen released by a cover crop is not as simple as analyzing the total amount of nitrogen in the cover crop biomass. Only a portion of the nitrogen contained in the cover crop residues will be released as NH_4 and NO_3 during the life cycle of the following cash crop (Figure 3). The nitrogen released can be lost to the following cash crop through the same processes that affect nitrogen fertilizer, ammonia volatilization, denitrification, leaching, or immobilization. Several factors affect how quickly nitrogen is released (mineralized) from the cover crop. The ratio of carbon to nitrogen (C:N) in the cover crop residue, as well as the quality of the residue, such as the amount of carbohydrates or lignin, partially determines how quickly the cover crop decomposes. Soil moisture and temperature also affect decomposition.

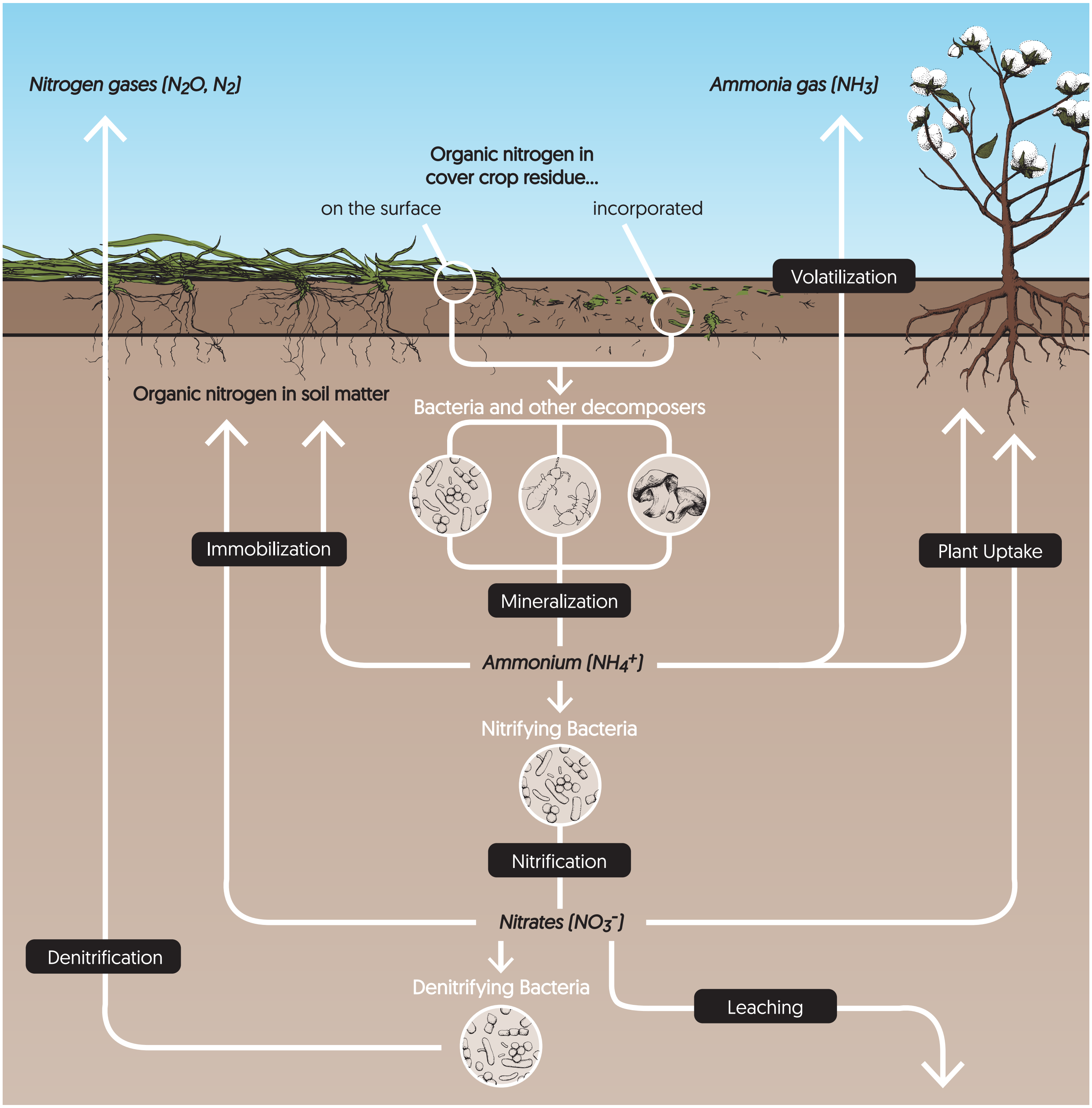


Figure 3. A schematic of nitrogen mineralization from cover crop residue showing the plant does not take up all of the mineralized organic nitrogen.

The C:N ratio affects cover crop decomposition because the bacteria using the carbon from the cover crop residue also need nitrogen. If the cover crop residue has enough nitrogen (a low C:N ratio) to supply the bacteria need, any excess nitrogen is released into the soil for plants to use. This process is called mineralization. However, if the cover crop residue does not have enough nitrogen (a high C:N ratio) to supply the bacteria need, the bacteria will take NH_4 and NO_3 from the soil to grow. This process is called immobilization. The C:N threshold between mineralization and immobilization is in the range of 20 to 40 depending on residue composition. The higher the C:N ratio of the decomposing residue above this value, the greater the amount of NH_4 and NO_3 that will be immobilized.

When grain cover crops are young (before heading stage), the C:N ratio is low (23) and some of the nitrogen in the plant will be released as the cover crop residue decomposes. Remember, this is not nitrogen fixed from the atmosphere, but nitrogen that was taken up from the soil as the grain cover crop grew. As the grain matures, the C:N ratio increases to around 50 or 60. At this stage, a grain cover crop residue needs additional nitrogen to decompose, and it can tie up or immobilize NH_4 and NO_3 temporarily. Legumes always have a relatively low C:N ratio due to higher nitrogen content in the cover crop residue.

Cover crop quality also affects how quickly the cover crop residue will decompose. The proportions of carbohydrates, cellulose, and lignin in a cover crop partially control how it breaks down. For example, plant residues with higher C:N ratios generally have more lignin and cellulose, which are structural components of plants, and are more resistant to decomposition than nonstructural carbohydrates such as starches or sugars. Plants with relatively high lignin and cellulose content (such as mature grains) decompose slowly. Mature grain cover crop residue will often persist through the summer and into the winter. Plants such as clovers, with relatively high carbohydrate content, break down very quickly. The majority of a 100% clover residue will often be decomposed within a month after the cover crop is killed.

Finally, for decomposition to take place, soil temperatures must be within a moderate range (about 45 to 95 degrees Fahrenheit). Optimum conditions are at around 95 degrees and the rate of decomposition increases steadily from 45 to 95 degrees provided that soil moisture does not limit the rate of decomposition. If there is not sufficient moisture in the soil (between field capacity and the lower limit for evapotranspiration), the decomposer bacteria cannot thrive and work. However, if the soil is saturated, decomposition also slows down.

All of these factors make it difficult to predict the amount of nitrogen that will be released from a cover crop and when it will be released. Both the amount and timing are important for a farmer to know.

Figure 4. A mature cereal rye cover crop in Screven County, Georgia. Cereal rye at this stage has a high C:N ratio and may immobilize nitrogen.

Cover Crop Nitrogen Availability Calculator

At a minimum, a farmer needs to know the amount of cover crop biomass and its nitrogen concentration to have an idea about how much nitrogen the cover crop can provide. The total cover crop nitrogen can be calculated and cut in half to obtain a rough estimate of the amount of nitrogen that will be available to the subsequent cash crop. This rough estimate will not give the farmer any idea about the rate of nitrogen release. The Cover Crop Nitrogen Availability Calculator is a web-based tool that uses cover crop biomass and quality with soil temperature and soil moisture data from a local weather station to predict the amount and rate of nitrogen that will be available to the following cash crop from the decomposition of the cover crop over the growing season.

The Calculator is based on the nitrogen subroutine of the CERES (Crop Environment Resource Synthesis) crop model. Two advancements have allowed the successful implementation of the Cover Crop Nitrogen Availability Calculator—analysis of the cover crop residue by near infrared spectroscopy (NIRS) and the Georgia Automated Environmental Monitoring Network. The use of NIRS allows the cover crop sample to be quickly analyzed for nitrogen, carbohydrate, cellulose, and lignin; characteristics that previously would have required time-consuming and more expensive wet chemistry. NIRS has been used extensively in analyzing forage quality, and it has now been adapted for cover crop quality. Soil temperature and moisture are taken from the Georgia Automated Environmental Monitoring Network, which has 82 weather stations around Georgia, allowing for a better estimate of decomposition under local conditions.

The Calculator predicts the amount of nitrogen available from the cover crop in pounds per acre. If the nitrogen amount is positive, it can be considered a nitrogen credit and the recommended amount of nitrogen fertilizer can be reduced by the credit amount. If the amount of nitrogen is negative, it would be considered a debit, and the recommended nitrogen fertilizer can be increased by that amount. For example, the Calculator predicted that there was 70 lb available N per acre in a black oats/crimson clover cover crop mixture. The following crop was grain corn with a yield goal of 150 bushels per acre and the recommended nitrogen fertilizer rate was 180 lb N per acre. The farmer could take a 70 lb N per acre credit and apply only 110 lb N per acre in this case (Figure 5).

It also produces a nitrogen release curve that shows when the cover crop nitrogen will be released over the growing season. The release curve can be used to help manage nitrogen fertilization to ensure the cash crop is receiving nitrogen when it needs it most (Figure 5). In the example, the black oats/crimson clover mixture shows a steady release over the growing season.

The Calculator can also predict immobilization in heavy residues with low percentages of nitrogen. For example, Figure 6 shows a negative amount of available nitrogen and the release curve of a high biomass sorghum-Sudangrass cover crop. This curve shows that because of the low amount of nitrogen and the high amount of biomass, the nitrogen in the decomposing cover crop will not be available to the cash crop in the fall and a small amount of additional nitrogen is needed for the cover crop residue to decompose. In this case, a producer may want to add extra nitrogen fertilizer to offset the immobilization occurring in the soil.

Lab: **8284**
Client: **Julia Gaskin**
Sample ID: **Black Oat/Crimson Clover**

Weather - Average of 5 years

Mondays	Nitrogen (lbs N/ac)
Date	Cover Crop
04/13/2015	9
04/27/2015	18
05/11/2015	32
05/25/2015	44
06/08/2015	54
06/22/2015	62
07/06/2015	66
07/20/2015	70

The Nitrogen (N) reported above from cover crop decomposition is considered a N credit (if positive) or debit (if negative). The amount of N recommended by a routine soil test may be reduced by the N credit or increased by a debit.

Example for credit:

Recommended N = 150 lbs/Ac
Cover Crop N = 50 lbs/Ac
Recommended after credit: 150 - 50 = 100 lb N/Ac

Example for debit:

Recommended N = 150 lbs/Ac
Cover Crop N = -50 lbs/Ac
Recommended after debit: 150 + 50 = 200 lb N/Ac

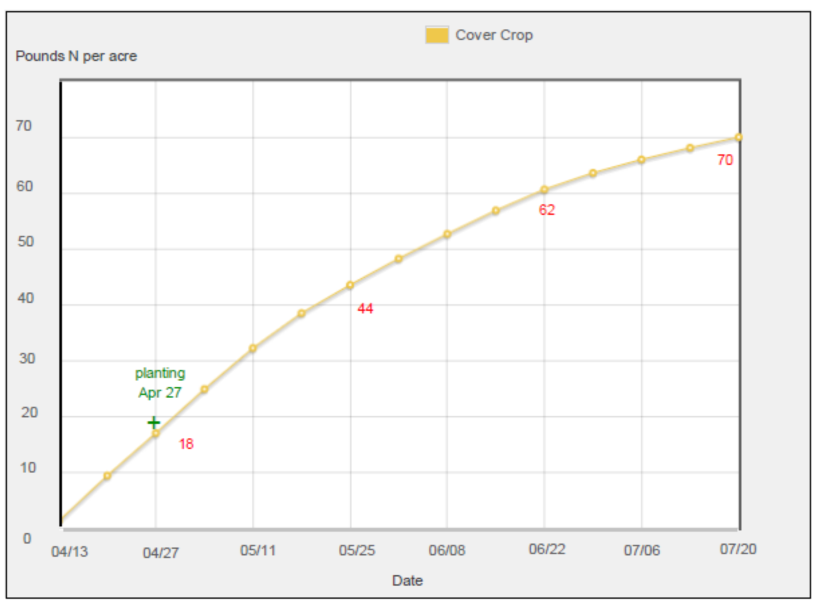


Figure 5. Example of the Cover Crop Nitrogen Availability Calculator outputs. The last line of the table shows the cumulative amount of nitrogen released, and the graph shows the rate of release over the cash crop growing season.

Lab: **2611**
Jane Doe
Sample ID: Sorghum-sudangrass

		Average of 5 years
	Tuesdays	Nitrogen pounds per acre
Day	Date	Cover Crop
8	09/18/2015	-0
22	10/02/2015	-1
36	10/16/2015	-2
50	10/30/2015	-2
64	11/13/2015	-2
78	11/27/2015	-3
92	12/11/2015	-3
106	12/25/2015	-3

The Nitrogen (N) reported above from cover crop decomposition is considered a N credit (if positive) or debit (if negative). The amount of N recommended by a routine soil test may be reduced by the N credit or increased by a debit.

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Recommended N = 150 lbs/Ac
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Example for debit:

Recommended N = 150 lbs/Ac
Cover Crop N = -50 lbs/Ac
Recommended after debit: 150 + 50 = 200 lb N/Ac

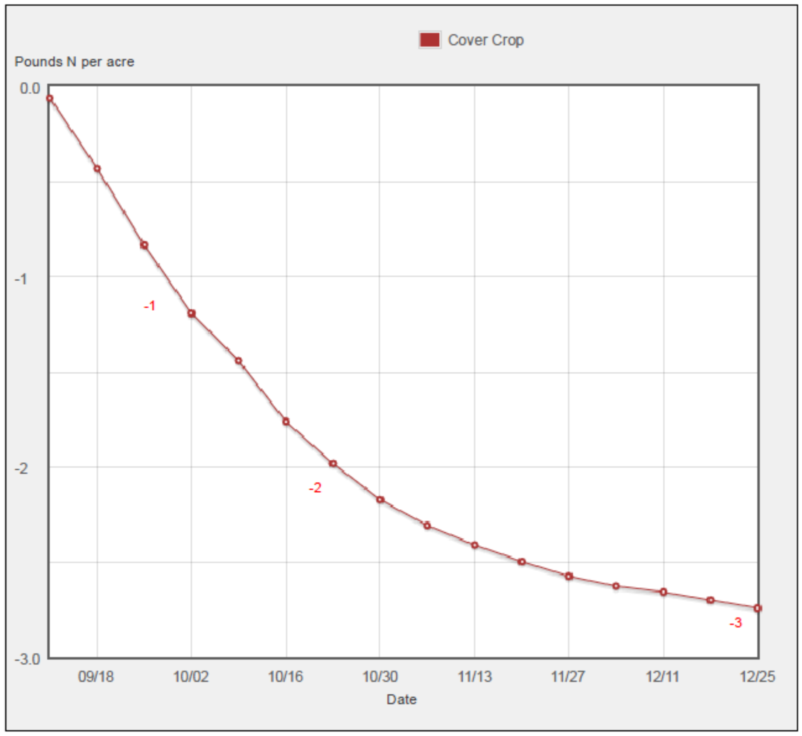

Figure 6. Example of the Cover Crop Nitrogen Availability Calculator output showing nitrogen immobilization by the heavy residue of the sorghum-Sudangrass cover crop.

Using the Calculator

The Cover Crop Nitrogen Availability Calculator is available through the University of Georgia's Agricultural and Environmental Services Laboratories (http://aesl.ces.uga.edu/mineralization/). A cover crop sample is required for analysis, as well as the measurement of the amount of cover crop biomass in your field. ***Measuring the amount of biomass in the field is a key piece of information.*** You will need to weigh the fresh biomass from a known sampling area. For instructions on taking a representative cover crop sample and calculating cover crop biomass, refer to "Cover Crop Biomass Sampling" (Circular 1077) found at extension.uga.edu/publications and contact your county Extension agent.

The submission form can be found on the Agricultural and Environmental Services Laboratory Website at: http://aesl.ces.uga.edu/forms/CoverCropNAvailabilitySubmission.pdf

It is critical that you fill out ***all*** of the information on the submission form. The Calculator cannot be run without this information. This includes:

- Your contact information,
- The county,
- Whether your farm is "organic" or "conventional,"
- The fresh cover crop biomass,
- Whether the cover crop is left on the soil surface or incorporated,
- The date the cover crop was killed or incorporated,
- The expected planting date for upcoming crop,
- The type of cover crop or cover crops, and
- Whether the cover crop is a grass/legume mixture, and if so, whether legumes are more than 40% of the mixture.

Let’s look at why this information is needed. Contact information is needed to send out the results. The county allows the laboratory to select the nearest weather station to determine the soil temperature and moisture that would best represent your location. The designation “organic” or “conventional” allows the laboratory to select soil conditions that reflect your agricultural practices. Organic represents soils that typically have more soil organic matter than conventional soils. If you have used conservation tillage with cover crops for many years, you should also choose this option.

The fresh biomass weight that is measured when the sample is collected is critical. It is used with the moisture content determined by the laboratory to calculate a dry biomass weight used in the Calculator. The Calculator also needs information on whether the cover crop is left on the surface or incorporated into the soil to model mineralization. The date when the cover crop was killed or incorporated is used to start the modeling process, and the planting date of the cash crop is used on the graph to help you visualize how much nitrogen is available at that point in time.

Finally, the information on the type of cover crop or cover crops is needed to measure the percent nitrogen, carbohydrates, cellulose and lignin properly. If you have a cover crop mixture with both grasses and legumes, the laboratory needs to know if legumes are more than 40% of the mixture. If so, the sample will be analyzed using a calibration for legumes.

Interpreting the Results

Once your sample has been analyzed, you will receive results from the Calculator (Figures 7a and 7b). The first page contains the Calculator inputs from the submission form sent with the cover crop sample as well as the results from the cover crop sample analysis by NIRS (Figure 7a). Notice in the first section, there is information listed about the soil, including organic carbon, initial inorganic nitrogen, potentially mineralizable nitrogen, depth of the soil layer, and bulk density. These values are not tied to the particular field unless you submit separate soil samples for additional analysis, but are representative values for the physiographic area in which your production system is located (see discussion of “organic” and “conventional” above). This information is used in the background of the Calculator and having specific values for a particular field does not change the aboveground cover crop nitrogen value appreciably.

The second block on the first page contains the NIRS results from the cover crop sample (Figure 7a). First, the cover crop biomass on a dry matter basis is reported based on the fresh weight of the cover crop sampled in the field and the percent moisture of the sample measured in the laboratory. Next, the percent nitrogen, carbohydrates, cellulose and lignin in the cover crop sample is reported. The biomass and percent nitrogen gives the total amount of nitrogen in pounds per acre in the cover crop. The amount of carbohydrates, cellulose and lignin predicts the rate of nitrogen release. As discussed above, cover crops with large amounts of carbohydrates and lower amounts of lignin and cellulose will decompose rapidly, while those with low amounts of carbohydrates and higher lignin and cellulose will decompose more slowly.

The second page contains the results for available nitrogen (Figure 7b). The table shows the cumulative amount of available nitrogen released from the cover crop for each two-week period in the growing season. The final line in the table is the cumulative amount of available nitrogen for the growing season. Remember, if this number is positive, it can be subtracted from the recommended nitrogen fertilizer rate as a nitrogen credit (Figure 7b). If the number is negative, you should consider increasing the recommended nitrogen fertilizer rate by that amount (a nitrogen debit; Figure 6). The graph may help you visualize the rate of nitrogen release.

The Calculator only predicts available nitrogen from the aboveground cover crop biomass. As such, it is a conservative estimate of the amount of nitrogen potentially available. Nitrogen is also mineralized from the roots (belowground biomass) and from soil organic matter. At this point, we are not able to model these processes accurately. In studies in Georgia, the amount of nitrogen released from soil and belowground biomass has ranged from 0 to 80 lb N per acre. Sandy soils with low soil organic carbon (about 0.5%) will release smaller amounts of nitrogen over a growing season. Clayey soils with high soil organic carbon (>2.5%) may release 60 to 70 lb N per acre. This nitrogen stored in the soil should be considered a fertility bank and will provide a slow release of nitrogen over the growing season.

7/13/2016 Nitrogen Availability Calculator

Model based on data from the **Watkinsville-USDA - J. Phil Campbell Sr. Natural Resources Conservation Center** weather station.

Enter the following values:

Parameter	Value		Range
Farm type	◉ Organic	○ Conventional	
Date of cover crop kill/incorporation:	4/6/2015	mm/dd/yyyy	
Planting date for upcoming crop	4/27/2015	mm/dd/yyyy	
Representative soil data was selected for your location.			
Organic carbon in the soil	3.02	%	0.1 - 5 %
Initial inorganic N in soil	18.24	lbs/acre	0 - 100
Potentially Mineralizable N (Hot KCl)	13.79	mg N/kg	0 - 30
Depth of soil layer	6	inches	
Bulk Density	1.5	g/cm^3	

Parameter	Value
Nutrient sources were	○ applied on the soil surface ◉ incorporated into soil
Output data on a 2-week ▼ basis.	
☐ Advanced options	

Cover Crops

Parameter	Value		Range
Cover Crop biomass:	4107	lbs/A	
Nitrogen in cover crop:	2.76	%	0 - 100%
Carbohydrates in cover crop:	50.90	%	0 - 100%
Cellulose in cover crop:	46.73	%	0 - 100%
Lignin in cover crop:	2.36	%	0 - 100%
Carbohydrates + Cellulose + Lignin should equal 100%			

Figure 7a. Example of the input screen for the Cover Crop Nitrogen Availability Calculator.

7/13/2016 Nitrogen Availability Calculator

Average of 5 years

	Mondays	**Nitrogen pounds per acre**
Day	**Date**	**Cover Crop**
8	04/13/2015	8
22	04/27/2015	19
36	05/11/2015	28
50	05/25/2015	34
64	06/08/2015	38
78	06/22/2015	41
92	07/06/2015	43
106	07/20/2015	44

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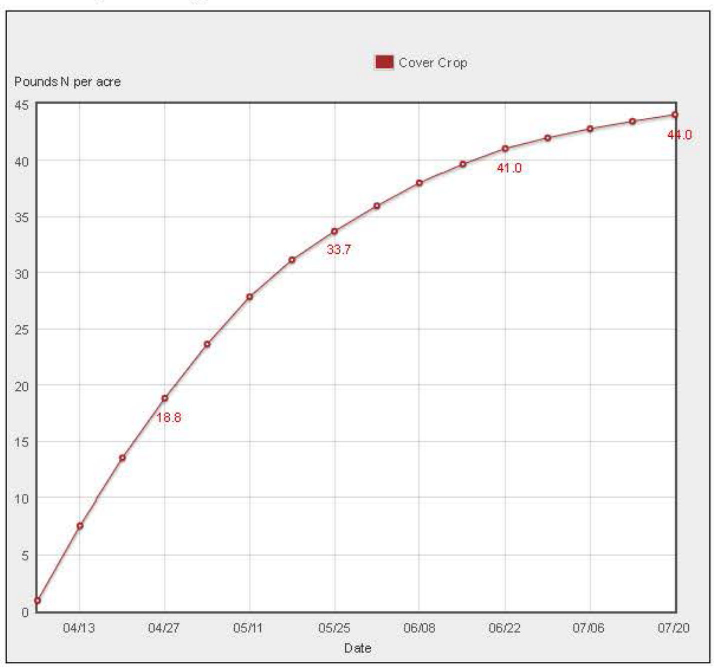

Figure 7b. Example of the outputs for the Cover Crop Nitrogen Availability Calculator.

Summary

In addition to many other benefits, cover crops provide direct contributions to fertility by scavenging nutrients and fixing nitrogen. The Cover Crop Nitrogen Availability Calculator helps quantify the nitrogen contribution of a cover crop to a following cash crop or the loss of available nitrogen due to immobilization. Use of the Calculator will help farmers more effectively manage nitrogen fertilizer.

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