Fertilizing Cover Crops - Do You Have to Put Some In to Get More Out?

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BACKGROUND

The 2017 Ag Census (USDA/NASS, 2019) reported a 30% increase in mid-Atlantic acres cover cropped between 2012 and 2017. However, timing and method of cover crop planting are critical determinants of nitrogen capture, biomass production, and species-dominance in cover crop mixtures. Many cover-cropped acres are relatively ineffective. Most cover-cropped acres achieve minimal biomass, groundcover, and N-capture due to late planting and/or low soil fertility.

Wang and Weil (2018) studying a corn silage system on a Maryland dairy farm found that where an early –planted radish cover crop contained 120 kg N/acre in the above ground biomass, the mineral N in the upper meter of soil was depleted by only 40 kg N/ha, suggesting that the other 80 kg of N may have been taken up from a depth below the first meter. Hirsh and Weil (2019) subsequently studied soil under 45 mid-Atlantic crop fields and reported that residual end-of-summer mineral soil nitrogen (N as nitrate + ammonium) in upper 2 meters (7 ft) averaged 250 kg N / ha. About half of this residual N (125 kg N /ha) was found 1 meter in depth.

Sedghi and Weil (2022) reported that having cover crop roots clean up soluble N deep in the profile before the onset of winter is critical to capturing N and reducing nitrate leaching all winter. Planting cover crops in Maryland after early October is generally too late to clean up the deep soil profile before

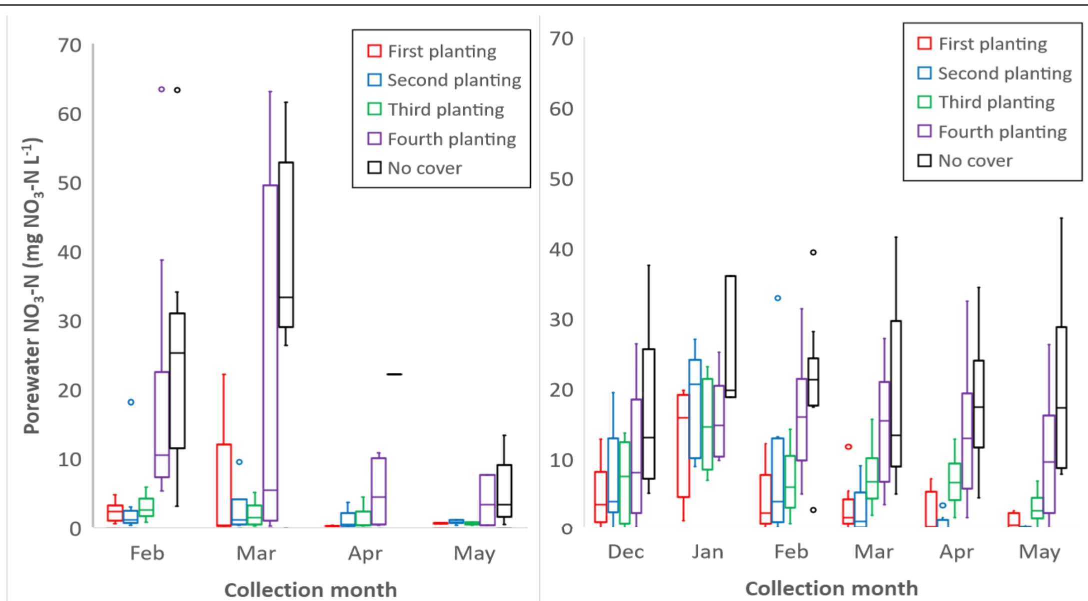

Figure 1. *Effect of cover crop planting date in fall on nitrate concentration in leaching water during the following winter and early spring. Boxplots of porewater NO_3–N concentrations between fall and spring at a sandy soil site at CMREC for two years (A= plantings from late August to late Sept, 2016-17; B=plantings from mid-September through mid-October, 2017-18). The cover crop was a 3-species mix in all cases. (Sedghi and Weil, 2022)*

winter and is therefore ineffective in reducing N leaching (Figure 1). Only vigorously growing, early-planted cover crops can capture the deeper nitrogen before it leaches away over winter.

Figure 2. Appearance after crop harvest of radish cover crops that were inter-seeded at the same time (11 Sept.) into standing corn (left) and soybean (right), both growing on sandy, low-organ ic matter soils on Maryland Eastern Shore.. In the low-N environment of the corn residue the stunted, N-deficient radishes appear to have taken up only 5 to 10 kg N/ha. In contrast, the radishes in the soybean residue appear to contain about 100 kg N/ha. Photos by James Lewis.

In addition to early planting that allows enough degree days for deep rooting, effective capture of N deep in the soil profile also requires sufficient levels of available nutrients, especially nitrogen, for vigorous cover crop growth. Paradoxically, the most effective cover crop species for capturing excess N are also very responsive to N and will not grow vigorously in N poor soils. Thus, cover crops may need N to capture N. Despite the large pool of plant available nitrogen in deep soil layers, topsoil may be depleted of nitrogen at fall cover crop planting time because of leaching, crop-uptake, and immobilization. Immobilization and depletion of topsoil N is more of an issue in corn residue than in soybean residue (Figure 2). Low N in the topsoil in fall is especially likely on the sandy coastal plain soils such as those common on the Mid-Atlantic Coastal Plain. Web Soil Survey (USDA/NRCS, 2020) indicates sandy soils where low nitrogen in topsoil is most likely cover approximately 400,000 acres of cropland in New Jersey, Delaware, and Maryland.

We hypothesize that low N availability in the topsoil may stunt cover crop growth and prevent their roots from reaching large pools of residual N deep in the soil profile before it leaches away to groundwater (Figure 3, left). We further hypothesize that small nitrogen applications to early-planted cover crops in low-nitrate soils may stimulate early more vigorous growth and deeper rooting. We further hypothesized that this deeper rooting may allow cover crops to increase N capture by substantially more than the small amount of N applied (Figure 3, right). For example, an investment of 20 kg of N at the time of seeding a non-legume cover crop (such as rye or radish) might increase the N uptake in fall from as little as 5 to 10 kg to as much as 50 to 60 kg N per hectare.

Put another way, because of the presence of deep, leachable N, we hypothesize that the apparent nitrogen use efficiency (NUE) may exceed 100% in N-fertilized cover crops with the increased N uptake due to accessing N deep in the soil profile that more shallow-rooted unfertilized plants could not access. Apparent NUE is defined as:

NUE (%) = 100 * (N in fertilized plants) – (N in unfertilized plants)/(N rate applied)

Since NUE for corn and other grains is typically less than 50% (Baligar et al., 2001), achieving a NUE for cover crop fertilization greater than 100% may seem unlikely. However, when cash crops are fertilized in spring the large pool of deep soil soluble N has usually been already lost to leaching over the winter.

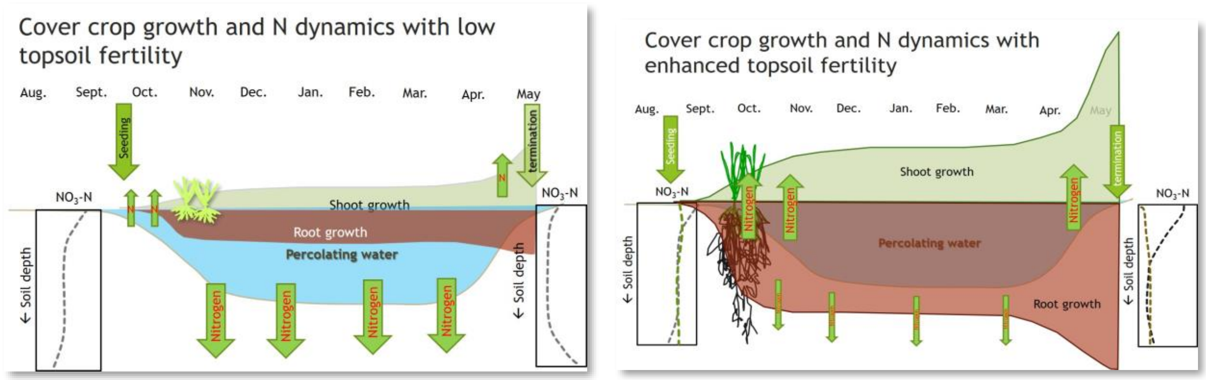

Figure 3. Conceptual diagram explaining how a cover crop N capture might be affected by soil fertility in early fall. (Left) A cover crop planted in early September into a low N topsoil ceases root growth in October at a shallow depth and immobilizes only a small amount of soil nitrate-N compared to the amount leached deeper into the soil profile. (Right) A similarly planted cover crop fertilized with a small amount of N might vigorously grow deeper roots and take up a large amount of soil NO_3-N from deep in the soil allowing only small N leaching losses.

We could very little published research on fertilizing cover crops. In Iowa, a study (Evans, 2019) was conducted recently on fertilizing radish cover crops with dairy manure applied on the surface or tilled in before radish planting. The tilled in manure more than tripled the biomass of radish produced. In another study (Reiter et al., 2008) applied N to a rye cover crop before cotton on sandy soil in Alabama. They fertilized the cover crop two months ahead of planting cotton and measured NUE values of 135% and 97% for the cover crop N uptake in two of the three years of the study. In another Alabama study (Balkcom et al., 2018) with cotton and rye cover crop, application of fertilizer or poultry manure to the cover crop in November or December resulted in an increase in rye biomass from 2,000 to 6,000 kg/ha, but with a low N tissue concentration and a cover crop NUE of only about 37%. In the Alabama studies, the N fertilizer was applied in December or February, possibly too late to allow the rye roots to catchup with the rapidly leaching nitrogen in the deep soil layers. Although research on fertilizing cover crops is scarce, there is quite a bit of farmer interest in the practice (Bechman, 2017; Dobberstein, 2016; Robison, 2012; Stewart, 2019).

We proposed that, under Maryland conditions, small fertilizer applications may stimulate cover crops to provide improved net water-quality, soil-conservation, carbon, and soybean yield benefits. Although fertilizing cover crops in fall with N is not allowed in the State of Maryland agricultural cost-share program (MAC) for cover crops, we believed that if we produced sufficient data that showed the above hypotheses were true, then MDA would likely revise the program to allow it under appropriate circumstances (e.g., below a certain topsoil nitrate threshold). We expected that the fall soil nitrate threshold would be similar to that proposed for a pre-plant soil NO_3–N test for winter wheat to help identify fields where starter N will produce economic returns and reduce potential NO_3–N leaching losses. Forrestal et al. (2014) documented successful use of a fall nitrate test for fall application of nitrogen to winter wheat showing that when nitrate-N in top foot of soil is less than 9 ppm, fall nitrogen application is likely to increase wheat yields. We hypothesized that a somewhat similar but earlier nitrate test in late-August/early-September could predict the value of a small nitrogen application shortly after cover crop seeding, especially when interseeding early into high nitrogen uptake and high C/N ratio crops like corn.

Project Objectives

The overall goal of the project was to enhance the effectiveness of cover cropping in reducing nitrogen leaching over the winter and spring, especially where manure application is rare and/or soil texture is coarse. Our objectives were 1) to determine whether small nitrogen applications in fall can increase cover crop nitrogen – capture benefits with apparent nitrogen use efficiency exceeding 100%. 2) to develop a practical in-field nitrate-test for evaluating where fall nitrogen fertilization of cover crops is justified.

MATERIALS AND METHODS.

The research involved field experiments at several sites over three years (Table 1).

In 2020 we established two replicated field experiments at the Beltsville Facility of the University if Maryland Central Maryland Research and Education Center (CMREC) in which we interseeded two types of cover crops into corn. One experiment was conducted on a field with dominantly Downer soils with loamy sand to sandy loam textures in the profile. The other field experiment was approximately 3 km away in a field with predominately Christiana soils with silt loam to silty clay textures. Corn was planted on 16 May 2020 in 76 cm apart rows using a no-till planter. Cover crops were interseeded into a corn crop on 26-27 June 2020 using a special interseeder drill developed by Penn State University that drills three rows 19 cm apart between 76 cm apart corn rows. The main plots were 9.14 m wide and 54.9 m long. The three main plot treatments were 1) a no-cover control with some weeds only during winter (No-Cover), 2) a rye cover seeded at 134 kg seed per hectare (Rye), and 3) a three-species mixture (3-Way) of 4.5 kg forage radish (rad), 78 kg rye, and 17 kg crimson clover (clover) per hectare. These main plots were dived into 9.14 m wide x 18.3 m long subplots with three levels of N fertilizer spray-applied soon after corn harvest: 0, 17 and 34 kg/ha of N as Urea Ammonium Nitrate solution on 21 October 2020 at the sandy field (39a) and on 23 October at the silty field (7e). On 09 December 2020 green ground cover percentage was measured using the CANOPEO mobile phone app (Patrignani and Ochsner, 2015) to take a 10 second vertical video while walking diagonally across each subplot. The above ground biomass was then sampled by clipping all cover crop and weed shoots 1 cm above the soil in two 0.25 m^2 quadrats per subplot. The sampled tissue was dried at 65 ^oC to constant weight, weighed, and ground in a Wiley mill to pass a 1 mm sieve. The ground tissue was then analyzed for total N and C by dry combustion (LECO).

Because the available farm equipment for applying fertilizer required that fertilization wait until after crop harvest leaving little growing season for the cover crop to respond in 2020, in 2021 and 2022 we established field experiments with hand-application of fertilizer solution to paired 0.5m^2 mini-plots in standing corn crops. Once interseeded cover crops had emerged and produced true leaves, the plots were delineated by colored flags with wire stems short enough to not interfere with the combine at harvest. This approach allowed us to apply the N fertilizer so as to maximize the growing degree days left in the fall for the cover crop to respond to the treatment. It also allowed us to select areas of uniform cover crop stand and species composition for the paired unfertilized and fertilized plots. These mini-plot experiments were established on sandy soils in two fields at CMREC and on commercial farms in Caroline County, Md on the Easter Shore with four to ten replications per site (Table 1). Nitrogen was applied by sprinkling an aqueous solution of ammonium nitrate over the cover crop mini-plot at the rate of 1 liter/m^2 such that foliar uptake as well as soil uptake was possible. There were two treatments: with and without N fertilizer. In 2021 N was applied at 22.4 kg/ha. Because there was little response to the applied N in 2021, in 2022 the rate was doubled to 44.8 kg/ha.

In both 2021 and 2022 we measured soil nitrate, green ground cover, cover crop aboveground biomass, and cover crop tissue N and C content. To measure soil nitrate-N we collected six soil cores at the time of fertilization (0-15 and 15-30 cm deep) from around and withing 1 meter of each pair of plots, composited the six cores, transported the samples on ice in coolers to the lab, rapidly forced air-dried at room temperature, and sieved the soil to < 2 mm. We analyzed 0.5 *M* K_2SO_4 extractable (1:5 soil to solution ratio) nitrate- and ammonium-N in the dry sieved soil samples. To analyze for nitrate-N we used salicylic acid and colorimetric determination (Cataldo et al., 1975).

We measured the percent green groundcover using the CANOPEA Android app (Patrignani and Ochsner, 2015) at the time of fertilization and again at the time of biomass measurement.

To measure biomass, in late fall 2021 and 2021 (Table 1) all vegetation within a 0.5-m^2 mini-plot was clipped 1 cm above the soil surface. We separated cover crops by species (if multiple species were present) and placed them into paper bags. Both the shoots of radish and the fleshy radish root were collected. The samples were cleaned with tap water to remove any soil. The biomass was then dried at 65 ˚C to constant weight and recorded the dry weight. This dry biomass was ground to < 1 mm and analyzed for total C and N by high temperature combustion and gas chromatography using a LECO instrument (Campbell, 1992).

From the aboveground biomass dry weight and tissue N content we calculated the amount of N taken up per hectare as:

Dry matter (kg ha^{-1}) × N concentration (kg kg^{-1}) = N uptake (kg N ha^{-1})

We compared the difference between unfertilized and fertilized cover crop N uptake to the amount of N applied. We ran linear and non-linear regressions to determine any relationship between extractable soil nitrate- or ammonium-N in 0-30, 0-15 or 15-30 cm depth and the cover crop N uptake and the N uptake and dry matter production response to fertilization. The significance of cover crop dry matter, green cover, change in green cover between September and December, tissue N content, and N uptake response to fertilization was determined using a General Linear Models (GLM) analysis in SYSTAT 13 statistical software package (SYSTAT, 2022) with a split plot design for 2020 (cover crop type as the main plot and N application rate as the subplot factor). For the 2021 and 2022 mini-plot pairs, GLM was used with Sites, Blocks nested within Sites, and Fertilization as categorical factors. Fertilization was considered a fixed effect, while sites and blocks were considered random effects.

Table 1. Characteristics and operation dates for all 16 study sites used in 2020, 2021, and 2022.

Site Name	No. of Reps	Cover Crop Species & kg seed/ha	Cover Crop Planted	N Applied	Biomass Collected	N Inputs for Previous Crop (kg/ha)	Irrigation	Dominant Soil Series	Crop in 2020, 2021, 2022	Year in Study
CMREC 39A	4	112 kg/ha Rye and a mix of 84 kg/ha Rye, 4.5 kg/ha Radish, 17 kg/ha Crimson clover	6/26/20	10/21/20	12/13/20	0, 100, 160 N at planting	Not Irrigated	Downer	Corn, Soy, Corn	2020
CMREC 7E	4	112 kg/ha Rye and a mix of 84 kg/ha Rye, 4.5 kg/ha Radish, 17 kg/ha Crimson clover	6/27/20	10/23/20	12/13/20	0, 100, 160 N at planting	Not Irrigated	Christiana	Corn, Soy, Corn	2020
CMREC 39A	12	112 kg/ha Rye and a mix of 84 kg/ha Rye, 4.5 kg/ha Radish, 17 kg/ha Crimson clover	8/30/21	9/4/21	11/8/21	0, 100, 160 N at planting	Not Irrigated	Downer	Soy, Corn, Soy	2021
CMREC 39D	10	A mix of 84 kg/ha Rye, 4.5 kg/ha Radish, 17 kg/ha Crimson clover	8/30/21	9/4/21	11/7/21	160 N at planting	Not Irrigated	Downer-hamonton Complex	Soy, Corn, Soy	2021
Holly Rd	4	Radish 14 kg/ha	8/20/21	9/11/21	11/20/21	162.5 N at planting	Not Irrigated	Ingleside sandy loam	Soy, Corn, Soy	2021
Lister	8	Barley 112 kg/ha Radish 14 kg/ha	8/19/21	9/11/21	11/20/21	2722 chicken manure, 2722 compost, 90 N at planting	Irrigated	Woodstown sandy loam	Soy, Corn, Soy	2021
Zion-Dry	4	Radish 14 kg/ha	8/20/21	9/11/21	11/20/21	162.5 N at planting	Non-Irrigated	Hurlock sandy loam	Soy, Corn, Soy	2021
Zion-Irrigated	4	Radish 14 kg/ha	8/20/21	9/11/21	11/20/21	162.5 N at planting	Irrigated,	hambrook sandy loam	Soy, Corn, Soy	2021
CMREC 39A	12 for each cover crop	112 kg/ha Rye and a mix of 84 kg/ha Rye, 4.5 kg/ha Radish, 17 kg/ha Crimson clover	9/1/22	9/23/22	12/7/22	0, 112, 180 N at planting	Not Irrigated	Downer	Corn, Soy, Corn	2022
CMREC 39D	8	A mix of 84 kg/ha Rye, 4.5 kg/ha Radish, 17 kg/ha Crimson clover	9/1/22	9/23/22	12/7/22	180 N at planting	Not Irrigated	Downer-hamonton Complex	Corn, Soy, Corn	2022
Duke	8	Radish 14 kg/ha	8/15/22	9/17/22	12/2/22	162.5 N at planting	Non-Irrigated	hambrook sandy loam	Corn, Soy, Corn	2022
River	8	Radish 14 kg/ha	8/15/22	9/17/22	12/2/22	162.5 N at planting	Non-Irrigated	Ingleside sandy loam	Corn, Soy, Corn	2022

RESULTS AND DISCUSSION

Fall 2020 Responses

Our ability to conduct research in 2020 was hindered by Covid-19 travel restrictions and the absence of in-person presence of student workers. However, we did establish two replicated field experiments at the Beltsville research farm in which we interseeded two types of cover crops into standing corn.

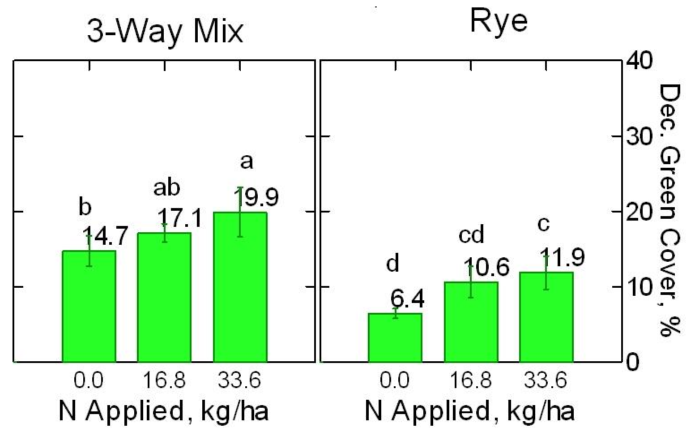

Figure 4 Percent green groundcover measured in early-December (using the Canopeo app) for cover crops interseeded into corn as affected by application of 0, 15 or 30 kg N/ha in mid-October.

Although only 4 kg /ha of radish seed was included in the mix, the radish appeared to be the dominant species in the 3-species cover crop vegetation in fall after corn harvest. The 3-Way cover crop provided almost twice as much ground cover as the pure rye cover crop. Overall, across a sandy and a silty site, green groundcover measurements made in early December when the cover crop growth had reached its maximum did show a significant response to the N applied in October for both cover crop types (Figure 4).

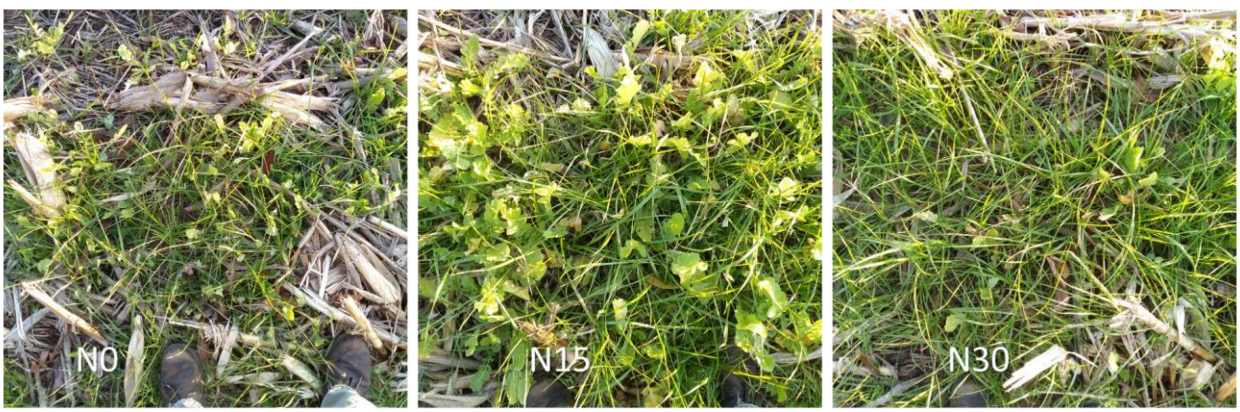

Figure 5 Appearance of the 3-species mixed cover crop growing on the silty soil site on 09 December after application of N as UAN on 21 October 2020 at 0, 15 or 30 lb N /acre (0, 16.8, 33.6 kg/ha).

The effect of applying N as UAN on 21 October 2020 at 0, 16.8, or 33.6 kg/ha is shown by the appearance of the 3-species mixed cover crop growing on the silty soil site on 09 December (Figure 5). On the sandy soil, the 33.6, but not the 16.8, kg N /ha rate caused some leaf burn on radish and clover (Figure 6). Probably because of this injury, the mixed species cover crop with 16.8 kg N /ha appeared to have more vigorous growth and covered a larger percentage of the ground surface in some plots than the cover crop fertilized with 33.6 kg N/ha.

Figure 6 Foliar injury of radish (left) and crimson clover (right) growing on sandy cause by application of 35.6 kg/ha of nitrogen as UAN solution. No foliar injury was observed at the 17.8 kg/ha N rate, or at either rate on the silty soil.

We hypothesized that small nitrogen applications to early-planted cover crops in low-nitrate soils might stimulate early growth and deeper rooting that, in turn, might allow cover crops to increase N uptake by substantially more than the small amount of N applied. For example, an investment of 30 kg of N at the time of seeding a non-legume cover crop (such as rye or radish) might increase the N uptake in fall from a paltry 5 to 10 kg N / ha without fertilizer to more than 50-100 kg N / ha with fertilizer, or an apparent N fertilizer use efficiency substantially greater than 100%. Achieving this nitrogen capture bonus would require that N be applied early enough that there is still enough warm weather to allow the cover crop to grow in response. It would also require the occurrence of soils that are low in available N in the topsoil but hold substantial N in the subsoil.

The effect of post-corn-harvest N application on interseeded cover crop biomass dry matter measured in 13 December 2020 is shown in Figure 7. There were trends towards higher biomass with N application, but the N effect was significant only for the rye cover crop, especially on the silty soil (Field 5-7E). The response by the rye on the silty soil was similar in magnitude to the response trend in the 3-Way mix on the sandy soil (Field 5-39A). The greatest significant increase in cover crop dry matter was from 246 kg/ha to 689, an increase of 443 kg/ha of rye dry matter.

Although we did not analyze the N content of the rye tissue, we can assume that N in the unfertilized rye tissue was approximately 1.5% and even if the N in the fertilized tissue increase to as high as 2.5%, the increase in N uptake would be only from 3.7 kg N/ha at 0 N applied to 17.2 kg N /ha at 33.6 kg N/ha applied. This would represent an increase in N uptake of 13.5 kg N /ha (17.2-3.7), an apparent N recovery of only 40%, far below the > 100% apparent recovery that would be needed to justify fertilizing the cove crop to improve N capture.

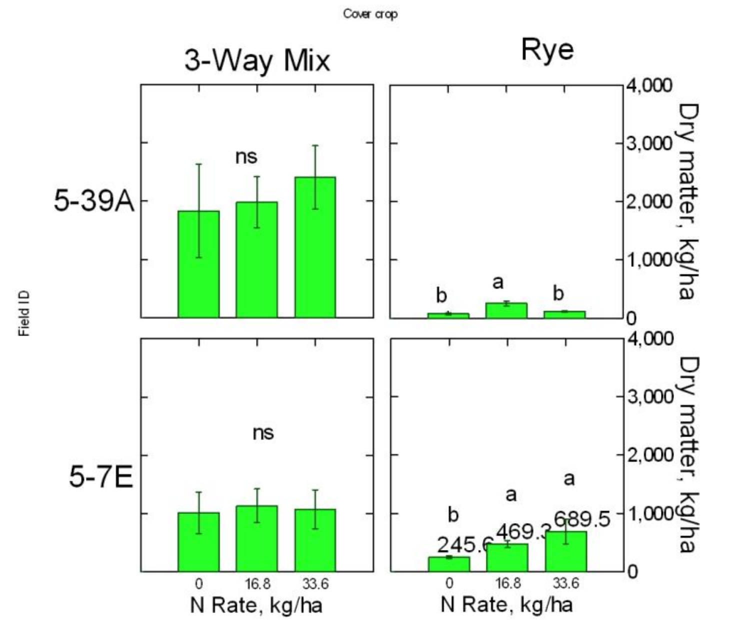

Figure 7 Effect of N applied to interseeded cover crop after corn harvest on cover crop biomass measured in early Dec. 2020. The N effect was significant only for the rye cover crop.

These small responses to applied nitrogen were not what we hypothesized would occur. In Fall 2020 neither the N concentrations in the cover crop tissue (only radish was analyzed, see Figure 8) nor the cover crop dry matter produced by December showed the large responses we hypothesized would occur.

Results from 2021-2022

In the second year of this project, we made a number of changes in our methods in response to challenges encountered in the first year. Because of observed salt injury to some cover crop foliage at the 33.8 kg N/ha rate, and the added complexity of testing three N rates, we simplified the treatments to just two: No N applied versus 20 kg N/ha applied as a solution of ammonium nitrate. Because we were not able to have custom operators apply differing rates of N in strip plots across the field using high clearance sprayers, we opted to use much smaller plots fertilized by hand, but with many more replications. We established 10 pairs of plots in one field at CMREC and 12 pairs in another for a total of 22 replications and 44 plots on that research station's sandy soils. We also collaborated with two farmers in Caroline County, MD to use four commercial fields where cover crop seed was flown on in August into standing corn (Table 1). A map of plot locations in one of these fields (near Ridgley, MD) is shown in Figure 9. The lack of a strong response to N in the 2020 treatments may have been due to the late timing of the N application, after the interseeded cover crops had been growing for several months without any applied N. We speculated that by the time the N was applied in mid-October there were not enough growing degree days left in the season to allow the cover crop plants to take advantage of this soil fertility boost. Therefore, in Fall 2021 we applied the N to the interseeded cover crop at early corn senescence when the cover crop was just a few cm tall, instead of waiting until after corn harvest, a difference of about 5 weeks or 4-500 growing degree days.

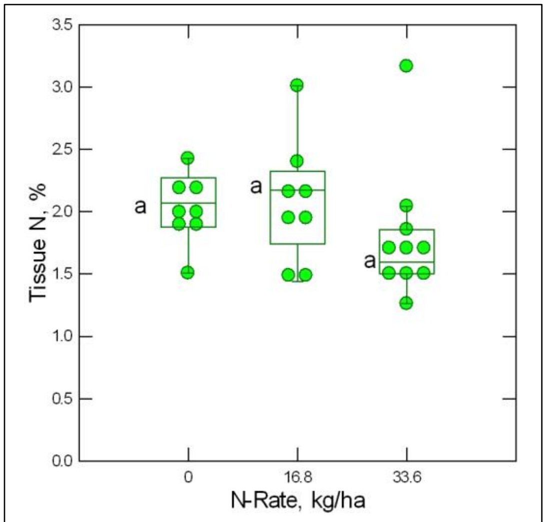

Figure 8 N applied to an interseeded cover crop after 2020 corn harvest had no significant effect on radish tissue N concentration in early Dec. 2020. Data are for radish cover crop growing on both sandy and silty soils.

Figure 10. Map showing locations of 8 replications of paired microplots within a commercial crop field. The image incudes soil map boundaries and a cross section of land elevations.

The plots were flagged (Figure 10) and geo-located and 6 soil cores 30 cm deep (cut into 0-15cm and 15-30 cm segments) were collected in a circle around each pair of plots. At the time of N treatment and plot delineation, the cover crops were already in early growth, having been aerially seeded about two weeks before. One plot in each pair was fertilized with a solution of ammonium nitrate equivalent to 20 kg N/ha (18 lbs N/acre). We returned to the plots in late November to early December and collected all above ground cover crop and weed biomass. If radish was present its fleshy root was also collected. The CANOPEO image analysis app was used to measure green groundcover percentage for each plot in September at plot establishment to ensure that plots were comparable and at the time of biomass collection to provide a correlated measure of cover crop performance. Figure 10 shows that the green ground cover percentage was very similar in the fertilized and unfertilized plot in each replicate pair.

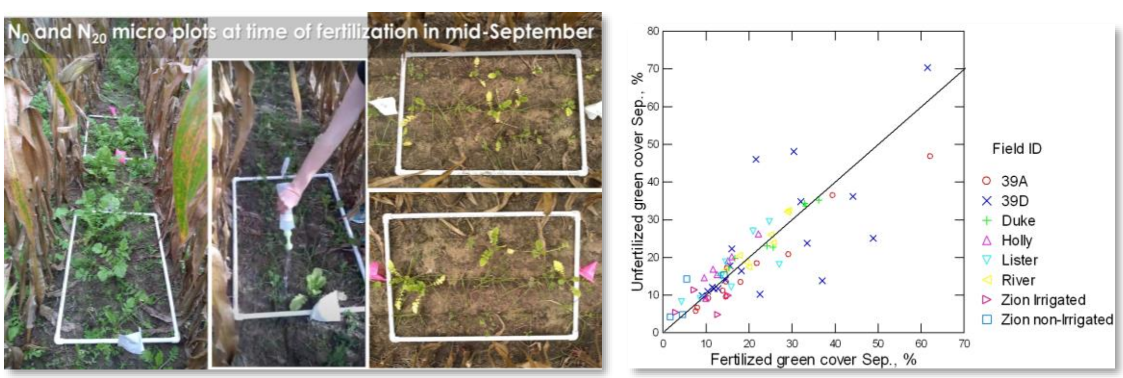

Figure 9 (Left) Micro plot establishment and application of N solution to one plot in each pair. Pink flags delineated unfertilized and white flags delineated the fertilized mini-plot. (Right) The green ground cover percentage was very similar in each replicate pair's fertilized and unfertilized plots. The black diagonal line is the 1:1 line where the paired plots would be identical in green ground cover.

In the 2021 experiments, nitrogen uptake by the cover crops varied significantly by plant species or type of tissue (radish root versus radish shoot). Figure 11 shows the nitrogen uptake for each type of cover crop and for weeds in g N / m^2. These values can be multiplied by 10 to give kg N/ha. It is readily apparent that for each of the cover crop types there was virtually no difference in N uptake whether fertilizer was applied or not. Figure 11 also shows the total N uptake by all cover crop species at each of the six study sites used in 2021. At several sites the response to fertilizer appeared to be negative, but

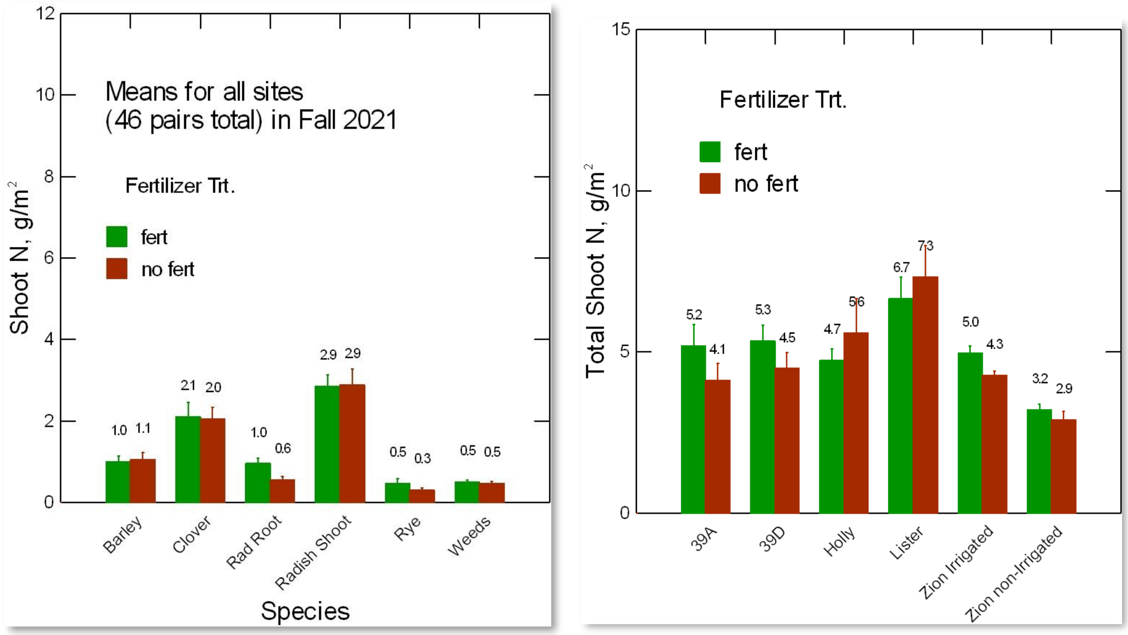

*Figure 11 In the 2021 experiments, nitrogen uptake by cover crops varied significantly by the site where they were grown (left) and by plant species and type of tissue (radish root v. shoot) (right), but not by whether fertilizer was applied (green bars) or not (brown bars). Note that g N m^{-2} * 10 = kg N ha^{-1} and the fertilized (fert) treatment was 20 kg N/ha.*

The only significant responses were in the two sandy fields at CMREC (39a and 39d) where the fertilized cover crops took up 1.1 and 0.8 g /m^2 (11 and 8 kg N /ha) more than the unfertilized cover crops. Thus, even in the fields with significant N uptake responses, the magnitude of the responses fell far short of the 20 kg N/ha that would have confirmed our goal of stimulating additional uptake exceeding the amount of N applied.

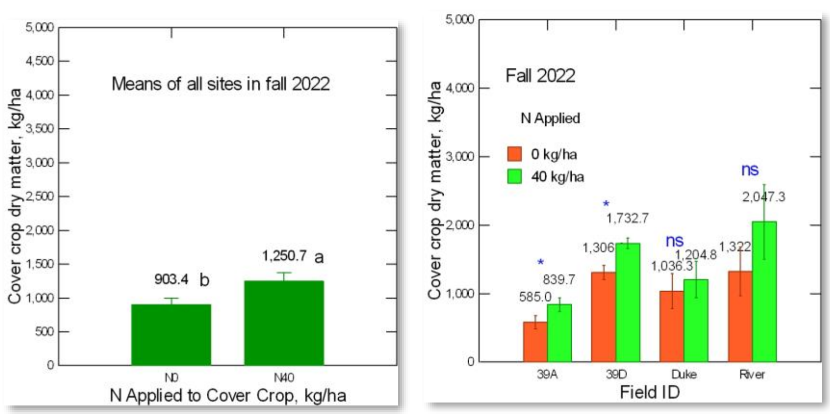

Figure 12 Cover crop dry matter response by interseeded cover crops to the application of 40 kg/ha of fertilizer nitrogen in early September. (Left) Means of all 2022 sites. (Right) Data for each of the four individual sites.

Figure 12 shows the cover crop dry matter response to the application of 40 kg N/ha. The graph on the left shows the dry matter production for the fertilized and unfertilized treatments averaged across all four sites used in 2022. The average dry matter production response was statistically significant, with the fertilized cover crops producing an average of 1,251 kg /ha as compared to 903 kg / ha for the unfertilized cover crops, a difference of 348 kg/ha dry matter. Although the N concentration in these dry matter samples have not been analyzed yet, we can assume that the average nitrogen content is ~2% as was the case in 2021. If that is the case, this difference in dry matter would represent approximately 7 kg / ha of additional N uptake in response to the application of 40 kg / ha of fertilizer nitrogen to the cover crop. Even if the fertilizer did somewhat increase the nitrogen concentration in the cover crop tissue, which was not the case in 2021, it is not possible that this average dry matter response represents enough N uptake to surpass the amount of N applied. The right-hand panel in Figure 16 shows the cover crop dry matter produced with and without nitrogen fertilization at each of the four sites used in 2022. As in 2021, only the two research station fields (39a and 39d) exhibited statistically significant responses, although the trend was for a positive response in dry matter production at all four sites. The largest of the significant responses was in field 39d where the fertilized cover crop produced 427 kg/ha more than the unfertilized. Again, if we assume an average nitrogen concentration in the tissue of 2% this dry matter response represents an additional uptake of approximately 8.5 kg N /ha. Therefore, the additional N uptake for even the largest response of any of the four sites falls far short of the 40 kg N / ha applied.

Even though the responses in dry matter production and nitrogen uptake were relatively small, they did vary from site to site and among replications within each site. Therefore, we attempted to correlate the

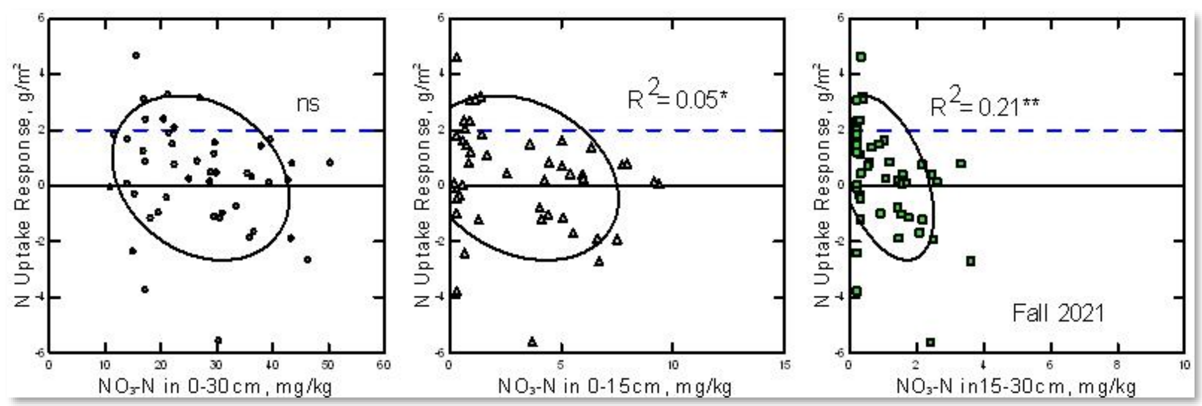

Figure 13 The relationship between the cover crop response to the application of N fertilizer in terms of N uptake per unit of land area and the soil nitrate-N concentration in the upper 30 cm (left), the upper 15 cm (middle) or the 15 – 30 cm depth (right). The blue dashed line represents the response that would be needed to achieve an increased N uptake greater than the 20 kg N/ha (2 g/m^2) N applied to the fertilized treatment in 2021.

magnitude of the responses with the concentrations of extractable mineral nitrogen in the soil at the time of cover crop fertilization. Figure 14 shows the responses of dry matter production on the left and ground cover on the right regressed against the nitrate nitrogen concentration in the upper 30 cm of soil for all sites in 2021 and 2022. Neither response variable exhibited a significant relationship with soil nitrogen. We also examine the relationship between these response variables and nitrate or ammonia in 0 to 15 cm or 15 to 30 cm depths and in no case was the relationship significant (data not shown).

Since we had tissue nitrogen and nitrogen uptake data for the 2021 experiments, we were able to investigate the relationship between soil nitrogen and the nitrogen uptake response to fertilizer application for that year. Our hypothesis was that the response would be greater where the soil nitrogen levels were lower, and this general trend was seen to some degree if we compared the nitrogen uptake response to the nitrate nitrogen in the 15 to 30 cm soil depth (far right panel, Figure 15). The relationship was much weaker for the regression of the nitrogen uptake responses against nitrate concentrations in the upper 15 cm of soil (middle panel Figure 15). There was no significant relationship between nitrogen uptake responses and the mineral nitrogen concentrations in the upper 30 cm of soil (far left panel, figure 15). The dashed blue line in Figure 15 indicates the nitrogen uptake response that would be required to equal the amount of nitrogen applied in that year, 20 kg/ha or 2 g/m^2. Only six of the 48 individual pairs of plots gave a response that was above this level, while 14 individual pairs of plots actually gave a negative response to the application to fertilizer. Earlier work to establish that fall application of N to winter wheat could be justified if soil nitrate concetrations were below 6 mg N/kg soil were based on the yield response by wheat the following summer. In contrast, we we interested in the response of cover crop in the fall before winter sets in because fall N uptake is the main mechanism by which cover crops reduce N leaching over the winter and early spring. It is possible that the lack of a larger response was due to insufficient growing degree days occuring between the N application and the onset of winter dormancy. Our hypothesis of a larger response and > 100% apparent N use efficiency was based on the occurrence of large pools of N deeper thathe upper 30 cm but within reach of vigorus fall cover crop root growth. While this was the case in the study by Hirsh and Weil (2019) who measured nitrogen to 2 m deep in similar sites (and several of the same sites), we did not confirm the presence of such a N pool in this study.

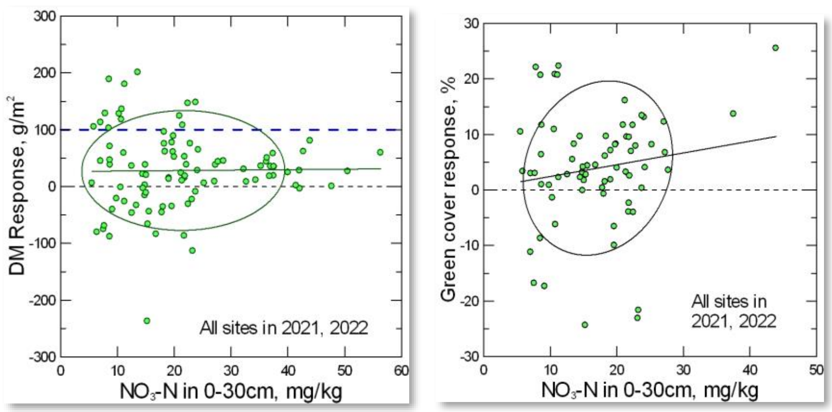

Figure 14 The relationship between nitrate-N concentration in the upper 30 cm of soil and the cover crop response to the application of N fertilizer in terms of dry matter (DM) production (left) and percent ground cover (right). Neither of these relationships was significant. The blue dashed line represents the appropriate amount of DM response that would be needed to achieve an increased N uptake greater than the N applied.

CONCLUSIONS

Based on the lack of consistent and large responses in either dry matter production or nitrogen uptake in any of the 14 site-years, we have to reject our hypothesis that a small application of nitrogen fertilizer to cover crops in early fall would stimulate additional nitrogen uptake in excess of the amount of nitrogen applied.

With the data available we were not able to predict what level of nitrate in the soil, if any, would justify the application of nitrogen fertilizer to early interseeded cover crops in corn.

Therefore we do not recommend the application of even small amounts of N fertilizer to cover crops in early Fall if the objective is to enhance the reduction of N lossses by leaching over the winter and spring.

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