ADDITION OF NEW SPECIES TO COVER CROP BMP

Addition of New Cover Crop Species with Nitrogen Reduction Efficiencies for Use in Phase 5.3.2 of the Chesapeake Bay Program Watershed Model

New Cover Crop Species Proposed:
Annual Ryegrass
Annual Legumes
Annual Legume plus Grass Mixtures
Brassica (winter hardy)
Forage Radish
Forage Radish plus Grass Mixtures
Triticale
Oats (winter hardy)
Oats (winter killed)

Recommendations for Approved by the Water Quality Goal Implementation Team's Watershed Technical and Agricultural Workgroups

Introduction

This document summarizes the recommendations of the 2012-2013 Cover Crop Expert Panel for several new cover crop species and crop mixtures, with accompanying nitrogen (N) efficiency estimates for inclusion in the Phase 5.3.2 of the Chesapeake Bay Program Watershed Model. The new cover crop species will be added within the existing Traditional Cover Crop definition; no other modifications of the existing practice definition are being recommended at this time. The report was approved and enacted for 2013 progress by the Water Quality Goal Implementation Team on October 15, 2013.

The Panel's membership was:

Panelist	Jurisdiction	Affiliation
Andy Clark	Maryland	Univ. of Maryland, Sustainable Agriculture Research & Education
Barbie Elliott	West Virginia	West Virginia Conservation Agency
Charlie White	Pennsylvania	Penn State University
Chris Lawrence	Virginia	USDA Natural Resources Conservation Service, Virginia
Dean Hively	Maryland	USDA & U.S. Geologic Survey

Patrick Bowen	West Virginia	USDA Natural Resources Conservation Service, West Virginia
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Paul Salon	New York	USDA Natural Resources Conservation Service, New York
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Ray Weil	Maryland	University of Maryland
Robert Baldwin	Delaware	Delaware Dept. of Natural Resources & Environmental Control
Ron Hoover	Pennsylvania	Penn State University
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Sjoerd Duiker	Pennsylvania	Penn State University
Tim Sexton	Virginia	Virginia Department of Conservation and Recreation
Wade Thomason	Virginia	Virginia Tech
Jack Meisinger	Maryland	USDA Agricultural Research Service (Panel Chair)
Mark Dubin	Maryland	University of Maryland (Panel Coordinator)
Technical support by Steve Dressing, Don Meals, Jennifer Ferrando (Tetra Tech), Jeff Sweeney (EPA CBPO), Matt Johnston (UMD CBPO) and Emma Giese (CRC).		

Practice Definition

The purpose of the cover crop practice is to reduce nutrient losses to ground and surface water by sequestering excess nutrients in a short-term crop grown after the main cropping season. Important elements of the practice include selection of the cover crop species, the planting time, and the seeding method. Cover crops are one of the most valuable management practices available for protecting water quality, especially groundwater quality, which is a difficult resource to protect from non-point sources of soluble nutrients like nitrate N.

The value of cover crops in reducing N leaching for an environmental benefit has been consistently demonstrated by multiple regional scientific papers which were utilized by the panel in evaluating the relative N reduction values for the additional recommended species. Examples of relevant papers include Meisinger et al., 1991; Staver & Brimsfield, 1998; and Dabney et al., 2009. Additionally, general reference sources such as the SARE Cover Crop Handbook and the Mid-Atlantic Water Program's 2007 Cover Crop Report also supported the recommendations.

Cover crops entered the Bay Model in 1997 and have been strongly endorsed by the USDA Natural Resources Conservation Service (NRCS), state environmental and agricultural agencies, and farm-producer advocacy groups like the American Farm Bureau and the American Farmland

Trust. More importantly, they have been widely adopted by agricultural producers across the Chesapeake Bay watershed primarily for conserving valuable N, but also because they provide other benefits such as adding soil organic matter, improving soil structure, and improving soil health. There are also some habitat benefits provided by an actively growing off-season crop compared to the traditional fallow-weed cover, as well as some social benefits derived from maintaining "green" landscapes during the fall-winter seasons. However, the water quality benefits for N were the only benefits considered by the panel for new cover crop species at this time.

The current cover crop practice is recommended for revision because the existing species of rye, wheat, and barley do not adequately capture the diversity and extent of current cover crop practices being deployed in the Watershed. The new cover crop species will be added within the existing Chesapeake Bay Program's Traditional Cover Crop BMP definition, thus no modifications of the existing definition are being recommended at this time. The purpose of this revision is to allow the Bay Model to better represent current cover crop cultural practices and acreages, which have significantly expanded since 2007 when the Cover Crop BMP was last revised.

Applicable USDA-NRCS Practices

The USDA Natural Resources Conservation Service (NRCS) standard for Cover Crop (CP 340) in the National Handbook of Conservation Practices (NHCP) is partially applicable to this practice. The NRCS CP 340 standard provides a general criteria and definition which potentially may provide most if not all of the attributes as the Chesapeake Bay Program partnership's Cover Crop BMP, but the information tracked and reported by NRCS for use by the partnership does not typically include specific practice details such as species, timing, method, and nutrient application. State Offices of NRCS may elect to incorporate additional guidance with the NHCP standard, as well as implement additional tracking and reporting elements of the CP 340, which could provide increased criteria compatibility and applicability to the related Cover Crop BMP. Additional information on the CP 340 standard may be obtained under the USDA-NRCS National Handbook of Conservation Practices (NHCP) (http://directives.sc.egov.usda.gov/viewerFS.aspx?hid=22299) and the Field Office Technical Guides (http://www.nrcs.usda.gov/technical/efotg/) for each state.

Description of New Species

Annual Ryegrass, also known as Italian Ryegrass, is a cool season annual grass that does a good job of accumulating nutrients, although it does not grow as well as rye during the colder months in the Bay watershed. It has an extensive soil holding root system that establishes quickly, which is the basis for its reputation as a soil erosion fighter. It is a common component of mixtures, where it is often aerial seeded (USDA, SARE 2007).

Annual Legumes and Grass Legume Mixtures include winter annuals that are primarily used to supply N to the next crop due to their ability to fix significant quantities of atmospheric N. However, they also provide a living crop that can scavenge small amounts of residual nutrients as well as provide some erosion protection during the spring runoff season (USDA, SARE, 2007). In the Bay watershed, the most common annual legumes are Hairy Vetch and Crimson Clover. The Panel recommends combining these two legume species, and other winter annual legumes, into one category because all the existing data on legume recovery of residual N studied either hairy vetch and/or crimson clover. Another reason to include pure legume stands is to provide a way to credit grass-legume mixtures by weighting mixtures according to the common planting densities of the grass, which can absorb significant quantities of fall N, and the legume, which absorbs much less fall N. The popularity and diversity of grass-legume mixtures is increasing, so having both components of a mixture in the cover crop BMP will provide a means for estimating the N Reduction Efficiency for a wide range of grass-legume mixtures. Thus, the Panel recommends adding both the Annual Legume and Annual Legume plus Grass categories to the Phase 5.3.2 update.

Brassicas (winter-hardy) – Canola and Rape – are proposed for inclusion in the model. Both are technically rapeseed, and both can take up significant amounts of N, often comparable to rye, but only if planted early. The winter-hardy Brassicas provide full fall-winter-spring crop growth and residue cover that avoids possible residue decomposition losses while providing soil cover to manage erosion (USDA, SARE, 2007).

Forage Radish, also known as tillage radish, is a popular deep-rooted cover crop that grows fast with warm temperatures and an ample supply of N. It can recover substantial quantities of residual N, and often accumulates as much, or more, N in the fall than rye. However, it is subject to winter killing following a few days below 25 F. After winter-kill the radish residues decompose rapidly, leaving the soil bare and making it vulnerable for some nitrate-N leaching depending on weather and soil conditions, during the remaining winter and early-spring seasons (USDA, SARE, 2007).

Forage Radish and Grass is listed as a separate group because: i) it combines two distinctly different species, each contributing their own advantages to the resulting mixture, and ii) there are good data available for estimating an initial relative nitrogen reduction efficiency (RNRE) for this mixture. The general biological characteristics and uses of Forage Radish and Grass cover crops can be gleaned from their accompanying descriptions in the Forage Radish and Triticale species sections.

Oats (winter-hardy and winter-killed) is a cool season annual cereal having varieties that are winter hardy in some areas of the Bay watershed, and some varieties that are winter killed. Oats are primarily used as a short-term N scavenger with secondary benefits of reducing soil erosion.

In circumstances where herbicides are not used a winter-killed oat variety is often preferred to winter-hardy cereal covers (USDA, SARE, 2007).

Triticale is a cool season annual cereal that is a cross between wheat and rye, giving it characteristics from each parent. It serves the dual purpose roles of being a N scavenger and an erosion fighter. It grows almost as well as rye in cold months, but is easier to manage in the spring because it is less subject to the rapid spring growth that can present management difficulties with rye.

Effectiveness Estimates

The N effectiveness estimates are the only water quality parameter included for the new species because: 1) cover crops primarily function to trap or sequester N, with only minor reductions for phosphorus (P) and sediment; and 2) there are very few conservation-tillage era studies on surface runoff losses of P or sediment reductions for cover crops. The Panel recommends that a place holder, or interim, value of “0” be used for the P and sediment effectiveness estimates for all new species, to be replaced later with the Panel’s recommended values derived from best available data or from estimates provided from an independent agricultural model such as APEX.

Relative Nitrogen Reduction Efficiency (RNRE) Estimates

Effectiveness estimates for N reduction by new cover crop species were initially developed as values relative to the accepted N reduction efficiency of rye, termed “Relative Nitrogen Reduction Efficiency” or RNRE by the Panel. The average RNRE values adopted by the Panel are given in Table 1. Note that the RNRE values shown are contingent on the cover crop being planted at the recommended planting time(s) only.

Table 1. Average RNRE, number of individual studies contributing to the average, and recommended planting times for the new cover crop species and species mixtures[1]

Proposed New Species or Species Mixtures	Relative Nitrogen Reduction Efficiency (relative to Rye)	Number of Individual Studies	Recommended Planting Time [2]
Annual Ryegrass	0.66	5	Early and Normal
Annual Legume	0.16	4	Early and Normal
Annual Legume + Grass	See Table 2	NA	Early and Normal
Brassica (winter hardy)	0.70	13	Early only
Forage Radish	0.58	12	Early only

Forage Radish + Grass	See Table 2	NA	Early and Normal
Triticale	0.86	10	Early, Normal, Late
Oats (winter hardy)	0.55	11	Early and Normal
Oats (winter killed)	0.40	4	Early only

[1] Seeding methods are not listed because every new species will use existing seeding methods of drilled, other, aerial/soybean, and aerial/corn according to the existing relative relations between these seeding methods in the current model.
[2] Early is more than two weeks before the average frost date, Normal is between the average frost date and two weeks before that date, Late is within three weeks after the average frost date.

An example interpretation of the RNRE values is that, on average, the total N uptake of Annual Ryegrass was 66% of the corresponding rye N uptake.

The RNRE estimates for the new species were all derived from replicated field studies reported in peer reviewed papers, current Land Grant University (LGU) cover crop or forage species trials, graduate student theses, or outside grant research projects at LGUs. Each of these trials was required to have a rye treatment with either total N or ^{15}N uptake, or dry matter, measured in the spring at a time when a traditional cover crop would be terminated, or in the fall if the cover crop was not winter hardy. The presence of the rye N uptake or dry matter data provided a watershed wide "internal standard" that allowed *a direct comparison of each new species with rye, within each individual study*. This comparison involved simply calculating the ratio of the quantity of total N or ^{15}N uptake, or dry matter, in the new species to the corresponding measurement in rye, this ratio (e.g. = $(\text{total N uptake})_{\text{species 'A'}}$ / $(\text{total N uptake})_{\text{rye}}$) defines the term "Relative Nitrogen Reduction Efficiency (RNRE)" used throughout this report, with the word "relative" in this context meaning "relative to rye". The Panel calculated the final RNRE for each new species from the average of applicable individual studies. Further details and examples of calculating the RNREs are in Attachment A.

A major advantage of comparing all the new species to rye is that the Bay Phase 5.3.2 Model calibration already includes rye as a cover crop. Thus, the final N effectiveness estimate for each new species can be made by simply multiplying the RNRE by the existing value of the rye N effectiveness (which is already in the model with adjustments for spatial scale-up from plot to field, and adjustments for the hydrologic partitioning of N losses to ground water vs. surface runoff). Using the RNREs with the current rye N effectiveness values thus eliminates the need to recalibrate the Phase 5.3.2 models for the new species (Pers. Comm. Jeff Sweeney, 4-24-2013). Further details and examples of calculating the final N effectiveness values for the new species are given below and in Attachment A.

It can be seen in Table 1 that annual legumes are the poorest at recovering N compared to rye, but if they are grown in a grass mixture their N conservation improves substantially because all the grasses have higher RNRE than the legumes (see discussion below for Table 2). A pure stand of forage radish, over the course of the entire fall-spring (Sept. to late April) cover crop season, is credited with recovering about 58% as much N as pure rye, which includes the likely loss of some N after the forage radish is killed by frost (commonly in mid-late Dec.) followed by decomposition of the radish residues with no growing cover crop present. However, a cover crop made up of a forage radish plus grass provides a continuous growing cover crop that can trap N released by radish decomposition. Thus, a somewhat higher N recovery would be expected for radish-grass mixtures compared to pure radish (see discussion below for Table 2), because most grass species (except for oats) have higher N recoveries than radish. The grouped winter-hardy brassica species have a higher RNRE of 0.70 compared to forage radish because they are not killed by frost and maintain an actively growing crop throughout the winter and spring. The total N uptake of triticale was about 85% of the corresponding rye N uptake and the N credit of winter-hardy oats was 55% of rye, while the N credit for the winter-killed oats was 40%, which adjusts for likely loss of some N during decomposition of oat residues in the winter through spring seasons.

The recommended planting periods for each of the new species are also listed in Table 1. The Panel recommended these dates based on the agronomic optimums for establishing each species, with particular attention given to the last planting dates that would likely produce acceptable growth and avoid seeding failure.

Recommended N Effectiveness Estimates
The RNREs from Table 1 form the basis for estimating the final N Effectiveness estimates for pure stands in the Phase 5.3.2 update of the Model. Table 2 illustrates this calculation process for each new entry and also allows comparisons of two planting-date windows (early vs. normal) and two establishment methods (drill seeded vs. aerial seeding into soybeans).

Table 2. Examples of new cover crop species, and cover crop mixtures, RNREs and final N effectiveness values for selected planting and seeding methods in the Coastal Plain, Piedmont, or Karst physiographic regions of the Bay Model.

Proposed New Species, or Reference Species (i.e. Rye)	Relative Nitrogen Reduction Efficiency (relative to rye) & Mixture Estimation Method [1]	Final Nitrogen Effectiveness Phase 5.3.2

----------- Early planting by Drill seeding (high soil contact) -----------		
Annual Ryegrass (ARG)	0.66	0.30
Annual Legume	0.16	0.07
Annual Legume + Grass	Avg. N Effectiveness (Legume + Avg. Grass) [2]	0.20
Brassica (winter hardy)	0.70	0.32
Forage Radish	0.58	0.26
Forage Radish + Grass	Avg. N Effectiveness (Radish + Avg. Grass) [2]	0.29
Triticale	0.86	0.39
Oats (winter hardy)	0.55	0.25
Oats (winter killed)	0.40	0.18
Rye (Ref. Species)	1.00	0.45
------ Early planting, Aerial seeding in Soybeans (low soil contact) ------		
Annual Ryegrass (ARG)	0.66	0.20
Annual Legume	0.16	0.05
Annual Legume + Grass	Avg. N Effectiveness (Legume + Avg. Grass) [2]	0.14
Brassica (winter hardy)	0.70	0.22
Forage Radish	0.58	0.18
Forage Radish + Grass	Avg. N Effectiveness (Radish + Avg. Grass) [2]	0.20
Triticale	0.86	0.27
Oats (winter hardy)	0.55	0.17
Oats (winter killed)	0.40	0.13
Rye (Ref. Value)	1.00	0.31
---------- Normal planting by Drill seeding (high soil contact) ----------		
Annual Ryegrass (ARG)	0.66	0.27
Annual Legume	0.16	0.06
Annual Legume + Grass	Avg. N Effectiveness (Legume + Avg. Grass) [2]	0.19
Brassica (winter hardy)	NA [3]	NA
Forage Radish	NA [3]	NA
Forage Radish + Grass	Avg. N Effectiveness (Radish/2 + Avg. Grass) [2]	0.22
Triticale	0.86	0.35
Oats (winter hardy)	0.55	0.23
Oats (winter killed)	NA [3]	NA
Rye (Ref. Value)	1.00	0.41

[1] A complete listing of the N Effectiveness values is given in Table 1 of Attachment B.

[2] Average of: the N effectiveness value of the species, and the average N effectiveness values of all the grasses; which provides the estimate of the mixture's N effectiveness.
[3] Pure stands only recommended for early planting time, not for normal planting time.

Calculating the final N effectiveness values for each new species simply involved multiplying the RNRE for each new species by the corresponding rye N effectiveness value that is currently in the calibrated model for that setting. For example, in the Atlantic Coastal Plain, Piedmont, or Karst regions an early-seeded cover crop of annual ryegrass using a drill would be assigned a final N effectiveness value of 0.30 ((0.66 for ARG)*(0.45 for rye planted early by drill)). It is interesting to note in Table 2 that the triticale (which is a cross between rye and wheat) N effectiveness value of 0.39 (as estimated through the RNRE approach) agrees very well with the prior N efficiency averages already in the model for rye (0.45) and wheat (0.31), which provides a rye-wheat average of 0.38 for early-planted drilled covers.

The N effectiveness values for the two mixtures were estimated after first calculating the N effectiveness values for all pure-stand entries, as above; then calculating the mixture N effectiveness value. This involved use of a "generic grass" that is the average N effectiveness value across all the grass species in the model for a particular planting period and seeding method. To illustrate this for the early-planted drilled legume-grass mixtures: the N effectiveness value for the "generic grass" is the average N effectiveness across all grass species (rye, wheat, barley, annual ryegrass, triticale, winter-hardy oats, and winter-killed oats), which is 0.32. Next, this average grass N effectiveness is averaged with the corresponding annual legume N effectiveness of 0.07 to produce a final N effectiveness for a drilled early-planting legume-grass mixture of 0.20 (average of 0.32 and 0.07, rounded off). It is noteworthy that the legume-grass mixtures have substantially higher N effectiveness values than pure legumes, which results from the higher RNRE of grasses compared to legumes (see Table 1). The same approach was used for the early-seeded Forage Radish plus Grass mixtures that produced a final radish-grass N effectiveness value of 0.29 (average of 0.32 and 0.26).

It should also be noted that using the above "generic grass" approach is expected to underestimate the value of mixtures, because rye is probably the most common grass used in mixtures and rye has the highest N effectiveness of all the grasses. However, the Panel supported using the "generic grass" approach because it has a much lower burden for record keeping and reporting, while still providing an avenue for including mixtures into the Phase 5.3.2 update. If suitable data can be obtained from states for estimating the average relative proportions of grasses in their cover crop mixtures (e.g. 50% of mixtures used rye, 30% triticale, 20% annual ryegrass) then an improved estimate of the grass contribution to cover crop mixtures can be developed.

For Forage Radish plus Grass mixtures planted in the normal period (later than the recommended period for radish), the radish early-planting N effectiveness value was discounted 50% before averaging with the “generic grass” value, in order to adjust for the slower radish growth in the fall compared to the early-fall period and still allow normal credit for fall growth of the “generic grass” in the mixture. Thus, a drilled Forage Radish plus Grass mixture planted in the normal period received a N effectiveness value of 0.22 (the average of one-half of the radish drilled early-planted N effectiveness or 0.13 [0.26/2] and the average N effectiveness of all drilled grasses planted in the normal period which is 0.31).

The above approaches for cover crop mixtures produced final N effectiveness values for early-planted drilled radish-grass mixtures that are 0.09 higher than the corresponding legume-grass mixtures (see Table 2), but this radish-grass vs. legume-grass advantage decreases for normal planting to 0.03 (see Table 2). These N effectiveness differences for radish vs. legume mixtures are consistent with the fact that forage radish has higher N recoveries than annual legumes, especially for early plantings.

The results of corresponding calculations of N effectiveness in Table 2 are included to allow direct comparisons of two other common seeding methods (drilled vs. aerial seeding into soybean) and two other planting times (early vs. normal) with each scenario based on the current rye N effectiveness value that is already in the model for the corresponding seeding methods and planting periods. The complete list of N effectiveness values for all relevant planting periods and seeding methods is given in the Technical Requirements section (see below) of this report.

The Panel recommends maintaining the aerial seeding category as two separate classes, one for soybean and one for corn, for the new species and species mixtures. This recommendation resulted from a lack of data to reject the proposition that any of the new species differed from the cereal grains in their aerial establishment success, and that aerial seeding into soybeans is generally more successful than into corn, as documented in the previous Cover Crop Panel Report (MAWQP. 2007. Reduction for Aerial Seeding. p. 110-113).

Phosphorus and Sediment

The panel held a face-to-face meeting in Frederick MD, to discuss approaches for estimating the phosphorus (P) and sediment (S) reduction efficiencies for the each new species and mixture. It was decided to continue the “relative to rye” approach that was used for N (above) for each new entry, and to multiply the resulting “relative to rye” value by the existing P or S reduction efficiency in Phase 5.3.2 to arrive at the final P and S effectiveness values. It was also decided to use Best Professional Judgment (BPJ) to estimate the “relative to rye” values, due to a lack of experimental data. It was suggested that each panelist develop their BPJ estimate by using the RNRE as a reference point, and then adjust the RNRE based on their BPJ of the residue production for the new entries. Each member was then requested to fill out an anonymous "ballot" listing their final BPJ estimate, based on their assessment of residue production compared to rye. Residue production was selected as a critical parameter because of the well-known relation between residue cover and soil loss (increasing residue-cover reduces soil loss), and the similar general relationship between sediment loss and P loss. The resulting anonymous BPJ estimates of relative P and S reductions were tabulated from the ten responding panelists and were reviewed on a follow-up conference call that considered several ways to summarize the voting data (see Appendix A). After consideration, the panel voted unanimously to summarize the individual "relative to rye" P and S reduction efficiencies with a simple average across all respondents. The resulting P relative reduction efficiencies and P effectiveness estimates are given Table 3, with Table 4 listing the corresponding S summary.

Table 3. Examples of new cover crop species, and cover crop mixtures, Relative Phosphorus Reduction Efficiencies and final Phosphorus Effectiveness values for early plantings and all seeding methods in the Coastal Plain, Piedmont, and Karst physiographic regions of the Bay Model.

Proposed New Species, or Reference Species (i.e. Rye)	Relative Phosphorus Reduction Efficiency (relative to rye) as estimated by Panelists Best Professional Judgment	Final Phosphorus Effectiveness Phase 5.3.2
----------- Early planting, all seeding methods, high tillage -----------		
Annual Ryegrass (ARG)	0.70	0.10
Annual Legume	0.38	0.06
Annual Legume + Grass	0.66	0.10
Brassica (winter hardy)	0.65	0.10
Forage Radish	0.40	0.06
Forage Radish + Grass	0.54	0.08
Triticale	0.81	0.12
Oats (winter hardy)	0.63	0.09
Oats (winter killed)	0.37	0.06
Rye (Ref. Species)	1.00	0.15

Table 4. Examples of new cover crop species, and cover crop mixtures, Relative Sediment Reduction Efficiencies and final Sediment Effectiveness values for early plantings and all seeding methods in the Coastal Plain, Piedmont, and Karst physiographic regions of the Bay Model.

Proposed New Species, or Reference Species (i.e. Rye)	Relative Sediment Reduction Efficiency (relative to rye) as estimated by Panelists Best Professional Judgment	Final Sediment Effectiveness Phase 5.3.2
----------- Early planting, all seeding methods, high tillage -----------		
Annual Ryegrass (ARG)	0.73	0.15
Annual Legume	0.42	0.08
Annual Legume + Grass	0.75	0.15
Brassica (winter hardy)	0.65	0.13
Forage Radish	0.44	0.09
Forage Radish + Grass	0.62	0.12
Triticale	0.85	0.17
Oats (winter hardy)	0.68	0.14
Oats (winter killed)	0.41	0.08
Rye (Ref. Species)	1.00	0.20

The BPJ estimates show a strong relationship between the P and the S relative reduction efficiencies because both estimates emphasized residue cover, although the P reduction efficiencies were consistently somewhat lower than S. However, some noteworthy differences occur between the results in Tables 3 and 4 compared to the N results in Table 1. For example, the P and S "relative to rye" estimates for an annual legume is about 0.4 in Tables 3 and 4, while the corresponding N estimate is 0.16 in Table1; which is due to the legume providing residues as a result of N fixation, while legume N-fixation was not credited as residual-N recovery in Table 1. Another noteworthy difference occurred with forage radish, which is a species that winter kills and leaves minimal residues in the spring. The forage radish growth habit results in a lower P and S "relative to rye" values of about 0.42 in Tables 3 and 4, compared to a residual-N recovery estimate of 0.58 in Table 1.

Negative Pollution Reductions

The Panel did not find dependable quantitative data documenting possible negative pollution reductions, i.e. examples where the cover crop acted as a nitrogen source. However, examples of negative pollution reductions would be possible from leaching losses during residue decomposition of a nitrogen fixing legume cover crop. Therefore, the lack of dependable data on negative pollution reductions will have to be evaluated at a later time when reliable quantitative data are available.

Additionally, the Panel did not find reliable data, nor a suitable mechanism for estimation, of the scenario where cover crops might relocate N from groundwater transport (the major transport pathway assumed in this report) to either surface water transport or to direct deposition. Examples of potential relocations of cover crop N would be deer or avian grazing of cover crops, with subsequent deposition of urine and/or feces in stream corridors or wetlands (e.g. by deer), or for direct deposition into streams or the Bay (e.g. by geese). Therefore, the lack of reliable data on N relocation from cover crops into other potential N loss pathways will have to be evaluated at a later time when reliable data are available and a suitable mechanism for estimating this N relocation have been developed.

References

Coale, F.J., J.M. Costa, G.A Bollero, and S.P. Schlosnagle. 2001. Small grain winter cover crops for conservation of residual soil nitrogen in the mid-Atlantic Coastal Plain. Am. J. Alternative Agric. 16(2):66-72

Dean, J.E., and R.R. Weil. 2009. Brassica cover crops for nitrogen retention in the Mid-Atlantic coastal plain. J. Environ. Qual. 38:520-528

Duiker, S.J. 2013. Unpublished results from a cover crop after corn silage trial in 2011-2012 and 2012-2013 across the state of PA.

Fernando, S.W. 1996. Effects of Winter Cover Crops Following Potato (Solanum tuberosum L.) on Soil Nitrate and Soil Fertility in the Columbia Basin. PhD thesis, Oregon St. Univ. Dept. Crop Sci. major prof. Alvin R. Mosley.

Personal Communication from: Finney, DM and JP Kaye. 2013. Cover crop cocktails to enhance nitrogen management. PSU Extension Handout.

Houser, C., W.S. Harkcom, and M.H. Hall. 2013. Short-lived cool-season grass trial. pp.16-19. In 2012 Forage trials report. Coop. Ext. Serv. PA St. University, St. College, PA.

Lounsbury, N.P. 2013. Data on total N content and NO3-N content of winter killed oats from MS thesis “Spring seedbed characteristics after winterkilled cover crops”.

Muller, J.C., D. Denys, G. Borlet, and A. Mariotti. 1989. Influence of catch crops on mineral nitrogen leaching and its subsequent plant use. pp.85-98. In J.C. Germon (ed.) Management systems to reduce impact of nitrates Elsevir Sci Pub. NY, NY.

Ranells, N.N. and M.G. Wagger. 1997. Nitrogen-15 recovery and release by rye and crimson clover cover crops. Soil Sci. Soc. Am. J. 61:943-948.

Salon, P. NRCS Cover Crop demo study 2010. Unpublished data from Big Flats NY NRCS Plt. Introduction Stn.

Shipley, P.R., J.J.Meisinger, and A.M. Decker. 1992. Conserving residual corn fertilizer nitrogen with winter cover crops. Agron. J. 84(5): 869-876.

Smith, S.R., W. Thomason, B. Benson, D.Starner, and D. Dixon. 2009. Virginia small grain forage variety testing report: long-term summary (1994-2004). Virginia Coop. Extension Pub. No. 418-019, VA Poly. Inst. and State Univ., Blacksburg, VA.

Staver, K. Cover crop demo study 2004. Unpublished data from Wye Res. & Edu. Center. Queenstown, MD.

Thomason, W.D. Unpublished results from VA Radish and Mixed Species data, 3 yr average values (2010-2012).

Virginia Cooperative Extension. Small grain forage variety testing, annual reports 2005-2012. VA Poly. Inst. and State Univ., Blacksburg, VA.

White, C., and R.R. Weil. 2010. Forage Radish Cover Crops Increase Soil Test Phosphorus Surrounding Radish Taproot Holes. SSSAJ 75:121-130.

White, C., and R.R. Weil. Unpublished nitrogen data from 2010 forage radish cover crop study.

Attachment A contains a detailed description of the specific literature sources and the calculations of the RNRE for each new species or mixture. The following paragraphs describe how the Panel used relevant references to determine the RNRE for each of the proposed new cover crop species.

Description of RNRE Estimation Process for New Species

Annual Ryegrass

The Panel used five individual studies from within the Bay watershed to estimate the RNRE; two from PA, two from MD, and one from NY. For all studies, cover crops were planted in the early- or normal-planting period and all harvests were in mid-April to early May (MD and PA), or in mid-May (NY), which is consistent with spring crop development.

The five site-years of data were summarized by calculating a simple weighted average (each mean was weighted by the number of site-years it contained), which produced a final weighted average RNRE of 0.66 that is listed in Tables 1 and 2.

A summary of the studies and methods to estimate the Annual Ryegrass RNRE follows:

a) The PA data (Houser et al.,2012 and 2013) were from the “Short-lived cool-season forage trial” planted in 2011 and 2012 that received 30 lbs starter N/ac in the fall and 100 lbs N/ac in the spring for all entries, including the rye reference entry. The PA data consisted of the yearly average total N uptake across five annual ryegrass varieties that were all present in 2011 and 2012, which contributed two individual site-years of data having an average RNRE of 0.77.

b) The MD data were from the peer-reviewed publication of Shipley et al, (1992) that added a luxury amount of ^{15}N labeled fertilizer to corn and measured the fall residual soil ^{15}N, followed by establishment of fall cover crops of annual ryegrass and rye, and measurement of the ^{15}N in these covers the following spring. This study was conducted in the 1986-87 and 1987-88 cover crop seasons on the Eastern Shore of MD. The average RNRE from these two site-years was 0.68.

c) The NY data are from an unpublished NRCS study in 2010 that evaluated cover crop planting dates (three Sept. planting dates) and compared spring dry matter (DM) production from annual ryegrass to that of rye. The Panel chose to accept DM data as a surrogate for total N uptake since annual ryegrass and rye are both cool-season grasses, and because the NY data added information capturing the large north-south range of growing conditions within the Bay watershed. The NY data were averaged across the three planting dates which produced a RNRE of 0.40 for annual ryegrass.

Annual Legumes and Grass Legume Mixtures

There were only two peer-reviewed studies, each with two site-years of data, available for estimating the RNRE for annual legumes in the Bay watershed. This is because ^{15}N is needed to directly estimate the recovery of fall N in a legume, which also contains N derived from decomposition of soil organic matter plus large quantities of N derived from atmospheric fixation. Both of these studies used early and normal planting dates along with a mid-April harvest.

The four site-years of ^{15}N data produced a final weighted average estimate for the annual legume RNRE of 0.16. The Panel recommends that the estimate for an Annual Legume plus Grass mixture should be the average of the annual legume and the “generic grass” component.

A summary of the two Bay area annual legume studies is given below, along with a summary of two other studies that provide corroborating data for the results from the Bay area research:

a) The peer-reviewed ^{15}N publication of Shipley et al. (1992), described above in the Annual Ryegrass section, also documented the recovery of fall ^{15}N labeled fertilizer by hairy vetch, crimson clover, and rye in a silt loam soil on Maryland's Eastern Shore. The average RNRE from the 1986-87 and 1987-88 cover crop seasons was 0.22 for hairy vetch and 0.17 for crimson clover, which gives a combined average RNRE for Annual Legumes of 0.19.

b) The second peer-reviewed ^{15}N publication was by Ranells & Wagger (1997) who added ^{15}N labeled nitrate to fall seeded crimson clover, rye, and a crimson clover plus rye mixture in a loamy sand soil on North Carolina's Eastern Shore. The average RNRE for crimson clover over the 1993-1994 and 1994-1995 cover crop seasons was 0.09. The lower ^{15}N recovery by crimson clover in the North Carolina study is likely due to greater ^{15}N leaching in the coarse-textured loamy sand soil, compared to the finer-textured silt loam in Maryland. The average N efficiency of the crimson clover plus rye mixture converts to a N effectiveness value of 0.25, which is satisfactory support for the "generic grass" N effectiveness of 0.20 in Table 2. No other studies could be found in the literature that would provide other estimates of the N effectiveness of Annual Legume plus Grass mixtures.

c) Two other studies were identified that provided corroborative data on N recoveries by legumes vs. grasses, and on the value of legume-grass mixtures. These studies could not be used to estimate a RNRE because they did not have a direct comparison with rye. Gabreil and Quemada (2011) conducted a ^{15}N recovery study with barley and hairy vetch in Spain and reported that barley recovered 10% of the residual ^{15}N, while vetch recovered only 1%. In Oregon, Feaga et al. (2010) used multi-year field lysimeter data to document that the average nitrate concentration in drainage below grass covers that was 34% less than without a cover; while a vetch-triticale mixture averaged 19% less than without a cover. These two studies support the view that grasses are much better than legumes at recovering residual N, and that a legume-grass cover is about half as effective as a pure grass cover at reducing the nitrate concentration in soil drainage water.

Brassicas (winter-hardy)

The Panel reviewed 13 site-years of data. Studies from within the Bay watershed include three site-years from a peer-reviewed Maryland study, six site-years from an unpublished Virginia study, and one site-year from a Pennsylvania extension publication. Other studies that the Panel considered valid and which had a direct comparison to rye, were from peer-reviewed research done in Oregon (two site-years) and France (one site-year).

Rape and canola are grouped together because they have similar fall and spring growth in the Bay watershed. Both should be planted early; they survive the winter and continue to accumulate biomass and N in the spring, as well as provide soil cover for erosion control.

The 13 site-years of data were initially summarized by calculating a simple weighted average as for the other species, which produced a final weighted average RNRE of 0.80. However, due to high pre-planting available N and very early planting in some site-years, and because of the wide range of N uptakes for rape; the Panel unanimously voted to recommend a more conservative RNRE of 0.70.

The data summary for rape and canola listed in Tables 1 and 2 are:

a) The largest data set is from the Eastern and Western Virginia studies (Pers. Comm. Wade Thomason, 2013) from studies in 2010-2012 (3 site-years each). The studies include rye, pure oats and an oat plus canola mixture. Cover crops were planted in the early-planting period for each location and followed cash grain-crops. The average canola N uptake value (57 lbs N/ac) was estimated by subtracting the pure oat uptake (17 lbs N/ac) from the oat/canola mixture uptake (74 lbs N/ac), while the rye N uptake was 98 lbs N/ac. Thus, the average RNRE for canola from these six site-years was 0.62.

b) The Maryland data (Dean and Weil, 2009) are based on one site-year (2004) from the Piedmont and two site-years (2003) from the Coastal Plain. In two of these studies, rape and rye were planted following mowing of a soybean crop that added an estimated 207 lbs of readily decomposable N/ac to the soil. The average RNRE for rape from these three site-years was 1.2. However, due to the high N environment in these studies, the Panel voted unanimously to adjust the final efficiency for rape as described above.

c) The Pennsylvania data (Finney and Kaye, 2013) came from one site-year (2011). The Hagerstown soil was conventionally tilled following an oat crop; rye and rape were planted in late August and harvested in mid-May. The rape N uptake was 108 lbs N/ac compared to 67 lbs N/ac for rye, giving a RNRE of 1.6.

d) Data from France (Muller, et al., 1989) was included because it had a rye cover crop whose N uptake values were similar to a high N supplying site in the Bay watershed. These data (one site-year) followed wheat and also demonstrate the effect of slightly later planting (but still in the early-planting period) on rape N uptake, which was harvested in early March. Rye N uptake was 120 lbs N/ac, but the rape N uptake was 23 lbs N/ac due to overwinter damage that would be common in the more northern areas of the Bay watershed. The resulting RNRE for rape was 0.19, which illustrates the highly variable performance of brassicas.

e) Data from Oregon (Fernando, et al., 1996) was included because the Adkins fine sandy loam and rainfall pattern is similar to the Bay watershed. The other cover crops in this study (rye, wheat and triticale) also had N uptakes that corresponded well with data from the Bay watershed. Two site-years of data were reported (1992-1993 and 1993-1994) as part of this

Ph.D. thesis. Cover crops were planted in mid-September and harvested in mid-March or early-April. The average rye N uptake was 102 lbs N/ac while rape was 68 lbs N/ac, giving a RNRE of 0.62.

Forage Radish

Twelve site-years of forage radish N uptake data, with corresponding rye data, were available from Maryland, Pennsylvania, and Virginia with all planting done during the early planting period. All harvests were in the fall before frost killing, which is consistent with crop development.

The 12 site-years of data were initially summarized by calculating a simple weighted average as for the other species, which produced a final weighted average RNRE for forage radish of 1.00. However, due to high pre-plant available N and very early planting in some site-years, and because of the wide range of N uptakes for forage radish compared to rye; the Panel chose to conduct an anonymous poll to allow each member to interpret the data and submit their estimate of the radish RNRE. The Panel then pursued detailed discussions about various interpretations of the data. The Panel concluded by voting unanimously to recommend acceptance of the average RNRE from the anonymous poll, which is 0.58.

The summary for the forage radish data is given below:

a) The largest data set is from the Eastern and Western Virginia studies (Pers. Comm. Wade Thomason, 2013) in 2010-2012, with each area contributing 3 site-years of data. These studies included fall N uptakes for pure rye and pure radish, with the details of this study given in the Brassica (winter-hardy) section above. The average N uptakes, in lbs N/ac, in Eastern Virginia were 62 and 53 for rye and radish, respectively. The corresponding N uptakes (lbs N/ac) for the Western Virginia were 134 and 96 for rye and radish, respectively. These six site-years of data produced an average RNRE for forage radish of 0.79.

b) The Maryland data are from Dean and Weil (2009) and unpublished data from C. White's Ph.D. thesis. The studies have two site-years from the Piedmont and three site-years from the Coastal Plain. In three of these studies, the radish and rye were planted following mowing of a soybean crop that added several hundred pounds of N/ac to the soil. The average fall N uptake for the rye from these five site-years was 106 lbs N/ac, while the corresponding value for forage radish was 130 lb N/ac. These data provide a RNRE of 1.23.

c) The Pennsylvania data were from an Extension demonstration study from one site-year (2011), which is described above in the Brassica section. The forage radish N uptake was 27 lbs N/ac compared to 67 lbs N/ac for rye, giving a RNRE of 0.40.

Forage Radish and Grass

The Panel used individual studies from Pennsylvania and Virginia that provided 15 site-years of data for estimating the RNRE for Forage Radish plus Grass mixtures, with virtually all of the studies using rye as the grass species. All studies were planted in the early or normal planting period and all harvests were in mid-April to early May, which is consistent with crop development in the spring.

The 15 site-years of Forage Radish plus Rye data were initially summarized using a weighted average based on the number of site-years in each mean, which produced a final RNRE of 0.86 and a N effectiveness for early-planted drill-seeding of Forage Radish plus Rye of 0.39 (0.86*0.45). However, the Agriculture Work Group requested that the Forage Radish plus Grass mixture use the same estimation approach as the legume-grass mixture. Accordingly, the final N effectiveness of early-planted drill-seeded forage radish plus "generic-grass" category in Table 2 is 0.29 (= average N effectiveness of forage radish (0.26) and the "generic grass" (0.32)), which is somewhat less than the above estimate of 0.39 if rye is the dominant component in the mixture because the other grass covers (especially oats) recover less N than rye. The Panel recommends that future updates of the Cover Crop BMP consider using individual grass species rather than a "generic grass", because that would provide incentive to use the most efficient grass species in the Bay watershed. Another alternative would be to use a weighted average of the "generic grass" species, rather than a simple average, with the weighting factor being based on estimates of the most common grass species used in cover-crop mixtures in the watershed.

A summary of data and methods used to estimate the initial Forage Radish and Grass RNRE follows:

a) The Pennsylvania Cover Crop after Corn Silage Trial was the main source of data. This is an unpublished (still in progress) data set from Dr. Sjoerd Duiker containing one year of data from 10 different on-farm field locations across Pennsylvania. Each location followed silage corn and contained a direct comparison of the total N uptake of rye vs. a forage radish plus rye mixture. The average RNRE from these 10 site-years of data was 0.89.

b) The other Pennsylvania data came from two site-years from the "Short-lived cool-season forage trial" of Houser et al. (2011 and 2012) that is described in the Annual Ryegrass section. In this trial rye was compared to a mixture Forage Radish plus Annual Ryegrass, which produced a RNRE of 0.76.

c) Data from Virginia is from three site-years of data from the Radish and Mixed Species trial (Pers. Comm. Wade Thomason, 2013) that is summarized in the Brassica section. The trial contains three years of western Virginia data comparing rye with a mixture of forage radish plus rye plus annual ryegrass (a three species mixture containing two grasses). The resulting RNRE is 0.79.

Oats (winter-hardy) and Oats (winter-killed)

Virginia provided the most complete data base for winter-hardy oats, which was 11 years of data (Smith et al., 2009) comparing total N uptake from a single winter-hardy variety with corresponding data from rye. The Panel recommended that the planting periods for winter-hardy oats be early and normal, while the planting period for winter-killed oats should only be early. The winter-hardy oat data provided the base line for estimating the winter-killed RNRE, which is described in more detail below. The Panel's recommendation for the RNRE of winter-hardy oats is 0.55, and for winter-killed oats is 0.40.

A summary of the data and the methods to estimate the RNRE of winter-hardy and winter-killed oats follows:

a) The source of data for winter-hardy oats was the Virginia small grain forage variety testing report: long-term summary (1994-2004) reported by Smith et al. (2009). In this study, cover crops received 25-30 lbs starter-N/ac in the fall and 60 lbs N/ac in the spring for all entries, including the rye reference entry. The Virginia study documented the average total N uptake for a single winter-hardy oat variety and a single rye variety that were both present in 11years of the long-term study, thus providing 11 site-years of data having an average RNRE of 0.55.

b) The winter-killed oat RNRE was estimated from the above winter-hardy oat data base that was adjusted for estimates of over-winter N loss. One adjustment was based on the assumption that all the fall nitrate-N content of oats was lost (nitrate data provided by pers. comm. with Ms. Natalie Lounsbury, Univ. MD), which amounted to an 18% loss of the oat total N. The second approach was based on the loss of total N in the oat residues during the over-winter period from another unpublished three-year Virginia trial studying Radish and Mixed Species Cover Crops (Pers. Comm. Dr. Wade Thomason, 2013), which amounted to a 36% loss in oat total N. These two loss estimates for winter-killed oats were averaged together and related to the rye N uptake, which resulted in a RNRE for winter-killed oat of 0.40.

Triticale

The Panel used individual studies from Maryland, New York, Pennsylvania, and Virginia that provided ten site-years of data for estimating the RNRE for triticale. All studies were planted in the early or normal planting period and all harvests were in mid-April to early May or in mid-May (NY), which is consistent with crop development in the spring. These studies did not include a late planting, but the Panel recommends including a late-planted category. This is the same procedure used by the 2007 Cover Crop Panel for the late planting category of rye and wheat (MAWQP, Cover Crop Report, 2007).

The ten site-years of triticale and rye data were summarized using a weighted average based on the number of site-years in each mean as before, which produced a final RNRE of 0.86 for triticale that is listed in Tables 1 and 2.

Summaries of the triticale data include:

a) The Maryland cover crop studies with triticale were the peer-reviewed paper of Coale et al. (2001) and unpublished 2004 data from Dr. Ken Staver. Each study contributed one site-year. The Staver data provided N uptake data and a RNRE of 0.84. The Coale et al. (2001) N uptake data resulted in a RNRE of 1.15, which indicates that triticale took up about 15% more N than rye – a fact that should be occasionally expected since rye was one of the parents of triticale.

b) The New York data are from the same unpublished 2010 NRCS cover crop planting date study that is described in the Annual Ryegrass section. The New York data were averaged across the three planting dates which produced a Relative DM Production Efficiency of 0.64 for triticale.

c) The Pennsylvania data from the "Short-lived cool-season forage trial" planted in 2012 (Houser et al., 2013) are the basis for the RNRE. A summarized description of this study is given in the Annual Ryegrass section. The triticale total N uptake contributed a single site-year of data having an average RNRE of 0.70.

d) The largest triticale data set came from the Virginia small grain forage variety testing report: long-term summary (1994-2004) reported by Smith et al. (2009). The crops in the Virginia study received 25-30 lbs starter-N/ac in the fall and 60 lbs N/ac in the spring for all entries, including the rye reference entry. The Virginia data consisted of the average total N uptake for a single triticale variety and a single rye variety that were both present in 6 years of the long-term study, thus providing six site-years of data having an average RNRE of 0.88.

Application of Practice Effectiveness Estimates

The units of measure and load source for the cover crop N reduction efficiencies in this report are the percentage reduction of the estimated N lost through groundwater recharge at the bottom of the root-zone. This boundary condition is analogous to the reduction efficiencies for a surface runoff BMP which is an edge of field loss. The N reduction efficiencies in Phase 5.3.2 considered hydrologic flow region by dividing the watershed into two major hydrodynamic regions: the Mesozoic Lowlands/Valley and Ridge Siliciclastic, and the Coastal Plain/Piedmont and the Crystalline/Karst Settings; with the former region having a somewhat smaller subsurface-edge-of-field factor of 0.65 compared to the latter region that has a corresponding factor of 0.85 (Cover Crop Panel Report MAWQP 2007). The subsurface-edge of field flow factors reflect the somewhat lower groundwater recharge and higher surface runoff in the upland regions of the watershed compared to piedmont and coastal regions.

This practice is applicable to agricultural cropland throughout the whole Chesapeake Bay watershed, and is most commonly applied to land growing annual crops such as grain crops, vegetable crops, fallowed land, and annual forage crops. The load reductions from cover crops apply to bottom of the root-zone and cover a broad scale because the reductions primarily impact groundwater quality that recharges both local and regional aquifers which provide base-flow water to streams and rivers. The baseline condition for these cover crop N reduction efficiencies is a winter fallow with natural weed cover. Cover crops are an annual practice with the most common pre-BMP being a recently harvested field with surface crop residues and the post-BMP being the field with residues from the terminated cover crop plus any remaining crop residues from the previous crop. This report assumes the use of a traditional cover crop that is not harvested in the spring. Cover crops are known to have varying performances across the Bay watershed, and these performance differences are indirectly accounted for by adjusting the "normal" planting season to the average frost date of the county or sub-watershed. Using the average frost date indirectly accounts for differences in latitude and altitude across the watershed, which are two important factors affecting cover crop establishment and performance.

Cover crops are an annual practice with non-cumulative effects for this report, although cover crops can contribute to a modest increase in soil organic matter that could sequester both carbon and nitrogen. The potential cumulative effects will have to be addressed in future reports. The lag-time for cover crops would be the fall establishment season, which would be only one or two weeks for covers planted within the early, normal, or late planting categories or for covers established by aerial seeding vs. drilling. The somewhat longer establishment times for later plantings and aerial seeding have been included in the estimated nitrogen reduction efficiencies carried forward from the previous Cover Crop Report (Cover Crop Panel Report MAWQP 2007). This practice could interact with conservation tillage BMPs because cover crops are a common element in conservation tillage systems and can deliver some phosphorus and sediment reductions. However, this report only considers nitrogen reductions, so the phosphorus and sediment interactions with conservation tillage will be taken up at a later time. Ancillary benefits of cover crops include, over time, increased soil organic matter, increased soil cation exchange capacity, increase water-holding capacity, and improved soil quality. There are also some habitat benefits provided by an actively growing off-season crop compared to the traditional fallow-weed cover, as well as some social benefits derived from maintaining "green" landscapes during the fall-winter seasons.

This recommendation only adds additional species of cover crops onto the existing Traditional Cover Crop BMP. The previous panel defined the panel as an annual practice which will can be

applied onto applicable agricultural cropland acres. Annual agricultural visual assessment practices have subsequently been categorized by the Chesapeake Bay Program's Agriculture Workgroup as Single-Year Visual Assessment BMPs. The panel recommends that the appropriate verification guidance associated with this category of BMPs be implemented by the partnership in the verification of acres reported under this BMP.
The panel recommendations for defining, tracking and reporting to the Chesapeake Bay Program partnership models for the cover crop BMP is compatible with and supports the agricultural BMP verification guidance subsequent developed by the Agriculture Workgroup.

The panel recommends that jurisdictions should always report the most specific information available to them for cover crop implementation. Data reported for CBP purposes should preferably include all elements listed in the panel recommendation report (See Question 5). If any of this information is not reported, the default conditions for the unreported category will be the lowest nitrogen reduction benefit for that category in the approved expert panel report. If relevant, the phosphorus and sediment benefit associated with this model nitrogen reduction will also apply. If the lowest reduction benefit for the missing category is “0” or “NA,” then “0” is used for model credit.

Data Gaps and Research Needs

The Cover Crop Panel’s future research recommendations are:

a) Include some measure of fall residual N in the version 6 Model, to allow adjustment of N effectiveness for small vs. medium vs. large levels of residual N and provide possible targeting of cover crops to high residual N locations.

b) Include some measure of soil properties (drainage class, slope, texture, etc.) in the version 6 Model so estimates of N, P, and sediment effectiveness can be more accurate.

c) Conduct research to quantify the N losses during the winter-spring decomposition period of winter killed covers, especially the fate of forage radish N.

d) Conduct research on phosphorus and sediment losses from cover crops used in modern conservation tillage systems, especially cropping systems with silage corn.

e) Provide for grass-specific mixtures in version 6 Model, i.e. allow mixtures to have their own specific grass component rather than a “generic grass”, to increase the incentive for planting the most efficient N scavengers.

f) Provide for nutrient, especially phosphorus, accumulation and decline in soils as affected by cover crops.

Attachments

- Attachment A: details and examples of calculating the RNREs

- Attachment B: Technical Requirements for Entering Cover Crops BMPs into Scenario Builder and the Watershed Model
- Attachment C: Initial Expert Panel survey summary, conducted by Tetra Tech
- Attachment D: Expert Panel meeting minutes/notes/attendance

Summary of New Cover Crop Species N, P and sediment Reduction Efficiencies, Oct. 27, 2014.

Cover Crop Species	Relative N Reduction Efficiency [1] (RNRE) (Relative to Rye)	Relative P Reduction Efficiency [3] (RPRE) (Relative to Rye)	Relative Sediment Reduction Efficiency [3] (RSRE) (Relative to Rye)
Annual Ryegrass	0.66	0.70	0.73
Annual Legume	0.16	0.38	0.42
Annual Legume + Grass	NA[2]	0.66	0.75
Brassica (winter hardy)	0.70	0.65	0.65
Forage Radish	0.58	0.40	0.44
Forage Radish + Grass	NA[2]	0.54	0.62
Triticale	0.86	0.81	0.85
Oats (winter hardy)	0.55	0.63	0.68
Oats (winter killed)	0.40	0.37	0.41

[1] Data for each N Reduction Efficiency are on the following tabs,
(the yellow highlighted cell in each tab is the final value used)

[2] The final N Effectiveness was the Average of: the N Effectiveness value of the species, and the average N Effectiveness values across all grasses in the same planting date and seeding method (see Cover Crop Report for details).

[3] Relative to Rye values for phosphorus and sediment were developed by a survey of Cover Crop panel members (see "P_sed_efficiencies" tab for full survey results)

Summary of New Cover Crop Species N Reduction Efficiencies, Sept. 13, 2013.

Proposed New Species	Relative N Reduction Efficiency [1] (RNRE) (Relative to Rye)	Number Site-Years	Planting Dates
Annual Ryegrass	**0.66**	**5**	**early and normal**
Annual Legume	**0.16**	**4**	**early and normal**
Annual Legume + Grass	**NA[2]**	**NA**	**early and normal**
Brassica (winter hardy)	**0.70**	**13**	**early**
Forage Radish	**0.58**	**12**	**early only**
Forage Radish + Grass	**NA[2]**	**NA**	**early and normal**
Triticale	**0.86**	**10**	**early, normal and late**
Oats (winter hardy)	**0.55**	**11**	**early and normal**
Oats (winter killed)	**0.40**	**4**	**early only**

[1] Data for each N Reduction Efficiency are on the following tabs,
(the yellow highlighted cell in each tab is the final value used)

[2] The final N Effectiveness was the Average of: the N Effectiveness value of the species, and the average N Effectiveness values across all grasses in the same planting date and seeding method (see Cover Crop Report for details).

Pooled SS from Legumes (3 df)	0.044054
Pooled SS from Annual Ryegrass (2 df)	0.194071
Pooled SS from triticale (8 df)	0.293511
Pooled SS from Forage Radish + Grass (9 df)	0.083565
Pooled SS from Oats (winter hardy, with 10 df)	0.174791
Total Poolded SS (32 df)	0.789992
Total Poolded Var (32 df)	0.024687
Total Poolded Std Dev (32 df)	**0.157122**
Examples of Std Error of mean for N = 4 :	**0.079**
Examples of Std Error of mean for N = 9 :	**0.052**
Examples of Std Error of mean for N = 16 :	**0.039**

Note: this is the variability from across years or sites within the species tabs (not across reps within a study).

Summary of CC N Reduction Efficiency Literature for Legumes and Legume-Grass Mixtures

				Percent Recovery of 15N in above-ground DM						Percent Recovery relative to Rye					
Literature Citation	**Notes**	**Plt. Date**	**Har. Date**	**Rye**	**Ann. Ryegrass**	**Hairy Vetch**	**Crimson Cl.**	**Weeds**	**Other**	**Rye**	**Ann. Ryegrass**	**Hairy Vetch**	**Crimson Cl.**	**Other**	**Weeds**
Shipley, P.R., J.J.Meisinger, and A.M. Decker. 1992. Conserving residual corn fertilizer nitrogen with winter cover crops. Agron. J. 84(5): 869-876.	Poplar Hill, MD; Lower Eastern Shore **Mattapex silt loam**, mod. well-drained; shallow water table. 336 kg N/ha 15N fert corn, stalks disked 2X then NT plt, No fall fert N, four covers and a control, Abruzzi rye, Marshall ryegrass, Dixie Crimson Clover, Hairy Vetch, and a weed control (chickweed). Used Above-grd 15N in covers as % of fall soil 15N, data from Table 3, Harvest II, 336 kg N/ha, 1987 & 1988 divided by (1- (% of TN in roots) fr. p.875)	Sept. 22, 1986	April 20, 1987	51%	See An. Ryegr. Tab	18%	11%	4%	NA	1.000	See An. Ryegr. Tab	0.351	0.222		0.083
		Oct. 5, 1987	April 14, 1988	69%	See An. Ryegr. Tab	6%	8%	14%	NA	1.000	See An. Ryegr. Tab	0.080	0.108		0.197
			Avg.	60%	See An. Ryegr. Tab	12%	9%	9%		1.000	See An. Ryegr. Tab	**0.216**	**0.165**		**0.140**
				Rye			**Crimson Cl.**		**Rye-Crim Cl. Mix**	**Rye**			**Crimson Cl.**	**Rye-Crim Cl. Mix**	**Weeds**
Ranells, N.N. and M.G. Wagger. 1997. Nitrogen-15 recovery and release by rye and crimson clover cover crops. Soil Sci. Soc. Am. J. 61:943-948.	Kinston NC: Coastal Plain, **Norfolk loamy sand**, very well drained, sandy clay loam subsoil, no water table mentioned, Prev. corn crop fert. @ 150 kg N/ha, field micro-plots 2mX3m fert with 50 kg $^{15}NO_3$-N /ha from KNO_3 approx. 1 wk after planting. Species were (varieties not given) rye, crimson clover, and rye + crimson clover mix. All covers sampled in mid-April (samples in Dec & March not used due to v. small harvest area). Used above-grd 15N in covers as % recovery of fall applied 15N from Table 2, for 1992-93 and 1993-94 seasons.	Oct. 8, 1992	~ April 15, 1993	35%			4%	1.0%	13%	1.000			0.114	0.371	0.029
		Oct. 1, 1993	~ April 15, 1994	42%			3%	0.5%	24%	1.000			0.071	0.571	0.012
				39%			4%		19%	1.000			**0.093**	**0.471**	**0.020**

Avg. All Legumes	**0.158**
Avg. Leg.+Gr. Mix	**0.471**
Avg Weeds	**0.080**
Avg. Std Dev (3 df):	0.100756241
Avg. Var (3 df):	0.014685
Pooled SS (3 df):	0.044054

Other Literature Citations	**Notes**	**Plt. Date**	**Har. Date**
Gabreil, J.L. and M. Quemada. 2011. Replacing bare fallow with cover crops in a maize cropping system: Yield, N uptake and fertiliser fate. European J. Agronomy 34: 133-143.	Irrigated corn for grain with ~210 kg 15N/ha from enriched NH4NO3 followed by unfertilized covers of vetch or barley. Mediterannean climate. calcarious silt loam soil. Used micro plot, measured soil 15N after corn and before cover planting and 15N uptake of covers in spring, including roots. The 3-yr avg cover crop recovery of the fall 15N to 1.2m deep in the soil was vetch only 1.2% and barley 10.6%. **Therefore, these data support the fact that legumes are quite poor recyclers of fall N, even in a much different climate and soil than MD.**		
Feaga, J.B., J.S. Selker, P.D. Richard, and D.D. Hepmhill. 2010. Long-term nitrate leaching under vegetable production with cover crops in the Pacific Northwest. Soil Sci. Soc. Am. J. 74:186-195.	An 11-year study of deploying a cover crop vs. fallow after vegtables in OR. Vegetables were sweet corn, brocoli, or snap beans in any year with only one vegetable grown each year. Had 3 N rates: none, a normal Ext. Recc. Rate, and one rate inbeteween. Only had one cover crop treatement each year that was compared to fallow each year. Cover crops were either rye, triticale, or a vetch-triticale mix. The cover crops were thus confounded with years and provide only a crude comparison of the effect of cover crops. Leaching was well monitored w/ large (0.31m X 0.85m) passive capillary wick lysimeterplates at a depth of 1.2m. **The only useful ~comparison was that the NO3-N conc. in the drainage below the grass covers (rye or triticale) 9-yr avg. was 34% less than w/out a cover, while the mix (vetch-triticale) averaged 19% less than w/out a cover. So the mixture performed approx. half as well as the pure grasses.**		

Summary of CC N Reduction Efficiency Literature for Annual Ryegrass

Literature Citation	Notes	Plt. Date	Har. Date	Percent Recovery of 15N in above-ground DM: Rye	Ann. Ryegrass	Hairy Vetch	Crimson Cl.	Weeds	Other	Percent Recovery relative to Rye: Rye	Ann. Ryegrass	Hairy Vetch	Crimson Cl.	Other
	Poplar Hill, MD; Lower Eastern Shore													
Shipley, P.R., J.J.Meisinger, and A.M. Decker. 1992.	**Mattapex silt loam**, mod. well-drained; shallow water table,	Sept. 22, 1986	April 20, 1987	51%	40%	See Leg. Tab	See Leg. Tab	4%	NA	1.000	0.795	See Leg. Tab	See Leg. Tab	
Conserving residual corn fertilizer nitrogen with winter	336 kg N/ha 15N fert corn, stalks disked 2X then NT plt,	Oct. 5, 1987	April 14, 1988	69%	39%	See Leg. Tab	See Leg. Tab	14%	NA	1.000	0.560	See Leg. Tab	See Leg. Tab	
cover crops. Agron. J. 84(5): 869-876.	No fall fert N, four covers and a control,		Avg.	60%	40%	See Leg. Tab	See Leg. Tab	9%		1.000	**0.678**	See Leg. Tab	See Leg. Tab	
	Abruzzi rye, Marshall ryegrass, Dixie Crimson Clover,													
	Hairy Vetch, and a weed control (chickweed). Used													
	Above-grd 15N in covers as % of fall soil 15N, data from													
	Table 3, Harvest II, 336 kg N/ha, 1987 & 1988 divided													
	by (1- (% of TN in roots) fr. p.875)													

Literature Citation	Notes	Plt. Date	Har. Date	Total aboveground DM, kg DM/ ha: Rye	Ann. Ryegrass	DM Production Relative to Rye: Rye	Ann. Ryegrass
Salon, P. (Pers. Comm. 2013). NRCS Cover Crop demo study 2010.	One year study of various cover crop species with three planting	Sept 1 & 15 & 29, 2010	May 11, 2011				
Unpublished data from Big Flats NY NRCS Plt. Introduction Stn.	dates (Sept. 1, 15, and 29) and harvested May 11, 2011. Species						
	were Rye (Aroostock) and an un-named Triticale plus an un-named			6258	2477	1.000	**0.396**
	Annual Ryegrass. Only DM data available. Took average across						
	all 3 Sept planting dates to provide additional observations.						

Literature Citation	Notes	Plt. Date	Har. Date	Total aboveground N, kg N/ ha: Rye	Ann. Ryegrass	TN Uptake Relative to Rye: Rye	Ann. Ryegrass
Houser, C., W.S. Harkcom, and M.H. Hall. 2013.	Two years of study of various short-lived forage species and varieties. All	Sept. 19, 2011	April 26, 2012	137	145	1.000	**1.058**
Short-lived cool-season grass trial. pp.16-19. *In* 2012 Forage trials	entries received 30 lbs N/ac in the fall and 100 lbs N/ac in spring.	Sept. 24, 2012	May 2, 2013	191	92	1.000	**0.482**
report. Coop. Ext. Serv. PA St. University, St. College, PA.	Data from "Cut 1" that is late-boot stage. Replicated PA St study for all						
	entries. Used average of 5 Ryegrass entries listed as Annual Ryegass						
	(Marshall & Rootmax) and Italian Ryegrass (Bardelta, Barherta,						
	Barmultra II); and the one Rye variety (Aroostock).						

Annual Ryegrass Wtd (# Yrs) Avg: 0.658

Avg. Std Dev (2 df):	0.287221
Avg. Var (2 df):	0.097035
Pooled SS (2df):	0.194071

Summary of CC N Reduction Efficiency Literature for Triticale

Literature Citation	Notes	Plt. Date	Har. Date	Measure	Rye	Triticale	Relative measure	Rye	Triticale
Smith, S.R., W. Thomason, B. Benson, D.Starner, and D. Dixon. 2009. Virginia small grain forage variety testing report: long-term summary (1994-2004). Virginia Coop. Extension Pub. No. 418-019. VA Poly. Inst. and State Univ., Blacksburg, VA. Virginia Cooperative Extension. Small grain forage variety testing, annual reports 2005-2012. VA Poly. Inst. and State Univ., Blacksburg, VA.	These data are from a long-term forage production trial in VA. All species received 25-30 lbs N/ ac in the fall and 60 lb N/ ac in the spring. They were harvested by developmental stage (not calendar date), but the data were screened so all data reflect harvests done in mid- to late-April. All harvests contain DM production, and crude protein that was converted to TN by dividing by 6.25. Wade Thomason reviewed all the 1994-2012 data from this trial and selected the varieties with mid-April harvest dates for inclusion in this summary. The varieties were: "Wheeler" Rye and "Trical 102" Triticale. Note: number of years in summary value vary. rye has 11 yrs, triticale 6 years. For calculation across studies use 6 years as the weighting factor for these data.	Various dates in October	Various dates mid-late April (boot stage)	Total aboveground N, kg N/ ha	184	161	Production relative to Rye	1.000	**0.875**
Coale, F.J., J.M. Costa, G.A Bollero, and S.P. Schlosnagle. 2001. Small grain winter cover crops for conservation of residual soil nitrogen in the midAtlantic Coastal Plain. Am. J. Alternative Agric. 16(2):66-72	Used one MD location at Wye, soil was a Mattapex silt loam, the Pop Hill site was dropped due to later planting of rye and goose feeding damage (pers comm F.Coale). Prior crop had 4 rates of poultry litter, that were estimated to supply approx. 0 (no addition), ~150, ~300, and ~450 kg of plant available N/ ha. Four small grains were grown as fall cover crops: rye (Wheeler), triticale (Trical 498), wheat (Madison), and barley (Nomini). Covers sampled in spring just before killing, analyzed the total above ground dry matter for total N. Averaged across all N rates.	Oct. 26, 1996	April 10, 1997	Total aboveground N, kg N/ ha	47	54	TN Uptake Relative to Rye	1.000	**1.149**
Staver, K. (Pers. Comm. 2013). Cover crop demo study 2004. Unpublished data from Wye Res. & Edu. Center, Queenstown, MD.	One year study of various cover crop species and varieties planted early (early Oct probably) or late following sweet corn (probable high residual N, but fall NO3 not documented). Spring harvest at four times, but only used the April 20 harvest used. Measured aboveground DM and TN uptake.	Early October	April 20, 2004	Total aboveground N, kg N/ ha	87	73	TN Uptake Relative to Rye	1.000	**0.843**
Salon, P. (Pers. Comm. 2013). NRCS Cover Crop demo study 2010. Unpublished data from Big Flats NY NRCS Plt. Introduction Stn.	One year study of various cover crop species with three planting dates (Sept. 1, 15, and 29) and harvested May 11, 2011. Species were Rye (Aroostock) and an un-named Triticale plus an un-named Annual Ryegrass. Only DM data available. Took average across all 3 Sept planting dates to provide additional observations.	Sept 1 & 15 & 29, 2010	May 11, 2011	Total aboveground DM, kg DM/ ha	6258	3979	DM Production Relative to Rye	1.000	**0.636**
Houser, C., W.S. Harkcom, and M.H. Hall. 2013. Short-lived cool-season grass trial. pp.16-19. *In* 2012 Forage trials report. Coop. Ext. Serv. PA St. University, St. College, PA.	One year of study of various short-lived forage species and varieties. All entries received 30 lbs N/ac in the fall and 100 lbs N/ac in spring. Data from "Cut 1" that is late-boot stage. Replicated PA St study for all entries. Only one Triticale variety (Fridge) was harvested when rye was harvested. (all other Triticale's were 1-2 weeks after rye). One rye variety was in the study (Aroostock).	Sept. 24, 2012	May 2, 2013	Total aboveground N, kg N/ ha	191	133	TN Uptake Relative to Rye	1.000	**0.696**

Triticale Wtd (# Yrs) Avg: 0.857

Std Dev (3 df):	0.229116
Var (3df):	0.052494
From above Pooled SS (3 df):	0.157482
From VA 6 yr data[1] Pooled SS (5 df):	0.136029
Total Pooled SS (8 df):	0.293511

[1] see spreadsheet: "Va Tech Sm Gr Forage Test 1994-2004 418-019 Raw data & 2005-2010 Extracted data.xlsx" cell "AG31"

Summary of CC Literature for Other Refs for N Reductions for Triticale

Other Literature Citations	Notes	Plt. Date	Har. Date	Rye	Triticale	Production relative to Rye: Rye	Production relative to Rye: Triticale
Ort, S.B., Q.M. Ketterings, K.J. Czymmek, G.S. Godwin, S.N. Swink, and S.K. Gami. 2012.Carbon and Nitrogen Uptake of Cereal Cover Crops Following Corn Silage. What's Cropping Up? Nutrient Management Spear Program, PRODAIRY, Dept Animal Science, Cornell Univ. News Letter vol23 no.2, Cornell Univ. Ithaca, NY.	On-farm individual field trials with one species per field, no within field replication. Reps from different fields and different farm operators. Number of fields varied depending on number of volunteered fields. Rye Plt dates (18 fields) Sept 12-Oct 12, 2011; Triticale Plt dates (9 fields) Sept 9-Sept 13, 2011; Oats Plt Dates (4 fields) Sept 9-Sept 16, 2011. Variable manure added to fields, comparisons not made within one field nor within one manure treatment. **Didn't use any data from this source, because no direct comparisions**	See Notes					

Fernando, S.W. 1996. Effects of Winter Cover Crops Following Potato (Solanum tuberosum L.) on Soil Nitrate and Soil Fertility in the Columbia Basin. PhD thesis, Oregon St. Univ. Dept. Crop Sci. major prof. Alvin R. Mosley.

On an Adkins fine sandy loam at the Hermiston Agric. Research and Extension Ctr of Oregon St. Univ. on a Adkins fine sandy loam following potato crop, had been cropped for > 50 yrs. Precip + Irrig. in cover crop season 92-93 was 307mm and the 93-94 season was 150mm. Covers were Rye (cv. Wheeler), winter wheat (cv. Stephens), winter barley (cv. Hesk), spring barley (cv.Steptoe), Triticale (cv. Whitman), and rape (cv. Humus). Covers not fertilized, only had residual NO3-N from potatoes, which was 160 kg n/ha in fall 1992 & 62 kg N/ha in fall 1993. Covers killed by plowing at times shown.

These data agree surprisingly well with all our cover crop data

Plt. Date	Har. Date	Rye	Triticale	W. Wheat	W. Barley	Spr. Barley	Rape	Rye	Triticale	W. Wheat	W. Barley	Spr. Barley	Rape
		---------- kg N/ ha in cover crop above grd DM at spring killing ----------						Relative N Uptake compared to Rye					
Sept. 18, 1992	April 5, 1993	133	95	98	116	74	100						
Sept. 20, 1993	March 15, 1994	71	76	76	65	45	35						
	Average:	**102**	**86**	**87**	**91**	**60**	**68**	**1.00**	**0.84**	**0.85**	**0.89**	**0.58**	**0.66**

Monks, C.D., T. Basden, J.L. Hatton, M.L. McFarland, S.M. Poland, and E. Rayburn. 1997. Cover crop response to late-season planting and N application. J. Prod. Agr. 10(2): 289-293

Northern & Southern West VA. Covers all followed corn for grain and were fertilized in the fall (took an average across all fert. N rates). Northenr soils: Wharton silt loam and Clarksburg silt loam. Southern soil: Cookport fine loam. Corn soil disked twice before shallow incorporation seeding. Fall fert. N rates: 0, 20, 40, 60 lbs N/ ac , averaged across all the fert. N rates. Measured total above ground DM, not total N. Had two rye varieties Abruzzi and Pastar, averaged across these varieties. Had one Triticale variety Wittmack.

These data have v. low DMs due to ??, set aside as an outlier.

Plt. Date	Har. Date	Total above ground DM, lbs/ ac: Rye	Triticale	Relative: Rye	Triticale
South W VA	South W VA				
Oct. 5, 1992	May 11.1993	943	232	1.000	0.246
North W VA	North W VA				
Oct. 26, 1993	May 29.1994	1884	467	1.000	0.248
Oct. 7, 1994	April. 26, 1995	1793	710	1.000	0.396
	Avg.	1540	470		0.297

Summary of CC N Reduction Efficiency Literature for fall seeded Oats (winter hardy)

Literature Citation	Notes	Plt. Date	Har. Date	Rye	Oats	Production relative to Rye: Rye	Production relative to Rye: Oats	Year	Rye	Oat
				Total aboveground N, kg N/ ha						
Smith, S.R., W. Thomason, B. Benson, D.Starner, and D. Dixon. 2009. Virginia small grain forage variety testing report: long-term summary (1994-2004). Virginia Coop. Extension Pub. No. 418-019, VA Poly. Inst. and State Univ., Blacksburg, VA. Virginia Cooperative Extension. Small grain forage variety testing, annual reports 2005-2012. VA Poly. Inst. and State Univ., Blacksburg, VA.	These data are from a long-term forage production trial in VA. All species received 25-30 lbs N/ ac in the fall and 60 lb N/ ac in the spring. They were harvested by developmental stage (not calendar date), but the data were screened so all data reflect harvests done in mid- to late-April. All harvests contain DM production, and crude protein that was converted to TN by dividing by 6.25. Wade Thomason reviewed all the 1994-2012 data from this trial and selected the varieties with mid-April harvest dates for inclusion in this summary. The varieties were: Wheeler Rye, and SS 76-30. Note: number of years in summary value vary, but rye has 11 yrs and oats 11 years. For calculation across studies use 11 years as the weighting factor for these data, if other data can be found.	Various dates in October	Various dates mid-late April (boot stage)	184	102	1.000	**0.554**			

Oats (fall) Avg. (11 yrs) : 0.554

Total Pooled SS[1] (10 df): 0.174791295

[1] see spreadsheet: "Va Tech Sm Gr Forage Test 1994-2004 418-019 Raw data & 2005-2010 Extracted data.xlsx" cell "AE32"

Summary of CC N Reduction Efficiency Literature for fall seeded Oats (normally winter kills)

Literature Citation	Notes	Plt. Date	Har. Date	Rye	Oats	Production relative to Rye: Rye	Production relative to Rye: Oats
				Total aboveground N, kg N/ ha			
Thomason, W. Unpublished VA Radish and Mixed Species data, from 3 yr average values (2010-2012).	Data for the Eastern & Western regions, avg of 3 years of data	Eastern	Winter (Dec?)	32	29		
		Western	Winter (Dec?)	87	79		
		Eastern	Spring (Apr?)	62	21		
		Western	Spring (Apr?)	134	13		
		Eastern	Avg Winter	60	54		
		Western	Avg Spring	98	17		
				Avg winter-spr loss	-37		
Smith, S.R., W. Thomason, B. Benson, D.Starner, and D. Dixon. 2009. Virginia small grain forage variety testing report: long-term summary (1994-2004). Virginia Coop. Extension Pub. No. 418-019, VA Poly. Inst. and State Univ., Blacksburg, VA. Virginia Cooperative Extension. Small grain forage variety testing, annual reports 2005-2012. VA Poly. Inst. and State Univ., Blacksburg, VA.	These data are from a long-term forage production trial in VA. All species received 25-30 lbs N/ ac in the fall and 60 lb N/ ac in the spring. They were harvested by developmental stage (not calendar date), but the data were screened so all data reflect harvests done in mid- to late-April. All harvests contain DM production, and crude protein that was converted to TN by dividing by 6.25. Wade Thomason reviewed all the 1994-2012 data from this trial and selected the varieties with mid-April harvest dates for inclusion in this summary. The varieties were: Wheeler Rye, and SS 76-30. Note: number of years in summary value vary, but rye has 11 yrs and oats 11 years. For calculation across studies use 11 years as the weighting factor for these data.	Various dates in October	Various dates mid-late April (boot stage)	184	102		
				Avg winter-spr loss	-37		
			Est. Spr. If killed	184	65	**1.000**	**0.353**
		Est. Spr, only NO3-N lost (18% of TN[1])		184	84	**1.000**	**0.455**

[1] Pers. Comm. from Ms. Natalie Lounsbury UMCP who shared her MS thesis ("Spring Seedbed Characteristics after Winter-killed Cover Crops") data on total N content and NO_3-N content of winter killed oats.

Combined Avg. Rel to Rye **0.404**

Summary of CC N Reduction Efficiency Literature for Forage Radish

Literature Citation	Notes	Site Yr	Plt. Date	Har. Date	Rye	Oats+Canola	Oats	Est. Canola	Site-years	Percent Uptake relative to Rye: Rye	Percent Uptake relative to Rye: Canola
		Eastern	various fall dates	various spring dates	62	67	21	46	3	1.000	0.742
Thomason, W. Unpublished data. Cite as Personnel Communication	Data for the Eastern & Western regions, avg of 3 years of data	Western	various fall dates	various spring dates	134	81	13	68	3	1.000	0.507
VA Radish and Mixed Species data,											
from 3 yr average values (2010-2012)					98	74	17	57			0.625
	CMREC2- Beltsville, MD. Loamy sand soil. Radish, rye, and				**Rye**	**Rape**				**Rye**	**Rape**
Dean, JE and RR Weil. 2009. Brassica cover crops for	**rape were planted on Aug. 25 following mowing of a**	CMREC2	August 25, 2004	Oct/Nov & April/May	73	84			1	1.000	1.152
nitrogen retention in the Mid-Atlantic coastal plain.	soybean crop that contributed 208 kgN/ha as an organic N source	WREC1	August 19, 2003	Oct/Nov & April/May	38	41			1	1.000	1.093
J. Environ. Qual. 38:520-528.	WREC1- Wye, MD. Silt loam soil. Radish, rye, and rape were	WREC2	September 24, 2003	Oct/Nov & April/May	84	118			1	1.000	1.410
	planted on Aug. 19 following sweet corn harvest. Residual N										
	fertilizer from sweet corn was available as an N source.					81.2					1.218
	WREC2- Wye, MD. Silt loam soil. Radish, rye, and rape were										
	planted on Sept 24 following mowing of a soybean crop										
	that contributed 250 kgN/ha as an organic N source.										
	At CMREC2, Rye cleaned out the profile as well as Radish in November. In April, radish profile had elevated NO3 to 75cm, totaling ~25 kgN/ha										
	At WREC 1&2 Rye cleaned out the profile as well as radish in November and January. At WREC2 in April, Radish had elevated NO3 to 75cm, totaling ~ 20 kgN/ha										
					Rye	**Rape**				**Rye**	**Rape**
Finney, DM and JP Kaye. 2013. Cover crop cocktails to	Hagerstown soil, State College, PA. Cover crops planted in late August.		Late August 2011	mid-May 2012	67	108			1	1.000	1.612
enhance nitrogen management.	Previous crop oats. Soil moldboard plowed prior to cover crop										
PSU Extension Handout	establishment.										
					Rye	**Rape**				**Rye**	**Rape**
Muller, J.C., D. Denys, G. Borlet, and A. Mariotti. 1989. Influence of catch	Soil and plant samples from unfertilized covers planted after wheat in		October	early March	120	23			1	1.000	0.192
crops on mineral nitrogen leaching and its subsequent plant use. Pp85-98.	France. One year of data. Covers were rye and rape.										
In J.C. Germon (ed.) Managemnt systems to reduce impact of nitrates											
Elsevir Sci Pub. NY, NY.											
					Rye	**Rape**				**Rye**	**Rape**
Fernando, S.W. 1996. Effects of Winter Cover Crops	on an Adkins fine sandy loam at the Hermiston Agric. Research		Sept. 18, 1992	April 5, 1993	133	100			1	1.000	0.752
Following Potato (Solanum tuberosum L.) on Soil Nitrate	and Extension Ctr of Oregon St. Univ. on a Adkins fine sandy loam		Sept. 20, 1993	March 15, 1994	71	35			1	1.000	0.493
and Soil Fertility in the Columbia Basin. PhD thesis, Oregon	following potato crop, had been cropped for > 50 yrs. Precip + Irrig.			Average:	102	68					
St. Univ. Dept. Crop Sci. major prof. Alvin R. Mosley.	in cover crop season 92-93 was 307mm and the 93-94 season was										
	150mm. Covers were Rye (cv. Wheeler), winter wheat (cv. Stephens),										
	winter barley (cv. Hesk), spring barley (cv.Steptoe), Triticale										
	(cv. Whitman), and rape (cv. Humus). Covers not fertilized, only had										
	residual NO3-N from potatoes, which was 160 kg n/ha in fall 1992 &										
	62 kg N/ha in fall 1993. Covers killed by plowing at times shown.										
	(These cover species data agree v. well with our Bay Watershed data)										
								Total	13	Wtd Avg:	0.804
										Panel Vote:	**0.70**

Pooled Std Dev (6 df): 0.505533
Pooled Var (6df): 0.255564 — Note: this is 10 times the pooled variance calculated on the Species Summary tab.
Pooled SS (6 df): 1.533385

Summary of CC N Reduction Efficiency Literature for Forage Radish

Literature Citation	Notes	Site Yr	Plt. Date	Har. Date	kgN/ha uptake by cover crops (Rye and Rape in Spring, Radish in Fall): Rye	Rape	Radish Shoot	Radish Root	Percent Uptake relative to Rye: Rye	Rape	Radish Shoot
	CMREC2- Beltsville, MD. Loamy sand soil. Radish, rye, and										
Dean, JE and RR Weil. 2009. Brassica cover crops for	**rape were planted on Aug. 25 following mowing of a**	CMREC2	August 25, 2004	Oct/Nov & April/May	73.2	84.3	148.0	69.7	1.000	1.152	2.022
nitrogen retention in the Mid-Atlantic coastal plain.	**soybean crop that contributed 208 kgN/ha as an organic N source**	WREC1	August 19, 2003	Oct/Nov & April/May	37.8	41.3	44.2	33.5	1.000	1.093	1.169
J. Environ. Qual. 38:520-528.	WREC1- Wye, MD. Silt loam soil. Radish, rye, and rape were	WREC2	September 24, 2003	Oct/Nov & April/May	83.7	118.0	155.0	60.6	1.000	1.410	1.852
	planted on Aug. 19 following sweet corn harvest. Residual N										
	fertilizer from sweet corn was available as an N source.										
	WREC2- Wye, MD. Silt loam soil. Radish, rye, and rape were										
	planted on Sept 24 following mowing of a soybean crop										
	that contributed 250 kgN/ha as an organic N source.										

At CMREC2, Rye cleaned out the profile as well as Radish in November. In April, radish profile had elevated NO3 to 75cm, totaling ~25 kgN/ha
At WREC 1&2 Rye cleaned out the profile as well as radish in November and January. At WREC2 in April, Radish had elevated NO3 to 75cm, totaling ~ 20 kgN/ha

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Literature Citation	Notes	Site Yr	Plt. Date	Har. Date	Rye	Rape	Radish Shoot	Rye	Rape	Radish Shoot
Personnal Communication from:										
Finney, DM and JP Kaye. 2013. Cover crop cocktails to	Hagerstown soil, State College, PA. Cover crops planted in late August.		Late August 2011	mid-May 2012	67.0	108.0	27.0	1.000	1.612	0.403
enhance nitrogen management.	Previous crop oats. Soil moldboard plowed prior to cover crop									
PSU Extension Handout	establishment.									

White, C and RR Weil. Unpublished Nitrogen Data from study below.

Literature Citation	Notes	Site Yr	Rye	Radish Shoot	Rye	Radish Shoot
White, C. and RR Weil. 2010. Forage Radish Cover Crops	CMREC- Greenbelt, MD, sandy loam soil.	BARC08	141.4	160.1	1.000	1.132
Increase Soil Test Phosphorus Surrounding Radish Taproot Holes	BARC-SF- Silt loam soil	BARC09	191.2	142.9	1.000	0.747
SSSAJ 75:121-130.	In both sites cover crops were planted after corn silage.	CMREC08	27.6	88.7	1.000	~~3.214~~

Literature Citation	Notes	Site Yr	Plt. Date	Har. Date	Rye	Radish Shoot	Rye	Radish Shoot
Thomason, W. Unpublished data. Cite as Personnel Communication								
VA Radish and Mixed Species data,	Data for each region is an average of 3 years of data	Eastern	various fall dates	various spring dates	62	53	1.000	0.855
from 3 yr average values (2010-2012)		Western	various fall dates	various spring dates	134	96	1.000	0.716

Note:		
Pers. Comm. from Ms. Natalie Lounsbury UMCP who shared her MS thesis	% NO3 in radish tissue is 16% for shoots and 29% for roots	
("Spring Seedbed Characteristics after Winter-killed Cover Crops") data	averaged over 4 site years	
on total N content and NO_3-N content of winter killed oats.	Oats also had 16% NO3 in shoots averaged over 4 site years	

	Rye	Rape	Radish Shoot
Wtd (by # site-years) Average	1.000	1.316	**1.003**

Panel voted N Reduction Efficiency **Forage Radish Poll:** **0.575**

Literature Citation	Notes	Plt. Date	Har. Date	Rye	Radish+Grass	# Site-Years	Rye	Radish+Grass	
				Total aboveground N, kg N/ ha					
Houser, C., W.S. Harkcom, and M.H. Hall. 2013. Short-lived cool-season grass trial. pp.16-19. *In* 2012 Forage trials report. Coop. Ext. Serv. PA St. University, St. College, PA. (used spreadsheet from Sjoerd Duiker having the 2010-2011 and the 2012-2013 data for all entries, not just those on above website)	Two years of study of various short-lived forage species and varieties. All entries received 30 lbs N/ac in the fall and 100 lbs N/ac in spring. Data from "Cut 1" that is late-boot stage. Replicated PA St study for all entries. Used the Radish+Rootmax entry (Radish+Annual Ryegass) to capture the mixture performance relative to Rye (Aroostok).	Sept. 19, 2011	April 26, 2012	137	145	1	1.000	**1.058**	
		Sept. 24, 2012	May 2, 2013	191	87	1	1.000	**0.455**	0.757
Duiker, S.J. 2013. Pers. Communication of results from a Cover Crop after Corn Silage Trial done in 2011-2012 and 2-12-2013 across the state of PA.	Two years of data from an multi-location across PA study evaluating cover crop mixtures following silage corn harvest. Each locat had 4 reps and either 7 (2012) or 8 (2013) cover crop mixtures as well as a pure rye (Aroostock) cover, and a Radish+Rye mixture that was used for these calculations. There were 10 PA locations in 2012 and 9 in 2013. All cover crop treatments measured DM and TN uptake at the boot stage.	Aug-Sept 15, 2011 (?)	??	104	92	10	1.000	**0.885**	0.885
Thomason, W.D. Pers. Communication of results from VA Radish and and Mixed Species data, 3 yr average values (2010-2012).	These data are from a VA cover crop study having radish, rye, and other mixed species (2, 3, and 4 component mixtures). The entire study was repeated in two VA regions (Eastern & Western). It had ? replicates, and measured DM and TN in the winter (at the end of growing season) and in the spring (at the end of the spring season). Used only the spring season TN uptake from the Western VA region (it's the only region that had a Radish+Grass mixture, actually it was Rad+Rye+AnnRyeGr)	Various dates in October	Various dates mid-late April (boot stage)	134	106	3	1.000	**0.791**	
					Total # Site-Yrs:	15			

Rad+Grass Wtd (# site-yrs) Avg: 0.849

Note: these data for Radish + Grass mixtures were not used due to the need to use a "generic grass" to simplify reporting, see Cover Crop Report.

From 2011 CC after C Silage, Pooled Std Dev (9 df): 0.096359
Pooled Var (9df): 0.009285
Pooled SS (9 df): 0.083565

Recommended relative-to-rye phosphorus reduction efficiencies (RPRE) and relative-to-rye sediment reduction efficiencies (RSRE) based on best professional judgment of panel members.

Panelist	Annual Ryegrass		Annual Legume		Legume + Grass Mix.		Brassica (winter hardy)		Forage Radish		Forage Radish + Grass Mix.		Triticale		Oats (winter hardy)		Oats (winter killed)	
	RPRE	RSRE	RPRE	RSRE	RPRE	RSRE	RPRE	RSRE	RPRE	RSRE	RPRE	RSRE	RPRE	RSRE	RPRE	RSRE	RPRE	RSRE
Anonymous A	0.6	0.7	0.2	0.5	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.5	0.9	0.4	0.4	0.3	0.3
Anonymous B	1.0	0.9	1.0	0.7	1.1	1.0	1.2	0.9	0.6	0.7	0.9	1.0	1.0	0.9	0.9	0.9	0.8	0.8
Anonymous C	0.7	0.7	0.2	0.3	0.6	0.6	0.6	0.6	0.4	0.5	0.5	0.5	0.9	0.9	0.3	0.4	0.3	0.4
Anonymous D	1.0	1.0	0.5	0.5	1.0	1.0	0.7	0.7	0.6	0.6	0.6	0.6	0.9	1.0	0.7	0.9	0.4	0.4
Anonymous E	0.7	0.8	0.5	0.8	0.6	0.8	0.7	0.8	0.6	0.6	0.6	0.8	0.9	0.8	0.6	0.7	0.4	0.4
Anonymous F	0.7	0.8	0.5	0.4	0.6	0.7	0.7	0.4	0.6	0.3	0.6	0.5	0.9	0.9	0.8	0.9	0.4	0.5
Anonymous G	0.8	0.8	0.2	0.2	0.5	1.0	0.5	0.7	0.0	0.4	0.2	0.7	1.0	1.0	1.0	1.0	0.2	0.2
Anonymous H	0.7	0.7	0.2	0.2	0.4	0.4	0.7	0.7	0.3	0.3	0.5	0.5	0.9	0.9	0.6	0.6	0.3	0.3
Anonymous I	0.3	0.3	0.1	0.1			0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3		
Anonymous J	0.7	0.8	0.4	0.6	0.7	0.8	0.5	0.7	0.0	0.1	0.4	0.5	1.0	1.0	0.7	0.8	0.2	0.4
Average	**0.70**	**0.73**	**0.38**	**0.42**	**0.66**	**0.75**	**0.65**	**0.65**	**0.40**	**0.44**	**0.54**	**0.62**	**0.81**	**0.85**	**0.63**	**0.68**	**0.37**	**0.41**
Standard Error	*0.06*	*0.06*	*0.08*	*0.07*	*0.08*	*0.08*	*0.07*	*0.05*	*0.08*	*0.06*	*0.06*	*0.06*	*0.07*	*0.07*	*0.07*	*0.08*	*0.06*	*0.06*
Avgerage with high and low	0.68	0.76	0.33	0.41	0.66	0.71	0.61	0.69	0.35	0.45	0.54	0.60	0.81	0.86	0.66	0.69	0.33	0.39
Median	0.68	0.80	0.30	0.45	0.60	0.80	0.65	0.70	0.48	0.43	0.55	0.57	0.86	0.88	0.63	0.75	0.33	0.40

Cover Crop Total Nitrogen, Phosphorus, and Sediment Efficiency Estimates 10-27-14

Total Nitrogen Efficiency Estimates

Coastal Plain/Piedmont Crystalline/Karst Settings

Seeding method:	Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Species:	Rye		Rye		Rye		Rye		Wheat		Wheat		Wheat		Wheat		Barley		Barley		Barley		Barley	
Till:	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Early planting	0.45	0.45	0.38	0.38	0.31	0.31	0.18	0.18	0.31	0.31	0.27	0.27	0.22	0.22	0.12	0.12	0.38	0.38	0.32	0.32	0.27	0.27	0.15	0.15
Normal planting	0.41	0.41	0.35	0.35	NA	NA	NA	NA	0.29	0.29	0.24	0.24	NA	NA	NA	NA	0.29	0.29	0.24	0.24	NA	NA	NA	NA
Late planting	0.19	0.19	0.16	0.16	NA	NA	NA	NA	0.13	0.13	0.11	0.11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Mesozoic Lowlands/Valley and Ridge Siliciclastic

Seeding method:	Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Species:	Rye		Rye		Rye		Rye		Wheat		Wheat		Wheat		Wheat		Barley		Barley		Barley		Barley	
Till:	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Early planting	0.34	0.34	0.29	0.29	0.24	0.24	0.14	0.14	0.24	0.24	0.2	0.2	0.17	0.17	0.1	0.1	0.29	0.29	0.25	0.25	0.2	0.2	0.12	0.12
Normal planting	0.31	0.31	0.27	0.27	NA	NA	NA	NA	0.22	0.22	0.19	0.19	NA	NA	NA	NA	0.22	0.22	0.19	0.19	NA	NA	NA	NA
Late planting	0.15	0.15	0.12	0.12	NA	NA	NA	NA	0.1	0.1	0.09	0.09	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Total Phosphorus Efficiency Estimates

Coastal Plain/Piedmont Crystalline/Karst Settings

Seeding method:	Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Species:	Rye		Rye		Rye		Rye		Wheat		Wheat		Wheat		Wheat		Barley		Barley		Barley		Barley	
Till:	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Early planting	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0
Normal planting	0.07	0	0.07	0	NA	NA	NA	NA	0.07	0	0.07	0	NA	NA	NA	NA	0.07	0	0.07	0	NA	NA	NA	NA
Late planting	0	0	0	0	NA	NA	NA	NA	0	0	0	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Mesozoic Lowlands/Valley and Ridge Siliciclastic

Seeding method:	Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Species:	Rye		Rye		Rye		Rye		Wheat		Wheat		Wheat		Wheat		Barley		Barley		Barley		Barley	
Till:	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Early planting	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0	0.15	0
Normal planting	0.07	0	0.07	0	NA	NA	NA	NA	0.07	0	0.07	0	NA	NA	NA	NA	0.07	0	0.07	0	NA	NA	NA	NA
Late planting	0	0	0	0	NA	NA	NA	NA	0	0	0	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Total Sediment Efficiency Estimates

Coastal Plain/Piedmont Crystalline/Karst Settings

Seeding method:	Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Species:	Rye		Rye		Rye		Rye		Wheat		Wheat		Wheat		Wheat		Barley		Barley		Barley		Barley	
Till:	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Early planting	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0
Normal planting	0.1	0	0.1	0	NA	NA	NA	NA	0.1	0	0.1	0	NA	NA	NA	NA	0.1	0	0.1	0	NA	NA	NA	NA
Late planting	0	0	0	0	NA	NA	NA	NA	0	0	0	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Mesozoic Lowlands/Valley and Ridge Siliciclastic

Seeding method:	Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Species:	Rye		Rye		Rye		Rye		Wheat		Wheat		Wheat		Wheat		Barley		Barley		Barley		Barley	
Till:	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Early planting	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0	0.2	0
Normal planting	0.1	0	0.1	0	NA	NA	NA	NA	0.1	0	0.1	0	NA	NA	NA	NA	0.1	0	0.1	0	NA	NA	NA	NA
Late planting	0	0	0	0	NA	NA	NA	NA	0	0	0	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Total Nitrogen Efficiency Estimates

Coastal Plain/Piedmont Crystalline/Karst Settings

Seeding method:	Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled	
Species:	Forage Radish		Forage Radish		Forage Radish		Forage Radish		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Annual Legume		Annual Legume		Annual Legume		Annual Legume		Legume plus grass mixture	
Till:	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Early planting	0.26	0.26	0.22	0.22	0.18	0.18	0.10	0.10	0.29	0.29	0.25	0.25	0.20	0.20	0.12	0.12	0.07	0.07	0.06	0.06	0.05	0.05	0.03	0.03	0.20	0.20
Normal planting	NA	NA	NA	NA	NA	NA	NA	NA	0.22	0.22	0.18	0.18	NA	NA	NA	NA	0.06	0.06	0.06	0.06	NA	NA	NA	NA	0.19	0.19
Late planting	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Mesozoic Lowlands/Valley and Ridge Siliciclastic

Seeding method:	Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled	
Species:	Forage Radish		Forage Radish		Forage Radish		Forage Radish		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Annual Legume		Annual Legume		Annual Legume		Annual Legume		Legume plus grass mixture	
Till:	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Early planting	0.20	0.20	0.17	0.17	0.14	0.14	0.08	0.08	0.22	0.22	0.19	0.19	0.15	0.15	0.09	0.09	0.05	0.05	0.05	0.05	0.04	0.04	0.02	0.02	0.15	0.15
Normal planting	NA	NA	NA	NA	NA	NA	NA	NA	0.16	0.16	0.14	0.14	NA	NA	NA	NA	0.05	0.05	0.04	0.04	NA	NA	NA	NA	0.14	0.14
Late planting	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Total Phosphorus Efficiency Estimates

Coastal Plain/Piedmont Crystalline/Karst Settings

Seeding method:	Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled	
Species:	Forage Radish		Forage Radish		Forage Radish		Forage Radish		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Annual Legume		Annual Legume		Annual Legume		Annual Legume		Legume plus grass mixture	
Till:	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Early planting	0.06	0.00	0.06	0.00	0.06	0.00	0.06	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.06	0.00	0.06	0.00	0.06	0.00	0.06	0.00	0.10	0.00
Normal planting	NA	NA	NA	NA	NA	NA	NA	NA	0.04	0.00	0.04	0.00	NA	NA	NA	NA	0.03	0.00	0.03	0.00	NA	NA	NA	NA	0.05	0.00
Late planting	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Mesozoic Lowlands/Valley and Ridge Siliciclastic

Seeding method:	Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled	
Species:	Forage Radish		Forage Radish		Forage Radish		Forage Radish		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Annual Legume		Annual Legume		Annual Legume		Annual Legume		Legume plus grass mixture	
Till:	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Early planting	0.06	0.00	0.06	0.00	0.06	0.00	0.06	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.06	0.00	0.06	0.00	0.06	0.00	0.06	0.00	0.10	0.00
Normal planting	NA	NA	NA	NA	NA	NA	NA	NA	0.04	0.00	0.04	0.00	NA	NA	NA	NA	0.03	0.00	0.03	0.00	NA	NA	NA	NA	0.05	0.00
Late planting	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Total Sediment Efficiency Estimates

Coastal Plain/Piedmont Crystalline/Karst Settings

Seeding method:	Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled	
Species:	Forage Radish		Forage Radish		Forage Radish		Forage Radish		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Annual Legume		Annual Legume		Annual Legume		Annual Legume		Legume plus grass mixture	
Till:	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Early planting	0.09	0.00	0.09	0.00	0.09	0.00	0.09	0.00	0.12	0.00	0.12	0.00	0.12	0.00	0.12	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.15	0.00
Normal planting	NA	NA	NA	NA	NA	NA	NA	NA	0.06	0.00	0.06	0.00	NA	NA	NA	NA	0.04	0.00	0.04	0.00	NA	NA	NA	NA	0.07	0.00
Late planting	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Mesozoic Lowlands/Valley and Ridge Siliciclastic

Seeding method:	Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled	
Species:	Forage Radish		Forage Radish		Forage Radish		Forage Radish		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Forage Radish plus grass mixture		Annual Legume		Annual Legume		Annual Legume		Annual Legume		Legume plus grass mixture	
Till:	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Early planting	0.09	0.00	0.09	0.00	0.09	0.00	0.09	0.00	0.12	0.00	0.12	0.00	0.12	0.00	0.12	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.15	0.00
Normal planting	NA	NA	NA	NA	NA	NA	NA	NA	0.06	0.00	0.06	0.00	NA	NA	NA	NA	0.04	0.00	0.04	0.00	NA	NA	NA	NA	0.07	0.00
Late planting	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Total Nitrogen Efficiency Estimates

Coastal Plain/Piedmont Crystalline/Karst Settings

Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Legume plus grass mixture		Legume plus grass mixture		Legume plus grass mixture		Triticale		Triticale		Triticale		Triticale		Annual Ryegrass		Annual Ryegrass		Annual Ryegrass		Annual Ryegrass	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0.17	0.17	0.14	0.14	0.08	0.08	0.39	0.39	0.33	0.33	0.27	0.27	0.15	0.15	0.30	0.30	0.25	0.25	0.20	0.20	0.12	0.12
0.16	0.16	NA	NA	NA	NA	0.35	0.35	0.30	0.30	NA	NA	NA	NA	0.27	0.27	0.23	0.23	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	0.16	0.16	0.14	0.14	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Total Nitrogen Efficiency Estimates

Coastal Plain/Piedmont Crystalline/Karst Settings

Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Killed		Oats, Winter Killed		Oats, Winter Killed		Oats, Winter Killed		Brassica (Winter Hardy)		Brassica (Winter Hardy)		Brassica (Winter Hardy)		Brassica (Winter Hardy)	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0.25	0.25	0.21	0.21	0.17	0.17	0.10	0.10	0.18	0.18	0.15	0.15	0.13	0.13	0.07	0.07	0.32	0.32	0.27	0.27	0.22	0.22	0.13	0.13
0.23	0.23	0.19	0.19	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Mesozoic Lowlands/Valley and Ridge Siliciclastic

Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Legume plus grass mixture		Legume plus grass mixture		Legume plus grass mixture		Triticale		Triticale		Triticale		Triticale		Annual Ryegrass		Annual Ryegrass		Annual Ryegrass		Annual Ryegrass	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0.13	0.13	0.10	0.10	0.06	0.06	0.29	0.29	0.25	0.25	0.21	0.21	0.12	0.12	0.22	0.22	0.19	0.19	0.16	0.16	0.09	0.09
0.12	0.12	NA	NA	NA	NA	0.27	0.27	0.23	0.23	NA	NA	NA	NA	0.20	0.20	0.18	0.18	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	0.13	0.13	0.10	0.10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Mesozoic Lowlands/Valley and Ridge Siliciclastic

Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Killed		Oats, Winter Killed		Oats, Winter Killed		Oats, Winter Killed		Brassica (Winter Hardy)		Brassica (Winter Hardy)		Brassica (Winter Hardy)		Brassica (Winter Hardy)	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0.19	0.19	0.16	0.16	0.13	0.13	0.08	0.08	0.14	0.14	0.12	0.12	0.10	0.10	0.06	0.06	0.24	0.24	0.20	0.20	0.17	0.17	0.10	0.10
0.17	0.17	0.15	0.15	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Total Phosphorus Efficiency Estimates

Coastal Plain/Piedmont Crystalline/Karst Settings

Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Legume plus grass mixture		Legume plus grass mixture		Legume plus grass mixture		Triticale		Triticale		Triticale		Triticale		Annual Ryegrass		Annual Ryegrass		Annual Ryegrass		Annual Ryegrass	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0.10	0.00	0.10	0.00	0.10	0.00	0.12	0.00	0.12	0.00	0.12	0.00	0.12	0.00	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00
0.05	0.00	NA	NA	NA	NA	0.06	0.00	0.06	0.00	NA	NA	NA	NA	0.05	0.00	0.05	0.00	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	0.00	0.00	0.00	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Total Phosphorus Efficiency Estimates

Coastal Plain/Piedmont Crystalline/Karst Settings

Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Killed		Oats, Winter Killed		Oats, Winter Killed		Oats, Winter Killed		Brassica (Winter Hardy)		Brassica (Winter Hardy)		Brassica (Winter Hardy)		Brassica (Winter Hardy)	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0.09	0.00	0.09	0.00	0.09	0.00	0.09	0.00	0.06	0.00	0.06	0.00	0.06	0.00	0.06	0.00	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00
0.04	0.00	0.04	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Mesozoic Lowlands/Valley and Ridge Siliciclastic

Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Legume plus grass mixture		Legume plus grass mixture		Legume plus grass mixture		Triticale		Triticale		Triticale		Triticale		Annual Ryegrass		Annual Ryegrass		Annual Ryegrass		Annual Ryegrass	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0.10	0.00	0.10	0.00	0.10	0.00	0.12	0.00	0.12	0.00	0.12	0.00	0.12	0.00	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00
0.05	0.00	NA	NA	NA	NA	0.06	0.00	0.06	0.00	NA	NA	NA	NA	0.05	0.00	0.05	0.00	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	0.00	0.00	0.00	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Mesozoic Lowlands/Valley and Ridge Siliciclastic

Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Killed		Oats, Winter Killed		Oats, Winter Killed		Oats, Winter Killed		Brassica (Winter Hardy)		Brassica (Winter Hardy)		Brassica (Winter Hardy)		Brassica (Winter Hardy)	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0.09	0.00	0.09	0.00	0.09	0.00	0.09	0.00	0.06	0.00	0.06	0.00	0.06	0.00	0.06	0.00	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00
0.04	0.00	0.04	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Total Sediment Efficiency Estimates

Coastal Plain/Piedmont Crystalline/Karst Settings

Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Legume plus grass mixture		Legume plus grass mixture		Legume plus grass mixture		Triticale		Triticale		Triticale		Triticale		Annual Ryegrass		Annual Ryegrass		Annual Ryegrass		Annual Ryegrass	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0.15	0.00	0.15	0.00	0.15	0.00	0.17	0.00	0.17	0.00	0.17	0.00	0.17	0.00	0.15	0.00	0.15	0.00	0.15	0.00	0.15	0.00
0.07	0.00	NA	NA	NA	NA	0.08	0.00	0.08	0.00	NA	NA	NA	NA	0.07	0.00	0.07	0.00	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	0.00	0.00	0.00	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Total Sediment Efficiency Estimates

Coastal Plain/Piedmont Crystalline/Karst Settings

Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Killed		Oats, Winter Killed		Oats, Winter Killed		Oats, Winter Killed		Brassica (Winter Hardy)		Brassica (Winter Hardy)		Brassica (Winter Hardy)		Brassica (Winter Hardy)	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0.14	0.00	0.14	0.00	0.14	0.00	0.14	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.13	0.00	0.13	0.00	0.13	0.00	0.13	0.00
0.07	0.00	0.07	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Mesozoic Lowlands/Valley and Ridge Siliciclastic

Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Legume plus grass mixture		Legume plus grass mixture		Legume plus grass mixture		Triticale		Triticale		Triticale		Triticale		Annual Ryegrass		Annual Ryegrass		Annual Ryegrass		Annual Ryegrass	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0.15	0.00	0.15	0.00	0.15	0.00	0.17	0.00	0.17	0.00	0.17	0.00	0.17	0.00	0.15	0.00	0.15	0.00	0.15	0.00	0.15	0.00
0.07	0.00	NA	NA	NA	NA	0.08	0.00	0.08	0.00	NA	NA	NA	NA	0.07	0.00	0.07	0.00	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	0.00	0.00	0.00	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Mesozoic Lowlands/Valley and Ridge Siliciclastic

Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn		Drilled		Other		Aerial/soy		Aerial/corn	
Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Hardy		Oats, Winter Killed		Oats, Winter Killed		Oats, Winter Killed		Oats, Winter Killed		Brassica (Winter Hardy)		Brassica (Winter Hardy)		Brassica (Winter Hardy)		Brassica (Winter Hardy)	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0.14	0.00	0.14	0.00	0.14	0.00	0.14	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.13	0.00	0.13	0.00	0.13	0.00	0.13	0.00
0.07	0.00	0.07	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA