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Adoption of cover crops in Pennsylvania's Chesapeake Bay watershed

S.W. Duiker and S. Richards

Abstract: Cover cropping is considered a very cost-effective practice to reduce losses of nitrogen (N) from cropland to surface waters, as well as mobile nutrients in the soil profile prone to being lost to ground water sources. Cover crops are an important component of states' commitment to improve water quality in the Chesapeake Bay. Since 2016, annual cover crop transect surveys have been performed in Pennsylvania's Chesapeake Bay watershed. The surveys show that cover crops were used on 39% of the annual crop area in the period 2016 to 2021, much higher than average cover crop use in the United States (5%). About two-thirds of the cover crop area is "commodity cover crops" that are harvested (which included both grain and forage harvesting in the surveys), while the other one-third is "traditional cover crops" that are not harvested. It appears that high cover crop adoption in Pennsylvania without generous subsidy payments is due in great part to their use for forage. However, at the moment, commodity cover crops receive no credit for pollutant reduction in the Chesapeake Bay Model if fall nutrients are applied, which means approximately two-thirds of cover crop implementation in Pennsylvania does not count toward nutrient pollution reduction to the Chesapeake Bay. Further, transect surveys are not considered a valid (or only partial) method of practice implementation and the present results are therefore not included when determining if states meet Total Maximum Daily Load (TMDL) limits. Considering their importance, the contribution of commodity cover crops to nutrient and sediment loss reduction from cropland needs to be better understood. Specifically, our study revealed the need to (1) clarify in Chesapeake Bay Model documentation that commodity cover crops include those harvested for forage besides those harvested for grain; (2) develop a tracking mechanism so that nutrient reduction credit from commodity cover crops can be recognized in the Chesapeake Bay Model; and (3) to review whether the lower N reduction credit from commodity cover crops than for traditional cover crops and lower credit for early planting are justified.

Key words: nitrogen—phosphorus—sediment—water quality

The Chesapeake Bay is one of the natural treasures of the United States; it is the largest of more than 100 estuaries in the country. It supports roughly 348 species of finfish, 173 species of shellfish, and 2,700 plant species. Approximately 35% (5.8 million ha [14.3 million ac]) of the bay watershed is located in Pennsylvania, 34% in Virginia, 14% in Maryland, and the rest is in New York, Delaware, and West Virginia (CBC 2020). Its location close to the nation's capital puts it in the bull's eye of public attention. Rapid loss of wildlife and aquatic life due to nutrient pollution in the late seventies led to the first Chesapeake Bay Agreement in 1983 when Maryland, Pennsylvania, Virginia, the District of Columbia, the US Environmental Protection Agency (USEPA), and the Chesapeake Bay Commission pledged to work together to address water quality in the bay. This was followed by the 1987 Chesapeake Bay Agreement with the specific goal to reduce nitrogen (N) and phosphorus (P) pollution entering the bay by 40% by the year 2000. In 1992, amendments were made to tackle the nutrient losses at their source in the watershed. In 2000 new goals were set by the Chesapeake Bay Program (CBP) Partnership with Delaware and New York joining the agreement. In 2002, West Virginia joined the Chesapeake Bay Agreement. Although significant progress was made, there was general recognition that nutrient losses from agricultural and urban land uses was not reduced sufficiently, leading to a renewed federal effort signed by President Obama in 2009 to speed up water quality improvement in the bay. In 2010, the inhabitants of the Chesapeake Bay watershed were put on a "pollution diet" as part of a Federal Total Maximum Daily Load (TMDLs) at the subwatershed level as required under the Federal Clean Water Act. Watershed Implementation Plans (WIPs) were formulated by the seven Chesapeake Bay jurisdictions with specific actions to meet the TMDL pollution load reduction goals by the year 2025, with intervening two-year milestones (Pennsylvania DEP 2022).

Cover crops have been identified as one of the most cost-effective management practices to reduce N losses from farmland to the Chesapeake Bay, with additional reductions in P and sediment at zero cost and positive side-effects on adoption of conservation tillage (CBC 2004; Wieland et al. 2009; Kaufman et al. 2014; Fleming 2017). The effectiveness of fall-planted cover crops to reduce nitrate (NO_3^-) loss (especially leaching) has been shown in many studies (Singer et al. 2011; Kaspar et al. 2012; Kladivko et al. 2014; Yeo et al. 2014; Shah et al. 2017; Ruffatti et al. 2019). Cover crops have been defined by the USDA as:

> Crops, including grasses, legumes, and forbs, for seasonal cover and other conservation purposes. A cover crop managed and terminated according to these guidelines is not considered a "crop" for insurance purposes. The cover crop may be terminated by natural causes such as frost, or intentionally terminated through chemical application, crimping, rolling, tillage, or cutting. Further, cover crops may be grazed or harvested for hay or silage, unless prohibited by the USDA Risk Management Agency (RMA) crop

Sjoerd W. Duiker (corresponding author) is professor of soil management and applied soil physics, Department of Plant Science, Penn State University, University Park, Pennsylvania. **Susan Richards** was executive director, Capital RC&D, Carlisle, Pennsylvania.

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insurance policy provisions. Cover crops cannot be harvested for grain or seed. (USDA NRCS 2014a, 2014b)

This definition varies from that used by the CBP, which allows harvesting of the cover crop for grain under the commodity cover crop category, if certain nutrient applications are withheld. In 2004, the estimated bay-wide potential of cover crops to meet pollution targets was estimated at 10.4 million kg N y^{-1} (23 million lb N yr^{-1}), 0.20 million kg P y^{-1} (0.44 million lb P yr^{-1}), and 0.19 million Mg sediment y^{-1} (0.22 million tn yr^{-1}), or 22%, 7%, and 24% of total reduction goals in 2004, respectively, at a cost of US$5.35 kg^{-1} of N removed (US$2.43 lb^{-1}) and additional reductions in the other pollutants for zero additional cost (CBC 2004). This estimate assumed cover crops would be planted early (seven days before average date of killing frost) on 50% of row crop area in the Chesapeake Bay watershed and would not receive any additionally applied nutrients. To keep track of the adoption of cover crops as part of Pennsylvania's commitment to reduce N, P, and sediment discharge to the Chesapeake Bay, a transect survey was started in 2016. We report the results of these annual surveys in this paper.

Materials and Methods

Road transect surveys used to survey tillage systems (www.ctic.org/resource_display) were adapted as a statistically robust method to estimate cover crop area for counties in the Chesapeake Bay watershed of Pennsylvania (figure 1). Tillage and crop residue data were also collected but are not reported here. The method was adapted by the Capital Resource Conservation and Development (Capital RC&D) Council and approved to track, report, and verify implementation of traditional cover crops (but not commercial cover crop or traditional cover crops with fall manure applications) by the USEPA in the Chesapeake Bay Model. Every year, the implementation of cover crops in about half of the 31 counties with significant crop area in the Chesapeake Bay watershed of Pennsylvania was surveyed, starting in 2016 (table 1). Of the 31 counties, 27 are (almost) entirely in the Chesapeake Bay watershed (figure 1) and were surveyed entirely. Only the portion within the Chesapeake Bay watershed in the remaining four counties (Berks, Chester, Somerset, and Indiana) was surveyed. For the present paper, county row crop areas were obtained from the 2017 USDA Census of Agriculture for conversion of cover crop percentages from the relevant transect surveys to an estimated cover crop area, which allowed the calculation of the total area of cover crops in the 31 counties, which could then be expressed as a percentage of total estimated annual crop area in this region. The area of perennial forage from the 2017 Ag Census was subtracted from county crop area so cover crop use in the Pennsylvania portion of the bay watershed is expressed as percentage of annual crop area. We used only the estimated percentage portion of crop area within the Chesapeake Bay watershed of the four counties that are partially in the Chesapeake Bay watershed in this calculation.

Transect surveys consisted of fall and spring sampling. Georeferenced sampling points along a prescribed driving route were monitored in the fall and revisited in the spring to determine if a cover crop was harvested, which would potentially identify it as a "commodity cover crop," or if it had received a fall manure application, in which case it was classified as "cover crop with nutrients applied." If cover crops were harvested for grain or forage they were considered "commodity cover crops" in the surveys. Surveys were split in a western and eastern region to consolidate surveys in alternating years. This helped to reduce travel time between counties and allowed recruitment of consulting technicians (CT) and data entry global positioning system (GPS) technicians (GT) from each survey region, thus limiting the number of staff involved, guaranteeing consistency and timeliness and reducing cost. Concentrating surveys in clustered counties also helped improve consistency and timeliness of quality control checks.

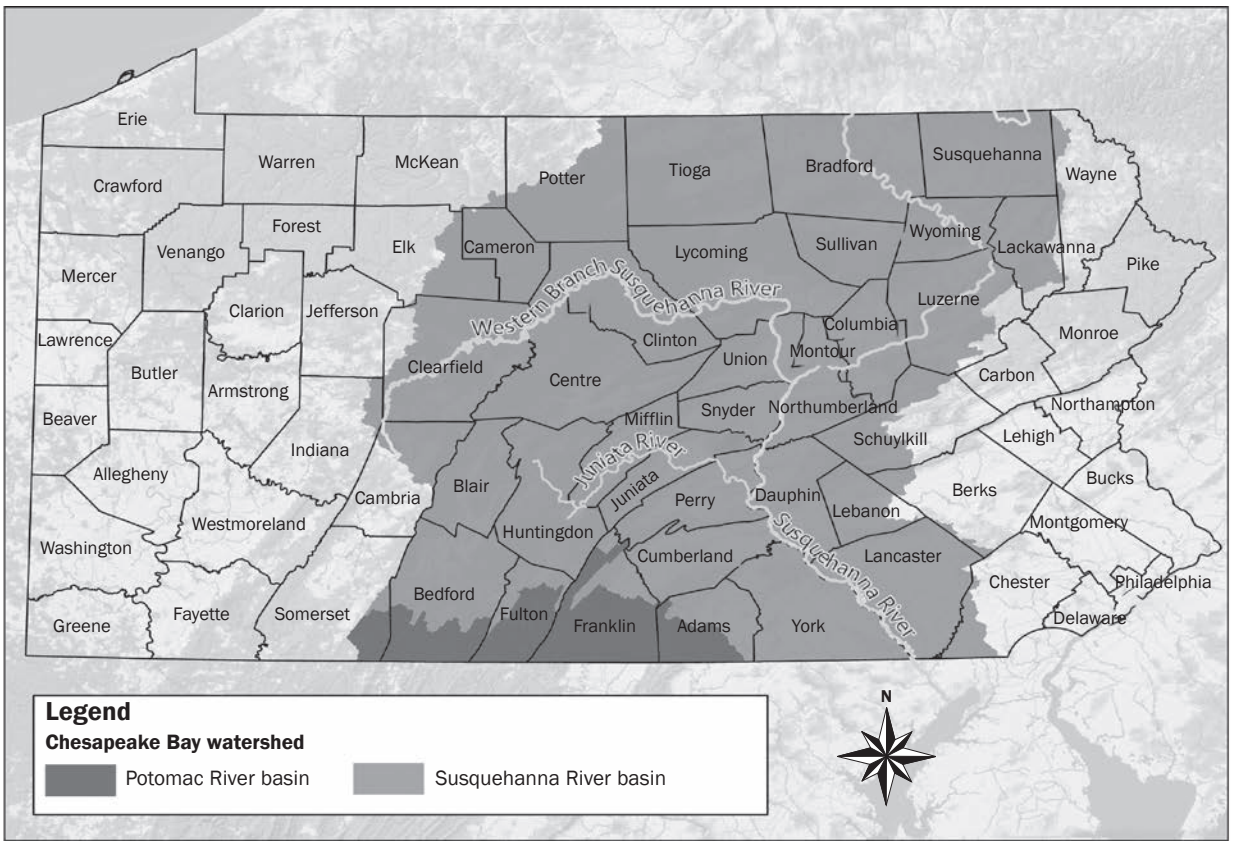
Transect survey routes and survey points along the route were laid out in 2012 using procedures adapted from those developed and tested by the Conservation Technology Information Center (CTIC). ArcGIS was used to follow the survey route and identify survey points. The routes and sampling points were reviewed every year and additional points were added if, due to some reason, some cropland was lost due to land use changes. This ensured the sample size was large enough to provide a minimum confidence interval of 90%.

The transect survey in each county had two phases: (1) a fall survey when cover crop planting was surveyed and (2) a spring survey when cover crop termination methods were surveyed. The spring survey was needed to determine if a cover crop was considered "traditional" (meaning no nutrients were applied to it in the fall or spring, and it was not harvested), "traditional with nutrients applied" (manure was applied in the fall only but the cover crop was not harvested), or "commodity" (cover crop was harvested for grain or forage). These distinctions were important for entry in the Chesapeake Bay Model because each cover crop category has a distinct nutrient reduction rating. However, in 2016 and 2017 "traditional with nutrients applied" was not measured, and in the remaining years it proved difficult to determine if a cover crop had received nutrients. Identifying and verifying if there were applications of additional nutrients is difficult to visually determine from a transect survey; thus, the method is not a CBP Partnership approved verification method for reporting either traditional with fall manure or commodity cover crops. The percentages recorded in the "traditional with fall manure" category were mostly nil or very low and are therefore not included in the traditional cover crop estimates, although they are included in total cover crop estimates.

The fall cover crop survey took place approximately four weeks after the average first frost date in each county. Spring cover crop surveys took place after spring planting and plant emergence and before canopy closure, typically between late May and the end of June, the timing of which would vary depending on the dynamics of the growing season. At each survey point in fall, the CT observed harvested crop, cover crop type, planting method (broadcast/aerial/interseeded, no-till drilled, conventional drilled, or other), cover crop density and height (for establishment date estimation), estimated days from planting, and, if possible, manure application. Cover crop type was one of the following: not emerged (NE), small grain/grass (SG), legume/broadleaf (LG), harvested oats (HO), mix of two or more cover crop species (MX), or other (O). In spring, planted crop, planting method (no-till or tillage), cover crop type (commodity or traditional), manure application, cover crop termination method (herbicide or tillage), and crop residue percentage were recorded.

A survey team consisted of three individuals, two of whom were assigned to survey multiple counties in order to achieve greater

Figure 1
The Chesapeake Bay watershed in Pennsylvania.



consistency between counties. The team consisted of the following:

1. A County Agriculture Agency employee to drive the team along the survey route. This was typically a Soil and Water Conservation District employee selected based on their knowledge of agriculture in the surveyed county.
2. A CT who surveyed multiple counties each year. Between four and six CTs were hired annually, selected based on their extensive experience as agricultural professionals working with agronomic crops.
3. A GT who also surveyed several counties per year. The GT would guide the team along the prescribed survey route, identify predetermined observation points, and enter the cover crop and crop residue data determined by the CT. The GTs were selected based on their experience with maps and using ArcGIS.

Prior to surveying, the CTs and GTs were required to attend a 6 h training by the lead CT that incorporated classroom and in-field activities and provided the technicians with photos and written survey procedures. Each spring, a minimum of 10% of the georeferenced county observations of a CT were separately verified by an independent CT. Any discrepancy was addressed, and a sample count error matrix was generated for each CT and used for adjustment of the data.

Area of cover crops for the period 2016 to 2021 was calculated by multiplying the percentage of cover crop determined in the surveys by total harvested cropland area minus that used for forage (land used for all hay and haylage, grass silage, and greenchop; table 24 in USDA NASS [2017]) in the 2017 Agricultural Census. When comparing our results with those of the CBP Best Management Practice reporting it should be noted that it uses 2012 and 2017 Census of Agriculture data as the 2017 report was not available during the full transect survey reporting period for their report. Because the Agricultural Census only takes place every five years, we used these cropland estimates, which would not have varied much in the period of performance. The average cover crop area and percentages reported in table 2 represent the averages of the three years the survey was done in the respective counties, with the exception of Berks, Chester, and Tioga, where the survey was done two times in the period of performance.

Results and Discussion

The total annual crop area in the Chesapeake Bay watershed portion of Pennsylvania was 597,000 ha (~1,475,000 ac) as estimated in the 2017 Agricultural Census (table 2). Cropland is concentrated in the south of Pennsylvania, with largest areas in Lancaster, York, and Franklin counties. The percentage of annual cropland planted to cover crops was almost 40%, with 23% commodity and 15% traditional cover crops. The proportion commodity cover crops is therefore almost two-thirds while traditional cover crops represent the other one-third of cover crop area. Within the Chesapeake Bay Model, traditional cover crops cannot be harvested while commodity cover crops are harvested. However, there is confusion whether "harvest" includes grazing and harvesting for forage. The baseline for commodity cover

Table 1
Pennsylvania counties, county crop area from 2017 Agricultural Census*, and years when cover crop transect surveys were performed.

County	Annual crop in hectares (ac)	2016	2017	2018	2019	2020	2021
Adams	32,532 (80,325)		✓		✓		✓
Bedford	20,436 (50,460)		✓		✓		✓
Berks†	5,933 (14,649)			✓		✓	
Blair	11,543 (28,500)		✓		✓		✓
Bradford	14,933 (36,871)	✓		✓		✓	
Cambria	10,986 (27,127)		✓		✓		✓
Centre	17,043 (42,081)	✓		✓		✓	
Chester†	10,483 (25,885)			✓		✓	
Clinton	6,467 (15,969)	✓		✓		✓	
Columbia	20,600 (50,863)	✓		✓		✓	
Cumberland	36,002 (88,893)		✓		✓		✓
Dauphin	14,325 (35,371)		✓		✓		✓
Franklin	50,240 (124,050)		✓		✓		✓
Fulton	5,925 (14,630)		✓		✓		✓
Huntingdon	10,909 (26,936)		✓		✓		✓
Indiana†	1,332 (3,289)			✓	✓		✓
Juniata	11,584 (28,602)		✓		✓		✓
Lancaster	87,119 (215,109)	✓		✓		✓	
Lebanon	24,102 (59,511)	✓		✓		✓	
Luzerne	5,134 (12,676)	✓		✓		✓	
Lycoming	14,228 (35,130)	✓		✓		✓	
Mifflin	10,786 (26,632)	✓		✓		✓	
Montour	6,901 (17,039)	✓		✓		✓	
Northumberland	27,841 (68,743)	✓		✓		✓	
Perry	17,750 (43,826)		✓		✓		✓
Schuylkill	18,451 (45,558)	✓		✓		✓	
Snyder	18,773 (46,353)		✓		✓		✓
Somerset†	1,700 (4,197)			✓	✓		✓
Tioga	8,859 (21,874)	✓		✓			
Union	12,915 (31,890)		✓		✓		✓
York	61,393 (151,587)		✓		✓		✓
Total	597,224 (1,474,626)						

*Crop area was calculated as total crop area minus perennial forage area.

†Only the cropland of these counties within the Chesapeake Bay watershed is reported here.

crop in the Chesapeake Bay Model is not fallow after a harvested crop (as is the case for traditional cover crops), but a small grain crop harvested for grain (CBP 2017, section 3.1). The only difference between a commodity crop and a commodity *cover* crop in the model is that the commodity cover crop does not receive nutrients in the fall. Nitrogen reduction credits for fall-planted commodity cover crops in the Chesapeake Bay Model are 5%, 10%, and 15%, respectively, for early, normal, and late planting periods (CBP 2017, section 3.1). However, Chesapeake Bay Model documentation does not explicitly specify whether "harvest" is only grain harvest or includes forage harvest and grazing (CBP 2017, Appendix A). Further, the USDA definition of "cover crop" includes the ability to either harvest a cover crop for forage or graze it but excludes those harvested for grain (USDA NRCS 2014a, 2014b). In the Chesapeake Bay Model, however, commodity cover crops can be harvested for grain (CBP 2017, Appendix A). This causes some to assume that traditional cover crops as defined in the Chesapeake Bay Model can be harvested for forage or grazed. This lack of clarity was carried forward in a Penn State survey meant to enhance transect survey data with producer survey data for cover crop reporting in the Chesapeake Bay Model. Because the term "harvesting" was not explained, authors report that "Consequently, there is the possibility that some producers may have had different understandings of what constituted 'harvesting,' being understood to mean grain harvesting over a 'harvested' use for forage" (Cook et al. 2022). This lack of clarity is also present with governmental, university, and nongovernmental organization (NGO) staff. However, in the cover crop transect surveys in Pennsylvania, "harvesting" was understood to include harvest for forage (grazing cover crops is still relatively uncommon in Pennsylvania and would not be a major proportion of commodity cover crops). This is clear because, for example, the area of commodity cover crops reported in a county like Lancaster County (on average 39,601 ha [97,856 ac], table 2) was more than four times the size of the area of predominant small grains wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and oats (*Avena sativa* L.) harvested for grain combined (8,288 ha [20,480 ac], from the 2017 Ag Census reported by USDA National Agricultural Statistics Service [NASS]). That traditional cover crops cannot be harvested for forage but need to be included in the "commodity cover crop" category seems in agreement with Chesapeake Bay Model documentation because it includes rye (*Secale cereale* L.) and triticale (*Triticum secale* L.) in the list allowed as "commodity cover crops" (CBP 2018, table A-5-2). Rye and triticale are almost never harvested for grain, but often used for forage. Nonetheless it is of high importance that the definition of "harvested," which distinguishes traditional from commodity cover crops, needs to be made clear in Chesapeake Bay Model documentation. In Pennsylvania, where the area devoted to cattle farming exceeds that used for grain production, cover crops are frequently harvested as forage to feed ruminant livestock. In counties where cattle farming is less common, cover crop use is lower. For example, in York County, only 6% of the farms are dairy or feedlots, and the cover crop percentage is 30% (19% commodity). In Lancaster and Lebanon, on the other hand, dairy and feedlots represent 31% and 12% of all farms, respectively, and cover crop use is greater than 60% in these counties (45% and 44% commodity cover crops, respectively). Besides becoming a resource that can be fed to cattle, there is also a larger time window for farmers to plant cover crops on dairy or beef farms. Crops

Table 2
Average cover crop area and percentage* for 2016 to 2021 in 33 Pennsylvania counties in the Chesapeake Bay watershed.

	Ag Census 2017	2016 to 2021					
County	Annual crop area (ha)	Commodity (ha)	Traditional (ha)	Total cover crop (ha)	Commodity (%)	Traditional (%)	Total cover crop (%)
Adams	32,532	5,060	5,718	10,778	16	18	33
Bedford	20,436	2,552	2,774	5,326	12	14	26
Berks†	5,933	2,574	1,244	3,818	43	21	64
Blair	11,543	3,076	2,617	5,693	27	23	49
Bradford	14,933	1,491	2,102	3,592	10	14	24
Cambria	10,986	3,311	1,478	4,790	30	13	44
Centre	17,043	1,846	1,946	3,792	11	11	22
Chester†	10,483	5,501	1,408	6,908	52	13	66
Clinton	6,467	884	1,584	2,468	14	24	38
Columbia	20,600	2,972	3,284	6,256	14	16	30
Cumberland	36,002	6,751	6,141	12,892	19	17	36
Dauphin	14,325	3,624	1,770	5,393	25	12	38
Franklin	50,240	14,891	6,444	21,335	30	13	42
Fulton	5,925	1,548	805	2,352	26	14	40
Huntingdon	10,909	2,928	1,012	3,939	27	9	36
Indiana†	1,332	175	288	271	13	22	20
Juniata	11,584	1,451	2,591	4,041	13	22	35
Lancaster	87,119	39,601	15,318	54,920	45	18	63
Lebanon	24,102	10,657	4,642	15,299	44	19	63
Luzerne	5,134	773	834	1,330	15	16	26
Lycoming	14,228	1,655	801	2,455	12	6	17
Mifflin	10,786	1,100	1,582	2,682	10	15	25
Montour	6,901	555	1,023	1,578	8	15	23
Northumberland	27,841	1,117	4,230	5,346	4	15	19
Perry	17,750	3,058	5,270	8,328	17	30	47
Schuylkill	18,451	2,512	1,262	3,773	14	7	20
Snyder	18,773	2,285	1,989	4,274	12	11	23
Somerset†	1,700	652	546	834	38	32	49
Tioga	8,859	1,316	660	1,976	15	7	22
Union	12,915	1,960	3,220	5,180	15	25	40
York	61,393	11,570	7,140	18,711	19	12	30
Total	597,224	39,444	91,722	230,332	23	15	39

*Percentages may not add up due to rounding and inclusion of "traditional cover crop with fall manure" in total cover crop estimates.

†Only Chesapeake Bay watershed portion was surveyed, with 2017 crop area in Chesapeake Bay watershed in that county listed.

grown on livestock farms such as corn (*Zea mays* L.) silage or high moisture corn are often harvested in September when there is still significant growing season left for cover crops to develop. In contrast, corn grain and soybeans (*Glycine max* [L.] Merr.) are harvested later when temperatures become cooler and cover crops develop little growth. If grain crops such as wheat, barley, or oats are part of the rotation, there is ample opportunity to plant cover crops. However, when considering wheat, barley, oats, corn grain, and soybeans in the entire state of Pennsylvania, the small grains only represent 13% of the area, while corn grain and soybeans represent 87%. Besides, in the south of Pennsylvania, the small grains are often followed by double cropped soybeans. Therefore, cover crops are less common on grain farms. This could affect cover crop use in the future because the number of dairy farms particularly is decreasing continuously. There were almost 11,981 dairy farms in the entire state of Pennsylvania in 1997, which decreased 42% to 6,914 in 2017. The number of dairy cows decreased in that period from 615,200 to 527,618, a 14% decrease. The area of corn silage decreased from 196,405 ha (485,327 ac) in 1997 to 143,051 ha (353,486 ac) in 2017, a 27% decrease. A decrease in livestock farms would probably result in a decrease in cover crop use and manure applications, which would likely affect water quality in the Chesapeake Bay.

The percentage of annual crop area planted to cover crops varied considerably between counties, from 17% in Lycoming County to 66% in Chester County. The highest percentage cover crop use was recorded in southeastern Pennsylvania, exceeding 60%

in Berks, Chester, Lancaster, and Lebanon counties (figure 2). In these counties, the proportion commodity cover crops was also higher (up to 78% of cover crop area) than the regional average. These counties are closer to the Chesapeake Bay and have higher cropland percentages respective to nondisturbed land such as forest than counties in the rest of Pennsylvania. Therefore, there is greater potential for nutrients and sediment from these southeastern counties to end up in the Bay. Cover crops help reduce that and their widespread use in southeastern Pennsylvania is therefore especially beneficial for water quality improvement.

There is an apparent, although gradual, increase in cover crop use in the region surveyed, increasing from approximately 40% to 45% over a six-year period (figure 3). However, annual variability is large with only 25% of surveyed annual cropland in cover crops in 2019. Further, the proportion of commercial and traditional cover crops changed by year. For example, in 2016 and 2020, commodity cover crops represented 75% and 65%, respectively, of all cover crops. On the other hand, commodity cover crops represented 57%, 55%, and 51% of all cover crops in 2017, 2018, and 2021, respectively. Cover crops can be used for forage or not, depending on the needs of the year. If a drought year precedes a cover crop, feed shortages may lead to more cover crop being harvested. If, on the other hand, the previous year had high yields, cover crops might be terminated without harvesting. Cover crops therefore become a risk management tool on animal farms—they will be used for forage if needed, but if not, they can be terminated without harvesting.

These surveys show that estimated cover crop adoption in the Chesapeake Bay watershed of Pennsylvania is much higher than the average adoption of cover crops in the United States, which was only 5.1% in 2017, although it increased from 3.4% in 2012 (Wallander et al. 2021). Cover crop adoption in 2017 in other states in the Chesapeake Bay watershed was reported to be 32% in Maryland, 16% in Virginia, and 9% in New York (Wallander et al. 2021). In this same survey, cover crop adoption was reported to be 17% in Pennsylvania, probably because commodity cover crops were not included. It is not clear how important commodity cover crops are in other states in the Chesapeake Bay watershed. According to CBP reporting in 2022, cover crops use in Pennsylvania was 20.4%, with no traditional cover crops with fall manure and only 0.7% of commodity cover crops reported. Our study also suggests that cover crop adoption in Pennsylvania was underestimated in the past. Cover crop adoption was estimated to be only 17% of planted crop area in 2017 by the USDA NASS (Wallander et al. 2021). This percentage is the same as the percentage of "traditional" cover crops in 2017 in

Figure 2
Average cover crop percentage of annual crop area per county (2016 to 2021).

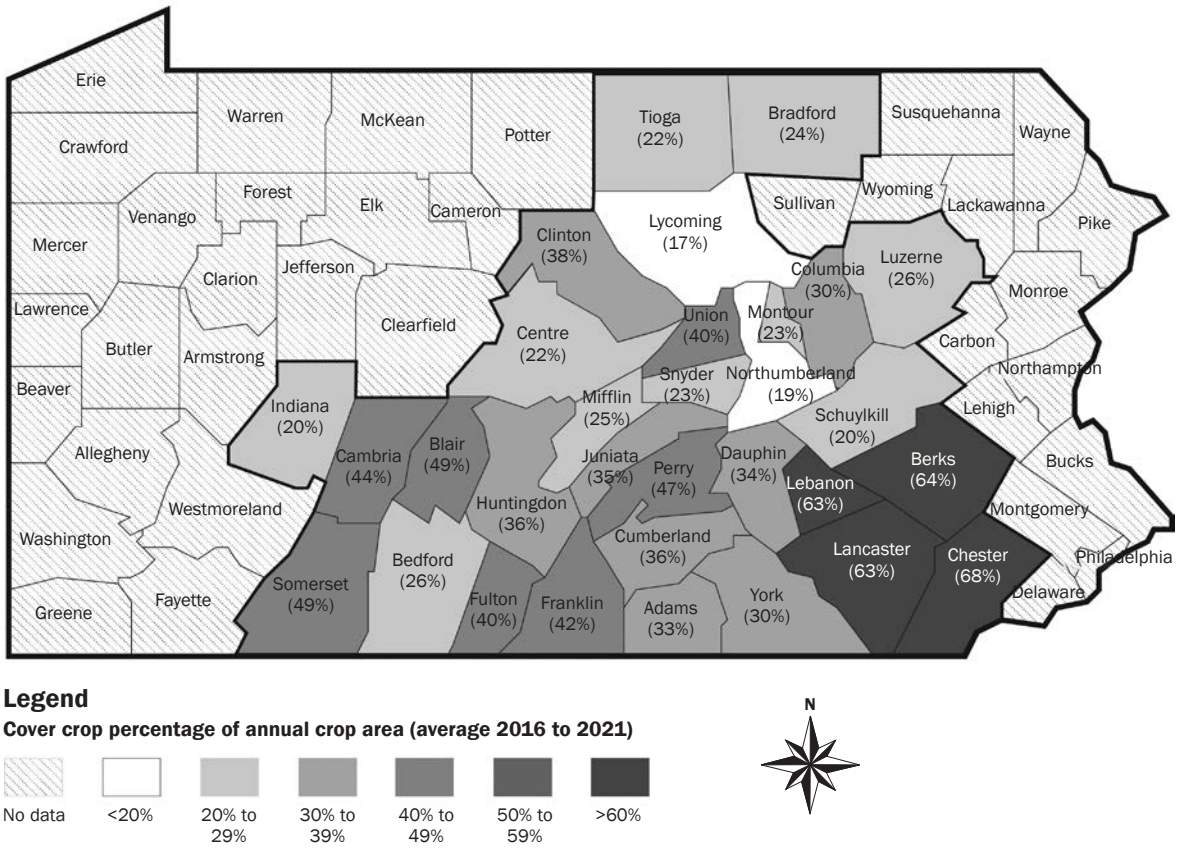
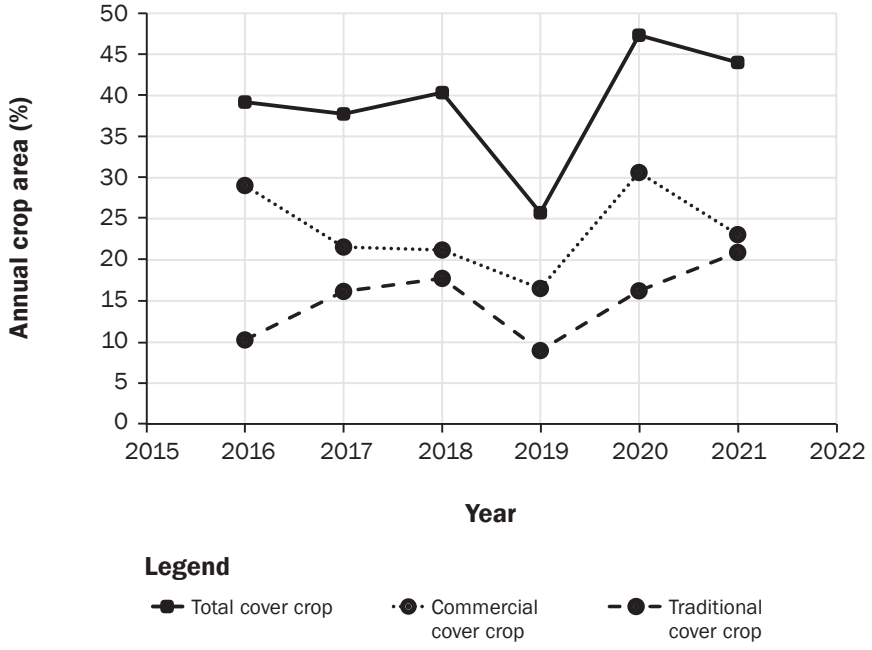


Figure 3
Percentage of annual crop area in Pennsylvania Chesapeake Bay watershed planted to cover crops from 2016 to 2021 (surveys in spring; for counties surveyed in each year, see table 1).



the current survey, so very likely commodity cover crops were excluded from that estimate. Another reason may have been the exclusion of cropland outside of the Chesapeake Bay watershed in the current survey. However, the total state area of corn, soybeans, wheat, barley, and oats was 900,00 ha (2.2 million ac) in 2017 (USDA NASS 2017), so this survey that only covered the Chesapeake Bay watershed represented approximately two-thirds of all the cropland in Pennsylvania. Although cover crop adoption may have been lower outside of the Chesapeake Bay watershed, it is not likely that total cover crop adoption would be that dramatically different because farm characteristics and support programs for cover crops are relatively similar in the rest of the state.

These surveys show the importance of commodity cover crops in Pennsylvania, representing two-thirds of total cover crop area in the Chesapeake Bay watershed portion of the state. However, in Phase 6 of the Chesapeake Bay Model, commodity cover crops are only credited toward achievement of N reduction goals *if no fall nutrients are applied to them*. If no fall nutrients are applied and additional applications are delayed until spring (March), there is a 5% N reduction credit given to early planted cover crops, 10% for normal, and 15% for late planted cover crops, with the baseline being a small grain commercial crop harvested for grain (CBP 2017). This nutrient reduction crediting is very different from that of traditional cover crops, where early planted cover crops get a higher rating than late planted cover crops, where the baseline is a summer crop followed by fallow. For example, an early planted "traditional" rye cover crop planted with low-till in the Mesozoic lowlands receives 34% N reduction credit, while the same cover crop planted late receives a 15% N reduction credit (CBP 2018). The credit for commodity cover crops is therefore lower (even when comparing with traditional cover crops with fall manure) and the effect of planting date is reversed. Unfortunately, transect surveys are currently not approved by the CBP Partnership to track, report, and verify either traditional cover crops with fall manure applications, or commodity cover crop implementation in the Chesapeake Bay Model (Mark Dubin, personal communication, October 13, 2022; Cook et al. 2022). Transect surveys are only approved to track traditional cover crop implementation, but with conservative crediting because planting dates and cover crop species cannot be determined with certainty with this tracking method (Mark Dubin, personal communication, October 13, 2022; Cook et al. 2022). Efforts are underway to combine data from transect surveys and other data sources to assign higher credit to traditional cover crops in Pennsylvania in the Chesapeake Bay Model. In Phase 6.0 of the Chesapeake Bay Model, traditional cover crops with fall manure applications receive 70% of the N-reduction credit of traditional cover crops (CBP 2017). Our survey results suggest that the benefits of commodity cover crops for achievement of pollutant reduction need to be better understood. These cover crops remove large quantities of nutrients from the soil. At 6.7 Mg ha^{-1} (3 tn ac^{-1}) of dry matter, a ryelage cover crop typically contains 190 kg N ha^{-1} (170 lb ac^{-1}) and 30 kg P ha^{-1} (27 lb ac^{-1}) in aboveground biomass and additional nutrients in belowground biomass. The nutrients in the harvested portion of the cover crop are removed from the field and fed to livestock. These nutrients are taken up from the soil and therefore not subject to loss to surface waters after harvest (although they may be partly returned to the field as manure). These vigorous cover crops also protect the soil from erosion. It therefore seems that commodity cover crops do provide a large environmental benefit for water quality that is currently undervalued. Our study revealed the need to (1) clarify in Chesapeake Bay Model documentation that commodity cover crops include those harvested for forage besides those harvested for grain; (2) develop a tracking mechanism so that nutrient reduction credit from commodity cover crops can be recognized in the Chesapeake Bay Model; and (3) to review whether the lower N reduction credit from commodity cover crops than from traditional cover crops and lower credit for early planting are justified.

Summary and Conclusions

Annual cover crop transect surveys in the Chesapeake Bay watershed portion of Pennsylvania show that cover crops are used on 39% of planted cropland, much higher than the national average of 5%. Approximately two-thirds of these cover crops are "commodity cover crops" (which included forage harvest in the survey), while unharvested cover crops make up the other one-third. The results call for a better understanding of the environmental benefits of harvested cover crops that seem currently undervalued in the Chesapeake Bay Model. Specifically, our study revealed the need to (1) clarify in Chesapeake Bay Model documentation that commodity cover crops include those harvested for forage besides those harvested for grain; (2) develop a tracking mechanism so that nutrient reduc-

tion credit from commodity cover crops can be recognized in the Chesapeake Bay Model; and (3) to review whether the lower N reduction credit from commodity cover crops and lower credit for early planting are justified.

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