Perspective
Thinking across and beyond disciplines to make cover crops pay

Ray Weil* and Amy Kremen
Department of Environmental Science and Technology, University of Maryland, College Park, Maryland, USA

As the name implies, a *cover* crop consists of plants grown primarily to keep the land *covered*, especially during the off-season or between cash crops. In temperate regions like most of Europe and North America, a cover crop sown immediately after the main crop harvest in fall is considered a winter cover crop. It will grow in the fall, either subjected to frost-kill or go into relative dormancy during the dead of winter, and then, if winter-hardy, recommence growth in very early spring before soils are warm and dry enough for the next cash crop. If the climate is sufficiently mild, such cover crops may produce substantial above-ground dry matter (3000–6000 kg ha^{-1}) and nearly complete ground cover before being terminated. For many decades, the use of cover crops has been promoted mainly to prevent the severe soil erosion that winter and spring rains can bring if soils are left bare. In addition, it is widely recognized that regular use of winter cover crops – as compared to bare fallow over winter – can provide enough carbon input to build – or at least slow the decline of – soil organic matter. For these reasons, many scientists view cover crops as an essential tool in managing farmland for long-term sustainability.[1]

A considerable amount of cover crop research has been conducted in the mid-Atlantic region of the USA during the past three decades. Most of this research focused on just a handful of cover crop species, mainly cereal rye and hairy vetch, which were found to be well adapted to the region's climate and cropping systems. With the advent of programs to restore the health of the Chesapeake Bay, most cover crop research in Maryland has been directed towards using cover crops to capture residual mineral nitrogen (N) before it can leach away in the fall. Extensive research on coastal plain soils has demonstrated the ability of a rye cover crop to greatly reduce the loss of N to groundwater from maize grown in no-till production systems.[2] However, relatively little has been done to demonstrate direct benefits to the farmer from the use of cover crops.

One economic benefit that has been well quantified is the ability of legume cover crops, under some conditions, to replace by biological N_2 fixation most or all of the fertilizer N needed for optimal production of nitrogen-demanding crops. However, under realistic conditions, research indicates that it costs about as much to grow and manage a hairy vetch cover crop as the value of the N fertilizer it saves.[3,4] While biologically fixed N is likely to become more profitable as the cost of N fertilizer rises, legume cover crops grown alone are not very effective at capturing residual fall N.

Although not often discussed by researchers, farmers recognize that growing a cover crop adds extra expense, complexity and uncertainty to the already risky business of farming. Under some circumstances, certain cover crops have interfered with crop production by using up water stored in the soil profile, by immobilizing N needed for the cash crop and by becoming weedy or producing excessive residues, hampering crop stand establishment or harvest. The most obvious direct costs associated with cover crops include those for cover crop seed, labor, fuel, fertilizer and herbicide or tillage to kill the cover crop.

Given these considerations, the State of Maryland has for several years paid subsidies of \$50–100 per hectare for timely planting of cover crops with a goal of keeping at least 75% of Maryland's cropland acres under cover crops in winter. Despite this incentive, adoption rates remain relatively low, with only about 20–25% of cropland hectares receiving cover crops. We suspect that this is because most farmers in this region are not sufficiently aware of the direct benefits that cover crops potentially offer, possibly as a result of past research and extension work that emphasized cover cropping's role in N fixation, environmental protection and long-term soil resource conservation. Although nearly all farmers desire to be good stewards of their land, most face tight (or negative) profit margins and cannot afford to engage in environmental altruism without first considering their operations' bottom line and efficiency goals. Lacking credible information and examples that might convince them otherwise, many farmers have reached the conclusion that cover crops are simply not worth the cost and trouble.

* Correspondence to: Ray Weil, Department of Environmental Science and Technology, University of Maryland, College Park, MD
E-mail: rweil@umd.edu
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It was against this background that our group* at the University of Maryland began a cover crop research program with the goals of researching and publicizing new cover crop options that provide multiple direct benefits (or services) to farmers. The motivation for this new cover crop research effort was heightened when the senior author visited southern Brazil in 2000 and observed great enthusiasm for cover crops, including species little known back in Maryland. Particularly noteworthy was the conviction expressed by farmers and some researchers that a radish they called 'Nabo' (oilseed radish, *Raphanus sativus* L.) helped alleviate problems with subsoil compaction. Subsoil or plow pan compaction is a problem that nearly every Maryland farmer has to some degree, and many spend large amounts of money on deep tillage implements and large tractors to combat it. Perhaps farmers in Maryland would be interested in this new cover crop as a way to address their soil compaction problems. Our cover crop research might integrate the study of compaction alleviation with the study of N leaching to identify potential benefits to both farmers and society.

Once we began to search the literature in earnest, it seemed that various species of Brassicaceae (Fig. 1) offered the most potential for providing farmers with new cover crop options that might offer benefits sufficient to make them economically attractive. The list of potential cover crop services possible for integrated investigation grew as we learned about research in other parts of the world. Some of the potential benefits stem from glucosinolates: sulfur-rich compounds that brassica cover crops contain in large quantities. When broken down, glucosinolates form bio-toxic secondary products (isothiocyanates and others) whose potential to control weeds, disease, insects, and nematodes has been reviewed extensively.[5] A large body of work on the effect of brassicas on plant parasitic nematodes includes using mustards in wheat or potato crops,[6] and mustard and rape in sugar beet crops.[7] Brassica cultivars have also been found to effectively suppress troublesome weeds,[8] possibly because glucosinolate breakdown products may inhibit weed seed germination by reacting with seed enzymes. Our own observations and research in northern Europe[9] suggested that the brassicas also might offer special opportunities for agronomic and environmental nitrogen management.

Figure 1. Three of the brassica cover crops (mustard, rapeseed and forage radish) studied in the project.

Our research strategy has been to highlight benefits and the feasibility of integrating cover crops into farmers' rotations, thereby encouraging cover crop use and limiting cost-share dependence. We justified our approach to cover crop research by the hypothesis that when farmers are able to see the combined value of two or three concrete benefits, they will come to regard cover crops as a profitable farming practice worth adopting.

For university faculty, development of an interdisciplinary and farmer participatory applied research program can present some real challenges. On-farm research involves greater risks and logistical challenges and also may require a range of expertise outside a researcher's area of training. Within the realm of academia, researchers may be pressed to constrain their work to a single discipline. Yet most farming practices and problems are interrelated and inherently interdisciplinary. Research practical enough to directly address farmers' questions is typically conducted by outreach or extension personnel and published in the form of extension bulletins and advisory reports that might not be read by non-extension academics.

Our approach – combining basic and applied research and involving farmers in the research process – is an outgrowth of the Farming Systems Research and Extension[10,11] approach developed in the 1970s and 1980s largely for developing country agriculture. What is somewhat unusual about our work is its explicit attention to issues relevant for a range of farm types, from conventional grain farms to diversified organic vegetable farms. Without being part of an institute or formalized interdisciplinary organization, our group consisted of an ad hoc collaboration between several land-grant university faculty and extension educators from several departments and colleges, graduate and undergraduate students, and government agricultural scientists.

Competitive grants were awarded from diverse sources, including: the US Department of Agriculture Sustainable Agriculture Research and Education (SARE) program, which was interested in improving land care and farmer empowerment;

* *Project research team:* From the University of Maryland, College Park, MD: Dept of Environmental Science and Technology: Ray Weil, Soil Scientist; Bahram Momen, Statistician/Ecologist; Guihua Chen, Jill Dean, Amy Kremen, Yvonne Lawley, and Lisa Stocking, postgraduate students; Nematology Laboratory, Dept of Entomology: Sandra Sardanelli, IPM Coordinator; Maryland Cooperative Extension Service: Caragh Fitzgerald and David Almquist, extension educators, From the US Dept of Agriculture, Agric Res. Service, Beltsville, MD: John Teasdale, Weed Scientist and Research Leader, Sustainable Agric. Systems Lab; Inga Zasada, Nematology Laboratory.

US Environmental Protection Agency (through the Maryland Center for Agroecology), which was primarily interested in N capture and protecting the Chesapeake Bay; and the Maryland Soybean Board, a conventional farmers' commodity organization that was initially interested in new tools for solving soil compaction and other practical farming problems.

Perhaps one factor that helped integrate the various disciplines is the fact that the different aspects of the brassica cover crops were studied by graduate students working under the same advisor (the senior author), who recruited additional specialists as needed to assist with the research effort. Although each participant gained some material benefits from the collaboration (such as funds for equipment or assistance from graduate students supported by the project grants), the principal motivation for interdisciplinarity came from our interaction with farmers in the field, at workshops and winter conferences. Unlike the researcher who can specialize in a single discipline and largely control for, or even ignore other aspects, the farmer has to deal with the whole system. A conversation with a single farmer may bring up agronomic issues such as planting date, soil physics issues related to compaction, pest issues such as parasitic nematodes, and fertility issues such as the need for fertilizer to overcome N immobilization in spring. Furthermore, sharing the same research plots and overarching research goals promoted cross-disciplinary discussion, more nuanced understanding of individual topic areas, and in some cases the integration of data from several disciplines. For example, by working with soil scientists the nematologists on our team became increasingly aware of soil chemical and physical conditions. Similarly, soil fertility specialists came to understand the role that bacteriovore nematodes might have on nutrient availability to plants.

COVER CROP SERVICES

Alleviating effects of compaction

We hypothesized that cover crop roots would penetrate compacted subsoils in fall, winter and spring when the soil was wet and relatively soft, and that these roots would leave channels permitting access by summer crop roots through the compacted zone when soils are relatively dry and very hard (Fig. 2). Easier and deeper rooting by main crops should provide access to subsoil moisture during dry, high-transpiration periods during the summer. The effect of creating multiple small (~1 mm diameter) root channels is different from inducing porosity through mechanical tillage, and therefore measurement methods (penetrometer, bulk density) used to evaluate changes in compaction following tillage are not applicable when using cover crops. We used soil moisture sensors at 15 and 50 cm depths (above and below the plow pan) as well as a minirhizotron camera system and soil cores to study the 'bio-drilling' effect of fall cover crops and subsequent rooting patterns of the summer crop. Our early minirhizotron images confirmed that soybean roots would penetrate hard plow pans in summer by following channels made by a brassica cover crop the previous winter.[12]

Figure 2. Root holes (bio-drilling) and root remains in spring, some 4 months after cold temperatures killed the forage radish cover crop. Black pen (arrow) in hole for scale. Photo courtesy of R Weil.

During late summer drought stress, soil moisture sensors monitored hourly showed more rapid water use by maize roots (and more rapid recharge of soil moisture after rains) in the subsoil of plots previously growing forage radish compared to plots previously growing rye or no cover crop. The rye cover, however, provided more residue mulch than the radish and so conserved more water in the surface soil above the plow pan. Soil cores taken to 55 cm during this period revealed about 10 times as many maize roots in the subsoil where the radish had been grown compared to where no cover crop had been grown. In the surface soil (above the plow pan) maize roots were most numerous where a rye cover crop had been grown. As a result, we are now investigating a cover crop mixture of rye and forage radish as the best bet to reduce crop water stress throughout the summer as well as prevent soil erosion in spring.

Weed suppression

In our initial compaction-related work using brassicas we observed a striking pattern of weed suppression. Plots where forage radish had grown in the fall and winter-killed were left almost bare of residues in spring and were remarkably weed-free (Fig. 3). We are now working to quantify the weed suppression by forage radish, determine its duration with respect to the following summer crop, and determine whether the mechanism of this suppression involves only resource competition in the fall or allelopathy, or both.

Weed-suppressive cover crops may be an important alternative weed management strategy for reducing the environmental impacts and expense of herbicides, especially as more weed species develop resistance over time to one or more herbicides. For organic

Figure 3. Weed-free condition of soil in spring after winter-killed forage radish cover crop, which left only a thin film of decayed residues (right plot) compared to rye cover crop plot (left). Photo courtesy of Y Lawley.

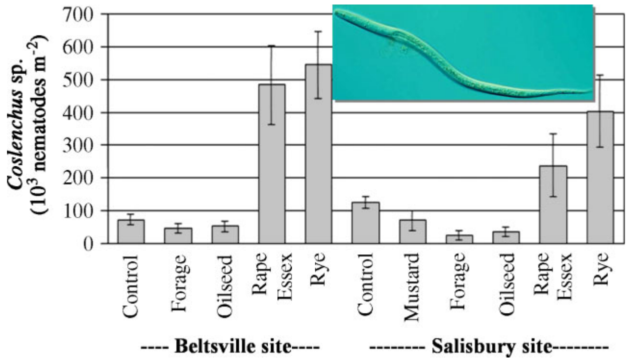

Figure 4. *Coslenchus* sp. nematodes in the upper 15 cm of soil at two sites in August 2005 as affected by cover crop treatments planted in August 2004. Graph and photo courtesy of L Stocking.

farmers who do not have many herbicide options and rely heavily on tillage for weed control, a cover crop that winter-kills yet effectively suppresses weeds could represent a new opportunity to incorporate some degree of no-till planting conservation tillage into their farming systems.

We rated percent live weed cover in plots planted in either forage radish, rapeseed, rye, or a no-cover control treatment at four locations in Maryland in spring 2005. The three cover crop treatments all had the same low level of weed cover, even though the rape and rye plots were densely vegetated with live cover crops, while the winter-killed radish plots had little residue and almost no live plants of any kind. Although forage radish can effectively suppress early spring weeds, we have observed no stand or growth reduction of soybean or maize following forage radish. In fact, compared to no-cover crop plots, we have observed improved growth and seed yields of soybean following forage radish (as high as 400 kg ha^{-1} increase in yields at the site with the best cover crop stands in 2004).

Effects on soil nematodes

We studied the potential for brassica cover crops to 'bio-fumigate' for nematode suppression at two sites with loamy sand surface soils and differing management practices. We initially focused on soybean cyst nematode (SCN, *Heterodera* sp.), a major pest in our region. To ensure high populations of SCN, we grew a SCN-susceptible soybean cultivar for 2 years. While the dramatic increases in SCN populations during the second year confirmed the need for rotation, we observed little difference in SCN populations among cover crop treatments. We did observe that early-season SCN hatch was increased by some brassica cover crops, suggesting their possible potential as a trap crop.

Some effects were noted on other parasitic nematodes. Rye planted alone or in combination with brassicas increased stubby root nematode (Trichodoridae family) initially, but the differences were no longer evident by the end of main crop growing season. Mustard appeared to actually host (increase) several genera of plant parasitic nematodes. Forage radish tissues were more lethal to certain parasitic nematodes in our lab bioassays compared to our field trials. This may be due in part to the fact that only one of our field sites had a serious population of parasitic nematodes. Also the cover crops were not always completely uniform and in some cases their biomass was not as large as expected. Nonetheless, we feel that in the cropping systems and environments in which we tested them, the brassica cover crops failed to show evidence of real potential for practical management of particular targeted nematode genera.

Perhaps the most interesting nematode data stemmed from our team members' interest in looking beyond just plant parasites to investigate how the brassica cover crops affected the bacteriovores, fungivores, predators, and omnivores of the whole nematode community. Identifying specimens to the genus level, we consistently found that bacteriovorus nematodes were much more abundant in plots that had radish cover crops compared to control plots, even 6 or 8 months after the radishes had winter-killed. Bacteriovores can influence N cycling, and the ecological implications of this finding needs further study. We also observed dramatic increases of *Coslenchus* sp. following rye and rapeseed cover crops at both sites (Fig. 4). Because it is not known whether these nematodes feed primarily on fine root hairs or on fungal hyphae, the ecological functions again are not clear but warrant further research. Enrichment and channel indices[13] used to describe the nematode community suggest that the radishes may favor a bacterial decomposition pathway, while rapeseed, rye, and the control treatments may favor a fungal decomposition pathway.

Nitrogen capture and release

Rapid establishment and root growth in fall when the air is cool but soils are still warm make the brassicas especially well-adapted to capture residual soluble nitrogen before this major water pollutant has a chance to leach down to the groundwater. With tissue N concentrations ranging from 2.0 to 3.5% and dry matter ranging up to 6000 kg ha^{-1}, the brassicas took up more N in the fall than rye, which is the standard N capture cover crop in our region. Taking deep soil cores during autumn, we have observed that the brassicas rapidly depleted soluble N from the soil profile down to 150 or 180 cm.

In addition to N capture in the fall, we were interested in the pattern of N release in spring and summer. One issue investigated was the potential for spring N leaching if the captured N was mineralized too soon. Another issue was the synchronicity between N release in surface soils (0–30 cm) from cover crop residues and N use by summer cash crops. Having members of the same research team investigate these agronomic and environmental issues had its pay-offs. For example, although little spring N leaching from winter-killed forage radish residues was observed in finer textured soils (silt loams with clay loam subsoils), data from sandy soils showed that a flush of nitrate-N released in early spring is susceptible to leaching. Figure 5 shows the loss of nitrate-N from surface (0–20 cm) soils immediately after a rainy period in April, and its nearly concomitant increase in the soil pore water sampled at 120 cm. We suggest, therefore, that the radish cover crop should be followed by an early planted cash crop that can recapture and utilize this N. Regardless of leaching losses, sufficient N remained in surface soils through the cash crop planting period to induce a N response. In mid-June both corn (V6 stage) and pre-nodulated soybean seedlings produced more dry matter and had higher tissue N when following forage radish as compared to when following rye or no-cover crop. This early season response carried through to a grain yield difference in some site years, but not in others.

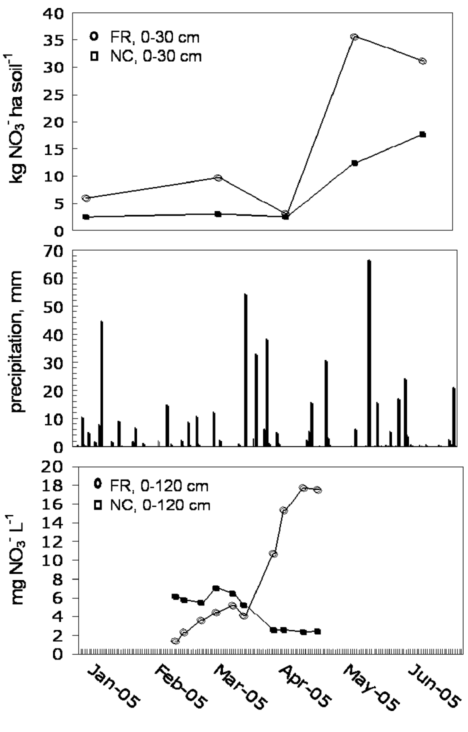

Figure 5. Nitrate-N in the surface 30 cm and in the soil pore water at 120 cm depth in a sandy soil during the winter and the spring in plots either planted to forage radish (FR) or not planted with a cover crop (NC) the previous fall. Graph courtesy of A Kremen and J Dean.

Soil conservation

The rapid decomposition of radish residues, which left only a thin residue 'film' on the soil in spring was of some concern regarding soil erosion. Although our plots were not designed to allow measurement of sediment losses, we regularly looked for signs of erosion. The lack of any rills, soil pedestals or sediment wash from the forage radish plots suggests that the thin film of decayed radish residue remaining on the soil surface from late winter through early spring offered at least some protection against erosion. We did measure soil infiltration rates at two sites using a portable rainfall simulator and found that infiltration was so rapid in the forage radish plots (as a result of the large holes left by the radish roots, pictured in Fig. 2) that it required a very high applied rainfall intensity (26 cm h^{-1}) to generate any runoff from the those plots. One farmer collaborator who has steeply sloping soils expressed concern about the low amount of residue left by forage radish. He worked with us to develop a system of mixing black oats (*Avena strigosa* L.) with forage radish to produce a cover that winter kills, but also leaves a longer lasting residue that should be more effective at reducing erosion on steep slopes.

Other aspects of our project still in preliminary stages include: (1) effects on arbuscular mycorrhizal fungi (AMF) symbiosis in the cash crops (one year of brassica winter-cover cropping reduced AMF infection in soybean); (2) phosphorus cycling (3 years of radish cover crops markedly increased soil test P in the upper 45 cm of soil, probably by translocation of deep profile P); (3) possible remediation of high-P soils using brassica cover crops (total P removal by above-ground radish parts was as high as 40 kg P ha^{-1} in 3 months); (4) effects on soil-borne plant diseases (e.g., possible suppression of *Rhizoctonia* root rot of soybean); and (5) characterization of specific glucosinolates in the species of brassica that we have been studying.

Integrating research efforts

As one might imagine, combining the study of so many different impacts on the soil system presented many challenges. In the field, efficiency required that we often use the same field experiment plots for many types of measurements, some of which were not entirely compatible with each other. For example, the need to maintain weed-free plots in order to compare cash crop yields, nitrogen capture, leaching, and mineralization among cover crop treatments was in conflict with the goal of quantifying natural weed populations in these plots. Glyphosate-resistant soybean and maize cultivars presented a useful tool

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in this regard, as weeds could be allowed to grow for some time before being 'sprayed out'. Careful planning was necessary to coordinate farming and sampling operations and avoid disturbing various types of instrumentation (e.g., lead wires from buried soil moisture and temperature sensors, protruding large polycarbonate tubes used for viewing roots with the minirhizotron camera, and numerous smaller protruding suction lysimeter tubes used to sample soil pore water at 120 cm depth). In light of the numerous measurements being made throughout the year, precautions were taken to minimize plot disturbance, such as standing on boards when soil was wet in order to distribute weight, and defining set areas within plots for obtaining deep soil cores and cover crop biomass samples. Combining, or at least relating, disparate datasets to understand the relationships among the many variables measured (creation of macropores, root growth, nitrate leaching, nematode ecology, etc.) presents an ongoing challenge. Likewise, the diversity of cover crops investigated raises some difficult questions: How can we compare cover crop N uptake between a species that winter-kills in December (e.g., forage radish) and one that grows until it is killed in spring (e.g., rapeseed)? How should we compare the biomass of rye (which has an above-ground shoot quite distinct from its very difficult-to-collect, fibrous root system) to forage radish (which has a large fleshy taproot that is not only easy to collect, but also may be largely above ground)?

Collaboration with farmers

In addition to establishing field experiments at several research stations, we solicited the participation of farmers to conduct on-farm trials, some replicated, some not, in order to broadly test the feasibility of using brassica cover crops within different cropping systems. We encouraged farmers to participate in the design of the trials, as well as in their implementation. In the process, we learned from farmers about important practical considerations and benefited from their innovative ideas concerning cover crop management. For example, farmers found that sowing oats in mixture with forage radish was often not successful because the radish smothered out the oats. Working with a farmer in the field, we tried sowing these species in separate rows by taping closed every other hole in the large seed box filled with oat seed and taping closed opposite alternate holes in the small seed box filled with radish seed. The results were excellent (Fig. 6) and the farmer has since experimented with such configurations as three rows of oats alternating with two rows of radish. Another farmer, a successful producer of certified organic vegetables on a 100 ha farm, designed and implanted a trial to test the use of forage radish to suppress weeds in the row between his black plastic-covered beds.

One concern voiced by many farmers was the difficulty of achieving early sowing (late August being optimal), which seems to be necessary to produce

Figure 6. Alternate rows of oats and forage radish in early fall on sloping land of a long-term no-till farm field in Pennsylvania. Photo courtesy of S Groff.

vigorous fall growth of the brassica cover crops. While dairy farmers harvesting corn silage and farmers with highly diverse rotations had little trouble finding open fields in late August, the fields of typical grain farmers in our region are occupied by soybean or maize crops that are not harvested until late October or early November. Several conventional farmers with large fields suggested that the seed might be applied by airplane while the maize or soybean crop was maturing in the field. We hypothesized that the usually moist fall weather, falling of senescing crop foliage, and the opening crop canopy would provide conditions suitable for cover crop seed germination and early growth. We helped two farmers design a replicated simple strip design and they hired an airplane applicator to seed the cover crop. While the seed distribution pattern needed some adjusting, where the seeds fell in sufficient quantity and the maize was harvested early enough, strong stands of forage radish cover crop were achieved, suggesting promise for this technique. Because other farmers suggested that their cropping systems could most easily accommodate an early spring planting, we are conducting several experiments, both on farms and on research stations, to test the feasibility and implications of this approach. Our preliminary observations suggest little residual nitrate remains on coarse textured soils by spring and that spring-planted brassica cover crops would therefore need to be fertilized with N. In addition, we have observed that, compared to fall plantings, radish and rapeseed planted in early spring quickly flowered and produced much smaller roots.

Farmers who have seen our field plots or tried some seeds have been universally impressed with the extremely vigorous fall growth of the forage radish and the nearly weed-free condition of the radish plots in the spring. For organic vegetable farmers this opens the possibility of enjoying the soil-building and time-saving benefits associated with no-till planting for early crops. Several organic farmers collaborated with us in planting brassica cover crops in fall 2005 and plan to test the no-till planting concept in spring 2006.

A farmer from Pennsylvania who was the first farmer to collaborate with the project in 2001 has 'parked' his subsoiler chisel plow and substituted forage radish for alleviating compaction in the many field driveways where heavy harvest vehicles annually compact his soil. Frustrated with the difficulty of obtaining seed, he saw a business opportunity and in spring 2005 he sowed 4 ha of forage radish for seed production. In his first year, he quickly sold enough seed to 60 farmers to plant 400 ha of the cover crop. In 2006 he increased his seed production and sold enough to plant 800 ha.

Farmer interest notwithstanding, our data are too preliminary at this time to accurately estimate the extent to which (if at all) brassica cover crops can enhance farm profitability. One way of estimating the profitability of using a cover crop involves the cost of a standard practice (partially) replaced by the cover crop. For example, if the cover crop captures and returns 150 kg N $ha^{-1}y^{-1}$ that would have been lost to leaching, and the residues decompose as rapidly as those of brassicas do, the extra N kept in the system may be upwards of \$100 ha^{-1} in saved fertilizer costs. Documentation of actual fertilizer replacement value would of course be best documented by a N fertilizer rate–response experiment. Other cover crop functions, such as compaction alleviation by bio-drilling and early-season weed suppression, are likely to save the cost of such conventional practices as performing deep subsoil tillage (let alone purchasing the necessary equipment and larger tractor) and some herbicide applications (one farmer reported saving \$25 ha^{-1} because he did not need an initial burn-down herbicide application when no-till planting corn into the weed-free residue of winter-killed forage radish). While any one of these savings may not surpass the costs of growing a cover crop, a combination of two of them would almost certainly do so.

In terms of yield response, our data indicate profitable responses at some sites. At our site with no-till managed sandy soils, the radish plots produced about \$110 ha^{-1} extra soybean (450 kg ha^{-1}) in 2004 and about the same value in additional corn grain (900 kg ha^{-1}) in 2005, compared to the no-cover plots. We estimate the cost of using forage radish (seed and sowing) or rapeseed (seed, sowing and termination herbicide) cover crops at about \$65 ha^{-1}. Therefore, at this site, the return to using a brassica cover crop was about \$50 ha^{-1}.

Spreading interest

We estimate that we have reached about 700 people, including 500 farmers, in face-to-face events (field days, twilight tours, conferences) during the past 3 years of the project. We have been joined in this effort by collaborating extension educators, and mainstream and alternative print and electronic media have picked up the 'story'.[14,15] The State of Maryland has now included a brassica (rapeseed) in its cover crop subsidy program aimed at reducing N loading to the Chesapeake Bay. Our free-of-charge distribution of small packets (0.5–5 kg) of brassica cover crop seeds to more than 80 farmers or extension agents has proved to be a highly effective method of generating interest. We included a postcard response form with the seed and about half of the seed-ecipients contacted us via the postcards, or by phone or e-mail, to let us know how they were using the seed. Their applications ranged from attempting to 'bio-drill' compacted pasture soils to suppressing weeds in the normally bare ground along rows of nursery trees. We certainly gained many ideas that we would not have thought of without these informal collaborations.

All in all, the interdisciplinary nature of this research has been invigorating and the collaboration with farmers has been inspiring. We feel that we have learned as much from farmers as they have learned from us. They have been very receptive to the idea of trying new multiple-function cover crops and have done more to promote new cover cropping practices than we could hope to do.

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