# POTENTIAL AND LIMITATIONS OF COVER CROPS, LIVING MULCHES, AND PERENNIALS TO REDUCE NUTRIENT LOSSES TO WATER SOURCES FROM AGRICULTURAL FIELDS

T.C. Kaspar, Plant Physiologist, USDA-ARS, National Soil Tilth Laboratory;
E.J. Kladivko, Professor of Soil Physics, Agronomy Dept., Purdue University;
J.W. Singer, Research Agronomist, USDA-ARS, National Soil Tilth Laboratory
S. Morse, Senior Fellow, Agronomy/Plant Genetics, University of Minnesota
D. Mutch, Cover Crops/Field Crops IPM Specialist, KBS, Michigan State University

## I) Introduction

A) <u>What is the definition of the specific practice that would be recommended?</u>

1) Cover crops, living mulches, and perennial crops can extend the active growing season of agricultural systems. Lengthening the growing season, increases the total annual water and nutrient uptake while providing living soil cover and reducing nutrient and sediment losses into surface waters. The conversion of the prairies or other native vegetation ecosystems to summer annual grain crops resulted in a shortening of the growing season. Summer annual grain crops, like corn and soybean, accumulate water and nutrients and provide living cover for only about four months (mid-May to mid-Sept), whereas in natural systems some living plants are actively accumulating nutrients and water whenever the ground is not frozen (at least 7 months; April-Oct.). As a result, soil nutrients in summer annual cropping systems are susceptible to losses in part because there are extended periods during each year when living plants are not removing nutrients from the soil.

2) Cover crops are literally "crops that cover the soil" and may be used to reduce soil erosion, reduce nitrogen leaching, provide weed and pest suppression, and increase soil organic matter (Fig. 1). Winter cover crops are planted shortly before or soon after harvest of the main grain crop and are killed before or soon after planting of the next grain crop. Small grains, such as oat, winter wheat, barley, triticale, and winter rye, are excellent winter cover crops because they grow rapidly in cool weather, withstand moderate frost, and their seed is relatively inexpensive or can be produced on site. Many varieties of winter rye, triticale, and winter wheat can overwinter in the Upper Mississippi basin and continue growing in the spring. These winter-hardy cover crops must be killed with herbicides or tillage prior to planting corn or soybean. Oat, barley, spring wheat, and some rye, winter wheat, and triticale varieties are not winter-hardy in this region. Because the non-winter-hardy small grains don't survive the winter, they don't need to killed prior to planting the main crop, but they also don't produce as much shoot or root growth as winter-hardy small grains planted after full season grain crops. When the non-winter-hardy small grains are seeded in August after short-season crops or by overseeding, they can produce substantial biomass. Legumes are also excellent cover crops and they fix nitrogen as an added benefit. However, if nitrogen is available in the soil, legumes will take up N rather than fix it. Legumes, however, usually don't grow as well as the small grains during the fall and winter months, they accumulate less soil N than the small grains, their seed is relatively expensive, and most must be killed with tillage or herbicides in the spring. Grasses (such as

annual ryegrass) and brassicas (such as oilseed radish, oriental mustard, and forage radish) are also potential cover crops. Cool season grasses and brassicas grow well in cool weather, but winter hardiness is species and location dependent. The brassicas have been shown to suppress nematodes, some diseases, and winter annual weeds. Seed costs are higher and seed is usually more difficult to obtain than small grain seed.

3) Living mulches are defined by Hartwig and Ammon (2002) as cover crops planted either before or with a main crop and maintained as a living ground cover throughout the growing season (Fig. 2). Often the living mulches are perennial species and are maintained from year-to-year. Ideally the growth of the living mulch is suppressed when the main crop is growing and increases as the main crop matures or when it is no longer present. Perennial legumes (such as alfalfa, red clover, kura clover, birdsfoot trefoil, crownvetch, and white clover) and perennial grasses (such as orchardgrass, reed canarygrass, and turfgrasses) can be used as living mulches. Currently, living mulch systems are being used in vineyards and orchards, but their use in annual grain crop systems is mostly experimental at this time. The main problem with living mulch systems is that the living mulch competes with the main crop for water and nutrients, which can reduce main crop growth and yield. Living mulch management to reduce stress on the grain crop during the growing season needs to be improved before they will be widely adopted in annual grain crop systems.
4) Perennials are crops growing for multiple years from a single planting that would replace annual grain crops as the cash crop (Fig. 3). Currently, the most common perennials found in agricultural systems in the Upper Mississippi basin are forages (grasses and legumes) planted for hay, grazing, or pasture. Perennials also include tress and woody species grown for nut, fruit, or wood production (apples, grapes, hazelnuts, poplars, and walnuts). In the future, perennial biomass crops (switchgrass and poplar), and perennial grains and oil seed crops (Illinois bundleflower, wheat, sunflower, and flax) may become more important.

B) <u>What is the logic/process behind the practice?</u>

1) Soluble nutrients in the soil, like nitrate and dissolved phosphorus, are susceptible to leaching losses. When plants are present and actively growing they remove water and soluble nutrients from the soil and this decreases the downward movement of water and nutrients in the soil. Because cover crops, living mulches, and perennial crops grow earlier in the spring and later in the fall than annual grain crops, they extend the season of active water and nutrient uptake beyond that of annual grain crops. For all three of these practices the amount of nutrient uptake is proportional to the amount of growth of these plants. Ideally a cover crop or living mulch accumulates most of its nutrients when the main crop is not actively growing (or nutrient demand by the main crop is low) and when the nutrients accumulated would have been susceptible to leaching losses. Additionally, for cropping systems with cover crops and living mulches it is assumed that annual fertilizer applications are lower or the same as what would be applied to the main crops without cover crops. In the case of perennial cropping systems, the perennials are the main crop and for them to reduce nutrient losses relative to an annual grain crop they must maintain nutrient uptake for a larger portion of the year and they must be managed

in such a way as to minimize nutrient losses from applied fertilizers or manures. Less frequent tillage of perennials relative to annual crops also reduces mineralization of soil organic matter and nutrient loss, while the more established root systems scavenge nutrients from a larger soil volume.

2) Because cover crops, living mulches, and perennial crops increase surface cover, anchor residues (e.g. main crop residues for cover crops and living mulches), increase infiltration, and reduce both rill and interrill erosion, they reduce phosphorus, potassium, and pesticide losses and movement associated with soil erosion. Additionally, because these practices increase infiltration we would assume that they would reduce runoff volume and thus, losses of dissolved phosphorus, nitrogen, and pesticides in surface runoff.
3) Cover crops, living mulches, and perennial crops normally begin growth and water use earlier in the spring and then continue water uptake later into the fall than most annual grain crops. This extended period of water use normally reduces the volume of drainage water and thus, reduces leaching losses of nitrate and dissolved phosphorus.

**II) Potential**

A) <u>What are the estimated range and mid-range values for percent loss reductions given a defined "extent of practice application?</u>

1) Winter cover crops and rye cover crops specifically can reduce water flows, nitrate concentrations, and total nitrate load in tile drainage. Effectiveness of the rye cover crop varies with growth of the cover crop, weather, and management of the main crops. More growth of the cover crop will result in greater reductions in nitrate leaching, but growth of cover crops can be limited by cold temperatures, water stress, nutrient availability, and delays in establishment. Similarly, lack of precipitation and soil freezing may eliminate or greatly reduce nitrate leaching losses and thus, reduce the impact of the cover crop. Lastly, reducing N fertilizer rates and applying N fertilizer closer to the time of crop uptake will also reduce nitrate leaching and the impact of the cover crop. Reductions in nitrate load observed with a rye cover crop range from 13% in Minnesota to 94% in Kentucky (Table 1). We hypothesize that the smaller reduction in the nitrate load in the Minnesota study compared with the Kentucky study would be partly caused by less cover crop growth and frozen soils in Minnesota. Additionally, combining a winter cover crop with other nitrogen best management practices can also effectively reduce nitrate losses. A study in Indiana reduced nitrate loads by 61% with a reduction in fertilizer N rates and a winter wheat cover crop following the corn crop.
2) No direct information on nitrate losses is available for living mulches, but it is assumed that the reduction of N losses would be similar to or greater than that of cover crops because the living mulches would be present all year.
3) Perennial crops, like alfalfa, can result in extremely low nitrate concentrations and losses in drainage water, due to both nitrate uptake and water use. Compared with a continuous corn system, Randall et al., (1997) observed a 97% reduction in annual nitrate load with unfertilized (no N) alfalfa. Management of forage or pasture, however, using high rates of fertilizer or manure or intensive grazing may result in substantial nutrient losses. Additionally, killing, plowing down, or stresses, like drought, can cause substantial losses of N from legume perennial forages or pastures

unless another crop is present for N uptake. Thus, perennials can reduce nitrate losses substantially, especially if no nitrogen fertilizer is applied, but nitrate losses depend to some extent on management. However, we assume that perennials will usually lose substantially less N than annual grain crops if they receive similar amounts of N fertilizer.

4) Another way to consider the potential impact of cover crops, living mulches, and perennials may be to consider the cumulative impact that these practices could have in a more diversified and integrated agricultural system. A recent Minnesota study (Rolf et al., 2005) examined how diversifying cropland with more living cover, perennials, and longer season plants can impact water quality. Two side by side 160 acre fields were studied over three years. One field was planted to a corn-soybean rotation on 96% of the area. The other field had corn and soybeans on 46% of the area and integrated various small grains (30% of total area), alfalfa (14%) and native grasses (10%) into the cropping system. Each field received some nitrogen each year, with the more diverse system receiving on average slightly more total nitrogen, all from organic sources. Over the three year evaluation of the tile discharge, the more diverse system reduced average total annual nitrogen loss by 73% and stayed below the drinking water standard of 10 ppm.
5) All three of these practices should reduce losses of nutrients associated with soil erosion and surface runoff. In Iowa, rye and oat cover crops reduced rill erosion following soybean in a no-till system by 79 and 49%, respectively. We estimate that losses of P and K to surface waters, which are linked to sediment losses, might be reduced by a similar amount relative to no-till. Sharpley and Smith (1991) summarized research on the effect of cover crops on total P losses and found that the reductions in total P losses ranged from 54 to 94% (Table 2). They also pointed out, however, that the effects of cover crops on soluble P in runoff were more variable and did not always result in reductions. There is evidence that soluble P can be lost in runoff flowing over plant residues. However, plant water use and infiltration would be expected to increase with cover crops, living mulches, and perennial crops, which should reduce the volume of runoff.

B) <u>What is the predicted timing/delay and "seasonality" of reductions?</u>

1) Most nitrate losses in drainage water occur during the periods of the year when the ground is not frozen, the soil is near saturation, and the annual grain crop is not actively growing. In the northern part of the region this would be mostly from the spring thaw through mid-June. In much of the southern part of the region (Ohio, Indiana, Illinois, Missouri), nitrate losses would occur in late fall, winter, and early spring, when most of the drainage occurs.
2) Reductions of nitrate leaching losses are most likely to occur when the cover crop, living mulch, or perennial crop is actively growing and taking up nutrients. For many winter-hardy small grains and cool-season perennial species the most active period of growth occurs in late spring, although there is also growth in late fall. For cool season species that do not overwinter, such as oats, oilseed radish, oriental mustard, substantial fall growth can occur if they are planted early enough. Even the relatively small amount of growth in the fall seems to reduce nitrate concentrations in the late fall and winter in areas where flow occurs during this time. Additionally, after cover crop death in winter or spring there is a carryover

effect due to the nutrients previously taken up by the cover crop or immobilized during early stages of decomposition.

3) Reductions of nutrient losses associated with erosion would most likely occur during the winter and early spring, when runoff and erosion potential are greatest.

C) <u>What is the degree of confidence of estimations (what are we more sure of, what do we know is only "directionally correct," what do we need more information on)?</u>

1) Confidence is high that cover crops will reduce nitrate losses when reasonable establishment and growth occurs. Magnitude of reductions is dependent on the growth of the cover crops, management of annual grain crops, and weather in a given year. In some years there may be less reduction of nitrate losses because the cover crops do not grow very much or because there is not very much nitrate leaching even without cover crops. More information is needed on: range/feasibility of cover crops to the North and West; cover crops effects on P losses; reduction of nutrient losses by cover crops on a field or watershed scale; cultivar or species selection; time of planting and termination; seeding rate; and effect of multispecies mixtures.

2) Confidence is reasonably high that living mulches will reduce nitrate losses if reasonable growth of the living mulch occurs and growth of the main crop is not reduced too much by the living mulch. The magnitude of reductions depend on the growth of the living mulch when the annual grain crop is not taking up any or limited amounts of nutrients. In some years growth of the living mulch may be limited or the living mulch could reduce the annual grain crop growth, both of which may reduce annual nutrient uptake and lessen the beneficial effects.

3) Confidence is extremely high that perennial crops would significantly reduce nitrate losses compared with an annual grain crop, if the perennial crop is not fertilized with N fertilizers or manures. If a perennial crop receives N fertilizer or manures at rates comparable to annual grain crops, the losses would still be expected to be less than that from the annual grain crop system.

4) Confidence is extremely high that all three of these practices would substantially reduce nutrient losses associated with erosion and overland water flow. Amount of reduction is dependent on amount of growth, surface cover, and anchorage of residues

## III) Important Factors

A) <u>How do site conditions (soils, topography, hydrology, climate) affect effectiveness in reducing nutrient losses?</u>

1) Unknown based on research, but we would speculate that reductions in nitrate losses may be greater for soils that are high in organic matter, at lower positions in the landscape, and relatively wet or poorly drained (provided cover crop, living mulch, or perennial growth is not limited by excessive water). Because cover crops, living mulches, and perennials are very effective at reducing erosion we would speculate that these practices would reduce losses or movement of P and K from upper and steeply sloped landscape positions or from areas of the field where overland water flow occurs.

2) Climate differences across the Upper Mississippi basin will affect the seasonality and the effectiveness of cover crops, living mulches, and perennials. All three practices will likely be more effective in reducing nitrate loads where the soils are

not frozen the entire winter and where much of the annual drainage occurs throughout the fall and winter season, rather than in a short drainage period of March-June. Additionally, these practices will be more effective where the climate favors growth of these plants between late summer and early spring. For example, more cover crop growth would be expected in the southeastern part of the Upper Mississippi basin, which is warmer and wetter from Sept. to May, than in the northwestern part of this region, which is colder and drier from Sept. to May. In Iowa, we developed an empirical relationship between oat cover crop fall growth and temperature and precipitation. We then used that equation and 40 years of climate data to predict the average fall growth across Iowa. Fig. 4 shows that predicted oat cover crop fall growth varies from 900 to 400 kg $ha^{-1}$ from southeastern Iowa to northcentral Iowa. Certainly, other factors would also limit growth, but in general we would expect that this general climate trend for fall growth would hold and that trends for spring growth of rye would be similar. Effectiveness of perennial crops will depend on whether their periods of active growth and nutrient uptake coincide with the annual periods of water movement through the profile. For example we speculate that a perennial forage crop consisting of warm season grasses may not be very effective at reducing nutrient losses in the Upper Mississippi basin because these grasses are not actively growing during the normal periods of annual drainage.

3) Length of the cover crop growing season will also determine their effectiveness in reducing nutrient losses. In general, the longer the time between planting and termination of the cover crop, the greater the growth and nutrient uptake. Normally, cover crops are planted after harvest of a grain crop and terminated before planting of the next crop. This can result in relatively short cover crop growing seasons in the northern parts of the Upper Mississippi basin. Feyereisen et al. (2003) used modeling to predict that in most years a rye cover crop planted in southern Minnesota on Oct 15 would reduce nitrate losses in drainage water by at least 25 kg $ha^{-1}$ if terminated on May 1 and by at least 36 kg $ha^{-1}$ if terminated on June 1. Thus, extending the cover crop growing season by developing management strategies to establish cover crops before main crop harvest or to terminate cover crops after main crop planting would improve the effectiveness of cover crops in northern parts of the Upper Mississippi basin.

B) <u>How does a range of weather conditions affect effectiveness in reducing nutrient losses?</u>

1) Weather affects cover crops, living mulches, and perennial crops effectiveness in reducing nitrate losses in two ways. First, if weather conditions are such that N mineralization and nitrate leaching are not favored then cover crops will not show much of an advantage over no cover crops. For example, in Iowa in some years little if any nitrate leaching occurs either because the soil profile was not recharged with water between harvest and planting of the grain crops, because the soil surface layers froze before recharge occurred, or because the soil remained so cold that N mineralization was greatly reduced. Second, if weather conditions limit cover crop, living mulches, or perennials establishment or growth, then their effectiveness will be reduced. Dry conditions, very cold conditions, or freezing of the soil surface in the fall or spring will limit cover crop growth, but will also limit N mineralization and nitrate leaching.

## IV) Limitations

A) <u>In terms of physical constraints, what percent of crop acres could benefit from this practice?</u>

1) We estimate that cover crops would show some reduction in nitrate losses on 70 to 80% of all corn and soybean acres. Establishment on some acres would be limited because of lack of rainfall in some years, late planting because of harvest delays, and poor soil conditions at time of planting. Reductions in nitrate loss and cover crop growth would be diminished in the northern part of the region because of cold temperatures and frozen soil between main crops and because of less growth of the cover crops. Benefits and cover crop growth also would be limited in the western part of the region (unless irrigated) because of water limitations for cover crop growth and nitrate leaching. Crop acres with more diverse rotations than a corn-soybean rotation may have even better opportunities for cover crops. Short season crops like vegetables, sweet corn, corn silage, seed corn, and winter wheat would be particularly suited to cover crops.
2) Living mulch systems are not ready for widespread adoption at this time in the Upper Mississippi basin in annual grain crop rotations, but have significant potential to be an important management option in the future. Living mulch systems can and should be used in orchards, vineyards, and tree plantations.
3) In general, perennial crops are limited by availability of adapted or improved genotypes, demand, processing facilities, infrastructure, and markets. Markets exist for some perennial crops or their products, such as pasture raised beef, dairy products, and timber. Forage crops can be widely marketed, but even those markets could be quickly saturated if a considerable number of acres were converted from corn and soybean production to forage production. Increased demand for grass-fed meat and dairy products and for bioenergy produced by direct combustion or through cellulosic ethanol production could rapidly open up new markets. We speculate that 20 to 30% of corn and soybean acres could be converted to perennial crops, if development of improved genotypes, processing facilities, infrastructure, and markets were encouraged and supported.

B) <u>In terms of cost constraints, what are the annualized costs expressed as $ per pound reduction?</u>

1) Cost estimates for living mulch - alfalfa establishment year (approx. every 3rd yr):
   (a) Alfalfa seed 10 lb/ac at $3.00/lb
   (b) Custom rate for planting alfalfa with grain drill  $9.65/ac
   (c) Generic Glyphosate $20.00/gal, 2 appl./yr at rate of 0.33 qt/ac = $3.32/ac/yr
   (d) Custom rate for spraying herbicide 2 appl./yr at $4.75/ac/appl = $9.50/ac/yr
   (e) Chopping/mowing living mulch 2 operations/yr at $7.15/ac/op = $14.30/ac/yr
   (f) Total =$121.05/ac/3 yrs =$40.35/ac/yr
   (g) Estimates are based on custom rates for field operations, which include fuel, labor, and machinery costs. Assuming that alfalfa would need to be reestablished every 3rd year, which may be too conservative. Assume that other living mulch species would have similar costs. Estimates do not include any potential yield decreases of annual grain crops caused by living mulches.
2) Cost estimates for a perennial alfalfa crop establishment year (approx. every 3rd yr; may last longer):

(a) Alfalfa seed 15 lb/ac at $3.00/lb
(b) Custom rate for planting alfalfa with no-till grain drill $9.65/ac
(c) Generic Glyphosate $20.00/gal, rate applied 1qt/ac = $5.00/ac
(d) Custom rate for spraying herbicide $4.75/ac
(e) Total =$64.60/3 yrs =$21.53/yr
(f) Although costs for establishment of a perennial alfalfa crop are presented here, because alfalfa is replacing the annual grain crop the difference between the annual return for selling the alfalfa and the return for the "normal" annual grain crop could be considered as the cost of practice. In some cases, including alfalfa in a rotation can be more profitable than a corn-soybean rotation (Singer et al., 2003). Also, costs presented are for no-till and alfalfa is commonly established following tillage.

3) Cost estimates for a rye cover crop:
(a) Rye seed (bagged) $6.00/bu plant at 1 bu/ac
(b) Custom rate for planting rye with no-till grain drill $9.65/ac
(c) Generic Glyphosate $20.00/gal, rate applied 1qt/ac = $5.00/ac
(d) Custom rate for spraying herbicide $4.75/ac
(e) Total =$25.40/yr
(f) Estimates do not include any potential yield decreases of corn crop following a rye cover crop. Costs can be reduced by using bulk or bin seed and operator-owned equipment, and by assuming that glyphosate application is part of no-till program.

4) Costs per pound reduction of nitrate losses.
(a) Based on Iowa and Minnesota data for rye cover crops if we assume a range of 20 to 50 kg ha$^{-1}$ reduction in nitrate-N loss (equivalent to 17.8 to 44.6 lbs ac$^{-1}$) then the costs per pound of reduction would range from $1.42 to $0.57 per pound for cover crops, $1.21 to $0.48 per pound for perennial alfalfa, and $2.27 to $0.90 per pound for an alfalfa living mulch. Costs per pound will vary and may be very high in years when little or no nitrogen is lost or when the cover crop, living mulch, or perennial crop does not establish or fails. Also, actual farmer costs are expected to be lower than custom rates on which our calculations are based and other environmental benefits are not credited to the practices.
(b) This may not be an appropriate question for some current or potential perennial-based systems because they are or may be economically viable through the sale of the perennial crop or its by-products and would have no cost for reduction of nitrate losses. Singer et al. (2003) found equal or greater returns for a five-year rotation, which included 3 years of alfalfa, than for a corn-soybean rotation. Additionally, a University of Wisconsin study (Kriegl and McNair, 2005) documents a 90% higher net income per cow from grazing based dairy operations than from confinement dairy farms. Additionally, increasing consumer interest in 100% grass-fed meat may also improve the profitability of forage or pasture perennial crops. The economics of other potential perennial systems, such as biomass energy, oil seed and grain crops has yet to be determined.

(c) Costs per pound of reduction of nitrate losses do not consider the other benefits of cover crops, living mulches, and perennial crops. These systems would result in agroecosystem benefits such as increased soil organic matter, reduced surface runoff of precipitation, increased wildlife diversity, reduced erosion, and increased diversity of soil organisms.

C) <u>In terms of production risks, will crop yields be reduced and/or be more variable?</u>

1) Corn yields may be reduced following winter-hardy small grain cover crops that are killed immediately before corn planting. We believe that most of this yield reduction is caused by a "rotation effect" similar to that of continuous corn. Yield reduction can be minimized by killing small grain cover crops 14 days before corn planting and using starter fertilizer. Corn yields following an oat cover crop, which dies when the ground freezes in the fall, or a legume cover crop are not reduced. Soybean yields are not reduced following any small grain cover crop unless low soil water content limits soybean germination and emergence. There is also a risk that the cover crop will not be completely killed the first time it is sprayed or tilled in spring. This would then require additional operations and may increase the risk of a yield reduction in the cash crop.
2) Living mulches can reduce corn and soybean yields by competing for water and nutrients during the growing season if they are not sufficiently suppressed by management or if the growing season is abnormally hot and dry.
3) Perennial crops such as alfalfa or forage or hay crops, which are replacements for the annual grain main crops, have somewhat different production risks than corn and soybean. For example, too much summer rainfall during drying of the hay is one such risk. Tree crops or woody perennials have different pests and in general spread weather related risks over many years. Fruit or nut crops can be highly susceptible to late spring frosts.

D) <u>Are there other limitations such as negative attitudes, lack of knowledge, additional equipment needed?</u>

1) Many producers are not familiar with cover crops, living mulches, or perennials.
2) Living mulch systems are not widely used with annual grain crops, due to lack of knowledge about how to manage these systems to reduce living mulch competition with the grain crop.
3) A grain drill is needed for planting many of cover crop, living mulch, and perennial species.
4) Perennial forage or hay crops require equipment (mowers, rakes, balers) not required for corn and soybean production.
5) Timeliness of cover crop and living mulch field operations in spring and fall will be limited by machinery and labor required for field operations associated with planting and harvesting of annual grain crops.
6) These systems are more complicated to manage and implement than some other practices to reduce nitrate losses such as reducing N fertilizer rates and applying N fertilizer in the spring rather than the fall. The additional management and risk are considered "a hassle" by many farmers.
7) Most producers in the Upper Mississippi basin would not see an immediate monetary benefit or reduction in costs from including cover crops and living

mulches in their farming systems and would have increased cost and labor to implement the practice.

8) There are limited markets for perennials such as harvested forages, including alfalfa, orchardgrass, red clover, and smooth bromegrass.
9) There is a great need for development of new perennial crops or new uses for well-known perennials.
10) There are limited seed sources and adapted cultivars or genotypes available for cover crops, living mulches, and some perennials. To our knowledge, there are no presently available cultivars that have been bred specifically for use as cover crops or living mulches.
11) There is a great need to quantify the nutrient loss reductions of these systems under a range of locations and growing conditions.
12) Cover crops, living mulches, and perennial crops do not enjoy the government risk protections that are provided to program crops under federal farm policy.
13) The nutrient losses of managed pastures need to be compared not only with the nutrient losses of corn-soybean annual grain crop systems but also with nutrient losses from a farming system with confined beef or dairy cattle.

## V) Other Issues

A) Are there any common misconceptions about this practice that need to be corrected?

1) There may be a misconception that pasture- or forage-based systems always have nutrient loss rates much less than annual grain crops because they are perennial. However, management of these systems for high productivity or application of high rates of fertilizer or manure may result in substantial nutrient losses.
2) There may be a misconception that pasture- or forage-based systems are always less profitable than annual grain crop systems.
3) There may be a misconception that cover crops, living mulches, and perennial crops will always result in substantial reductions in nutrient losses when in some years nutrients losses may be very low without these practices because of weather, management, and main crop growth. Additionally, in some years the cover crop, living mulches, and perennial crops may fail to establish or grow poorly.
4) There may be a misconception that fertilizer management alone will reduce nutrient losses from agricultural systems to environmentally acceptable levels and that cover crops, living mulches, and perennials are not needed. Because substantial amounts of nutrients originate from soil mineralization and decomposition of plant residues and because even optimum economic rates result in substantial nutrient losses, fertilizer management alone will not eliminate nutrient contamination of surface waters.
5) There may be a misconception that one management practice can be used to address nutrient losses to surface waters, when in reality a combination of practices will be needed to effectively address this problem.

B) Are there any potential positive or negative effects on other resources (e.g., soil, air, wildlife)?

1) Soil organic matter increases and soil quality improves from use of most cover crops, living mulches, forages, or perennial crops.
2) These systems may also reduce some pest and disease pressures (nematodes, disease, insects, weeds) but may also increase others (rodents, insects, weeds).

3) These systems increase plant diversity and provide food and cover for wildlife.
4) These systems reduce wind and water erosion and sediment load to surface waters.
5) These systems may improve water infiltration and help to remove excess water from the soil.
6) These systems may reduce surface runoff, concentrated or channel water flow, residue transport, accumulation of water in low areas of fields, and flooding potential.
7) These systems increase carbon sequestration in soils.
8) Perennial crops provide new cropping and market options for producers.
9) These systems could be used as a mechanism to make federal agricultural payments to producers in exchange for ecological benefits that would not conflict with World Trade Organization guidelines.

C) <u>What new information/research is needed to enhance the practice and/or accurately assess its benefits?</u>

1) Research is needed on adaptation of these systems to more northerly climates including: better adapted cultivars or species, strategies for quick establishment in fall, and consistent control in spring.
2) Information is needed on the potential geographic range of these practices.
3) Adaptation of water quality models to include cover crops, living mulches, and perennials is needed to estimate environmental benefits of these practices.
4) Information is needed on when to kill cover crops to optimize N uptake and N release for the cash crop, given that weather is variable and unpredictable.
5) Information is needed on long term cycling and balance of N and C in these systems and whether N fertilizer rates can be reduced in future due to improvements in SOM and N cycling.
6) Research is needed on management strategies to use cover crops and living mulches to trap N from manure application and recycle the N at an appropriate time for the next crop.
7) Screening, selection, and breeding programs are needed for new cultivars, genotypes, and species for use as cover crops, living mulches, or perennials.
8) Discovery and development of new oil, fiber, starch, or chemical products derived from perennial plants is needed.
9) Development of new production, harvesting, transporting, and processing technologies are needed for perennial crops.
10) Develop, strengthen, and support existing markets for products of perennial crops.
11) The economic viability of these systems need to be reevaluated in response to dramatic increases in fuel and energy costs.
12) Guidelines are needed for site/soil/landscape specific application of these practices to target areas in fields susceptible to nutrient loss.
13) Research is needed on minimizing the impacts on growth and yield of main cash crops by cover crops and living mulches.
14) Research is needed on the nutrient losses from intensively managed pastures and hay fields.
15) Research is needed on determining the effect of cover crops, living mulches, and perennial crops on P losses.

16) New management practices are needed to reduce the costs of implementing cover crops and living mulches.
17) Research is needed to evaluate cover crops and living mulches for biosuppression of nematodes, insects, and diseases.
18) Research is needed to evaluate cover crops, living mulches, and perennials for low input systems.
19) New strategies are needed for dissemination of information concerning these systems to overcome cultural and societal reluctance in both rural and urban populations to implement and accept these systems.
20) Quantification of the direct and indirect ecological benefits of these systems in diverse locations over a number of years is needed.
21) Watershed scale implementation projects are needed to access the potential for larger scale outcomes from these practices on water quality.

## VI Interpretative Summary

Cover Crops

Site conditions:

Cover crops may be less effective in the northern parts of the region because cold temperatures in late fall, winter and spring will limit cover crop establishment and growth.

Water quality improvement:

Reductions in nitrate load observed with a cover crop range from 13% in Minnesota to 94% in Kentucky.

Reductions in total P losses with cover crops ranged from 54 to 94%.

Cost:

Based on custom rates and bagged seed, establishment of a rye cover crop may cost up to $25/ac and costs per pound of N loss prevented may be $1.42 to $0.57/lb.

Extent of area:

We estimate that cover crops would show some reduction in nitrate losses on 70 to 80% of all corn and soybean acres.

Limitations for adoption:

Cover crops require time and money to establish and don’t provide short-term economic returns.

Many producers are not familiar with cover crops and their management.

Impact on other resources:

Corn yields may be reduced following winter-hardy small grain cover crops that are not killed until immediately before corn planting. This yield reduction can be managed by killing the cover crop 14 days before corn planting. In general, soybean yields are not affected by cover crops, if managed properly.

## Living Mulches

### Site conditions:

Living mulches may be less effective and will compete more with the main crop in the western parts of the region because of increasing frequency of drought and reduced precipitation during the growing season.

### Water quality improvement:

No direct information on nitrate phosphorus losses is available for living mulches, but it is assumed that the reduction of N and P losses would be similar to or greater than that of cover crops because the living mulches would be present all year rather than part of the year like cover crops.

### Cost:

Establishment of an alfalfa living mulch may cost up to 40.35/ac/yr and costs per pound of N loss prevented may be $2.27 to $0.90/lb. We expect these costs to decrease as management improves.

### Extent of area:

Currently, living mulches are not ready for widespread adoption in grain cropping systems, but may be in the future. Living mulches can and should be used in orchards, vineyards, and tree plantations.

### Limitations for adoption:

Information is needed on how to manage living mulch systems to reduce competition with the grain crop.

Cultivars or genotypes of perennial forage species suitable for use as living mulches are not available.

### Impact on other resources:

Living mulches can reduce corn and soybean yields by competing for water and nutrients during the growing season if they are not sufficiently suppressed by management or if the growing season is abnormally hot and dry.

## Perennial Crops

### Site conditions:

Perennial crops should be effective at reducing nutrient losses throughout the region.

### Water quality improvement:

Nitrate and phosphorus losses with perennials is assumed to be less than or equal to that of cropping systems with grain crops and cover crops. Nutrient loss reductions relative to grain cropping systems can be above 90%, but are partly dependent on fertility management of the perennial.

Cost:

Costs for establishment of perennials are relatively high, but unlike cover crops and living mulches, perennials produce significant economic returns. Because they replace the annual grain crop, it is more appropriate to compare their returns with those of grain cropping systems that are appropriate for a particular location.

Extent of area:

Perennial crops could be adopted throughout the region, but are limited by demand, processing facilities, infrastructure, and markets. We speculate that 20 to 30% of corn and soybean acres could be converted to perennial crops, if infrastructure, processing facilities, and markets were encouraged and supported.

Limitations for adoption:

Perennial crops are limited by demand, processing facilities, infrastructure, and markets.

There is a great need for development of new perennial crops or new uses for well-known perennials.

Impact on other resources:

By removing land from corn and soybean production, adoption of perennials may positively influence grain prices.

**References**


Angle, J.S., G. McClung, M.C. McIntosh, P.M. Thomas, and D.C. Wolf. 1984. Nutrient losses in runoff from conventional and no-till watersheds. J. Environ. Qual. 13:431-435.

Brandi-Dohrn, F.M., R.P. Dick, M. Hess, S.M. Kauffman, D.D.J. Hemphill, and J.S. Selker. 1997. Nitrate leaching under a cereal rye cover crop. J. Environ. Qual. 26:181-188.

Campbell, C.A., G.P. Lafand, R.P. Zentner, and Y.W. Jame. 1994. Nitrate leaching in a udic haploboroll as influenced by fertilization and legumes. J. Environ. Qual. 23:195-201

Dinnes, D.L., D.L. Karlen, D.B. Jaynes, T.C. Kaspar, J.L. Hatfield, T.S. Colvin, and C.A. Cambardella. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. Agron. J. 94:153-171.

Feyereisen, G.W., A. Mendez, G.R. Sands, B.N. Wilson, P.M. Porter, and J.S. Strock. 2003. Probabilistic assessment of the potential for winter cereal rye to reduce field nitrate-nitrogen loss in southwestern Minnesota. ASAE Paper No. 032323. American Society of Agricultural Engineers. St. Joseph, MI.

Glover, J. 2003. Characteristics and impacts of annual vs. perennial systems. Proc. Sod Based Cropping System Conf. 20-21 Feb., 2003, Quincy, FL pp 1-6.

Hall, J.K., N.L. Hartwig, and L.D. Hoffman. 1984. Cyanazine losses in runoff from no-tillage corn in "living mulch" and dead mulches vs. unmulched, conventional tillage. J. Environ. Qual. 13:105-110.

Hartwig, N.L., and H.U. Ammon. 2002. Cover crops and living mulches. Weed Sci. 50:688-699.

Jaynes, D.B., T.C. Kaspar, T.B. Moorman, and T.B. Parkin. 2004. Potential methods for reducing nitrate losses in artificially drained fields. p. 59-69. In R. Cooke. (ed.) Proceedings of the Eighth International Drainage Symposium, Sacramento, CA. 21-24 March 2004. ASAE, St. Joseph, MI.

Karraker, P.E., C.E. Bortner, and E.N. Fergus. 1950. Nitrogen balance in lysimeters as affected by growing Kentucky bluegrass and certain legumes separately and together. Bull. 557. Ky. Agr. Exp. Sta. Lexington, KY.

Kaspar, Z.C., J.K. Radke, and J.M. Laflen. 2001. Small grain cover crops and wheel traffic effects on infiltration, runoff, and erosion. J. Soil Water Conserv. 56:160-164.

Kladivko, E. J., Frankenberger, J. R., Jaynes, D. B., Meek, D. W., Jenkinson, B. J., Fausey, N. R. 2004. Nitrate leaching to subsurface drains as affected by drain spacing and changes in crop production system. J. Environ. Qual. 33:1803-1813.

Kriegl, T., and R. McNair. 2005. Pastures of plenty: Financial performance of Wisconsin grazing dairy farms. University of Wisconsin, Madison, WI. Available at http://www.cias.wisc.edu/pdf/grzgfin.pdf (Verified 12-13-05).

Langdale, G.W., R.L. Blevins, D.L. Karlen, D.K. McCool, M.A. Nearing, E.L. Skidmore, A.W. Thomas, D.D. Tyler, and J.R. Williams. 1991. Cover crop effects on soil erosion by wind and water. p. 15-22. *In* W.L. Hargrove (ed.) Cover crops for clean water. Proceedings of International Conference, Jackson, TN. 9-11 Apr. 1991. Soil and Water Conservation Society of America, Ankeny, IA.

Langdale, G.W., R.A. Leonard, and A.W. Thomas. 1985. Conservation practice effects on phosphorus losses from southern Piedmont watersheds. J. Soil Water Conserv. 40:157-160.

Martinez, J., and G. Guirard. 1990. A lysimeter study of the effects of a ryegrass catch crop during a winter wheat/maize rotation on nitrate leaching and on the following crop. J. Soil Sci. 41:5-16.

McCracken, D.V., M.S. Smith, J.H. Grove, C.T. MacKown, and R.L. Blevins. 1994. Nitrate leaching as influenced by cover cropping and nitrogen source. Soil Sci. Soc. Am. J. 58:1476-1483.

Meisinger, J.J., W.L. Hargrove, R.L. Mikkelsen, J.R. Williams, and V.W. Benson. 1991. Effects of cover crops on groundwater quality. p. 57-68. *In* W.L. Hargrove (ed.) Cover crops for clean water. Proc. of an international conf. April 9-11, 1991. Jackson, TN. Soil and Water Conservation Society, Ankeny, IA.

Morgan, M.F., H.G.M. Jacobson, and S.B. LeCompte Jr. 1942. Drainage water losses from a sandy soil as affected by cropping and cover crops. Bull. 466. Conn. Agr. Exp. Sta., New Haven, CT.

Nielsen, N.E., and H.E. Jensen. 1985. Soil mineral nitrogen as affected by undersown catch crops. *In* Assessment of nitrogen fertilizer requirement. Proc. NW-European Study Ground for the Assessment of Nitrogen Fertilizer Requirement. Netherlands Fert. Inst,. Haren, The Netherlands.

Owens, L.B., and J.V. Bonta. 2004. Reduction of nitrate leaching with haying or grazing and omission of nitrogen fertilizer. J. Environ. Qual. 33:1230-1237

Pesant, A.R., J.L. Dionne, and J. Genest. 1987. Soil and nutrient losses in surface runoff from conventional and no-till corn systems. Can. J. Soil Sci. 67:835-843.

Randall, G.W., D.R. Huggins, M.P. Russelle, D.J. Fuchs, W.W. Nelson, and J.L. Anderson. 1997. Nitrate losses through subsurface tile drainage in Conservation Reserve Program, alfalfa, and row crop systems. J. Environ. Qual. 26:1240-1247.

Ritter, W.F., R.W. Scarborough, and A.E.M. Chirnside. 1998. Winter cover crops as a best management practice for reducing nitrogen leaching. J. Contam. Hydrol. 34:1-15.

Rolf, K. 2005. Evaluation of alternative versus conventional farming systems impacts on subsurface drainage flow and water quality. M.S. Thesis. University of Minnesota, St. Paul.

Ryden, J.C., P.R. Ball, and E.A. Garwood. 1984. Nitrate leaching from grassland. Nature (London) 311:50-53.

Sharpley, A.N. and S.J. Smith. 1991. Effects of cover crops on surface water quality. p. 41-49. *In* W.L. Hargrove (ed.) Cover crops for clean water. Proc. of an international conf. April 9-11, 1991. Jackson, TN. Soil and Water Conservation Society, Ankeny, IA.

Singer, J.W., C.A. Chase, and D.L. Karlen. 2003. Profitability of various corn, soybean, wheat, and alfalfa cropping systems. [Online]. Crop Management doi:10.1094/CM-2003-0130-01-RS.

Staver, K.W., and R.B. Brinsfield. 1990. Patterns of soil nitrate availability in corn production systems: Implications for reducing groundwater contamination. J. Soil Water Conserv. 45:318-323.

Stout, W.L., S.L. Fales, L.D. Muller, R.R. Schnabel, and S.R. Weaver. 2000. Water quality implications of nitrate leaching from intensively grazed pasture swards in the northeast US. Agric. Ecosyst. Environ. 77:203-210.

Strock, J. S., Porter, P. M., Russelle, M. P. 2004.Cover cropping to reduce nitrate loss through subsurface drainage in the northern U.S. Corn Belt. J. Environ. Qual. 33:1010-1016.

Wyland, L.J., L.E. Jackson, W.E. Chaney, K. Klonsky, S.T. Kolke, and B. Kimple. 1996. Winter cover crops in a vegetable cropping system: Impacts on nitrate leaching, soil water, crop yield, pests and management costs. Agric. Ecosys. Environ. 59:1-17.

Yoo, K.H., J.T. Touchton, and R.H. Walker. 1988. Runoff, sediment and nutrient losses from various tillage systems of cotton. Soil Tillage Res. 12:13-24.

**Web Sites**

Singer, J., T. Kaspar, P. Pedersen. 2005. Small grain cover crops for corn and soybean [Online]. University Extension, Iowa State University, Ames, IA. http://extension.agron.iastate.edu/soybean/documents/PM1999._covercrops.pdf (Verified 12-13-05).

Sullivan, P. and S. Diver. 2001. Overview of cover crops and green manures [Online]. Appropriate Technology Transfer for Rural Areas (ATTRA), University of Arkansas, Fayetteville, AR. Available at http://www.attra.org/attra-pub/covercrop.html (Verified 8-16-05).

Sustainable Agriculture Network. 1998. Managing cover crops profitably [Online]. Sustainable Agriculture Network. USDA-ARS, National Agricultural Library, Beltsville, MD. Available at http://www.sare.org/publications/covercrops/covercrops.pdf (Verified 8-16-05).

UC SAREP. 2002. Cover crop resource page [Online]. University of California, Sustainable Agriculture Research and Education Program, Davis CA. Available at http://www.sarep.ucdavis.edu/ccrop/ (Verified 8-16-05).

Wilson, R., J. Smith, and R. Moomaw. 1993. Cover crop use in crop production systems [Online]. NebGuide. G93-1146-A Cooperative Extension, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln. Available at http://www.ianr.unl.edu/pubs/fieldcrops/g1146.htm (Verified 8-16-05).

Table 1. Literature summary of percent reduction in N leaching losses due to rye or ryegrass winter cover crops. Adapted in part from Meisinger et al., 1991.

| Reference | Location | Cover Crop | % Reduction in N leaching |
|---|---|---|---|
| Morgan et al., 1942 | Connecticut, U.S. | Rye | 66 |
| Karraker et al., 1950 | Kentucky, U.S. | Rye | 74 |
| Nielsen & Jensen, 1985 | Denmark | Ryegrass | 62 |
| Martinez & Guirard, 1990 | France | Ryegrass | 63 |
| Staver & Brinsfield, 1990 | Maryland, U.S. | Rye | 77 |
| McCracken et al., 1994 | Kentucky, U.S. | Rye | 94 |
| Wyland et al., 1996 | California, U.S. | Rye | 65-70 |
| Brandi-Dohrn et al., 1997 | Oregon, U.S. | Rye | 32-42 |
| Ritter et al., 1998 | Delaware, U.S. | Rye | 30 |
| Kladivko et al., 2004 | Indiana, U.S. | Winter wheat + less fert. | 61 |
| Jaynes et al., 2004 | Iowa, U.S. | Rye | 62 |
| Strock et al., 2004 | Minnesota, U.S. | Rye | 13 |

Table 2. Literature summary of percent reduction in total P losses in runoff due to barley, winter wheat, or legume winter cover crops. Adapted from Sharpley et al., 1991.

| Reference | Location | Cover Crop | % Reduction in Total P Losses in Runoff |
|---|---|---|---|
| Angle et al., 1984 | Maryland, U.S. | Barley | 92 |
| Langdale et al., 1985 | Georgia, U.S. | Rye | 66 |
| Pesant et al., 1987 | Quebec, Canada | Alfalfa/timothy | 94 |
| Yoo et al., 1988 | Alabama, U.S. | Wheat | 54 |

**Figure 1 Rye winter cover crop in April planted following corn silage.**

**Figure 2. Mustard living mulch growing in a corn crop.**

Figure 3. Perennial grass pasture system.

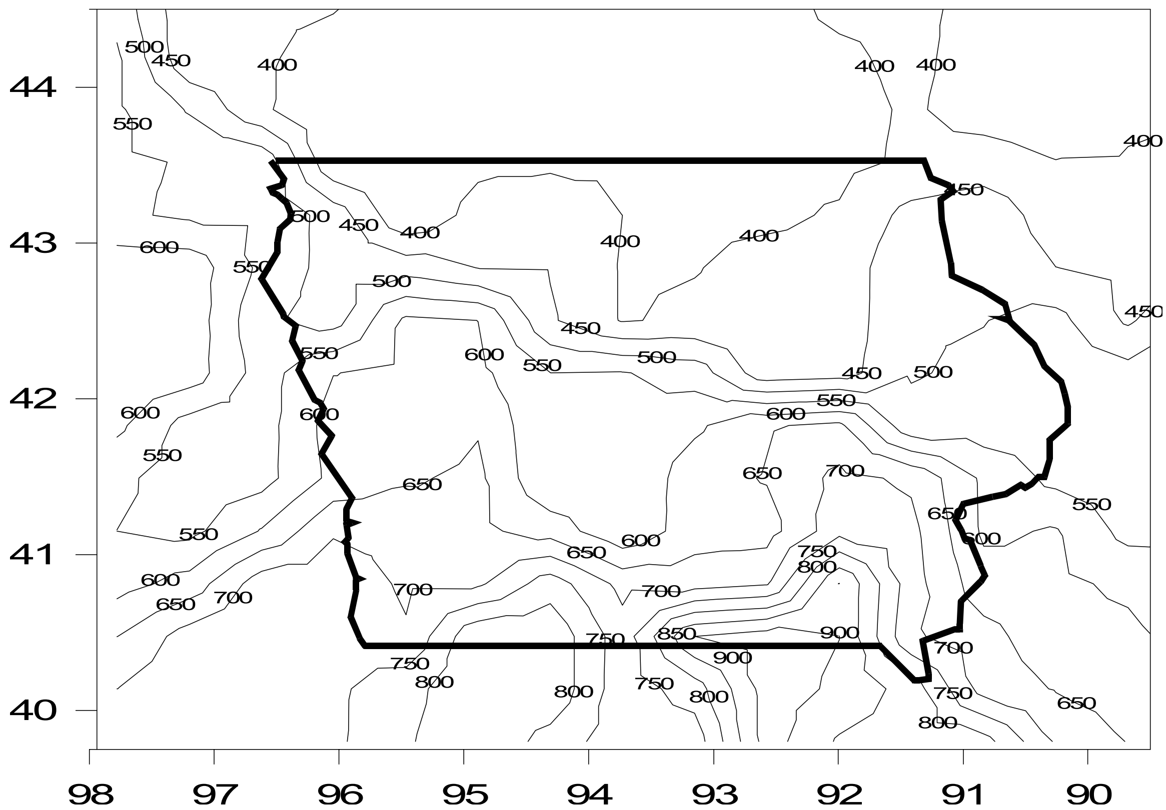


Fig. 4. Contour map for predicted fall production of oat shoot dry matter (kg/ha) vs latitude and longitude in Iowa.