

## INTEGRATED CROP-LIVESTOCK SYSTEMS

# Use of cover crops with integrated crop-livestock production systems

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Cover crops are of increasing interest in the hopes of solving some of the problems of contemporary agriculture. Some advantages of cover crops include holding the soil, thereby reducing erosion between monocultures (43); improving soil tilth, which increases water infiltration rates, thus increasing water and nutrient retention and cycling in agroecosystems (21); providing a targeted competitor that can compete with weeds and perhaps lessen dependence upon herbicides (19, 42); creating a disease break in short rotations of crops that share similar pathogens (31); serving as a nitrogen (N) trap to secure unutilized fertilizer within reach of the next crop (24); and, if leguminous, to provide biologically fixed N to the cropping system, thereby reducing the consumption of N fertilizer and, therefore, energy (14, 37).

All these advantages have been discussed, studied, and, to varying degrees, proven. The ultimate effect has been improved soil and water quality, which is the theme of this publication.

While each of these individual functions of a cover crop might be proven effective, it remains difficult to economically justify cover crops to practicing farmers (1). Planting and caring for a crop that apparently serves no immediate economic and harvestable purpose is both a foreign and unknown practice in much of the world. It is our contention that the

successful implementation of a cover crop, unless mandated or subsidized, may only come from a complete system in which the cover crop is both an integral component and has immediate economic value to the farmer. Such immediate value could come from incorporating ruminant livestock into the crop production system.

In addition, the integration of improved grazing and forage systems with beef cattle or sheep can reduce soil erosion and fertilizer needs. These ruminants fit into such a system because of their unique ability to utilize forages and prosper with minimal management. Profitable systems of ruminant production maximize forage use by the grazing animal and minimize fertilization, grain feeding, and the use of purchased supplemental feeds. Ruminant production is also a value-added enterprise because livestock and crop production can be mutually supportive. The animals can graze or be fed forages, including cover crops, that do not compete with humans for food and cycle nutrients through the decomposition of manure (6). The integration of economical livestock production systems with available forage resources can result in an economically profitable, environmentally sound, and biologically efficient alternative for those farmers who choose to invest the time and management necessary to make them successful.

### Cover crops as pasture

Agriculture rose from several regions of the globe that were characterized by diverse topography, soils, climate, and plant and animal communities (11). It was under such circumstances, perhaps, that the ecosystem itself demonstrated the sudden and dramatic impact humans could have upon the type

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of plants that grew or the behavior and accessibility of animals for hunting. Agriculture must have come from these observations and the notion that a concentrated harvest from some specific part of the food chain might ease the overall burden of food gathering.

In the thousands of years since the beginnings of agriculture, we have suffered a dilemma. Do we specialize, ease, and simplify our ecological surroundings to make our agricultural endeavors more convenient? Or, do we maintain the diverse genetics and complex ecology of plants and animals we know are necessary to perpetuate the system itself? The use of cover crops is one means of undomesticating the agricultural production system. Cover crops complicate the entire farm in which they are used. Just as scientists study individual cover crop characteristics and performance, so too do farmers often initially adopt the use of cover crops solely for a single purpose, such as erosion reduction or N<sub>2</sub>-fixing. Both the scientist and the practitioner soon realize, however, the broad effects that cover crops can have across the entire farming system.

While the cover crop does have a function within the cropping system, it also has the form of temporary pasture, or ley. Whether grass or legume, thinking of the cover crop as a temporary pasture can add immediate and unquestionable economic value to its use. By serving as a grazing resource for ruminant animals, the cover crops can be a high-quality source of feed. The presence of grazing livestock can also improve the pasture and succeeding cash crops if properly managed.

Many of the common cover crops offer excellent nutritional opportunities for ruminant livestock. Winter wheat (*Triticum aestivum* L.) grown for grain has long served as fall and winter pasture in the central and southern Plains (9). This practice could be used more widely in the North if producers used winter rye (*Secale cereale* L.). Such nonleguminous pastures provide excellent nutrition to breed and grow livestock.

Leguminous cover crops can also provide high-quality hay or grazing, although with certain legumes bloat or other antinutritional factors may have to be managed closely. Legumes are effective in improving animal performance when grazed and persist well in rotational grazing systems (16). Legumes have higher concentrations of crude protein, total nonstructural carbohydrates, and digestible dry matter, with a lower concentration of cell-wall constituents (fiber), compared with grasses (17). Therefore, legumes can be effective in supplementing lower-quality forages when added to the diet at the rate of 15%-30%. The addition of alfalfa may increase rate, extent, and overall digestibility of the diet. Brandt and Klopfenstein (7) found that the quality of the legume influences the amount needed for this response (15% high-quality alfalfa versus 30% medium-quality alfalfa). Legumes used in a crop rotation as a source of N would be available for this type of supplemental cattle feeding. Though limitations exist, cover crops, by their very nature of being young, temporary vegetative covers, make excellent quality forage.

The details, time, and skill required to manage both crops and livestock are obvious adoption barriers to seeing cover crops as pasture. It might be the next step, however, in rediscovery of the benefits contained within our undomesticated

and native ecosystems. We have demonstrated the advantages of mimicking native communities by extending the time in which vegetation grows through cover crops (22). Will we be equally willing to deal with the complexities of cycling at least a portion of it locally through ruminant animals?

## Livestock and cover crop performance

Cover crop pastures and livestock compliment each other. The need for legume-based cover crops has come from recognizing their need in maintaining long-term soil fertility for succeeding crops. A periodic legume pasture serves to maintain an individual field in early stages of succession, lending stability to later-planted crops (36). Ley pasture can also contribute to the availability of high-quality forage for livestock, either through haying or grazing. Haying must be considered a harvest because both the biomass and nutrients are removed from the field. Grazing is more complex. The grazing animal's removal and rapid cycling of the forage, and all the effects that come with it, can exert additional beneficial effects if properly managed.

Henry Wallace, of the Wallaces from Iowa who were secretaries of agriculture and farm magazine publishers, was passionate about the need for soil nutrient balance and the natural link between plants and animals. Writing nearly a century ago, Wallace said, "The Western farmer has now reached a point where, willing or not, he must elect to do one of three things: 1) Continue his present robbery of the soil by continuously growing of grain for sale in the world's markets and thus selling his land by piece-meal, 2) He may by supplying nitrogen in the clovers and returning nothing in the form of manure rob it more completely and reduce it to a more hopeless barrenness, 3) He may draw on the winds of heaven by means of the miracle-working tubercle in the roots of clovers, and then by the judicious use of the manure made on the farm in various ways restore the potash and phosphoric acid, trusting to the gradual disintegration of the rocks of which the soil is composed to keep up indefinitely their supply." (39).

Miracles aside, investigators have since demonstrated the importance of phosphorous (P) and potassium (K) fertility for legumes around the globe. There is, perhaps, no better example of P and K fertilizers permitting the adoption of leguminous cover crops than in South Australia (41) and New Zealand.

Livestock manure remains another viable alternative to meeting the soil-fertility requirements of intensive use of cover crops. That ruminant manure contains the complete range of nutrients that plants require, and roughly in the same proportions, should come as no surprise when both plant and animal are thought of as evolving from the same ecosystem.

As the ruminant consumes the cover crop, it also becomes included in the nutrient cycle of the field. In reviewing Australian pasture research, Hilder (15) reported the nutrients retained by grazing ruminants to be 25% with cattle and 4% with sheep. Researchers have reported recently in North Dakota, of all the plant biomass ingested, beef cattle retained 28% and sheep retained 15% in confinement-reared animals

where the forage was fed instead of grazed (unpublished data). These studies do not account for the mineral supplementation of the animals, which provides an additional supply of many minerals (including P) to the nutrient cycle and eventually succeeding crops.

While the nutrients retained are of importance to animal productivity, nearly 75% or more of the nutrients consumed are returned to the field. This cycling of nutrients is of great importance in maintaining soil fertility and crop productivity. After passing through the animal, however, the stability and plant availability of the nutrients is changed. Russell (32), calculated half-lives for humus from ryegrass (*Lolium perenne* L.) at 4 years, organic N from farmyard manure at 25 years, soil nutrients in the prairie after being cropped at 10 to 45 years, and humus from unmanured field plots that are 600 to 1,700 years old. Such data emphasize the great differences in time among various nutrient cycles, especially when animals are involved.

Though seemingly contradictory, a portion of the nutrient pool is also more quickly cycled when passing through ruminants. Nitrogen contained in the cover crop's leaves, for example, can be consumed and excreted in days. Such N has thus again been made plant-available and greatly reduced the time necessary to be cycled. Solid and liquid animal wastes differ greatly in their elemental composition and immediate plant availability (4). Solid wastes contain all the P, some stable forms of organic and inorganic N, and most of the minor nutrients. Urine contains mostly N, K, and sulfur (S) (15). We can readily observe evidence of such nutritional differences in pastures because legumes usually are stimulated near solid-waste patches, while grasses are stimulated near urine.

Nutrient cycling through manure can also be greatly influenced by the density of the grazing animals. Peterson et al. (27, 28) concluded that at normal stocking rates of 1 animal unit/acre pasture received little benefit from the animals because both liquid and solid waste was contained in small, dispersed patches. Hilder (15) reported that sheep may be of less use than cattle because they tended to congregate more and concentrate wastes in loafing areas. He also concluded that the fertility improvement of grazed, short-term pastures was caused more by the sheep's preference for the grasses, which would increase total legume growth and N fixation.

The question of groundwater contamination from nutrients, and the source of those nutrients, has been a source of controversy. Commoner (10) expressed the first major concern about the contribution of fertilizer N to water quality problems. Nitrate ( $\text{NO}_3$ ) concentrations in groundwater under forests, unfertilized pastures, and grasslands generally are cited as less than 2 parts per million (ppm)  $\text{NO}_3\text{-N}$  and often less than 1 ppm. But  $\text{NO}_3\text{-N}$  concentration under fertilized crops and animal production areas are commonly more than 5 ppm and have been reported as high as 100 ppm (29, 5).

Although heavily fertilized cropland usually is considered the primary source of  $\text{NO}_3$  groundwater contamination, legume cover crops and grazed cover crops of all kinds are also potential pollution sources. Nitrate leaching losses from a cover crop have been found to be up to 10 times higher than under unfertilized grass pastures. Likewise, researchers have

reported localized patches of urine from grazing to be equivalent to about 447 pounds N/acre for sheep and 848 pounds N/acre for cattle (35). Grazing management, such as short-duration grazing techniques, may hold promise for better manure distribution. And, unlike permanent or semipermanent pastures, short-term ley or cover crop pastures are rotated to cash crops. Shallow tillage operations may help distribute nutrient rich patches for more efficient crop uptake and use.

Inappropriate fertilizer applications are also sources of  $\text{NO}_3$  contamination in pasture situations. During a 5-year period, investigators monitored runoff from pastured watersheds on hillsides in eastern Ohio for water quality. In 7% of the events (64 of 890),  $\text{NO}_3\text{-N}$  concentrations exceeded 10 ppm, and 48 of the 64 events occurred within a 3-day period following application of N fertilizer on the watershed. Owens et al. (26) concluded that the closeness of the high  $\text{NO}_3$  concentrations and fertilization suggests that fertilizer, and not animal manure, was the major contributor of  $\text{NO}_3$  in this situation.

Continuing the debate on the source of contaminants, however, may not be as useful as coming to a more thorough understanding of nutrient movement and leaching processes (8). Just as with any commercial fertilizer application, proper management, application timing, and rates determine whether livestock manure is a soil amendment or a soil contaminant. If properly managed, cycling nutrients through livestock holds the potential to further conserve cover crop nutrients for later crop uptake.

Grazing can also help manage the cover crop's water use. Producers have long been concerned with competition for soil moisture between cover crops and cash crops. In the U.S. Great Plains, green-manure substitutes for fallow repeatedly have been discouraged because of their water consumption (2). Several approaches exist to limit water use to a tolerable level. Sims (34) has developed thresholds of water use in Montana, above which continued growth of the cover crop will be detrimental to wheat planted after the cover crop. While killing the cover crop with a tillage operation or chemicals is one possible solution, water use also can be limited by a periodic reduction in leaf area. Water use of cover crops in drought-prone areas can be managed to desirable levels by mowing or grazing, while retaining the presence and growth of the cover crop.

In more humid areas, water use may not be as critical to succeeding crops. Under some situations the cover crop's principal purpose may be to provide an actively transpiring surface to prevent downward movement of mobile soil nutrients. Winter cereals, particularly rye, have been used most frequently in such situations, and grazing management would have to reflect the needs of a rapidly transpiring cover crop. There is evidence that grazing can actually improve growth rate and thus maintain maximum water use, if producers achieve an optimal leaf area before grazing begins (23). The rate of grazing must then be managed to balance leaf removal with leaf regeneration capability. Under dense canopies, grazing may improve light penetration and increase overall interception of radiant energy by the transpiring leaves.

While weed suppression is one of the many desirable attributes of cover crops, teamed with grazing ruminants, weeds still can be managed selectively. Particularly where one or few plant species are present in the pasture, weeds are often preferred browse. Forwood et al. (12) found weed consumption to be greatest in beef steers when tame pastures of various grass-legume mixtures were least variable in composition. What motivates livestock to select certain plants is unknown, although researchers have postulated that such selectivity is based upon the animal's need for a diverse diet (3).

Grazing animals also can introduce weeds to the pasture through seed dispersal. The proportion of seeds that pass through a ruminant unharmed is a function of the digestibility of seeds and their ability to remain viable (40). These factors vary by plant species, but usually less than 10% of ingested seeds remain viable. Undesirable and foreign weeds that are introduced by livestock require attention and selective management.

Usually cover crops are needed for surface cover, but too much surface residue also can be detrimental in some situations by preventing adequate seed placement in no-till planting operations or reducing the soil temperature to the point of inhibiting early season crop growth (38). Integrating ruminant livestock into the system can offer an alternative management option to deal with each of these problems. Intensive grazing can substitute for such operations as mowing, tilling, or using herbicides to control vegetation while making the transition to the cash crop.

### Models of crop/livestock systems

Theoretically, crop and livestock production systems seem mutually beneficial. Yet, the separation of both into specialized production units has been the trend in the United States and much of the developed world. Viewing specific cases where the mutual benefits have been demonstrated may aid in the discovery of new cover crop-livestock systems that could be developed.

**Ley farming in South Australia.** We can learn much by studying the experiences of the wheat growing regions of

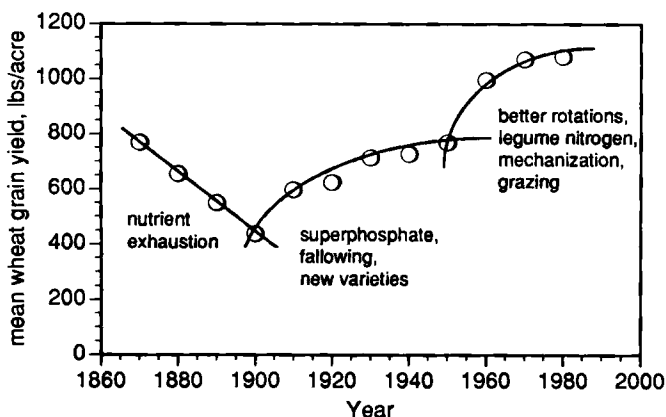


Figure 1. Three eras in Australian wheat productivity, as illustrated by 10-year mean, annual wheat yields (41).

southeast Australia. As Puckridge and French (30) and Webber (41) describe, what faced southern Australia in the late 1940s has a striking resemblance to much of today's world, including the U.S. Great Plains, for example:

1. Livestock products were in high demand and prices were high in relation to grains.
2. Cereal yields were falling and were increasingly dependent upon N fertilizer.
3. Soil erosion was widespread.
4. Farmers and the government were becoming concerned about environmental decline.

What followed was a switch from cropping systems largely void of livestock and rotation to systems in which rotation to leguminous cover crops depended economically upon the income from grazing sheep. This began another era in the evolution of Australian agriculture (Figure 1) and simultaneously raised the production of both crops and livestock. Furthermore, unlike the previous two eras in south Australian agriculture, these new crop-livestock systems also resulted in improved crop water-use efficiency; better soil structure; and greatly reduced dependency on mining soil nutrients, especially N.

Current limitations to a similar revolution in the U.S. Great Plains hinge on three critical factors: (1) an adequate breeding program specifically in search of ley cover crops; (2) willingness, and confidence, in livestock management and markets; and (3) a coordinated, long-term government policy that would foster the use of cover crops for fallow.

North Dakota State University, together with the Michael Fields Agricultural Institute, the University of Nebraska, and Kansas State University, currently are evaluating cover crop systems that could substitute for fallow under the U.S. Department of Agriculture's low-input sustainable agriculture program. Initial evaluations have concentrated on yellow blossom sweetclover (*Melilotus officinalis*), black medic (*Medicago lupulina*), and hairy vetch (*Vicia villosa*), although more than a dozen introduced and native species have been tried. Any one legume does not seem to possess all the traits necessary for a broadly adapted Great Plains cover crop. Under these conditions, ease of stand establishment and seed cost are important features, along with low or easily managed water use and general pest resistance. In North Dakota and Nebraska trials, alternative legumes, such as black medic, have used less soil water than traditional legumes, such as sweetclover, particularly at soil depths greater than 12 inches (13).

Both the sweetclovers and the medics seem to possess the diversity of germplasm needed to breed new genotypes specifically as cover crops suited to regional conditions. But no current program exists. Developing a cover crop with the seed vigor and winter hardiness necessary for persistence, combined with low water use and a small enough seed size to remain economical, remains the current challenge. Traditional yellow-blossomed sweetclover currently is being studied in combination with grazing and haying management in North Dakota to reduce water use and support an integrated crop-livestock system.

During the past several decades, combination crop-livestock farms on the Plains have given way to specialized

operations. Centralized feeding and processing has concentrated much of the beef cattle, leaving most of the region largely deficient of weaned calves. Because the soils of this region could greatly benefit from retaining the cover crop biomass produced, haying does not seem a viable option. Many producers are reluctant to obtain either cattle or sheep to graze ley pasture because of a lack of experience and time during critical crop management periods. Recent comparisons of crops-only versus crop-beef cattle operations found that livestock can increase the total labor required on an average central North Dakota farm by 56%, but only one-third of that additional time directly competed with crops during critical management periods. Net economic returns attributable to the added livestock increased whole farm income by 19% (unpublished data, Gardner, Watt, and Anderson).

Despite the economic returns possible from adding livestock, given current markets, the required labor and management expertise needed with livestock still present a barrier to broad-scale adoption. In most regions of the United States, producers have to own the livestock that could be used for cover crop grazing and management. In contrast, contract grazing of ley pastures from nomadic sheep herders is a common practice in southern Australia.

U.S. agricultural policy also must be considered when analyzing the limitations to broad-scale use of cover crops for fallow in the Plains. Mainly a wheat producing region, Plains' farmers have been enticed to grow wheat to keep global supplies adequate. It is unfortunate that the frequent encouragement of set-aside, or fallow, to help control supplies in the past few years was not coupled with encouraging the establishment of legitimate cover crops. Where such ley pastures have been established, they usually have had some restrictions for use as pasture or forage. With a limited demand for forages, making available such government subsidized forage or pasture production has been perceived to be economically unfair to the unsubsidized forage producer. Balancing the economic needs of individuals with the ecological needs of the landscape remains a global issue that must be resolved.

**Holistic crop/livestock models.** While the choice of whether to incorporate livestock with crop production currently remains largely economic and personal, rather than ecological, exposure to the more widely recognized holistic philosophies might be valuable to consider, especially because they seem to historically reoccur. The importance of the link between plants and animals is at the core of both biodynamics and holistic resource management.

The biodynamic movement could be considered one of the first organized attempts at reforming conventional 20th century agricultural production practices (18). The concepts originated from a series of lectures given by Rudolf Steiner to German farmers in 1924. Although the teachings were broad and all encompassing—outlining ecological, economic, social, and even spiritual changes that were suggested on the farm—the central theorem was based upon the belief that an integrated crop-livestock production system is necessary for long-term soil fertility. The concepts of a well-planned crop rotation, occasional green manuring, and the ability of composted livestock manure to replenish stable soil organic matter and

nutrients sounds all too familiar given the current interest in "alternative" agriculture (25).

Biodynamic farms have operated on an on-going basis since Steiner's lectures, mostly in Germany, but also in other parts of Europe and more recently in the United States. High productivity has been reported through the regular use of legumes and other crop residue; use of appropriate quantities of composted and slurry manure; and careful soil cultivation techniques, sensitive to soil biological activity. Biodynamic methods emphasize the need for cultural practices that promote net gains in the nutrients contained within the soil-plant system. While not excluding the use of synthetic fertilizers to do so, biodynamic practices encourage the use of ruminant livestock, particularly cattle, to transform the nutrients into forms that can be retained within the soil system.

Although biodynamic principals have yet to be, and may never be, examined thoroughly by disinterested third-party scientists, the recognition and relative success of integrating crop and livestock production is noteworthy. Particularly where leguminous cover crops are warranted, the increased need and expense of P, K, and other nutrients should be considered. Careful and appropriate management of livestock manure, as demonstrated in decades-old biodynamic farms, could be at least part of the solution to these long-term fertility needs.

Holistic resource management, a term coined and promoted by Allan Savory (33), is a more recent example of agricultural management strategies that link plant and animal performance. Developed and largely employed in permanent pasture and range situations, holistic resource management is a goal-oriented system that has challenged much of conventional range management thinking. It is an approach that views the whole—plants, animals, humanity, etc.—as one ecosystem functioning through four rudimentary processes: succession, the nutrient cycle, the water cycle, and the flow of solar energy.

The increasing interest in short-duration, rotational, and multispecies grazing can be attributed, at least in part, to the concepts of holistic resource management. It has drawn attention to the connection between grazing animal activity, soil physical conditions, and plant performance. And, while mostly seen as a system practiced on range plant communities, the concepts speak to agroecosystems as well. Holistic resource management would suggest that crops in polyculture and integration with animals would be more productive and ecologically stable than monocultures without animals. Such theory would suggest a reduced need for subsidies in the form of energy, fertilizers, and pesticides under a holistically managed agroecosystem. Biotic regulation would replace such subsidies within smaller field units of increasing biological and ecological complexity.

Holistic resource management theory may be able to contribute to the integration of cover crops and livestock in agriculture, but not before practical applications are well thought out. In most farm situations, the time and cost of employing holistic resource management concepts in using cover crops will be calculated using short-term economic comparisons. Whether appropriate or not, labor-use effi-

ciency often is overemphasized given a choice, and the mutual benefits of managing both the cover crop and the grazing ruminant may not be fully realized. Theory must be able to be used practically.

## Conclusions

Several obstacles remain in the development of successful cover crops. Water use and competition with the cash crop is an obvious challenge. So, too, is keeping the N fixed by leguminous crops within the rooting zone of the companion or succeeding crop. Beyond these biological challenges lie problems in farmer adoption of a crop that is often perceived as serving no immediate economical purpose. The need to investigate each of the biological functions, individually, and compare performance, risk, and cost back to the fertilizer, herbicide, or tillage that it replaces may in fact be a part of the adoption barrier. Successful use of a cover crop system necessitates managing the entire agricultural system. In many cases, that system must include livestock to be economically feasible.

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## Improved use of fertilizer, land, and climatic resources by interseeding a cool-season grass into a warm-season grass

S. R. Wilkinson and J. A. Stuedemann

'Coastal' bermudagrass [*Cynodon dactylon* (L.) pers] is a highly productive summer perennial forage that begins growth about April 15 and produces little growth after October 1 most years in the Southern Piedmont. Temperatures and rainfall are normally favorable for cool-season grass growth in October, November, part of February, March, and April.

Producers can increase land productivity by interseeding small grains in coastal bermudagrass. Using this practice has resulted in wheat (*Triticum aestivum* L.) grain yields of 25 bushels/acre, wheat silage yields of 3.0 tons/acre, rye (*Secale cereale* L.) forage yields of 1.8 tons/acre, or gains of 280 pounds steer live weight/acre over a 140-day interval (2).

Intensive areas of poultry production exist in the Southern Piedmont, often resulting in high rates of broiler litter application to land and consequent concern about nitrate (NO<sub>3</sub>-N) accumulation in streams and groundwater.

Herein, we report on interseeding rye in dormant Coastal bermudagrass to increase the use of land, climate, and managerial resources, with emphasis on use of N from broiler litter, and effects on NO<sub>3</sub>-N in drainage waters.

### Study methods

In this study we used coastal bermudagrass plots (14 feet by 70-feet), equipped with catchment tanks to collect total surface run-off. The soil type was Cecil sandy loam (clayey, kaolinitic, thermic, Typic Hapludult ) with a topsoil depth of 9 inches and a slope of 7%. We installed suction cup lysimeters at a depth of 6 feet to sample percolating soil water. Both run-off and soil water were analyzed for NO<sub>3</sub>.

We analyzed five treatments over a 7-year period: (a) control, not fertilized or interseeded with rye; (b) fertilized for first four years with 20 tons of broiler litter/acre/year, followed by no broiler litter for a 3-year residual period and not interseeded with rye; (c) a treatment identical to treatment b, except interseeded with rye; (d) fertilized for first 2 years at 80 tons of broiler litter/acre/year, followed by a 5-year residual period, and not interseeded with rye; and (e) a treatment identical to treatment d, except interseeded with rye.

We replicated each treatment twice in a randomized complete block design. We interseeded the rye by broadcasting it into the sward after the early October harvest of coastal bermudagrass.

We harvested the coastal bermudagrass monthly from May through October and harvested weeds or rye from November

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through April. Total N removals include N in rye, weeds, and coastal bermudagrass. Wilkinson et al. have described other study procedures (2, 3).

## Results and discussion

Total forage yields from the plots fertilized with broiler litter were much higher than those from the unfertilized plots

**Table 1. Forage yield and N distribution as affected by interseeded rye in Coastal bermudagrass fertilized with broiler litter, totals for 7 years.**

Item	Broiler Litter Treatments				
	No Rye	20 tons/acre		80 tons/acre	
	No Rye	Rye	No Rye	Rye	
N input (pounds/acre)	0	4,917	4,917	8,965	8,965
Forage yield and N uptake					
CBG yield (tons/acre)	5.0c*	43.7b	50.7a	41.5b	44.7b
Rye, or weeds yield (tons/acre)	0.8c	6.2b	10.6a	5.4b	10.8a
N uptake (pounds/acre)	164c	2,508b	2,953a	2,482b	2,628b
N recovery, forage (%)	-	48	57	26	28
Drainage water loss					
Surface run-off (inches)	24.5	22.6	4.4	5.3	16.6
Average NO <sub>3</sub> -N (ppm)	2c	6b	8ab	11ab	1c
NO <sub>3</sub> -N loss (pounds/acre)	0.4c	2.8bc	0.3c	8.9ab	10.5a
Percolate loss, 6 feet (pounds/acre)	11d	980b	622c	2,706a	2,430a
N recovery, soil water (%)	-	20	12	30	27
N recovery, soil (pounds/acre)†	1,015b	1,962a	1,698a	1,846a	1,961a
Total N recovery (%)	-	85	86	73	72

\*Means within row followed by different letters are significantly different ( $P < 0.05$ ).

†Because differences in soil storage were not significant, we used the mean for calculation of total N recovery.

**Table 2. Annual mean nitrate-N concentrations in soil water as affected by interseeded rye in coastal bermudagrass fertilized with broiler litter\*.**

Year	No Rye	Nitrate-N by Broiler Litter Treatments			
		20 Tons/Acre		80 Tons/Acre	
	No Rye	Rye	No Rye	Rye	
	ppm				
Back-ground†	2(0)‡	2(0)	< 1(0)	1(0)	1(0)
1	< 1(0)	4(0)	1(3)	61(83)	82(87)
2	< 1(0)	13(67)	8(32)	245(100)	250(100)
3	< 1(0)	76(100)	51(97)	129(92)	148(97)
4	< 1(0)	121(100)	56(97)	34(73)	6(20)
5	< 1(0)	33(82)	20(68)	8(25)	1(0)
6	< 1(0)	2(0)	3(0)	1(0)	1(0)
7	< 1(0)	2(0)	1(0)	2(0)	1(0)

\*Broiler litter applied first four years for 20-ton-acre treatments and first two years for 80-ton-acre treatments.

†Background represents 6 months sampling prior to treatment initiation. < 1 means concentrations < 0.5 ppm because all values rounded up from 0.5.

‡Numbers in parentheses refer to percentage of samples that exceeded 10 ppm NO<sub>3</sub>-N.

(Table 1). There was no difference in yield between the 20-ton/acre or 80-ton/acre broiler litter rates. Considerable weed growth occurred on the broiler litter-plots without rye. The primary weeds were chickweed (*Cerastium vulgatum*) and henbit (*Lamian amphlexicouele*).

Table 2 reports the measured soil water NO<sub>3</sub>-N concentrations at the 6-foot depth for the five treatments. Nitrate-N concentrations exceeded 10 ppm in the second year in treatment b and in the third year in treatment c. The rye cover crop did not affect NO<sub>3</sub>-N in soil water at 6 feet until the second year of the residual phase of the 80-ton/acre treatment (fourth year of the study).

The reduction in NO<sub>3</sub>-N percolating to 6 feet roughly corresponds to the increase in N removal in the harvested crop at the 20-ton/acre rate. The percentage of applied N accounted for was similar for treatment b and c (85% versus 86%) and for treatment d versus e (73% and 72%). Presumably, the N that was not accounted for was due to ammonia volatilization and/or denitrification losses.

Wilkinson and Stuedemann (2) reported that 160 pounds of additional N/acre was required for satisfactory wheat grain or silage yields when interseeded in coastal bermudagrass fertilized with 315 pounds N/acre/year. The impact that grazing has on the percolation loss of NO<sub>3</sub>-N in this system is not known.

## Conclusions

We demonstrated that interseeding rye was an effective way to capture some of the excess N applied to coastal bermudagrass. Results of this study imply that at maximum recommended rates of 10 tons of broiler litter/acre/year interseeded rye will effectively capture residual N applied to coastal bermudagrass; significantly lower NO<sub>3</sub>-N concentrations in percolating soil water; reduce N losses below the effective root zone of the coastal bermudagrass; provide an economic return in a high-quality forage (small grain); and thereby enhance use of fertilizer, land, and climatic resources.

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# On-farm economic and environmental impacts of cover on corn silage ground on a limited-resource-based Tennessee dairy farm

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The 1990 farm bill—The Food, Agriculture, Conservation, and Trade Act of 1990—contains several environmental initiatives that carry over from the 1985 Food Security Act. These initiatives illustrate the change in environmental awareness in the United States. Increasing pressures are being placed on this nation's agricultural sector, with erosion and chemical pollution at the top of the agricultural agenda. Conservation compliance may well lead to chemical compliance, and agriculture tomorrow likely will be different than what is being practiced today.

Conservation compliance calls for farmers to develop conservation plans on highly erodible land. Many of the options available to farms require the planting of a cover crop. The cover crop is supposed to retard erosion and prevent chemical runoff. As reported by Russell and Christensen, "One of the most frequently used conservation practices in the Southeast is establishment of permanent vegetative cover or cover crops. Such cover is relatively simple to establish, does not take land out of production, and once established, can be used for grazing cattle and other livestock. All States had more acres in this practice than in any other ACP practice in 1982" (5).

Herein, we examine the use of a cover crop after corn silage in eastern Tennessee. Farms in Tennessee are small, with the farmer typically working more than 200 days off of the farm. In addition, the area has many farms with small dairies and/or beef operations. Our analysis is centered around the farm firm's survival and the impacts that requiring a cover crop will have on recycling nitrogen (N) and the farm firm's ability to maintain its current operations.

We conducted the analysis using the Farm Level Agricultural, Resource, and Environmental modelling system (F.L.A.R.E.). F.L.A.R.E. is a system of simulation models for examining the economic and environmental consequences of alternative resource and commodity policies on agricultural producers (2). Briefly, the F.L.A.R.E. model is comprised of four components. The first is a budget generator that estimates costs of production for any farm, given specified resources and management. The second component is a plant growth simulator that calculates yields, input requirements,

and environmental impact information for the farm, based on management, climatological, conservation, tillage, environmental, and soils data. The third component is an optimizer that uses a linear or quadratic programming technique to establish an optimal farm organization. The fourth and central component is a farm simulator that incorporates data from the other components and evaluates the economic and environmental impacts of specific policy alternatives over a specified simulation period.

The F.L.A.R.E. model has the capability of providing useful and timely microeconomic information on a wide variety of policy issues. However, the ability of F.L.A.R.E. to provide such timely and accurate analyses depends upon the development of a set of representative farms for different geographic areas. Data requirements for these farms are fairly intensive, including demographic information about the farming community; farming practices information concerning growing season characteristics and variability; and resource information not only covering purchased farm equipment and machinery, but including information about the natural resource base of the farm. This level of detail can be used to construct a variety of representative farms for a region, state, or county level. The model also can be used at the producer level to help the producer make informed decision.

Little attention has been given to the limited-resource farm sector, even though the majority of farms in this area fit in this category. For this study, we defined a limited-resource farm as any farm having gross sales under \$40,000. Most limited-resource farms have equipment inventories of \$25,000 or less. These farms usually rely on an outside income to sustain the farming operation. The business goals of part-time farmers can be quite different from those of full-time farmers, placing more emphasis on the perceived amenities of living in a rural area, with only a secondary concern for profits. Because these farmers operate under capital constraints with different goals from the larger commercial farmer, limited-resource farms generally lag behind other farms in the integration of new technology.

Many of the farms in eastern Tennessee fit our description of the limited-resource farm. For this reason, we chose it as the general area for the development of the representative limited-resource farm. Row-crop farming is limited in eastern Tennessee because of rugged topography. Instead, many farms in this area produce tobacco, dairy products, livestock, and vegetables. The average size farm in the area is 147 acres, and a majority of the operators are part-time farmers, with 53.4% of producers reporting 100 or more days of off-farm work (1).

We chose Greene County as the specific site for the development of a representative dairy farm. The county historically has produced a mix of dairy, beef, hay, and tobacco. After designation of the proposed representative farm site, farm development was accomplished in four steps. The first step was to describe the farm, including typical farm products, size, operator characteristics, as well as climatological and other physical data. These data for Greene County were obtained from various sources (1, 7); we consulted numerous extension personnel at the state and county level on

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typical management practices; and Soil Conservation Service (SCS) soil scientists provided expertise on soils information. The second step was to determine the farm enterprises typical of farms in the area, including the crops grown, farm size, land tenure characteristics, and typical machinery complements. The third step was an evaluation of costs of production, including chemical, fuel, fertilizer, and machinery operating and inventory costs. Finally, alternative production activities were designed for the limited-resource farm.

## Farm Resources and Enterprises

The majority of the operators in eastern Tennessee own all of their land that is under cultivation. We determined the size of the representative farm for this analysis by the distribution of dairy farms in Greene County. The farm size was set at 153 acres, with 80 acres of pasture, 23 acres of hay, 18 acres of corn silage, 20 acres of woodlands, 2 acres of tobacco, and 10 acres for the farmstead. Land requirements for livestock were obtained from *Livestock and Forage Budgets 1990* (6), specifying 1.5 acres of pasture land per dairy and beef cow-unit (a cow-unit is the cow, her calf, her share of the replacement heifer herd, and her share of the bull) (1, 7).

Greene County is the largest dairy county in Tennessee. For the representative farm, we assumed a dairy herd of 35 head producing manufactured rather than Grade A milk (1). Generally, resource requirements are lower for manufactured dairies than for Grade A dairies. Dairy production is assumed to be 10,000 pounds of milk/cow, to be sold at \$11.00/hundredweight. The dairy herd will use 7 months of pasture. We assumed a 90% calf crop, with an annual 15% replacement rate for dairy cows. The 12 steers annually produced by the dairy cows are sold at 1-3 days old, and out of the 12 heifers born, 6 will be saved for replacement and 6 will be sold at 400 to 600 pounds. Waste generated from the dairy operation is collected in an open lot and periodically spread on the crop and pasture land (6).

We also assumed a 10-beef cow operation to exist on the farm. This cow-calf operation was assumed to have an 80% calf crop, with calves weaning for steers at 450 pounds and for heifers at 400 pounds. We assumed half of the calves were steers and that heifers held for replacement made up 10% of the herd. Heifers would calve at 2 years of age.

Along with the manufacture dairy and the beef cow enter-

prises, we chose tobacco, silage, and hay as the primary crop enterprises on the representative limited-resource farm to reflect the principal crops produced in the county. The livestock enterprises would use the hay and silage, returning manure to the corn and pasture. Tobacco would be the only cash crop. Acres planted for each crop and the corresponding yields were obtained from *Tennessee Agriculture 1989* (7) and used to develop the limited-resource farm's acreage and yield data.

## Production Costs

We obtained prices and use rates of production inputs for the farm from Tennessee budget data, *Tennessee Agriculture*, farm area management specialists, and county Extension personnel. Crop production costs and returns for the farm plan were developed by applying the above rates in the *North Carolina State Budget Generator* (3), which uses farm material prices and equipment data to develop detailed whole-farm crop budgets. The budget generator also requires the specification of machine operation time, labor time, and chemical application rates. Table 1 shows variable costs for each crop enterprise. Variable costs for the livestock budgets are not incorporated into the analysis.

Fixed costs were those associated with farm debt, insurance needs, and property taxes. Initial debts included long-term debt on the farm real estate and intermediate-term debt on equipment. We determined the total value of farm real estate by the value of farmland plus the value of any buildings, as reported in the *1987 Census of Agriculture* (1). We assumed the total long-term debt remaining 10% of the total farm value and was based on equity value reported in the *Tennessee Agriculture* (7). An equipment inventory was prepared by enterprise to determine total equipment needs for the farm. Purchase dates were assigned to each piece of equipment between 1969 and 1985. No new equipment was purchased for the farm. Purchase prices were determined for used farm machinery (4). The average value for equipment for Greene County farms was less than \$20,000. We assumed that when present equipment is replaced it would be replaced with used equipment.

## Methodology Employed

We used two of F.L.A.R.E.'s components extensively in this analysis. The Budget Planner was used to determine changes in costs. In addition, to get the environmental impacts of farming practice changes, we used the Erosion Productivity Impact Calculator (EPIC) (8).<sup>1</sup> Each of these simulation models requires detailed farm plans. The budget generator requires them for the entire farm, while the EPIC requires them primarily for the crop sequences or rotations concerned. In addition, because the study does not have direct impacts on the livestock enterprise, we assumed that those costs remain

<sup>1</sup> Williams, J. R., P. T. Dyke, and C. A. Jones. 1982. "EPIC -- A model for assessing the effects of erosion on soil productivity." Paper presented at the Third International Conference on State-of-the-Art in Ecological Modelling, Colorado State University, May 24-28, 1982.

**Table 1. Selected variable cash expenses, Greene County, Tennessee, representative limited-resource farm.**

Variable Input	Cash Expenses by Crop			
	Corn Silage	Tobacco	Hay	Pasture
	\$			
Seeds/plants	17.00	65.21	36.75*	-
Fertilizer	40.55	87.50	33.00	2.50
Chemicals	14.94	32.32	12.57	-
Repairs	12.68	132.34	33.22	26.40
Harvesting	95.68	806.00	39.97	-
Labor	88.48	602.24	90.06	77.28
Total	242.27	1,726.04	380.43	106.18

\*Establishment costs were prorated over 4 years.

**Table 2. yield and soil erosion estimates for corn silage under three alternative tillage/cover systems.**

Soil Name	Yields						Sheet and Rill Erosion					
	With Cover		Spring-tilled		Fall-Tilled		With Cover		Spring-Tilled		Fall-tilled	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
	tons/acre											
Berks	10.6	2.2	9.7	2.0	9.8	2.0	24.7	6.3	25.5	8.7	32.3	8.9
Bodine	12.9	1.7	12.2	1.8	12.4	1.5	10.6	3.0	11.4	3.8	15.6	4.3
Dunmore	12.4	1.5	11.7	1.7	11.2	2.1	40.5	22.1	53.2	17.4	73.7	21.2
Fullerton	10.7	1.6	10.0	1.6	10.2	1.4	40.1	9.7	40.5	12.7	50.9	13.6

fixed. However, we could have designed a farm plan that would have incorporated the grazing of the winter cover. This would have further complicated the findings of this study.

We ran the F.L.A.R.E. components under two sets of assumptions. The first set of assumptions did not incorporate the use of winter cover following corn silage. In the second alternative, the farmer planted rye as a winter cover crop. While wheat is a typical cover crop in eastern Tennessee, we used rye in this analysis because it is a good scavenger of surplus nitrogen (N) left in the soil by the previous crop. We assumed the rye was planted as soon as harvest is completed, and disked the following March.

We used both economic and environmental parameters in the comparison. Additional analysis was conducted using EPIC. We evaluated the analysis of the impact of cover crops two ways. First, it was run under the assumption that the farmer would continue standard recommended practices with regard to N application on the corn silage. Under this assumption, the same rates of fertilizers were applied with and without cover options. This assumption was altered by setting the automatic fertilization routine in EPIC on and allowing EPIC to determine the amount of fertilizers required. Finally, the tillage methods were altered to examine the impacts of cover under alternative residue management strategies. This was achieved by comparing the cover alternatives to fall-till and spring-till alternatives.

**Results**

**Costs of Production.** The additional operation prescribed for the farm does not add significantly to the production costs of the farm. The costs to plant a cover crop increase the costs of producing corn silage by \$16.00/acre. The largest expense item is the seed costs, estimated at \$14.00/acre. In a breakeven analysis of net returns for the corn silage component of this farm, yield must exceed 11 tons/acre and/or price must exceed \$18.00/ton before net returns per acre are positive. Planting cover increases production costs by the costs of the seed purchased and by the costs of additional field activity.

**Why Plant Cover?** To justify an expenditure on the farm, an examination of what impacts a cover crop will have on a farm’s resource base and its production capability is necessary. We used EPIC to estimate these impacts. EPIC requires detailed data on weather and the soil resources of the farm. This farm uses primarily Bodine as its soil input. However, we compared the sensitivity of this soil’s characteristics to three other soils: Berks, Dunmore, and Fullerton. With the assis-

tance of Paul Denton, soil scientist at the University of Tennessee, the information on the soils in the EPIC data base were adjusted to reflect actual Tennessee farming conditions. Because weather data for Green County was not available, we used weather data from the station in Knoxville, Tennessee.

EPIC simulated the growing of continuous corn for 50 years for each of the soil types. Farming practices were changed to reflect the percent cover during the winter months. The baseline farming practice required the farmer to disk the land in the spring. From that baseline, two alternatives were examined. In the first alternative, the farmer planted rye right after harvest and disked it up in March just prior to planting the corn seed. In the second alternative, the farmer disked right after harvesting, thus, reducing the amount of residue on the ground. (EPIC was run using corn. When the corn is harvested, however, residue is left on the field. When corn silage is harvested, a significant reduction in residue occurs. A disking following planting is incorporated into the analysis to simulate a reduction in residue. While the farm is growing corn silage, the growing of corn grain is used to serve as a proxy for the impacts cover will have on the farm firm’s resources and its productivity.)

Table 2 contains a comparison of the yields and erosion levels of the three systems for the four soils in the analysis. The soil benefiting most by a cover crop is the Dunmore soil. In both comparisons, Dunmore with a rye cover crop has better yields and reduced variation than in the residue management alternatives. While--with the exception of the Dunmore soil--we found no significant impact on erosion when comparing the cover crop alternative to the spring tilled alternative, there is a 25 percent reduction in sheet and rill erosion when comparing the cover crop alternative with the fall-tilled alternative. We suspect that the real gains lie somewhere between the two comparisons.

On these clay soils, leaching also increases as cover is incorporated and fertilization rates remain unchanged. By adjusting N applied to allow for the N incorporated by recycling, leaching can be reduced to levels that exist in the spring residue alternative. However, further research is required to evaluate the amount of N reduction that could occur in the risky environment under which the farmer is operating.

**Conclusions**

Planting a cover crop will reduce the need for effective residue management, increase yields, and reduce erosion. The increase in yields on several of the soils offsets the

increased costs of the cover crop. Therefore, especially for the Dunmore and Berks soils, from an economic standpoint, a recommendation of shifting from a non cover crop practice on corn silage to one that incorporates a cover crop is practical for the limited resource farmer. However, planting a cover crop might be misleading to the farmer because it may lead to the belief that erosion problems are under control. As can be seen from the analysis, erosion on all these soils still greatly exceeds the soil loss tolerance level for these soils. Leaching increases if N application is not altered. On this farm N is derived from not only commercial fertilizers but also the livestock enterprise. Analysis of alternatives to reduce erosion and N losses while using and incorporating a cover crop must be conducted.

The only way to control erosion on this farm so that it can protect its soil resources would be to dramatically change the farm's means of production. Land use changes would be required, and these changes would likely require a significant shift from the dairy herd to a cow/calf production operation on the farm. These changes, however, move beyond the scope of our present analysis.

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## Winter cover crop management in a high rainfall region with large waterfowl populations

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The farmland of the Fraser River Delta is some of Canada's most productive. The relatively high productivity of the Delta municipality is related to its unique combination of climate and soil. Delta receives about 39 inches of precipitation per year, of which three-quarters falls between November and April. The area also has the longest period of frost-free days in Canada, extending from April 15 to October 21. However, crop yields and reliability are declining as a result of continuous vegetable production with little crop residue or manure available to maintain soil organic matter (5).

Overwintering green manure crops is an obvious response to the region's soil degradation problems, but this option is of limited use to many farmers due to migratory waterfowl overgrazing, primarily wigeon (1, 2, 6). The Fraser River Delta supports about 200,000 ducks (primarily wigeons, pintails, green-winged teal, and mallards); 60,000 geese (Canada and snow geese); and 1,000 swans (trumpeter swans) over the winter (3). Seasonal populations, distribution and food preferences are relatively well known (2). Our objectives in this investigation were to determine which cover crop practices are most susceptible to crop depredation by waterfowl and to develop cover crop practices to reduce the problems associated with waterfowl depredation. Herein, we present some preliminary observations and suggest future research needs.

### Methods

In the fall of 1990, funding from Ducks Unlimited, Canadian Wildlife Service, and the British Columbia Federation of Agriculture (ARDCORP) permitted 1,000 acres in the Delta municipality to be seeded to winter wheat (*Triticum aestivum* L.). Many other growers also seeded cover crops on their own. We put exclosures in the fields and took plant samples once the fall accumulation of biomass ceased. We monitored fields and rated them for degree of soil cover, surface-water ponding, crop height, date of grazing, and area grazed. We investigated wigeon feeding behavior with respect to crop nutrition, suitability, growth stage, height, planting techniques, rates, and dates.

### Results and discussion

Areas outside the diked area and the farmland inside the dikes have different importance to waterfowl, with respect to habitat and feeding behaviors at different times of the year.

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Burgess (2) has described waterfowl seasonal distribution and food preferences in each of the areas. The following is a discussion of the relationship between waterfowl feeding habits and farm cover crop practices in chronological sequence of events.

1. In September, migratory duck populations are still small, with most of their feeding occurring in the tidal marshes. Migratory Canada geese are beginning to arrive in large numbers and are quick to come into any recently planted cover crop field in search of unincorporated seed. Seeding techniques that leave a lot of seed on the surface, such as simple broadcast, or those methods that only slightly incorporate the seed, such as broadcast and harrow or cultipack, result in a poor stand and are not recommended. Seeding methods that will effectively incorporate the seed, such as drilling or broadcast and disking, will establish quickly. The geese feeding tends to be a localized problem and much of the grazing tends to occur in and around the Alaskan Wildlife Refuge, where lure crops have been planted and farming practices do not disturb roosting and foraging behavior. Cover crops which are planted prior to the second week in September are usually established well enough to retain vigorous growth.

2. By October, the duck, geese, and swan populations increase substantially, and food availability on the tidal marshes during daylight hours becomes scarce due to the high tides that occur at this time of year. With the advent of hunting season, few ducks, geese, and swan are seen in agricultural fields during the day. Much of the waterfowl is located on the tidal flats and inside the Alaskan Wildlife Refuge. During the winter, the Canada and snow geese and trumpeter swans tend to stay in and around the refuge where there is little disturbance to their roosting and foraging behavior. Cover crop damage by geese and swans is minimal at this time.

3. From late October to January the migratory duck populations reach their peak and then decline to late-winter population levels. Once the rainy season commences and ponding occurs in fields, ducks (primarily mallards, pintail, green-winged teal and wigeon) are increasingly attracted to agricultural fields. When the hunting season begins (3rd weekend in October), the ducks begin their night flights onto agricultural fields. Hunting is only permitted during the day. The movements of ducks onto these fields is not obvious and some estimates have shown that 10 times more ducks flock to these fields at night than during the day (4). By early November, agricultural fields become increasingly flooded; wigeons, in small flocks that eventually turn into large flocks, begin to feed upon agricultural cover crops. By early December, mallards, teals, and pintails begin to feed in the fields. These dabbling ducks tend to depend more upon fields with ponding; they primarily consume weed seeds and some young shoots. Their primary feed source is seeds from the tidal marshes and they do little damage to cover crops. The numbers of ducks displaying night flight feeding behavior slowly increase until the end of hunting season in early January, after which the ducks are seen more frequently in the fields during the day.

4. By April the late stages of spring migration are underway and most ducks are present on the tidal marshes where once again the tides are low and the availability of food is high. Few

ducks are seen on agricultural lands.

This sequence of events shows the importance of (a) Delta agricultural lands in providing food for wintering ducks from late October or early November to March, (b) the Delta tidal marshes in providing food to waterfowl during September to October and from February to May, and (c) the Alaskan Wildlife Refuge in providing lure-crops to feed the wintering swans and geese. Of the four major duck species, wigeon is the only species that will consume entire crops in the field and depends upon these agricultural crops as a major source of food over the winter (2).

Seeding techniques, such as a simple broadcast or those methods that only slightly incorporate the seed, such as broadcast and harrow or cultipack, do not establish good stands and are not recommended. Seeding methods that will incorporate the seed to depth, such as drilling or broadcast and disking, will give rapid establishment and provide maximum soil surface protection. Cover crops that grow tall, such as fall-planted spring wheat, are probably least susceptible to wigeon consumption. Small grain crops that are planted prior to the second week of September establish well; adequate soil cover is obtained with 100 pounds/acre of seed, but seeding rates after this date need to be increased to 150 pounds/acre. Small grain cover crops that are planted in early October provide little soil protection, become easily flooded and/or ponded, and are the first crops to be consumed by wigeons. Legumes, such as clover, and newly planted pasture that are not well established prior to winter are also susceptible to wigeon consumption. Sheetwater, an important factor that may attract waterfowl to fields, is often not visibly present in fields with well-established ground cover.

Research directed at identifying innovative farm management techniques that will best incorporate cover crops into the present crop rotation will include (a) the underseeding of late-harvested crops, such as corn (*Zea mays* L.) to various mixtures of clover and cereals, such as winter wheat, barley (*Hordeum vulgare* L.), and fall rye (*Secale cereale* L.), to permit cover crops to become well established before the main crop has been harvested and (b) variety trials that will identify those cultivars of winter wheat, barley, and rye that are least susceptible to overgrazing, therefore, providing the best possible soil cover and use as a subsequent green manure.

While such research objectives may seem at odds with wintering waterfowl needs, they are, nonetheless, what is required to make farmlands in Delta sustainable. Without sound sustainable farming practices in place, the viability of a healthy farming community in Delta will be in jeopardy and therefore the waterfowl habitat itself. Crops that are harvested late and offer little opportunity to establish a cover crop, such as late potatoes (*Solanum tuberosum* L.), may be planted to winter wheat or fall rye, with the specific intention of feeding waterfowl or providing lure crops.

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