SOIL PRODUCTIVITY

Role of cover crops in recovery and maintenance of soil productivity

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A literature search reveals relatively few reports of soil productivity studies, including cover crops. We can conclude that the use of cover crops in recovery and maintenance of soil productivity is a relatively new concept or at least not universally recognized. This result, however, depends on the inclusiveness of the term cover crops. According to Hughes et al. *(13)*, cover crops are crops seeded on land needing to be protected from wind and water erosion and from nutrient losses by leaching and may often serve at the same time as green manure crops.

One natural resource glossary *(22)* defines a cover crop as "A close-growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production or between trees and vines in orchards and vineyards." The same glossary defines a green manure crop as "Any crop grown for the purpose of being turned under while green or soon after maturity for soil improvement." We wish to address the aspect of soil improvement, which is referred to in the latter definition of cover crop. As a conceptual framework is developed for determining the effect of a cover crop upon soil productivity and soil degradation, it seems necessary to give attention to green manuring as a clearer distinction is made between green manure crops and cover crops not used as green manure.

We will attempt to describe the cover crop practice in soil productivity terminology that involves the character of soil inputs, the expected soil responses, and impact on crop production. To accomodate a degree of universality, we will begin with the soil and climate dimensions of soil productivity.

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Land resource area

We can define soil productivity as the rate that a particular land site can accumulate energy in the form of vegetation. Although yield of target crop biomass may frequently be the primary focus, meaningful analysis of soil productivity must include an evaluation of the site variables that influence photosynthetic productivity from time to time throughout the year, for example, soil, climate, hydrology, species (cultivar), and crop culture. In table 1, we have labeled climate, hydrology, and soil as inherent land resource variables and listed selected variables associated with crop culture. Soil productivity specification depends upon characterization of the inherent land resource variables and knowledge of expected response to the selected crop culture. The empirical basis for soil productivity evaluation is very limited because of the inherent variable interactions that exist and the complex nature of the climate variable. Soil productivity models are, therefore,

Table 1. Land resource variables affecting soil productivity.

Inherent	*Selected*
Climate	Crop Culture
Hydrology	Species, cultivar
Soil	Crop sequence
	Energy import
	Tillage, fertilizer, pesticide, water
	Nutrient export
	Carbon export
	Retained biomass

commonly limited in application. We should examine the role of cover crops as a selected element of crop culture, and the impact of cover crops upon soil productivity will depend upon the inherent land resource variables.

The selected species and cultivar grown as a cover crop on a given site during a given period generates biomass that may be soil incorporated at some stage or allowed to remain on the soil surface. The soil inputs are organic matter and associated chemical compounds. The influence upon some soil volume depends upon the quantity and character of this mass, and a large number of soil, climate, and cultural variables. It is not surprising, therefore, that a variety of experience has been reported, including apparent contradictions. There may be short-term and long-term benefits from added nutrients and organic matter, and there may be positive or negative effects of mulching, depending upon latitude and crop culture. If a succeeding crop is intended, the consumption of soil water and nutrients by the cover crop, before it is incorporated or killed, may create a deficit for crop establishment. If a legume species is used, a welcome source of nitrogen (N) may be made available. The ever-present competition for light, water, and nutrients exists where crops are interplanted. Based on this brief description of the soil-crop-climate system involved in cover crop practice, we will evaluate the soil productivity influences. We will emphasize the role of cover crops apart from nutrient contributions, e.g., legume-N.

Cover crop biomass production

Essentially, the role of cover crops in recovery and maintenance of soil productivity has to do with crop biomass production and what is done with it. It is well known that soil processes and characteristics that impact plant growth can be significantly affected by additions of organic matter from cover crops. The quantity and quality of the available crop biomass then become prime concerns.

In 1939, Woodruff *(28)* observed that cultivation tends to destroy the natural aggregation of the soil by hastening the decomposition of the protective layer of organic colloids associated with virgin aggregates without supplying fresh organic matter to replace it. He further stated that the difference in productivity level of soils of different degrees of aggregate stability may be attributed to differences in the amount of water that penetrates the soil. Long-term cultural treatments on the Sanborn field near Columbia, Missouri, were the focus of his studies, including barnyard manure and green manure in crop rotations over 15 to 50 years. In 1989, Boyle et al. *(1)* reminded us that, through genetic selection, modern agriculture has translocated much of the carbon (C) to the more economically beneficial portion of crops. After harvesting the food and fiber from these plants, there may be less C returned to the soil than is released from the oxidation of soil organic matter. These observations bracket a half century during which a crop culture deficient in biomass inputs has been applied with a consequent degradation of soil processes and characteristics.

Researchers have performed many experiments that have included treatments that import organic matter to the crop site as mulch or manure. We will concentrate on crop biomass from cover crops grown on-site. It is important to distinguish between crop biomass that is soil-incorporated and that which is retained on the soil surface as a decomposing mulch. Cover crop biomass production for restoration and maintenance of soil productivity must provide sufficient quantities of a combination of recalcitrant and labile organic materials to sustain the physical, chemical, and biological processes essential to developing and maintaining a stable soil surface. Investigators have used both leguminous and nonleguminous species and attempted distinctions *(9, 27)*. Unfortunately, few studies have attempted to assess soil characteristics and process changes that can be attributed clearly to the biomass inputs of the cover crops. Much research has focused on crop yield and nutrient responses of less than 3 years, but not on the contribution to the soil organic matter pool and its consequences.

Green manuring

MacRae and Mehuys *(19)* reviewed reported effects of green manuring on soil organic matter levels and physical properties of temperate region soils. We can define green manuring as the process of turning a crop into the soil, whether originally intended or not, irrespective of its state of maturity, for the purpose of effecting some agronomic improvement. MacRae and Mehuys drew several conclusions:

1. Green manures maintain soil organic matter levels under particular, though not well-defined, soil conditions, and different plant species can vary widely in their effect. Rarely will green manuring increase soil organic matter levels.
2. Green manures do not necessarily improve the soil physical condition, even when green-manure additions maintain or increase total soil organic matter levels. Meaningful conclusions are difficult to obtain because of the fragmentary experimentation.
3. Improved crop performance may not be associated with improved soil conditions. Growing seasons with abnormal

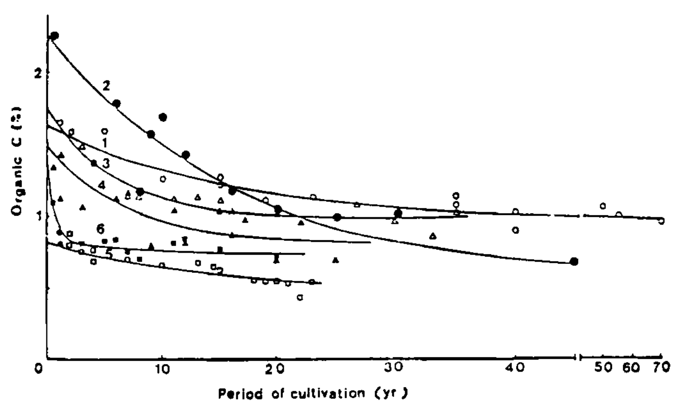

Figure 1. Decrease in organic C in the 0 - to 4-inch soil layer with the period of cultivation. Curves are numbered for as follows: (1) Waco clay (Typic Pellusterts), (2) Langlands-Logie clay (Typic Chromusterts), (3) Cecilvale clay (Typic Chromusterts), (4) Billa Billa loamy clay (Typic Chromusterts), (5) Thallon clay (Typica Chromusterts), and (6) Riverview sandy loam (Rhodic Paleustalfs) *(8)*.

weather conditions are when increased yields are most likely.

The review by MacRae and Mehuys *(19)* clearly makes the point that literature on green manuring on a global scale is voluminous but confusing. To limit confusion, they restrict their review to temperate-region experience by accepting the suggestion of Joffe *(14)*, who believes that effectiveness of green manures depends on the climatic zone in which they are used. MacRae and Mehuys also tabulate the factors influencing maintenance and accumulation of soil organic matter; they conclude that meaningful research must address the interactive nature of the system (Table 2). It seems clear that investigators have not measured primary system variables adequately in space and time to allow interpretation of system responses and possible extrapolation of the experience.

The adoption of green manuring presumes a crop culture that includes a significant amount of cultivation or tillage. It is well established that cultivation is exploitive and causes a decline in the content of soil organic matter *(26)* (Figure 1). This decline is usually accompanied by a decrease in the quantity of water-stable aggregates. It seems reasonable that the soil-improving effects of green manuring may be considerably damped and less frequently observed because of the negating effects of tillage.

Table 2. Factors influencing the maintenance and accumulation of organic matter in soil (*19*).

Climate
Temperature, solar radiation
Precipitation, evaporation
Soil and site
Elevation, slope, aspect, geographical location
Soil type
Texture
Structure, compaction
Native organic matter and humus content
Soil temperature
Soil moisture, aeration
pH
Mineral ion content
Plant cover—species, density, distribution, history of site
Microbial populations—species, density, distribution, history of site
Faunal populations—species, density, distribution, history of site
Use of fertilizers, lime, mulches, and pesticides
Tillage, cultivation, drainage, irrigation
Fire, e.g., burning of crop residues
Material Incorporated
Composition (e.g., carbohydrates, proteins, lignins, fats, waxes)
Quantity added per unit area
Moisture content
C:N ratio
Mineral ion content
Timing, method, and frequency of incorporation
Experimental Variables
Plot size, arrangement, number of replicates
Cultivation practices
Frequency of sampling
Sample size, shape
Technique for measuring variables

Cover crops and mulch

In addition to incorporating cover crops or retaining them on the soil surface as a mulch, there is the alternative of burning. Burning of crop residues has been practiced to varying degrees for a long time throughout the world, and researchers have performed many studies to describe burning's consequences *(23)*. Although we can document short-term benefits of residue burning, the processes of decomposition are circumvented and the contribution of the crop biomass to soil organic matter pool is greatly reduced *(22)*. Therefore, the practice has a negative effect on soil productivity. We will concentrate on cover crops retained on the soil surface as mulches in the following discussion.

Nonlegumes. Wagger and Mengel *(27)* reviewed the role of nonleguminous crops in the efficient use of water and N, and listed the most common species as rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.), and barley (*Hordeum vulgare* L.), which are small grain crops. Investigators have studied annual and perennial forage species in a cover crop context in both temperate and tropical regions, but only to a limited extent as important contributors to soil organic matter *(18, 7)*.

Campbell et al. *(5, 6)* reported experience with planting corn (*Zea mays* L.) and soybeans [*Glycine max* (L.) Merr.] into rye with an in-row chisel planter on Norfolk loamy sand (fine-loamy, siliceous thermic, Typic Paleudults). During 4 years of experimentation, the depletion of soil water by cover crops limited yields of the summer crops. They concluded that evapotranspiration of cover crops must be curtailed to allow recharge of 1.6 feet of surface soil by rainfall before planting date. They realized the mulch benefits during summer crop growth and maturation when there is adequate soil water at planting and during the early growth period.

Table 3. Winter cover crops, weight of mulch, and corn yields at Blacksburg, Virginia 1964 (*20*).

Cover Crop	*Mulch Dry Weight*	*Corn Grain* Yield*
	tons/acre	
Rye	3.25	3.50a*
Rye and Hairy Vetch	3.82	3.21ab
Ryegrass	1.09	3.26ab
Ryegrass and Crimson Clover	1.26	3.00bc
Oats	0.92	2.60cd
Oats and Vetch	1.22	2.41d
Weeds	1.07	2.35d

*Values in column not followed by a common letter are significantly different at 5% probability level.

Moschler et al. *(20)* compared rye, wheat, oats, barley, and Italian ryegrass (*Lolium multiflorum* Lam.) as wintercovercrops in Virginia on four soils prior to no-till corn over a 5-year period. These soils were Cecil (clayey, kaolinitic, thermic Typic Hapludults), Nason (clayey, mixed, thermic Typic Hapludults), Groseclose (clayey, mixed, mesic Typic Hapludults), and Woodstown (fine-loamy, siliceous, mesic Aquic Hapludults). They killed cover crops by applying herbicides at least 10 days before corn planting. For the cereal crops, the highest corn yields occurred where there was the most cover crop mulch. The range in cover crop biomass was 0.62 to 3.26 tons/acre in the order rye > wheat > barley > oats. Corn in rye yielded 44% more than conventionally planted corn on the average (Table 3). They suggested superior water conservation as the primary cause of yield difference. Killing the cover crop 17 days early tended to decrease yield (Table 4). Although Italian ryegrass produced less than 50% of the biomass produced by rye, the corn grain yields were only 6% to 14% less. Inclusion of hairy vetch (*Vicia villosa* Roth) or crimson clover (*Trifolium incarnatum* L.) in winter grain seedings slightly increased mulch but not corn yields.

Gallaher *(10)*, on Cecil soil in Georgia, found 46% and 30% greater corn and soybean grain yields, respectively, when he planted no-till into killed rye than into rye stubble after forage harvest. He attributed the difference to the more favorable soil-water regime under the rye mulch.

Although soil characteristics are infrequently measured, we can associate the nonlegume cover crop with more favorable soil-water regimes, attributable to both increased infiltration and reduced evaporation. The potential for soil-water deficiency at planting needs evaluation for each soil and climate situation, and appropriate crop culture adjustments are needed to achieve acceptable risk level.

Legumes. In review papers, Hoyt and Hargrove *(12)* and Frye et al. *(9)* discussed the role of legume cover crops in crop and soil management and in the efficient use of water and N, respectively. It is clear from these papers that the contribution of N by the legume cover crop is significant and the contributions to the soil organic matter pool are frequently considered minor. Bruce et al. *(4)*, in another review paper, attempted to focus on the effects of legumes on productivity by emphasizing the biomass as well as the N contribution. A comparison of the effect of legumes and nonlegumes on soil productivity by measuring the yield of a subsequent crop is difficult to interpret. It is, therefore, more meaningful to describe the effect upon key soil processes or properties.

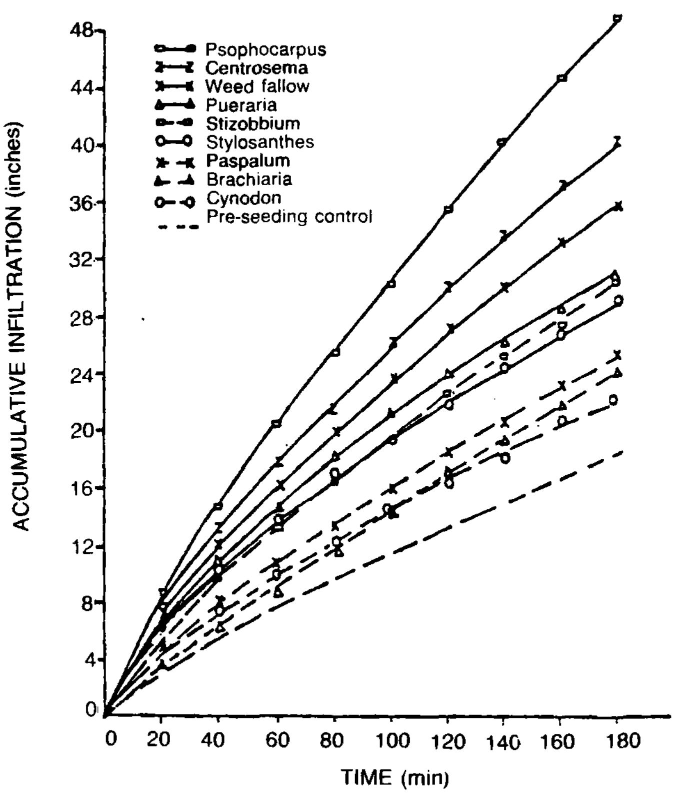

Figure 2. Effect of 2 years of grass and leguminous fallow on the infiltration characteristrics of a severely eroded tropical Alfisol *(16)*.

Table 4. Yield of cover crop mulch killed at two dates and subsequent corn yields at Charlotte Courthouse, 1964 (20).

Cover Crop	*Mulch Yield When Sprayed (tons/acre dry wt)* 3-24-64	4-10-64	*Corn Grain Yield When Cover Crop Sprayed* (tons/acre, 15.5% H_2O)* 3-24-64	4-10-64
Rye	1.65	2.63	1.41	1.63a‡
Ryegrass	0.27	1.34	1.37	1.37b
Oats	0.61	1.07	1.28	1.36b
Wheat	1.50	1.83	1.27	1.34b
Barley	1.19	1.80	1.16	0.94c‡
None (conventional tillage)			1.20 N.S.D.	1.17bc

*Yield values in vertical columns that are not followed by a letter in common are significantly different at 5% level.
‡Denotes significant difference at 5% level in corn yield between dates of spraying.

Cover crop mulch effects on soil

Lal et al. *(17)* reported the changes in the properties of a newly cleared, clayey, skeletal, kaolinitic, isohyperthermic Oxic Paleustalf near Ibadan, Nigeria, in response to mulching. This is an important study because it identifies important soil changes associated with quantity of mulch even though the mulch was not grown on site. They applied mulch rates of 0, 0.89, 1.79, 2.68, and 5.36 tons/acre of dry rice (*Oryza sativa* L.) straw twice per year for 2 years corresponding to the two growing seasons, which are defined by the bimodal character of annual rainfall distribution. They asked the important question of how much crop residue is required to minimize soil deterioration following deforestation for arable land use. Lal et al. made important physical and chemical soil measurements at time intervals. They found that mulch rates of 2.68 to 5.36 tons/acre/season were adequate to maintain satisfactory physical and chemical soil conditions as well as favorable activity of soil fauna. They concluded that a gradual replacement of a forest canopy by a continuous ground cover, as provided by a crop residue mulch, will arrest the rate of deterioration of soil quality and maintain productivity.

On a severely degraded Oxic Paleustalf near Ibadan, Nigeria, Lal et al. *(15, 18)* planted three grasses and five legumes to determine changes in soil conditions compared with a weed fallow. They reported significant improvements in soil organic matter, total N, cation exchange capacity, infiltration rate, moisture retention at low suctions, and soil bulk density under several species after 2 years. Lal *(18)* concluded that, in the tropics, soil organic matter can be built up and the soil structure improved even on eroded and degraded land by growing appropriate planted fallows for 2 or 3 years (Figure 2). But, we sense a contradiction when Lal *(16)* suggests incorporation, without qualification, of an appropriate cover crop. Sanchez et al. *(21)* state, "The first research imperative, therefore, is to quantify the biomass and nutrient content of above ground organic inputs in tropical agroecosystems.

Table 5. Mean stover yield, irrigation response, soil carbon, and water stable aggregates for each crop culture across three erosion classes and five years at Watkinsville, Gerogia (3).

Culture	*Stover Yield (tons/acre/year)*	*I-Io/Io†*	*Soil C**	*Water Stable Aggregates*
		%		
Conventional tillage soybeans				
Nonirrigated	3.9		0.89	52
Irrigated	7.0	0.816	1.06	71
Conventional tillage grain sorghum				
Nonirrigated	2.2		1.04	50
Irrigated	3.5	0.594	1.17	66
No-till grain sorghum into crimson clover				
Nonirrigated	5.4		2.33	87
Irrigated	6.4	0.197	2.42	90

*At 0-0.6-inch depth.
†Io, I = nonirrigated and irrigated, respectively.

A solid, scientifically rigorous data base obtained on well-characterized soils is the necessary first step toward a better understanding of the processes involved in the management of organic inputs." Perhaps by way of qualification, Sanchez et al. *(21)* also stated, "Rainfall agriculture in the seasonal semiarid tropics, however, is subject to great spatial and temporal variation in rainfall and unpredictable spacing between rainfall events. These differences affect both the amount of biomass produced and the amount of organic material decomposed in a year, with important implications for the management of organic inputs in tropical agroeco-systems."

We believe these statements are equally applicable to more temperate regions *(2)*. To reduce confusion and contradiction in the literature, it is necessary to recognize the basic character of the decomposing mulch-soil-crop system and allow these characteristics to determine experimental approaches. The justification for applying the practice of a cover crop with ensuing mulch is based on the necessity to physically protect the soil surface from erosion hazard and to provide decomposable biomass that will stimulate processes of restoration and stabilization of the soil surface, as well as create an increasing soil volume with dynamic soil organic matter pools.

The soil surface should be the plane of reference if we are to evaluate photosynthetic productivity of a particular soil-climate-crop system. A crop culture that continues to supply decomposing mulch materials at the soil surface will, in time, affect increasing soil depth and closely mimic undisturbed grass and forest systems. Tillage that mixes or incorporates the biomass disrupts the flow of energy and materials and can rapidly recreate an unstable soil surface that will not dependably infiltrate water (Figure 1).

Smith and Elliott *(24)*, in a recent review, stated, "Soil organic matter levels in semiarid regions are declining mainly because of intensive tillage practices which stimulate the microbiological decomposition of crop residues and residual SOM [soil organic matter] (i.e., humus). Adoption of new high-speed intensive tillage practices and machinery will only accelerate the problem. Moreover, the rate and amount of organic wastes and residues added back to the land are insufficient to offset the rate of decline. Loss of soil organic matter results in poorer soil structure, reduced infiltration rates, increased crusting, decreased water-holding capacity, increased resistance to root penetration, decreased nutrient availability, and accelerated soil erosion by both wind and water. While intensive tillage produces a flush of nutrients, such as N, with an associated yield increase, the short-term result and the flush of nutrients and crop yield will diminish with each tillage season."

Bruce et al. *(3)* conducted an experiment on slightly, moderately, and severely eroded surfaces of clayey, kaolinitic, thermic Typic Kanhapludults near Watkinsville, Georgia, including biomass inputs from three crop species: soybeans, grain sorghum [*Sorghum bicolor* (L.) Moench], and crimson clover. On each soil erosion class, they grew soybeans and grain sorghum following winter fallow with conventional preplant and postplant tillage; they also no-till-planted grain sorghum into crimson clover. To increase the range of biomass production, they grew the summer crops both with and without irrigation. They measured the effect of the crop biomass inputs from stover over 5 years by soil C content, water stable aggregates and microbial biomass C at 0 to 0.6, 0.6 to 1.2, and 1.2 to 3.15 inches; soil-water regime at 4, 10, 20, 40, and 60 inches; infiltration; erodibility; and occurence of earthworms.

Although their primary objective was to determine the surface soil modifications affecting soil-water regime in the summer season that can be attributed to crop biomass input under no-till and tilled conditions, Bruce et al. *(3)* made associated physical, chemical, and biological assessments. The effect of quantity of crop biomass inputs upon soil C level and aggregate stability at a given soil depth depended on soil texture, crop species, and tillage (Table 5). Infiltration rate after 1 hour of simulated rainfall on surfaces with the remain-

Table 6. Infiltration rate after 1 hour of simulated rainfall for three crop cultures with and without surface residue, March, 1988 (3).

	Infiltration by Crop Culture		
	Conventional Tillage Soybeans	*Conventional Tillage Grain Sorghum*	*No-Till Grain Sorghum Into Crimson Clover*
		inches/hour	
With residue	1.26a*	1.41a	1.96b
Without residue	0.94c	0.88c	1.82d

*Numbers followed by the same letter in a given row are not significantly different at the 5% level of probability.

ing crop residue removed was 100% greater for the no-till grain sorghum into crimson clover than for either grain sorghum or soybeans under conventional tillage (Table 6).

Investigators *(3)* demonstrated the essential stabilization of the soil surface for infiltration, which was well predicted by aggregate stability at 0 to 0.6 inches. Organic matter inputs as well as surface stabilization probably contributed to an enhanced abundance of earthworms and biomass in the no-till double-cropped treatment (Figure 3) that, in turn, may have contributed to the increased infiltration rate *(11)*. A significantly improved soil-water regime for grain sorghum no-till-planted into crimson clover also reflected this soil surface modification.

Conclusions

Cover crops have great potential in restoration and maintenance of soil productivity because they offer an on-site source of plant biomass to restore or maintain soil organic matter levels and soil biological activity. Most degraded soil conditions are the result of practices that have not supplied the quantity or quality of biomass to adequately maintain essential soil processes that are responsible for water and nutrient supply to the plant for effective photosynthesis. A prevailing condition of soil-limiting photosynthesis exists. Effective use of cover crops requires examination of the entire set of crop production objectives in relation to soil and climate.

Cover crop benefits to soil productivity accrue, and we do not often realize them in 1 or 2 years. Certainly, the quantity and quality of biomass input affect the results, but it also makes a large difference as to whether the cover crop is incorporated or allowed to remain on the surface as mulch. A decomposing surface mulch has clear advantages in soil restoration because it concentrates the soil changes at the crucial plane of the soil surface where we are most likely to note first-stage benefits. This means that tillage or stirring that stimulates oxidation and dilution of the decomposition products and disrupts soil faunal activities is eliminated. Soil productivity is climate-dependent; therefore, effect of cover crops will also be climate-dependent.

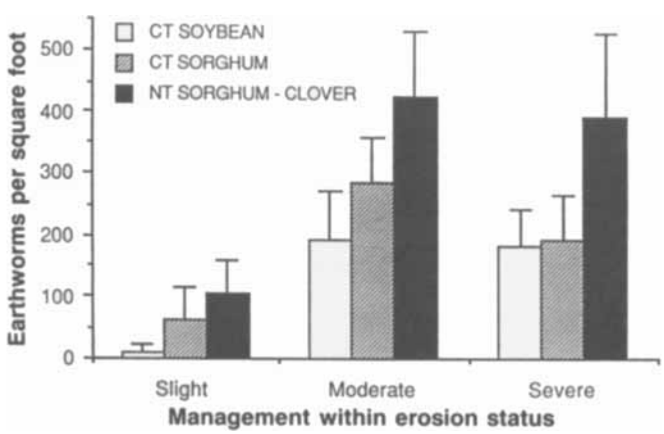

Figure 3. Earthworm densities in conventional tillage (CT) and no-till (NT) agrosystems on three erosion classes at Watkinsville, Georgia *(11)*.

We need to further investigate the role of cover crops in restoration and maintenance of soil productivity in a wide range of climates using a variety of crop species in order to describe the consequences of biological stimulation of the soil volume by decomposing surface mulches. The realization of fuller climate utilization with more effective use of on-site resources may become economically rewarding as imports to the crop culture become more expensive. We can obtain the greatest research contributions from teams of scientists having the training and experience to fully explore the soil and plant system that is involved in the range of climates, with particular attention to synchrony with the temperature and precipitation variables.

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Fall-planted spring oats: A low-risk cover crop to reduce erosion following soybeans

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Soil erosion during a corn-soybean [*Zea mays* L.; *Glycine max* (L.) Merr.] rotation is often greater than during continuous corn *(1, 3)*. Loss of residue cover following soybean harvest exposes soil to direct impact of raindrops. This, coupled with a deterioration in aggregate stability associated with soybean cropping, results in dispersion and transport of soil particles *(2)*. Water infiltration decreases as dispersed particles clog water-conducting pores; consequently, runoff increases. The cumulative effect of these processes is accelerated soil erosion. Use of a cover crop following soybeans might reduce erosion.

Several factors have discouraged adoption of cover cropping systems. First, additional money must be spent to establish the cover crop. Second, inclusion of a cover crop requires more intensive management and adds risk. For example, depletion of soil moisture by a cover crop during a dry spring can cause poor crop stands and reduced yields *(4)*.

We initiated a statewide study in Iowa during 1990 to evaluate fall-planted spring oats as a management option for reducing erosion following soybeans. Aboveground dry matter accumulated by oats prior to winterkill will supplement residue remaining after soybean harvest. Furthermore, because oats do not overwinter, this should minimize the risk of moisture depletion and eliminate the need for herbicides to kill the cover crop. Herein, we present data from the first oat dry matter measurement at 4 to 7 weeks after planting.

Methodology

We solicited cooperators for this project through Practical Farmers of Iowa (PFI), an organization committed to involving producers in on-farm research. We chose locations for the 1990-1991 season to represent a range of soil types across the state. Additional criteria were that sites must be rotated from soybeans to corn during the 1991 growing season and that all planting be done with 30-inch row spacings. The Holland and Yarmouth sites are on the farms of PFI members. The Sioux Center site is at the Agriculture Stewardship Center farm of Dordt College. The Boone site is an Iowa State University field location. Tillage systems included both no-till and ridge-till at Boone, ridge-till at Holland and Yarmouth, and conventional tillage at Soiux Center.

A popular midseason cultivar of spring oats ('Ogle') was

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planted at all locations. As soon as possible after soybean harvest, oats (120 pounds/acre) were planted with a no-till drill set to 7.5 inches between rows. We used the same drill, calibration setting, and seed lot at all locations. We adjusted coulters and press wheels as necessary to control planting depth and allow the drill to follow the contour of the soil surface. Additional planting treatments at Boone included oat seed broadcast 12 days prior to soybean harvest (beginning of leaf drop); broadcast immediately prior to soybean harvest; and broadcast immediately after soybean harvest. We broadcast seed by hand at 120 pounds/acre.

We determined the quantity of aboveground dry matter accumulated by oats prior to winterkill. We centered a frame, constructed from PVC tubing that measured 30 inches wide by 20 inches long, over an old soybean row. We photographed the area within the frame, counted and cut oat seedlings within this area at the soil surface, and estimated the weight per plant by dividing the total dry weight of all plants by the number of plants counted.

Results and discussion

Dates for planting oats with the drill ranged from September 26 at Boone to October 13 at Yarmouth. Good oat stands became established at all the locations (Table 1). Total aboveground dry weight and weight per plant were much greater at the Boone site than at the other locations. This probably reflects the greater time between planting and a subsequent period of below-freezing temperatures during the week of October 21. Earlier drilling at all sites would have been possible if weather conditions had not delayed soybean maturity and harvest.

When averaged across all planting methods at Boone, tillage system had no effect on either stand establishment or dry weight of oat seedlings (Table 2). The early broadcast treatment produced the largest plants; total dry matter accumulation was greater than for the drilled treatment even though there were fewer plants per unit area. Poor stand establishment resulted when we broadcast oats after the combine, and seed remained on top of soybean residue. We obtained better stands when seed was placed under the residue by broadcasting ahead of the combine. These plants were fewer in number and smaller than those placed below the soil surface with the drill.

We obtained only slightly lower values for total aboveground dry weight when we drilled oats after soybean harvest rather than broadcasting oats 12 days earlier into the standing crop (Table 2). It also appeared that seedlings from the drilled treatment were more resistant to frost damage following temperatures of less than 20°F that occurred several days after we harvested the dry weight samples. Drilled plants were probably more resistant to frost because the growing points of these plants were at or below the soil surface. The growing points of the broadcast seeded plants were above the soil surface.

Growth of oats during the first year of this study was lower than we desired. We observed more encouraging results at a location that was not part of this experiment. Effects of oats on infiltration, erosion, and the subsequent corn crop remain to be determined. Hopefully, fall-planted spring oats can be

Table 1. Population, total aboveground dry weight, and weight/plant of oat seedlings at all locations. Oat seed were planted with a no-till grain drill after soybean harvest.

Location	*Tillage*	*Days After Planting*	*Population (number/square foot)*	*Dry Weight (pounds/acre)*	*Seedling Weight Per Plant (grams)*
Boone	No-till	36	34ab*	136b	0.041b
Boone	Ridge-till	36	36a	161a	0.047a
Holland	Ridge-till	27	35ab	49c	0.015c
Sioux Center	Conventional	34	28b	26d	0.010d
Yarmouth	Ridge-till	32	33ab	37cd	0.012cd

*Values within columns followed by the same letter are not significantly different by $LSD_{0.05}$.

Table 2. Population, total aboveground dry weight, and weight/plant of oat seedlings as affected by tillage system and oat planting method. All data are from the Boone location.

	Population (number/square foot)		*Dry Weight (pounds/acre)*		*Seedling Weight Per Plant (grams)*	
Planting Method	*Ridge-till*	*No-till*	*Ridge-till*	*No-till*	*Ridge-till*	*No-till*
Broadcast						
Early	21*	21	179	179	0.093	0.087
Before combine	21	15	45	31	0.023	0.022
After combine	4	3	7	7	0.021	0.023
Drilled						
After combine	36	34	161	136	0.047	0.041
$LSD_{0.05}$						
Tillage (T)	NS		NS		NS	
Planting method (P)	3.6		26.3		0.009	
T×P	NS		NS		NS	

*All plants were harvested during the same two day period. This was 48 days after oat planting for the early broadcast treatment and 36 days after planting for all other treatments.

developed into a low-cost, low-risk approach to reducing erosion and improving tilth.

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Long-run impacts of cover crops on yield, farm income, and nitrogen recycling

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A query of AGRICOLA for the period January 1984 through July 1990 for articles with nitrogen (N) recycling or cover crop as key words produced a listing of 344 titles. None of these articles treated the use of cover crops to recycle N. A paucity of literature on the use of cover crops to recycle N is not unusual given the recent concern about N pollution of groundwater and the complex, costly, and long-run nature of setting up experiments to evaluate the impact of cover crops on recycling N.

DeCoursey *(1, 2, 3)* indicates that process models can be used as an aid to research in the fields of nonpoint source pollution. The Erosion-Productivity Impact Calculator (EPIC) is a process model that the Agricultural Research Service, Economic Research Service, and the Soil Conservation Service developed to evaluate the impacts of alternative crop production practices on a variety of yield and nonpoint-source pollution parameters *(4, 8)*. Because EPIC has a variety of subroutines that simulate plant growth processes and their impacts on soil structure, N, and phosphorus (P) pools and a wide variety of nonpoint-source pollution parameters, we used it in this analysis to evaluate the impacts of cover crops on N recycling. Investigators have used EPIC in a number of analyses, including the impacts of alternative conservation practices, tillage practices, and/or global climate change on yields and nonpoint-source pollution parameters *(5, 6, 8, 9)* [1].

Methodology

We used EPIC to simulate the impact of cover crops on N recycling. We designed a set of control crop rotations representative of soils in the Southeast and Corn Belt. We then added a cover crop to the rotations. The simulations were run for a 25-year period to allow for the incorporation of organic matter to the soil from the addition of cover crops to the rotation and to account for the extremes in variations of temperature and precipitation. Given that EPIC tracks the

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impact of cultural practices on the organic content of the soil and the N pool, it is possible to estimate changes in N pollution among various alternative production practices.

Incorporation of a cover crop into a rotation increases the relative content of organic matter in the soil over time. An increase in organic matter may increase N nonpoint-source pollution attached to sediment that leaves the field and as solutes in runoff, subsurface flows, and/or in leachates passing through the root zone.

Addition of a cover crop may reduce the quantity of water available to the major crops during the growing season by using part of the moisture that is stored in the soil over the winter period. If the reduction in available water is sufficient to cause stress and reduce yields, then the addition of a cover

Table 1. Estimated average N losses for specified treatments and rotations on soil 487 Norfolk-A, North Carolina.

	Average N Loss over a 25-year Simulation					
	From Top of Soil		*Through Soil*		*Total*	
Rotation and Treatment	*Pounds/acre*	*Change*	*Pounds/acre*	*Change*	*Pounds/acre*	*Change*
Corn, peanuts, cotton						
One fertilizer application						
No cover	7.6		54		61.6	
With cover	6.4	−16%	46	−15%	52.4	−15%
Split fertilizer						
No cover	5.6		54		59.6	
With cover	5.4	−4%	46	−15%	52.4	−12%
No cover						
One fertilizer application	7.6		54		61.6	
Split fertilizer	5.6	−26%	54	0%	59.7	−3%
With cover						
One fertilizer application	6.4		46		52.4	
Split fertilizer	5.4	−16%	46	0%	51.4	−2%

Table 2. Estimated average N losses for specified treatments and rotations on soil 257 Fuquay, North Carolina.

	Average N Loss over a 25-year Simulation					
	From Top of Soil		*Through Soil*		*Total*	
Rotation and Treatment	*Pounds/acre*	*Change*	*Pounds/acre*	*Change*	*Pounds/acre*	*Change*
Corn, peanuts, cotton						
One fertilizer application						
No cover	5.2		50		55.2	
With cover	4.8	−8%	41	−18%	45.8	−17%
Split fertilizer						
No cover	4.2		50		54.2	
With cover	3.8	−10%	41	−18%	44.9	−17%
With cover						
One fertilizer application	4.8		41		45.8	
Split fertilizer	3.8	−21%	41	0%	44.9	−3%
No cover						
One fertilizer application	5.2		50		55.2	
Split fertilizer	4.2	−19%	50	0%	54.2	−2%

Table 3. Estimated average N losses for specified treatments and rotations on Tama soil, Illinois.

	Average N Loss over a 25-year Simulation					
	From Top of Soil		*Through Soil*		*Total*	
Rotation and Treatment	*Pounds/acre*	*Change*	*Pounds/acre*	*Change*	*Pounds/acre*	*Change*
Corn, soybeans						
One fertilizer application						
No cover	25.1		30		55.1	
With cover	22.8	−9%	6	−80%	28.8	−48%
Split fertilizer						
No cover	24.1		30		54.1	
With cover	21.9	−9%	5	−83%	26.9	−50%
With cover						
One fertilizer application	22.8		6		28.8	
Split fertilizer	21.9	−4%	5	−17%	26.9	−7%
No cover						
One fertilizer application	25.1		30		55.1	
Split fertilizer	24.1	−4%	30	0%	54.1	−2%

crop may have a negative impact on farm income. EPIC will estimate the impact of adding a cover crop on yields. We can use the effect of cover crops on yields as a proxy to measure the impact of cover crops on farm income.

This analysis simulated the probable impact of adding cover crops to common rotations on N recycling and farm income for common rotations in two locations. We used the loss of N from the top of the soil and through the soil as measures of the effectiveness of cover crops to recycle N and reduce nonpoint-source pollution.

The soils we used in this analysis were Norfolk-A and Fuquay, located in Major Land Resource Area (MLRA) 133 in North Carolina, and Tama, located in MLRA 108 in Illinois. For Norfolk-A and Fuquay, we compared a corn, peanuts, cotton rotation with a corn, peanuts-cover crop, cotton-cover crop rotation. For Tama, we compared a corn, soybean rotation with a corn-cover crop, soybean rotation. We ran the control sets and the sets with a cover crop with a one-time fertilizer application and a split fertilizer application. For the one-time application, we assumed that all fertilizer is applied at planting. For the split fertilizer options, we used the same quantity of fertilizer as the automatic option but applied one-half of the fertilizer at planting and the other half 40 days later. A comparison between these two types of fertilizer applications should indicate if the timing of fertilizer applications tend to impact nonpoint-source pollution.

Snedecor points out that the model used may determine the success or failure of an experiment *(7)*. He also points out that the pairing of crop yields in successive seasons is an appropirate model, given the annual variations in yields. Because the interseasonal yields vary so much due to factors beyond the control of the scientist, the treatment must be applied every year with a pairing of yields.

Our analysis extended the pairing of observations to environmental parameters. We used the differences in the annual averages of the parameters in question for the different treatments to determine if there were significant differences in the treatments. Given that EPIC is set up to use identical weather patterns for the paired simulations, the differences test is the strongest test possible.

Results

The data presented in tables 1, 2, and 3 indicate that the addition of a cover crop has the following impacts:

1. Reduction in N losses from the top of the soil of 4% to 26%.
2. Reduction in N losses through the soil of 0% to 83%.
3. Reduction in total N losses of 2% to 50%.
4. Reduction in total N losses of 2% to 7% for the split-N application.
5. Negligible impacts on average yields.

None of these impacts were statistically significant. It is important to point out that treatments on these soils for the specified rotations reduced total N losses. Lack of statistical significance is due to the random nature of climatic events. Review of the annual data shows that treatments had positive and negative impacts, but on average, addition of cover crops and the timing of fertilizer application reduced total N losses.

Table 4. Estimated average yields by soil and rotation.

	One Fertilizer Application		Split Fertilizer	
Soil and Rotation	*No Cover*	*With Cover*	*No Cover*	*With Cover*
Norfolk-A				
Corn (bushels)	141	140	142	140
Peanuts (pounds)	3,330	3,331	3,331	3,334
Cotton (pounds)	612	596	612	596
Fuquay				
Corn (bushels)	155	153	156	153
Peanuts (pounds)	3,484	3,483	3,485	3,483
Cotton (pounds)	681	680	681	680
Tama				
Corn (bushels)	149	148	149	148
Soybeans (bushels)	41	43	42	43

This implies that changes in N losses are a function of the N that is available for movement and the storm event that produces sufficient precipitation to cause significant runoff and/or percolation. Changes in N losses due to subsurface lateral flows were negligible for these soils and treatments.

Economic impacts

Table 4 shows average yields for control and treatment groups. Addition of cover crops to the specified rotations on these soils had no significant yield impacts. The only economic impact would be the additional cost to the producer for adding a cover crop to the specified rotations. This cost could vary significantly by location and type of cover crop.

Conclusions

Adding a cover crop to the above rotations and soils should have a net benefit to society by reducing the potential for N to reach groundwater or surface water. More research is needed to determine the extent to which adding cover crops to recycle N will benefit society, to determine methods to maximize the amount of N trapped by cover crops and find out how it is made available for succeeding crops, and to determine the cost of reducing N pollution to the agricultural producers.

This information would assist society in determining the necessity for and the amount of compensation required to protect soil and water resources. For the alternatives considered and analyzed here, there is no economic incentive to the producer. The economic disincentives to the producer are equal to the cost of adding a cover crop to the rotation less the value of the N recycled by the cover crop.

Additional income could be obtained from the cover crop if it were used by livestock. However, the demand for winter forage is directly related to the demand for livestock products, which is beyond the scope of this analysis.

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