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Sod-Based Crop Rotations in the Southern Piedmont: Summary of Historical Research in Watkinsville

Alan J. Franzluebbers, Stanley R. Wilkinson*
USDA-Agricultural Research Service, 1420 Experiment Station Road, Watkinsville GA 30677-2373, Tel: 706-769-5631, Email: afranz@arches.uga.edu

Abstract

Sod-based crop rotations have been a part of the research history at the Southern Piedmont Conservation Research Center in Watkinsville GA. Several studies conducted from the 1940s to the 1980s focused on one of four topics related to sod-based cropping including (1) the effects of long rotation sequences on crop yield and soil erosion control, (2) the effects of short rotation sequences or cover crops on crop yield and soil fertility, (3) the effects of interseeding grain crops into living sods on enhancing productivity and utilizing animal manures, and (4) the effects of forage management on enhancing productivity and soil erosion control. This paper is a review of important results from this previous time so that future research can be targeted to fill gaps in our knowledge of how to sustainably manage sod-based cropping systems for high productivity and environmental quality.

Keywords: Corn; Cotton; Cover crops; Erosion; Forages; Nutrients; Runoff; Soil organic matter

Introduction

At the USDA–Agricultural Research Service farm in Watkinsville GA, many forage and cropping research projects have been conducted during the past 66 year. These data could contribute to an understanding of how sod-based cropping systems might fit into future agricultural productions systems in the southeastern USA. This report summarizes some of the soil, plant, and environmental responses from the historical research conducted in sod-based cropping systems. This history was divided into four primary topics with relevance to sod-based cropping systems including (1) long rotation sequences of 4-10 years with the sod used to slowly build soil fertility and tilth, (2) contemporary short-rotation sequences with legume cover crops to quickly fix N for subsequent crop utilization, (3) intercropping of annual row crops directly into perennial sods, and (4) forage management techniques for production and conservation. A fifth research topic with a large impact on soil conservation has dealt with reduced- and no-tillage crop production, but will not be covered in this summary. Readers can refer to several articles on this research topic including Bruce et al. (1995) and Langdale et al. (1992).

The Southern Piedmont Experiment Station in Watkinsville GA was established by the United States government on 1 January 1937 and administered by the Soil Conservation Service. Barnett (1986) compiled a report summarizing the first 50 years of progress at the research center.

“Much of the agriculture of the Southeast is based on clean-tilled crops grown on sloping land. Other land is in sod crops like coastal bermudagrass, tall fescue, and sericea lespedeza. These crops are grown on soils that are relatively infertile, highly erodible, low in organic matter, and easily compacted by rainfall and machine traffic. These soils respond well, however, to good management practices including adequate levels of plant nutrients and cropping systems that restore soil organic matter and soil structure and reduce machine traffic. Rains on clean-tilled soil cause high rates of runoff and soil losses. Rains of large volume and low intensity cause deep percolation that leaches plant nutrients from the soil. High temperatures most of the year cause rapid depletion of soil organic matter. These conditions, when uncontrolled, lead to environmental deterioration by concentrations of plant nutrients, sediments, and other pollutants in drainage waters. A long-range result is loss in the productive capacity of the soil. Cropping systems are needed to replenish soil organic matter, to maintain a high infiltration rate or low overland flow rate in order to reduce surface runoff and prevent soil erosion, to prevent leaching of plant nutrients from the soil, to restore soil fertility, and to maintain good soil structure. Studies were conducted at the Southern Piedmont Conservation Research Center to fulfill those needs.” (Carreker et al., 1977).

Long-Rotation Sequences of Grain–Fiber–Sod

Hendrickson et al. (1963a) wrote “The most promising single answer to the persistent row-crop erosion hazard on sloping land has been the increasing use of the highly protective grass-based crop rotations”. Describing research conducted in South Carolina, runoff from pastures averaged 10% of precipitation (compared with 20% for continuous cotton in Watkinsville) and soil loss from pastures averaged 0.1 ton/a (compared with 20 ton/a for continuous cotton in Watkinsville).

Cotton seed yield on land with a 7% slope increased with increasing years of sod in the rotation. During 1944-1947, continuous cotton yielded 785 lb/a, cotton with vetch cover crop yielded 870 lb/a (11% increase), cotton with vetch cover and rotated with corn/crotolaria yielded 991 lb/a (26% increase), cotton in a 3-year rotation with oat/lespedeza-lespedeza yielded 1070 lb/a (36% increase), and cotton in a 4-year rotation with vetch cover crop-corn-oat/lespedeza-lespedeza yielded 998 lb/a (27% increase) (Hendrickson, 1949).

Corn grain yield following plowing and disking of 5-year stands of either ‘Kentucky-31' tall fescue or ‘Coastal’ bermudagrass at 14 piedmont locations in Georgia and South Carolina averaged 58

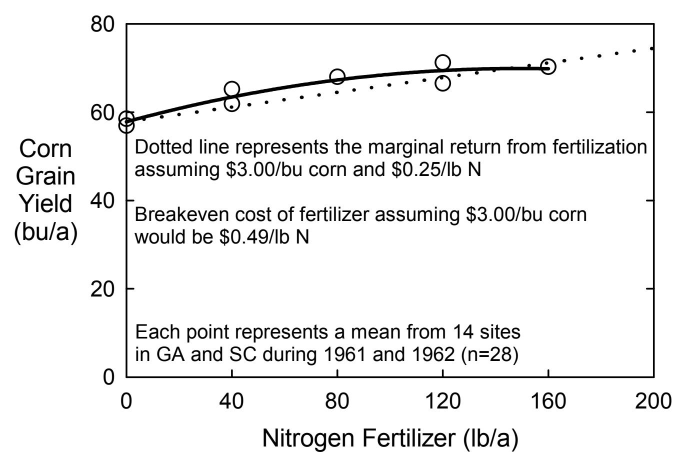

Fig. 1. Corn grain yield response to N fertilizer, along with the marginal return of fertilization. Data from Parks et al. (1961).

bu/a without fertilizer and 71 bu/a at maximum yield with an average of 114 lb N/a (Parks et al., 1969). With calculation of a marginal return of fertilization, yield without fertilization averaged 92% of maximum economic yield (achieved with an average N fertilization rate of 49 lb N/a) (Fig. 1). Breakeven cost of fertilization from this yield response curve following sod was $0.49/lb N. Yield response curves to N fertilizer in this area are typically much greater with continuous cultivation of row crops (e.g., yield without N fertilizer in continuous corn production would likely be <50% of yield with optimum fertilization). Relative corn grain yield in the 1st, 2nd, and 3rd years following termination of sod averaged 100, 97, and 92% with optimum fertilization (Parks et al., 1969).

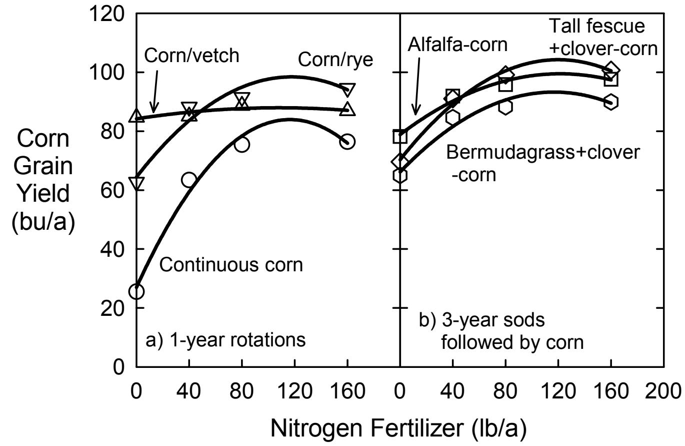

Fig. 2. Corn grain yield response to N fertilizer as affected by previous crop. Data from Adams et al. (1970a).

The effect of previous cropping and N fertilization on corn grain yield was determined from 1958 to 1964 (Adams et al., 1970a). Continuous corn yield was 84 bu/a with 106 lb N/a to achieve maximum economic yield (assuming $3.00/bu corn and $0.25/lb N) (Fig. 2a). Continuous corn yield without N fertilizer was only 31% of maximum economic yield. A 1-year rotation with vetch cover crop did not require any additional N to achieve the same yield as in continuous corn, resulting in a savings in N fertilizer. A 1-year rotation with rye cover crop required 101 lb N/a to achieve maximum economic yield, but boosted yield by 14 bu/a. Sod-based rotations of corn following 3 years of either alfalfa, tall fescue, or bermudagrass required 92 to 102 lb N/a to achieve maximum economic yield, but boosted yield by 9 bu/a following bermudagrass, 15 bu/a following alfalfa, and 20 bu/a following tall fescue (Fig. 2b). With 80 lb N/a applied to corn each year, 2nd year corn following tall fescue was 31 bu/a (47%) greater than under continuous corn, 3rd year corn was 40 bu/a (59%) greater, 4th year corn was 42 bu/a (62%) greater, and 5th year corn was 22 bu/a (32%) greater (Adams et al., 1970a).

Corn grown following sericea lespedeza exhibited phytotoxicity from surface but not from well-buried residues (Adams et al., 1973). Several weeks of decomposition prior to planting corn were found to be required to avoid phytotoxicity symptoms. Mineralization of N from sericea lespedeza leaves containing 1.5% N was 35% complete during 203 days of incubation, while net immobilization of N occurred from stems containing 0.7% N (Fig. 3).

The accumulation of organic matter under sod-based cropping systems contributes to the fertility of soil, especially from the supply of N through mineralization. Giddens et al. (1971b) demonstrated the benefit of sod on accumulation of organic matter and its subsequent mineralization in a greenhouse study with N uptake of sorghum–sudangrass (Fig. 4). Nitrogen uptake increased with number of years in tall fescue and decreased with number of years out of fescue. Although the authors stated that the growth response of sorghum–sudangrass following termination of tall fescue could not be attributed to any change in soil physical condition and was purely due to N availability, the difference in y-intercept between regressions "in fescue" and "out of fescue" resembles a rotation effect. Even today, rotation effects in addition to N availability are not completely understood. Rotation effects may be due to soil physical, chemical, and biological changes or interactions among these effects (Barber, 1972; Crookston, 1984; Jawson et al., 1993). Actual corn grain yield response following tall fescue sod followed a similar pattern to that demonstrated in the greenhouse. Yield without additional N fertilizer was greatly affected by the number of years "in fescue" and "out of fescue" (Fig. 5a). A rotation effect unrelated to N availability was clearly demonstrated by the greater yield following more compared with fewer years of tall fescue when an additional 100 lb N/a were added as fertilizer to all plots (Fig. 5b).

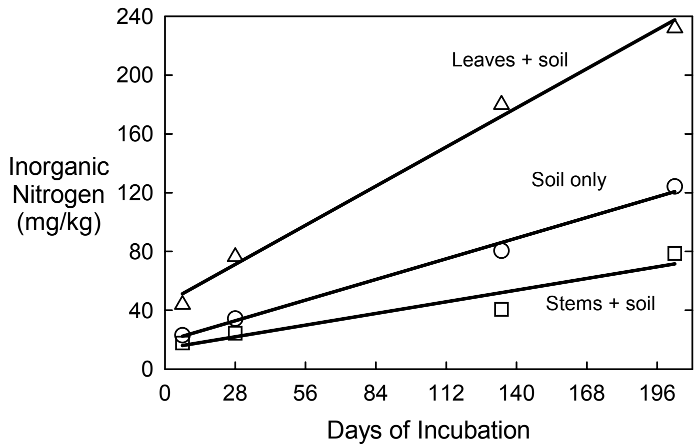

Fig. 3. Mineralization of N from soil and sericea lespedeza leaves and stems. Data from Adams et al. (1973).

From 1943 to 1948, soil organic N in the surface 6" of soil increased in multiple-year rotations with sod crops and decreased with continuous cotton cultivation (Gosdin et al., 1949). Soil organic N declined by 25 lb N/a/yr in continuous cotton and increased by 5 lb N/a/yr in a 2-year rotation of cotton/vetch-corn crotolaria. In 3-year rotations of oat/lespedeza-lespedeza-cotton/oat, soil organic N increased an average of 36 lb N/a/yr. By extending the rotation to 4 years with additional grain (oat/lespedeza-lespedeza-cotton/vetch-corn/oat), soil organic N increased only 17 lb N/a/yr. From 1948 to 1952 further increases in soil organic N were reported with the 3-year rotations, such that soil organic N

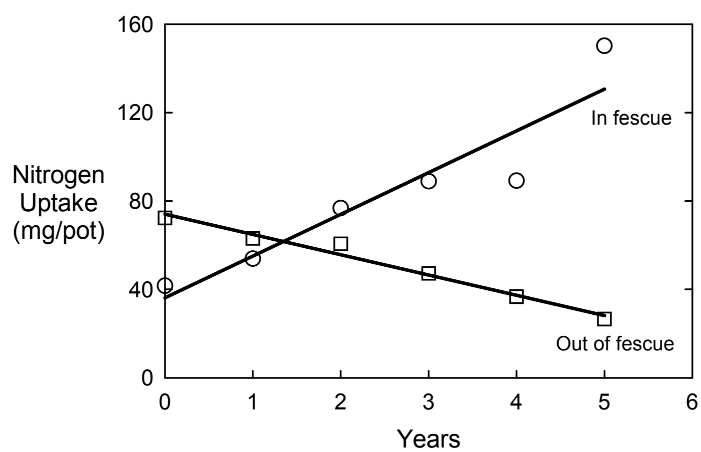

Fig. 4. Nitrogen uptake by sorghum-sudangrass grown in the greenhouse from soil that was collected at different times following tall fescue sod. Data from Giddens et al. (1971b).

was 50% greater than in continuous cotton (Barnett et al., 1961). Eight years after conversion to continuous cotton, soil organic N was only 10% greater than in long-term continuous cotton.

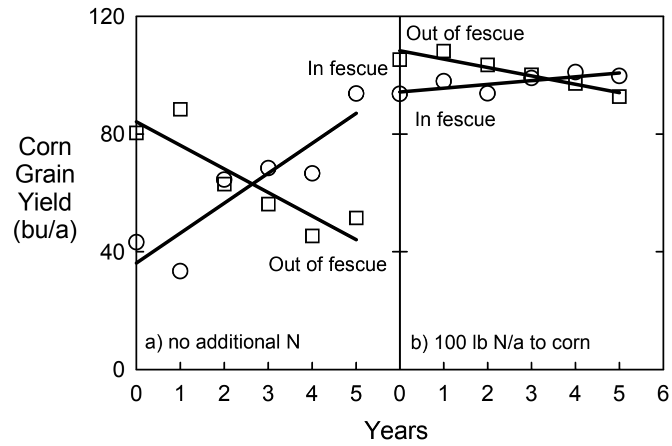

Fig. 5. Corn grain yield as affected by the number of years following tall fescue sod. Data from Giddens et al. (1971a).

Soil physical properties following sod crops improve. Water-stable aggregation was 22% under continuous corn, 30% under corn with rye cover crop, 31% under corn following 3 years of tall fescue, and 41% under continuous tall fescue (Carreker et al., 1968). Soil bulk density of the surface 6" was 1.62, 1.66, 1.59, and 1.62 g/cm^3, respectively. Available water-holding capacity was 0.07, 0.11, 0.09, and 0.08 in/in, respectively. Water infiltration averaged in spring and fall was 1.7, 2.4, 2.6, and 2.0 in/hr, respectively. Time for runoff to begin averaged 6.3, 6.6, 5.6, and 6.7 min, respectively. Annual water runoff averaged 2.5, 3.4, 1.6, and 0% of precipitation during 1962-1964, respectively.

The loss of soil through erosion in the Piedmont has been severe and its effect on crop production was assessed early on in the history of the research station. For every one inch of topsoil lost through erosion, yields of cotton, corn, and oat were reduced 34-40% (Adams, 1949). Conversion of land to sod crops was found to dramatically reduce water runoff and soil erosion (Fig. 6). Soil loss from April-September in 1941 was reduced by 35% following 2nd year Kobe lespedeza compared with continuous cotton (Carreker, 1942). Compared with continuous cotton, cotton seed yield following clover green manure was 31% greater and following 2nd year Kobe lespedeza was 93% greater. Soil loss during 1940-1944 averaged 28.8 ton/a from continuous cotton, but 4.6 ton/a from a 3-year rotation of oat/lespedeza-lespedeza-cotton (Carreker, 1946). Within the three years of the rotation, soil loss was 4.5 ton/a from oat/lespedeza, 0.4 ton/a from 2nd year lespedeza, and 8.9 ton/a from cotton. Carreker and Barnett (1949) demonstrated that the conservation benefit of a 2-year cotton rotation compared with continuous cotton was

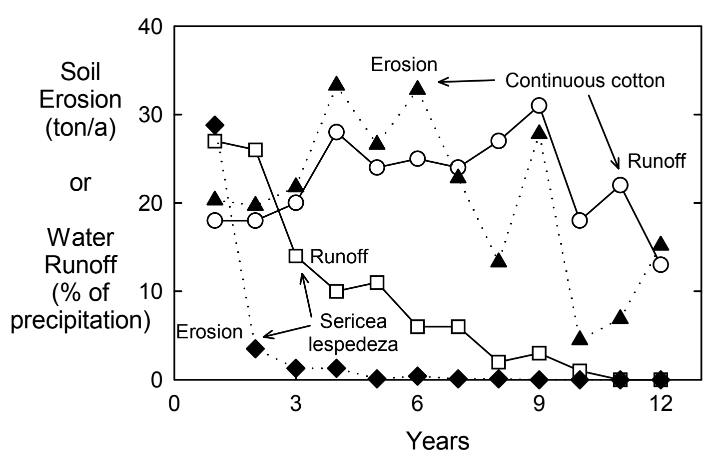

Fig. 6. Water runoff and soil loss from continuous cotton and sericea lespedeza. Data from Barnett (1965).

greater on steeper land and that of a 3-year rotation more effective than that of a 2-year rotation on steepest land (Table 1).

Table 1. Average annual water runoff and soil loss from continuous and rotated cotton cropping systems in Watkinsville GA from 1943-1948. Data from Carreker and Barnett (1949).

Cropping system	Water runoff (% of precipitation)	Soil loss (ton/a)
3% slope		
Cont. cotton	15	4.5
2-yr rotation	9	2.6
7% slope		
Cont. cotton	22	26.0
2-yr rotation	17	12.8
3-yr rotation	11	3.5
11% slope		
Cont. cotton	27	24.3
3-yr rotation	18	7.4

2-yr rotation was cotton/vetch-corn/crotolaria
3-yr rotation was oat/lespedeza-lespedeza-cotton

Annual water runoff was 14% of precipitation from continuous peanut and 7% during each year of a 2-year rotation of peant-oat/vetch/crotolaria (Hendrickson et al., 1963b). Annual soil loss on this land with 3% slope was 5.9 ton/a under continuous peanut and 1.4 and 1.0 ton/a in the peanut and oat/vetch/crotolaria phases of the rotation, respectively. On land with a 7% slope, water runoff was 20% of precipitation under continuous cotton from 1945-1952 and averaged 7% under a 3-year rotation of oat/lespedeza-lespedeza-cotton. Annual soil loss averaged 13.4 ton/a under continuous cotton and 1.7 ton/a under 3-year rotation (Hendrickson et al., 1963b).

Short-Rotation Sequences with Cover Crops

Adams (1950) wrote “There is no substitute for good rotations in a diversified agriculture. By establishing good stands of close-growing legumes on the land, an excellent base for crop rotations is provided.” Some recommendations for utilizing reseeding legumes were developed in Watkinsville during the late 1940s. Caley pea and vetch were broadcast onto land with kudzu to increase grazing potential during the cooler parts of the year. Ryegrass was found to be an excellent volunteer grass.

Vetch as a cover crop for continuous corn production supplied enough N that corn grain yield did not respond to additional N fertilizer (Fig. 2a). Adams et al. (1964) did not recommend rye as a cover crop for corn, since corn grain yield without N fertilizer following rye receiving 80 lb N/a was equivalent to continuous corn alone receiving 40 lb N/a, unless “rye were grazed or used for something other than increasing corn yields”. Soil organic C (0-6") following eight years of treatment averaged 4.7 g/kg under continuous corn, 6.2 g/kg under corn/vetch, and 6.7 g/kg under corn/rye (Adams et al., 1964).

Legume cover crops may supply sufficient N to succeeding corn crops, but only if residues are returned to the soil. Corn grain yield without N fertilizer was lower when cover crops were harvested for hay than when returned to the soil (Table 2). In addition, the effectiveness of legume cover crops to supply N to corn was increased when soil was not tilled compared to conventional tillage. The N fertilizer value of reseeding crimson clover has been estimated to be 80-120 lb N/a (Hargrove, 1982; Touchton et al., 1982). Corn yield response to N fertilizer with crimson clover as cover crop was minimal, even when removing clover residues prior to planting corn (Fig. 7).

Table 2. Corn grain yield (bu/a) during 1976-1977 with legume cover cropping (average of crimson clover and hairy vetch) as affected by tillage and N fertilization. Data from Hargrove (1982) provided by S.R. Wilkinson and J.R. Dobson.

Management	Conventional tillage	No tillage
Residues removed		
0 lb N/a	78	81
105 lb N/a	127	108
Residues returned		
0 lb N/a	103	115
105 lb N/a	128	128

Plant species that have been investigated in conjunction with conservation tillage system in the southeastern USA include, wheat, rye, oat, barley, ryegrass, hairy vetch, common vetch, lupin, crimson clover, orchardgrass, bluegrass, tall fescue, bermudagrass, and bahiagrass (Sojka et al., 1984).

Crimson clover overseeded into bermudagrass can provide biologically fixed N and improve productivity. Without additional N, overseeding of crimson clover provided the yield equivalent of 119 lb N/a in common bermudagrass alone (Fig. 8a) and 80 lb N/a in ‘Coastal’ bermudagrass alone (Fig. 8b). The amount of N fertilizer required to achieve maximum economic yield averaged 304 without clover and 244 lb N/a with clover. Even with this reduction in 60 lb N/a, forage yield was increased by 0.9 ton/a with both common (21% increase) and ‘Coastal’ bermudagrass (15% increase) (Carreker et al., 1977).

Sods Intercropped with Grain Crops

Cereal rye grain yield interseeded into a dormant stand of ‘Coastal’ bermudagrass was equivalent to rye grain yield seeded alone (Welch et al., 1967). Optimum rye grain yield was achieved with fertilization of 80 lb N/a along with 5 ton/a of ‘Coastal’ bermudagrass hay fertilized with 200 lb N/a. Intercropping of rye into bermudagrass allows full climate utilization, fewer tillage operations needed for sod-seeded rye than for conventional seedbed preparation, improved water infiltration and reduced soil

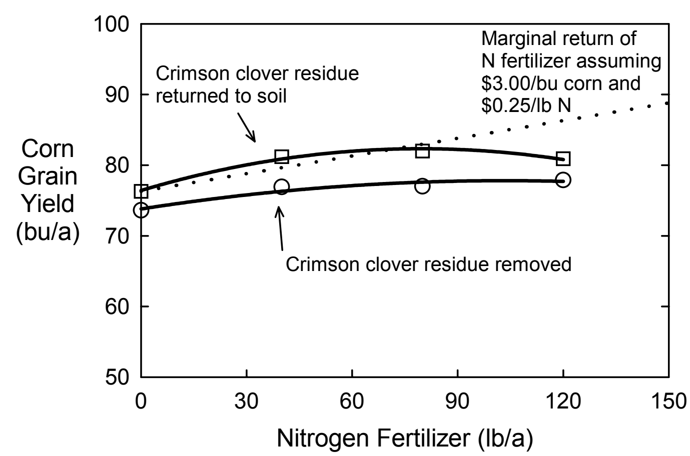

Fig. 7. Corn grain yield response to N fertilizer as affected by crimson clover cover crop management. Data from Touchton et al. (1982).

erosion hazard with sod seeding as compared to conventional seeding. Similar success was obtained with wheat interseeded into a dormant stand of ‘Coastal’ bermudagrass and harvested for either silage or grain (Carreker et al., 1977).

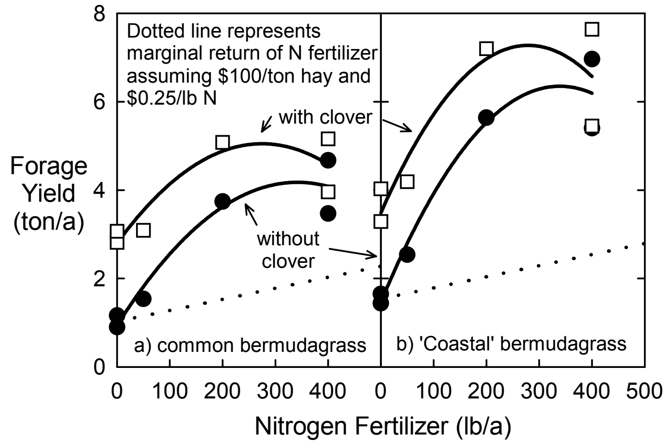

Fig. 8. Forage yield response to N fertilizer as affected by the overseeding of crimson clover. Data from Adams et al. (1967).

Corn interseeded into bermudagrass and tall fescue sods has been researched under both dryland and irrigated conditions. Corn grain yield during 1961-1962 on ‘Coastal’ bermudagrass sod averaged 82 bu/a with conventional plow-disk cultivation, 66 bu/a with lister planting, 60 bu/a with strip tillage (40% of area tilled), and 35 bu/a with no tillage and herbicide application under dryland conditions (Adams et al., 1970b). Under irrigation, yields were 126, 99, 102, and 76 bu/a, respectively. Grown on tall fescue sod, corn grain yield averaged 89 bu/a with conventional plow-disk cultivation, 77 bu/a with lister planting, and 16 bu/a with no tillage and herbicide application under dryland conditions. Under irrigation, yields were 149, 143, and 121 bu/a, respectively. ‘Coastal’ bermudagrass yield during the subsequent year to corn harvest was 1.4 ton/a following conventional cultivation, 3.4 ton/a following lister planting, 3.7 ton/a following strip tillage, and 4.5 ton/a following no tillage with herbicide application.

Corn planted without tillage into sprayed or live tall fescue sod receiving high rates of poultry litter was investigated in 1970-1971 (Carreker et al., 1973). Competition for water by tall fescue reduced corn grain yield, but planting into live sod allowed tall fescue to survive this disturbance (Table 3). Data suggests that as long as irrigation is available to overcome short drought periods, corn grain can be effectively harvested when planted into living tall fescue sod. The application of a high rate of animal manure may also be possible, since corn and subsequent tall fescue forage would provide suitable sinks for nutrient utilization throughout the year.

Table 3. Average corn grain yield during 1970 and 1971 and tall fescue herbage mass at the end of the growing season in 1971 as affected by tall fescue sod control and N application. Data from Carreker et al. (1973).

N application	Grain yield (bu/a)		Herbage
(lb N/a/yr)	Live sod	Killed sod	(ton/a)
Inorganic only			
429	48	180	2.8
Poultry litter + inorganic			
346	67	166	3.0
561	107	188	2.8
992	121	161	2.7
1859	79	96	3.2

During 1972-1973, corn interseeded into tall fescue sod with supplemental irrigation was further evaluated to optimize poultry litter application and row widths (Harper et al., 1980). Killing a 8"-wide band of sod with corn-row widths of 20" reduced sod by 40%, while planting corn in 40" row widths reduced sod by 20%. Results indicated that if 40% solar radiation transmission at maximum corn leaf area index were achieved, then tall fescue survival would be greatest. Depending upon a producer's objectives and environmental conditions, different corn-planting geometries could be used to shift the productive balance between corn and tall fescue (Table 4).

Table 4. Corn grain yield and tall fescue forage yield as affected by fertilization, row width, and corn plant population. Data from Harper et al. (1980).

Sod killed (%)	Plant density (1000/a)	Corn grain (bu/a)	Tall fescue (ton/a)	Total yield (ton/a)
Inorganic fertilizer (360 lb N/a/yr)				
20	7.5	73	3.7	6.8
20	10.2	85	3.4	7.3
20	13.8	105	3.3	8.1
20	28.4	115	2.4	8.5
40	17.5	129	2.5	8.6
40	20.9	140	2.4	9.3
40	29.2	144	1.9	8.7
40	49.0	97	1.4	7.4
Poultry litter (4 ton/a; 321 lb N/a/yr)				
20	8.7	75	4.3	7.7
20	11.2	88	4.3	8.2
20	13.7	92	3.8	7.7
20	24.6	91	3.4	7.8
40	16.4	100	3.2	7.9
40	19.2	104	2.7	7.4
40	26.7	104	2.0	7.4
40	52.2	100	1.5	7.8
Poultry litter (8 ton/a; 603 lb N/a/yr)				
20	9.0	104	4.9	9.6
20	10.7	112	4.0	9.2
20	14.2	131	3.3	9.4
20	27.1	158	2.8	9.8
40	18.0	142	3.1	9.6
40	21.9	163	2.1	9.9
40	29.4	166	1.8	9.9
40	49.3	139	1.5	9.3

The effect of supplemental irrigation on corn grain yield in tall fescue sod either killed completely or in 8" strips (20% kill) was evaluated from 1973-1976 (Box et al., 1980). Corn grain yield averaged 88 bu/a without irrigation and receiving 16" of rainfall during the growing season in strip-killed sod and averaged 136 bu/a with an additional 8" of irrigation during the growing season. Grain yield in completely killed sod with rye as a killed cover crop in subsequent years averaged 134 and 159 bu/a, respectively, under the same water regimes. Tall fescue forage yield when strip-killed averaged 2.7 ton/a without irrigation and 2.1 ton/a with the additional 8" of irrigation during the corn growing season. Rye forage yield was 2.7 ton/a with and without irrigation.

Corn interseeded with no-tillage into 20, 40, or 100% strip-killed tall fescue sod was compared with corn following conventional tillage of tall fescue sod at two inorganic fertilization regimes during 1974-1977 at Blairsville GA (Wilkinson et al., 1987). High corn grain yield could only be achieved with strip-killed sod with high N fertilization (Table 5). Again, depending upon a producer's need for grain or forage, different planting geometries of corn could be successfully used in incompletely killed tall fescue sod.

Management of Forages for Conservation

Overseeding of 'Coastal' bermudagrass with cereal rye can increase total forage production throughout the year. Management of bermudagrass and rye for determining optimum production was investigated during 1973-1975 (Wilkinson et al., 1975). Seeding rye on or before 25 September in 1973 required a light application of paraquat (1/8 lb/a) to maximize rye yield, but if rye were seeded after 25 September then no paraquat was needed. Rye forage yield of 1.3 ton/a was obtained with seeding on 25 September with light application of paraquat at the same time. When rye was seeded on 17 October without paraquat, 'Coastal' bermudagrass yield from harvests during the following spring were highest. Cereal rye that was broadcasted and disked into 'Coastal' bermudagrass produced similar forage yield to that which was no-till drilled at most planting dates from 4 October to 7 November 1974 (Wilkinson et al., 1975). When drilling rye on 4 October, rye yield was depressed compared with broadcasting/disking if 1/8 lb/a or no paraquat was applied.

Table 5. Corn grain yield and forage yield as affected by tall fescue management prior to planting and level of fertilization. Data from Wilkinson et al. (1987).

Management	Corn grain yield (bu/a)	Forage yield (ton/a)
130 lb N/a/yr		
Conventional tillage	151	1.1
No tillage (20% sod-kill)	24	3.9
No tillage (40% sod-kill)	64	3.1
No tillage (100% sod-kill)	161	1.9
260 lb N/a/yr		
Conventional tillage	161	1.5
No tillage (20% sod-kill)	92	2.9
No tillage (40% sod-kill)	126	2.5
No tillage (100% sod-kill)	191	1.5

Forage yield of 'Coastal' bermudagrass is highly dependent upon N fertilization and harvest frequency (Carreker et al., 1972). Under dryland conditions, maximum forage yield within a particular N fertilization regime was always achieved with harvest every 6 weeks (Table 6).

Interseeding rye into a winter-dormant stand of 'Coastal' bermudagrass under conditions of high fertility following disposal rates of poultry litter (80 and 316 ton/a during a 7-year period) effectively reduced the risk of groundwater contamination from nitrate leaching through the soil profile (Wilkinson et al., 1985). The estimated quantity of nitrate prevented from leaching through the soil profile was 400

Table 6. Average annual 'Coastal' bermudagrass forage yield under dryland and irrigated conditions as affected by harvest interval and N fertilization during 1964-1967. Data from Carreker et al. (1972).

	Nitrogen fertilizer (lb N/a/yr)		
Harvest interval	200	600	1000
Not irrigated			
2-week	1.7	3.4	3.7
4-week	2.9	5.5	5.7
6-week	4.2	6.5	7.0
Irrigated			
2-week	2.3	5.1	5.3
4-week	3.9	6.9	7.4
6-week	5.8	8.9	9.2

to 600 lb N/a (16-53% of total N leached without rye).

Table 7. Average annualized forage production of tall fescue interseeded with sorghum-sudangrass as affected by percentage of sod strip-killed with herbicide during 1973-1976. Data from Belesky et al. (1981).

Management	Summer yield (ton/a)	Winter yield (ton/a)	Total yield as tall fescue (%)
Tall fescue alone	2.3	1.0	100
Tall fescue interseeded with sorghum-sudangrass			
0% strip-killed	2.2	1.1	80
25% strip-killed	3.0	0.8	57
50% strip-killed	3.3	1.0	47
Tall fescue interseeded with sorghum-sudangrass and rye			
100% killed	3.5	1.3	0

Improving the productivity and maintaining the conservation benefit of a perennial tall fescue sod was evaluated by interseeding sorghum-sudangrass and cereal rye into tall fescue at various levels of strip killing (Belesky et al., 1981). Compared with tall fescue forage alone, interseeding with sorghum-sudangrass had no effect on total forage yield if tall fescue were not suppressed and increased total forage yield by 16 and 29% with 25 and 50% strip-killing of tall fescue, respectively (Table 7). Complete killing of tall fescue and planting sorghum-sudangrass and cereal rye yielded the highest forage yield, but this reduced the flexibility of the management strategies available by removing the perennial component.

During the establishment year of tall fescue managed for hay, water runoff was 11% of precipitation and soil loss was 0.8 ton/a (Barnett et al., 1972). During the second year, water runoff was 6% of precipitation and soil loss was 0.1 ton/a. Year-round, continuous grazing of a tall fescue pasture for three years with 0.6 cow-calf units/a resulted was evaluated for its effectiveness to control water runoff and erosion with rainfall simulations in 1970. At the end of winter when grass had just begun to grow, 50% of a 5.3" rainfall ran off, but resulted in only 0.2 ton/a soil loss. At the peak of tall fescue development in late spring, 46% of a 4.3" rainfall ran off and resulted in 0.2 ton/a soil loss. Since these simulations provided about 1/3 of an average year's erosion potential, an extrapolated annual soil loss from closely grazed tall fescue was estimated at 0.5 ton/a (Barnett et al., 1972). These data suggested to the authors that closely grazed tall fescue could provide excellent erosion control on Piedmont soils as steep as 7% when >75% of the soil surface is covered with vegetation to a height of 1-2".

Conclusions

This review has highlighted some of the important soil conservation and agronomic production results of sod-based cropping systems that were developed for the Southern Peidmont region and applicable to the southeastern USA. Perennial grasses and legumes are effective in increasing water infiltration from precipitation and decreasing soil loss, especially from the severe high-intensity thunderstorms that occur during the summer. Crop yield and soil fertility are often enhanced following sods, such that more efficient water and nutrient utilization can be expected. Legume cover crops are highly effective in supplying biologically fixed N to subsequent crops. Management of cropland with conservation tillage can increase the effectiveness of cover crops. Depending upon a producer's goals, intercropping of corn, small grains, or annual forages into living perennial sods can be successful with partial killing of sod with herbicides. Supplemental irrigation assures that intercropping systems will be be successful. Perennial forage production can be enhanced with several management techniques, including appropriate fertilization, harvest frequency, and overseeding. The effectiveness of perennial forage systems on soil erosion control, even when continuously grazed, has been noted.

Although these studies represent many years of research and individual studies represent multiple-year evaluations, there is still a lack of information on long-term continuous evaluation of many specific management systems. A systems approach, based on simultaneous determinations of agronomic productivity, plant nutrient utilization, environmental quality, and farm economics, is still needed to optimize the multiple goals of farmers and society. Benefits and weaknesses of these systems need to be more clearly defined and quantified.

Much more research is needed on the economic, agronomic, and ecological impacts of animal grazing systems in this region. The integration of grazed sods with crops will require knowledge far beyond agronomy alone.

Crop rotations with conservation tillage have been initiated in the region, but ongoing developments in herbicide and equipment technologies along with changes in crop utilization systems suggest much more research will be needed to develop better or more-efficient sod-based cropping systems in different environments.

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