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Corn and Soybean Yield Response to Crop Residue Management Under No-Tillage Production Systems

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ABSTRACT

Crop residues (stover) have many potential uses by society: food, feed, shelter, fuel, and soil amendment. Use of residues for purposes other than as a soil amendment may have serious negative consequences on crop productivity. This study was conducted to investigate the yield response of continuous corn (*Zea mays* L.) and continuous soybean [*Glycine max* (L.) Merr.] to removal or addition of crop residues under no-tillage management. The study was conducted near Lincoln, NE, on a Crete-Butler silty clay loam (fine, montmorillonitic, mesic Pachic Arguistoll-Abruptic Argiaquoll) with 1 to 2% slope. Crop residue was collected and weighed immediately after harvest in autumn. Quantity of residue to be returned to each treatment (0, 50, 100, or 150% of that produced) was calculated and uniformly spread over the plot area (12.2 by 12.2 m) by hand. Corn and soybean were planted into the established residue levels with no tillage the following spring. Data were collected on soil water, soil temperature, and grain and residue yield. A positive linear response was found between grain and stover yield and amount of residue applied to the soil surface. Each Mg ha^{-1} of residue removed resulted in about a 0.10 Mg ha^{-1} reduction in grain yield and a 0.30 Mg ha^{-1} reduction in residue yield. Quantity of applied residue accounted for 81 and 84% of the variation in grain yield of corn and soybean, respectively, and 88 and 92% of the variation in residue yield. Amounts of stored soil water at planting were closely associated with quantity of residue applied the previous year. Differences in total available water (soil storage at planting plus rainfall) accounted for approximately 70% of the yield variation associated with the residue treatments. Soil temperature (50-mm depth) and total available water accounted for nearly the same amount of variation in yield (80 to 90%) as quantity of residue, emphasizing the importance of these factors in evaluating response of crops to residue-management practices. Residue removal reduced grain and residue yields by amounts equal to 10 and 30%, respectively, of the quantity of residue removed. Residue effects on crop yield were induced mainly through changes in soil water and soil temperature.

Additional index words: **Soil water, Soil temperature, *Zea mays* L., *Glycine max.* (L.) Merr., Crop residue removal.**

RESIDUES play at least four roles in a crop-production system: (i) reduce soil erosion from both wind and water, (ii) supply plant nutrients, (iii) act as a mulch to reduce the rate of soil water loss, and (iv) modify soil temperature. The presence of 1 to 2 Mg ha^{-1} of crop residues on the soil surface on sloping lands can reduce water runoff and soil erosion losses by 40 to 80% compared with bare soil (Mannering and Meyer, 1963; Meyer et al., 1970). Siddoway et al. (1965) reported an exponential decrease in soil loss from wind erosion with increasing quantity of various residues applied to the soil surface. Surface crop residues not only reduce the loss of fertile soil, but also are a direct source of crop nutrients. Larson et al. (1978) estimated that crop residues from nine leading crops contain 40, 10, and 80% of the current fertilizer N, P, and K applications, respectively, to those crops. Surface residues also reduce rate of evaporative loss of soil water, especially after rainfall and during first-stage drying. Bond and Willis (1969) found a 10-mm day^{-1} reduction in surface evaporation losses for each 0.56 Mg ha^{-1} of additional rye (*Secale cereale* L.) straw applied to the soil surface up to 2.24 Mg ha^{-1}. However, even with the addition of 6.72 Mg ha^{-1} mulch, soil ultimately dried to nearly the same water content as bare soil. Therefore, time required to dry soil increased with amount of residue applied. At three locations in the Great Plains, Greb et al., (1967) also reported increased water storage with increased rates of wheat (*Triticum aestivum* L.) residue application. Depending on time of year or climate, effect of surface residues

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can be either beneficial or detrimental to crop growth. Voorhees et al. (1981) reviewed effect of mulch on soil temperature. Generally, in temperate regions when soils are warming, the average soil temperature at a 100-mm depth decreased 0.15 to 0.30°C for each 1 Mg ha^{-1} of small grain residue applied to the soil surface (Allmaras et al., 1973). In a tropical environment, where extreme temperatures often reduce crop yields, Lal (1974) reported an 8°C reduction in soil temperature at the 50-mm soil depth with application of 2 Mg ha^{-1} residue.

The purpose of this study was to investigate effect of removal and addition of crop residues on corn (*Zea mays* L.) and soybean [*Glycine max.* (L.) Merr.] production under no-tillage production systems. This study was part of a larger project to assess the influence of crop residue removal on cycling of crop nutrients and biological responses to changes in soil physical environment (Doran et al., 1984; Power et al., 1986).

MATERIALS AND METHODS

The experiment was conducted at the University of Nebraska Agronomy Research Farm, Lincoln, NE (40° 51′ N 96° 45′ W), on a Crete-Butler silty clay loam (fine, montmorillonitic, mesic Pachic Argiustoll–Abruptic Argiaquoll) with 1 to 2% slope. This experiment is a continuation of a study conducted by the authors in which a corn-sorghum [*Sorghum bicolor* (L.) Moench]-soybean rotation was employed (Doran et al., 1984). The rotation used in the previous experiment was discontinued for the duration of the present study, but residue amount treatments applied to each experimental unit were continued. The experimental site, therefore, had a treatment history of no-tillage and consistent residue amount treatments since 1978; however, from 1978 to 1980, crops were rotated, and from 1980 to 1983, fields were cropped continuously to either corn or soybean. During this study, corn was grown on soil treated with corn residue, and soybean was grown on soil treated with soybean residue. The sorghum treatment from the previous study was eliminated.

Treatments under investigation were 0, 50, 100, and 150% of the quantity of crop residue produced by the previous crop being returned to the soil surface after harvest. The basis for calculating these percentages was the quantity of residue produced on the 100% residue rate. Grain yield was measured at physiological maturity by mechanically harvesting six rows (4.6 by 12.2 m) in each plot. Grain weights were adjusted to 15.5 and 13% water content for corn and soybean, respectively. After grain harvest, residue yield was determined by clipping and raking an area 4.6 by 12.2 m in each plot and weighing the residue collected. Residue water content was determined after drying subsamples at 70°C. Residue yield is reported as dry weight. All remaining crop residue was clipped. Quantity of residue to be returned or removed was calculated, weighed, and uniformly spread over the plot (12.2 by 12.2 m) area by hand. Treatments were arranged in a randomized, complete block design with four replicates.

In spring, corn and soybean were planted without tillage except that which occurred during the planting operation. Both corn and soybean were planted with a Max-Emerge[3] type planter equipped with a ripple coulter ahead of double-disk openers. Corn was planted 29 Apr. 1980, 6 May 1981, 3 June 1982, and 11 May 1983 at 54 300, 42 000, 42 000, and 42 000 seeds ha^{-1}, respectively. Soybean was planted 7 May 1980, 21 May 1981, 4 June 1982, and 25 May 1983 at 271 700 seeds ha^{-1}. 'Cumberland' soybean (Group II) and B73×Mo17 corn were used throughout the experiment.

After plants had emerged, aluminum access tubes were installed to a depth of 1.80 m in each plot. The neutron-scatter technique was used to determine soil water content periodically during the growing season. Soil temperature at the 50-mm depth was determined with maximum-minimum thermometers from readings taken two to three times each week during 1982 on one replication of each crop. Access tubes and soil thermometers were placed in the planted row.

Data were analyzed by analysis of variance and single df comparisons.

[3] Mention of a trademark or proprietary product does not constitute a guarantee or warranty by the USDA and does not imply approval to the exclusion of other similar products.

RESULTS AND DISCUSSION

Grain and residue production for both corn and soybean showed a highly significant linear response to amount (Mg ha^{-1}) of residue returned to the soil surface (Tables 1 and 2). Over the range of residue amounts tested, only linear relationships between surface crop residues and grain or residue yield were found. Both corn grain and residue production differed among the years of study; however, only corn grain production was significantly affected by the treatment × years interaction. Soybean grain production had significant year and treatment × year effects. Soybean residue production did not differ over years and the treatment × year interaction was not significant.

For corn, the linear response during 1980 and 1983 was different from that in 1981 and 1982 (Fig. 1). The 1980 growing season (April through August) was characterized by above-normal temperatures (+1.2°C) and below-normal precipitation (−162 mm; 30% below normal). The months of July and August 1983 averaged 2.7°C above normal temperature and 105 mm below normal precipitation. These factors combined to produce yields in 1980 and 1983 that were 3 and 31% of the average of the other 2 yr. The interaction between years and applied residue for soybean grain yield was caused by a differential linear grain yield response between 1980 and 1983 (Fig. 1).

As stated above, the data indicate a significant ($p<0.05$) treatment × year interaction for grain yield in both crops (Tables 1 and 2). This would normally preclude combining data over years to generate a generalized equation for the grain and residue yield based on amount of residue applied to the soil surface. However, the interaction was caused by variance in the degree of positive slope of the regression line and not by differences in positive or negative responses. Also, the average response over years is very important, and a predictive equation based on a single-year response is of limited value. The nature of the interaction (Fig. 1) would suggest that combining data over years would give a generalized response as opposed to an unrealistic response.

The b values, standard errors, and r^2 values presented in Table 3 are for regression equations of corn and soybean grain and residue yields generated by using the average residue applied (Mg ha^{-1}) to each treatment over the 4-yr study as the independent variable and average grain or residue yield as the dependent variable (Mg ha^{-1}). Fourteen df were associated with

Table 1. Means and mean squares for corn grain and residue produced with various amounts of the previous crop's residue applied to the soil surface from 1980 to 1983.

Treatment	Grain yield 1980	1981	1982	1983	$\bar{x}$	Residue yield 1980	1981	1982	1983	$\bar{x}$
%	Mg ha^{-1}									
0	0.02	3.36	5.71	1.49	2.64	3.11	3.06	6.32	3.97	4.12
50	0.10	4.18	6.85	2.23	3.34	4.54	4.27	7.01	7.27	5.77
100†	0.22	4.97	7.72	1.78	3.67	4.97	5.34	7.54	7.16	6.25
150	0.41	5.76	7.75	1.80	3.93	5.89	5.87	7.79	8.75	7.08
$\bar{x}$	0.19	4.57	7.00	1.82	3.40	4.63	4.64	7.17	6.79	5.80

ANOVA Summary

Sources	df	Mean squares: Grain yield	Mean squares: Residue yield
Total	63	7.44	3.65
Blocks (B)	3	0.16	0.05
Treatments (T)	3	4.97***	24.88***
Linear (L)	1	14.06***	70.03***
Quadratic (Q)	1	0.77 NS	2.75 NS
Dev. from Q	1	0.07 NS	1.86 NS
B × T (Error a)	9	0.32	0.67
Year (Y)	3	144.83***	29.75***
T × Y	9	1.67***	1.51 NS
Error *b*	36	0.15	1.29

† Mean quantity of corn residue applied to the 100% treatment was 7.12, 4.96, 5.34, and 7.54 Mg ha^{-1} in 1980, 1981, 1982, and 1983, respectively. Quantities applied to other treatments can be calculated by taking the appropriate percentage of stated residue quantities.
***,NS Stated effect significantly different at the 0.1% level, and not significant, respectively.

Table 2. Means and mean squares for soybean grain and residue produced with various amounts of the previous crop's residue applied to the soil surface from 1980 to 1983.

Treatment	Grain yield 1980	1981	1982	1983	$\bar{x}$	Residue yield 1980	1981	1982	1983	$\bar{x}$
%	Mg ha^{-1}									
0	1.31	1.47	2.96	0.90	1.66	2.92	2.36	3.46	3.18	2.98
50	1.91	2.09	3.14	1.00	2.04	3.71	4.07	4.10	3.60	3.87
100†	2.09	2.59	3.19	1.04	2.23	4.58	4.71	4.39	4.54	4.55
150	2.30	2.80	3.21	1.12	2.36	4.95	5.38	5.29	4.81	5.10
$\bar{x}$	1.90	2.24	3.12	1.02	2.07	4.04	4.12	4.31	4.03	4.13

ANOVA Summary

Sources	df	Mean squares: Grain yield	Mean squares: Residue yield
Total	63	1.33	1.01
Blocks (B)	3	0.71	1.90
Treatments (T)	3	1.47***	13.50***
Linear (L)	1	4.17***	40.06***
Quadratic (Q)	1	0.24 NS	0.45 NS
Dev from Q	1	0.01 NS	0.00 NS
B × T (Error a)	9	0.10	0.32
Year (Y)	3	12.15***	0.27 NS
T × Y	9	0.24***	0.41 NS
Error *b*	36	0.03	0.28

† Mean quantity of soybean residue applied to the 100% treatment was 5.39, 4.58, 4.71, and 4.40 Mg ha^{-1} in 1980, 1981, 1982, and 1983, respectively. Quantities applied to other treatments can be calculated by taking the appropriate percentage of stated residue quantities.
***,NS Stated effect significantly different at the 0.1% level, and not significant, respectively.

Table 3. Regression equation coefficients relating average corn and soybean grain and residue yield (Mg ha^{-1}) from the average amount of residue applied to the soil surface (Mg ha^{-1}), using the equation: yield = $b_0 + b_1 \times$ residue applied.

Dependent variable	b_0	SE	b_1	SE	r^2
Corn					
Grain	2.91	0.17	0.13	0.02	0.80
Residue	4.34	0.31	0.29	0.04	0.86
Soybean					
Grain	1.53	0.10	0.09	0.02	0.84
Residue	2.73	0.18	0.30	0.03	0.92

each equation. Residue applied accounted for 84 and 81% of the variation in grain yield of soybean and corn, respectively. Also, approximately 90% of the variation in residue yield of both crops was explained by variation in residue applied. Each Mg ha^{-1} of residue applied resulted in 0.10 Mg ha^{-1} of additional grain production for corn and soybean. With both crops, about 0.30 Mg ha^{-1} of additional residue (stover) was produced for each Mg ha^{-1} of residue applied. Analysis of these data indicated only a linear response of yield to treatment; logically, this cannot be the case if residue application treatments exceeded the highest application rate (11.31 Mg ha^{-1}; 150% treatment in 1983, corn) used in this study. Consequently, extension of these data beyond this upper limit would not be advisable; however, the high levels of significance (Tables 1 and 2), the high r^2 (Table 3), and low CV (<8%) suggest the data are valid within the limits of residue applied.

Table 4. Means and mean squares of available soil water with various amounts of corn and soybean residue applied to the soil surface from 1980 to 1983. Available soil water was defined as water stored in profile (0 to 1.8 m) between −0.03 and −1.50 MPa at planting.

	Corn					Soybean				
Treatment	1980	1981	1982	1983	$\bar{x}$	1980	1981	1982	1983	$\bar{x}$
%	mm									
0	110	195	204	203	178	156	119	206	206	172
50	172	168	226	226	198	208	124	228	254	204
100†	226	180	230	257	223	250	166	251	260	232
150	223	208	244	252	232	243	188	244	220	224
$\bar{x}$	182	188	226	234	208	214	149	232	235	208

ANOVA Summary

Sources	df	Mean squares (Corn)	Mean squares (Soybean)
Total	63	1 805	2 434
Blocks (B)	3	1 740	1 228
Treatments (T)	3	9 546***	11 454***
Linear (L)	1	27 714***	27 269***
Quadratic (Q)	1	576 NS	6 241 NS
Dev from Q	1	349 NS	852 NS
Year (Y)	3	11 156***	25 616***
T × Y	9	2 394***	1 560*
Error *b*	36	519	482

† Mean quantity of residue applied to the 100% treatment for corn was 7.12, 4.96, 5.34, and 7.54 Mg ha^{-1} in 1980, 1981, 1982, and 1983, respectively; for soybean 5.39, 4.58, 4.71, and 4.40 Mg ha^{-1} in 1980, 1981, 1982, and 1983, respectively. Quantities applied to other treatments can be calculated by taking the appropriate percentage of stated residue quantities.

*,***,NS Stated effect significantly different at the 5.0 and 0.1% level, and not significant, respectively.

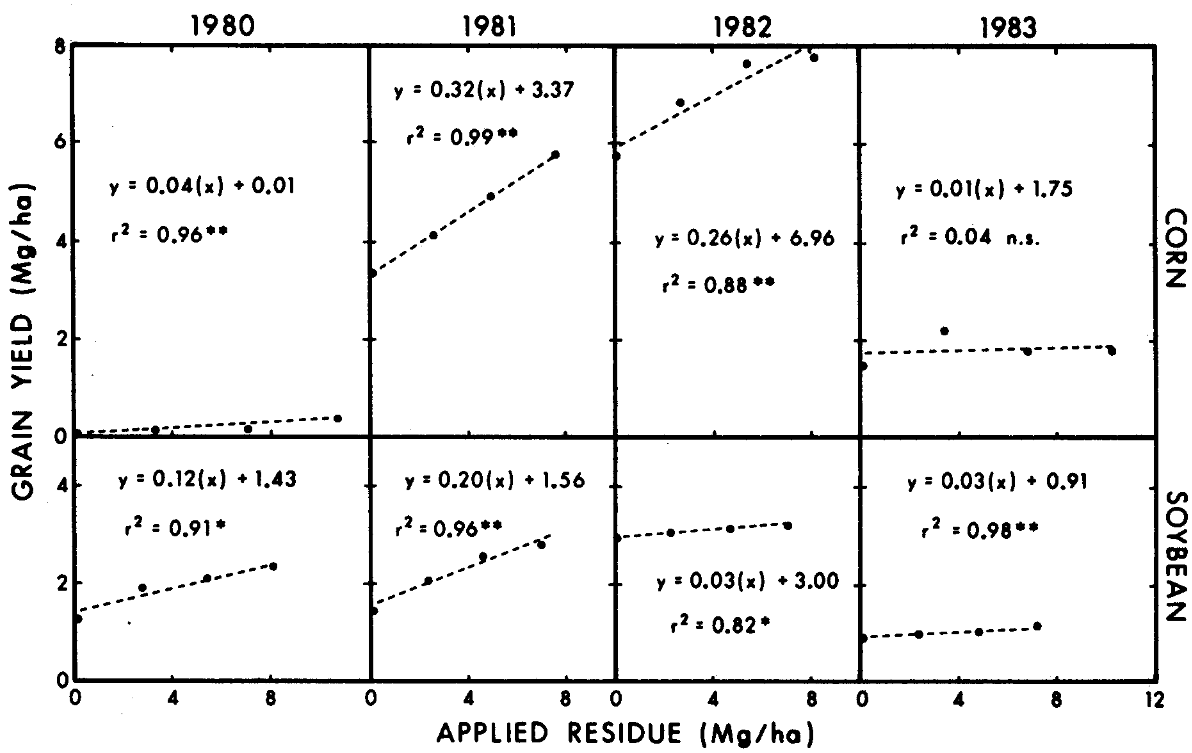

Fig. 1. Yearly grain yield response to amount of applied crop residue.

From these results, the benefit derived or loss incurred as a consequence of leaving or removing a specific quantity of crop residue was determined. The average production of residue for the 100% treatment in this study was 6.25 and 4.55 Mg ha^{-1} for corn and soybean, and resulted in a calculated grain yield of 3.65 and 1.94 Mg ha^{-1}, respectively. If 50% of the residue were removed or an additional 50% added, the grain production would decrease or increase by 0.38 and 0.21 Mg ha^{-1} for corn and soybean, respectively. At assumed prices [corn = $118 Mg^{-1} ($3.00 bu^{-1}); soybean = $220 Mg^{-1} ($6.00 bu^{-1})], this would be equivalent to about $45 and $46 ha^{-1} for the two crops, respectively. Residue production would change by 0.85 and 0.69 Mg ha^{-1} for corn and soybean, respectively.

Reasons for the increased yield with increased residue application have been suggested by several researches (Doran et al., 1984; Greb et al., 1967; Lal, 1974). Soil water conservation appears to be the most important of the several reasons suggested for the improved crop yields with increased residues applied to the soil surface. To determine the degree to which soil

Table 5. Regression equation coefficients for stated equation relating average stored water to average residue applied and average grain and residue yield to average total available water. Stored water measured near planting. Total water is stored water at planting plus rainfall from date of measurement through 31 August.

Dependent variable	Regression coefficients				
	b_0	SE	b_1	SE	r^2
Equation: Stored soil water (mm) = $b_0 + b_1$ [residue applied (Mg ha^{-1})]					
Corn	174	7	6	1	0.84
Soybean	175	10	8	2	0.71
Equation: Yield (Mg ha^{-1}) = $b_0 + b_1$ [total available water (mm)]					
Corn					
Grain	−4.49	1.76	0.02	0.00†	0.67
Residue	−12.46	3.24	0.04	0.01	0.74
Soybean					
Grain	−1.73	1.04	0.01	0.00†	0.66
Residue	−7.18	2.76	0.02	0.01	0.64

† Numbers rounded to zero.

Table 6. Regression equation coefficients for stated equation relating total available water and soil temperature to grain and residue yield.

Dependent variable	Regression coefficients						
	b_0	SE	b_1	SE	b_2	SE	r^2
Equation: Yield (Mg ha^{-1}) = $b_0 + b_1$ [total available water (mm)] + b_2 [soil temperature (°C)]							
Corn							
Grain	9.17	5.79	0.01	0.00†	−0.38	0.16	0.79
Residue	20.12	8.23	0.02	0.01	−0.91	0.22	0.90
Soybean							
Grain	8.31	3.02	0.00†	0.00†	−0.26	0.08	0.84
Residue	21.49	7.22	0.00†	0.00†	−0.74	0.18	0.87

† Coefficients rounded to zero.

Table 7. Coefficients of determination for regression equations relating total available water, soil temperature, and residue to grain and residue yield of corn and soybean.

Dependent variable	Independent variables	
	Total available water + soil temperature	Total available water + soil temperature + residue
	r^2	
Corn		
Grain	0.79	0.83
Residue	0.90	0.92
Soybean		
Grain	0.84	0.86
Residue	0.87	0.93

water conservation contributed to the yield increases noted in this experiment (Tables 1 and 2), regression analysis was used to determine the relationship between residue applied and stored soil water near the time of planting (Table 4). Approximately 84 and 71% of the variation in stored water were accounted for by the amount of surface residue for corn and soybean, respectively (Table 5). An average of nearly 175 mm of water was stored with no residue; a linear increase in soil water for each Mg ha^{-1} of residue applied to the soil surface resulted in storage of 6 and 8 mm of water for corn and soybean, respectively.

Total available water [stored soil water (to 1.8 m) plus rainfall from the date of soil water measurement (near planting, 15 June) until 31 August] accounted for approximately 70% of this variation in both grain and residue yield of corn and soybean (Table 5). The first unit of grain was produced with 224 and 173 mm of total available water for corn and soybean, respectively. Each additional mm of water produced 0.02 Mg ha^{-1} of corn and 0.01 Mg ha^{-1} of soybean grain. These results indicated that 80 to 90% of the total effect of residue on grain production of corn and soybean was accounted for by the soil water conservation effect of the residue.

When growing season average soil temperature (0%, 26.3°C; 50%, 24.7°C; 100%, 25°C; 150%, 24.3°C) was added to the regression analysis, 79 and 90% of the variation in corn grain and residue yield, respectively, were explained by the factors of total available water and soil temperature (Table 6). For soybean (0%, 27.6°C; 50%, 26.0°C; 100%, 26.0°C; 150%, 25.1°C), 84 and 87% of the grain and residue yield variation were explained by the same factors. These factors—available water and soil temperature—therefore, account for nearly all the variation in yield that resulted from the residue applications (Table 3). When quantity of residue applied was added to available water and soil temperature equations, the r^2 increased only slightly (Table 7) (Goodnight, 1982).

In summary, corn and soybean grain and residue yield were linearly related to amount of crop residue applied to the soil surface. Residue removal reduced grain and residue yields by amounts equal to 10 and 30%, respectively, of the quantity of residue removed. Residue additions resulted in comparable increases in grain and residue yields. Between 80 and 90% of the yield variation were accounted for by the variation in residue applications. Residue effects on crop yield were induced mainly through increased stored soil water and reduced soil temperature.

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