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CROP RESIDUE EFFECTS ON SOIL ENVIRONMENT AND DRYLAND MAIZE AND SOYA BEAN PRODUCTION*

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ABSTRACT

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The research reported here provides data on the effects of crop residues on the surface of no-till soil upon the soil environment and resulting biological activity, including crop growth. For maize (*Zea mays* L.) and soya bean [*Glycine max* (L.) Merr.] production in eastern Nebraska, U.S.A. (4 years of data), increasing crop residue rate decreased maximum soil temperatures at the soil surface by at least 5°C, and generally increased soil water storage by at least 50 mm. Availability and uptake of nitrogen from the soil organic matter and applied fertilizers (and for soya bean from decomposition of crop residues) were increased by increasing the crop residue rate from 0 to 150% of the quantity left after grain harvest of the previous crop. Hardly any of the nitrogen in maize residues was used by the next crop. These changes in the soil environment resulted in less stress on crops produced on residue-covered soil than for those on bare soil. Consequently, each Mg ha^{-1} of crop residues on the soil surface increased grain and stover production by approximately 120 and 270 kg ha^{-1} for maize, and 90 and 300 kg ha^{-1} for soya bean, respectively. Results show that there are major direct crop growth benefits from leaving crop residues on the soil surface, in addition to cumulative benefits that may result from reduced erosion losses and enhanced soil organic-matter contents.

INTRODUCTION

Tillage affects placement of crop residues and the physical arrangement of the soil matrix. These, in turn, affect the environment of the soil (water and temperature regimes, aeration and substrate distribution) which, to a large degree, controls the biological life supported by the soil. Tillage has two direct effects on soil environment: (1) mechanical disturbance of the soil, directly altering porosity and pore geometry and (2) crop residue placement, affecting both porosity and carbon supply for microbiological activity. In no-till systems of agriculture, compared to more conventional

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mechanical methods, direct soil disturbance is minimized, and crop residues are typically left on or near the soil surface.

Doran and co-workers (Doran, 1980a, b; Linn and Doran, 1984; Broder et al., 1984) studied the soil environment under various tillage methods for a number of soils, crops and climates across the United States. These and other studies generally indicate that the upper 75 mm of no-till soil is less porous than that of tilled soils, resulting in higher water content, slower rates of oxygen diffusion and lower temperatures (Army et al., 1961; Aase and Siddoway, 1980; Carter and Rennie, 1984). Thus, environments of no-till surface soils are frequently less oxidative than those for tilled soils.

Crop residues on the surface of no-till soils may act as an insulator, further decreasing soil temperature and reducing evaporation from the soil surface (Aase and Siddoway, 1980; Gupta et al., 1983; Carter and Rennie, 1984). Bond and Willis (1969), in a controlled environment, showed that, while increasing quantities of crop residues on the soil surface reduced the evaporation rate, the duration of first-stage drying is lengthened. However, the water content to which soils will dry (given sufficient time) is not changed by the presence of residue on the soil surface. Thus, residue-covered soils tend to have greater water contents compared to bare soil except after extended droughts. This phenomenon has been verified in field situations by several investigators (Russel, 1939; Army et al., 1961; Aase and Siddoway, 1980; Cannell et al., 1980; Tanaka, 1985). Because of the greater heat capacity of water compared to air, radiant energy would increase temperature of dry soil more than that of wet soil (Gupta et al., 1983; Potter et al., 1985).

While the effects of crop residues on the soil surface on water conservation and temperature regimes have frequently been documented, seldom have the effects of these changes in soil environment been documented in terms of microbial activity, nitrogen transformations and subsequent crop response and yield. Such information is needed for adequate computer simulation modeling of the process-controlled biological phenomena that control crop growth. Consequently, the research reported here was initiated to document and quantify the changes in soil environment resulting from residue cover, and relate how these changes in soil environment affect biological activity within the soil.

MATERIALS AND METHODS

Four replications of two sets of 12.1 × 12.1-m field plots were established on a Crete-Butler silty clay loam (fine, montmorillonitic, mesic Pachic Arguistoll-Abruptic Argiaquoll) at Lincoln, NE, U.S.A. One set of plots was continuously cropped to maize (*Zea mays* L.), and the other set to soya bean [*Glycine max* (L.) Merr.]. Average annual precipitation for the site is 705 mm, with 65% received from May—September. Mean January and July temperatures are -5 and 26°C, respectively. Slope at the experimental area was $< 2\%$, and there was little evidence of significant runoff.

Treatments consisted of 0, 50, 100 and 150% of the quantity (dry weight) of residues produced by the previous crop uniformly spread (flat) over the soil surface immediately after harvest. Consequently, residue weight for a given treatment varied from year to year, depending on the quantity produced previously (see stover and straw weights produced, Table I). Values ranged from 0 to about 15 and 8 Mg ha^{-1} for maize and soya bean, respectively. Residues were usually kept in place over winter by covering the experimental area with polypropylene mesh (25-mm opening). No tillage was employed during the experiment or for 3 years previous to the experiment, when a rotation of maize—sorghum [*Sorghum bicolor* (L.) Moench]—soya bean had been used. For the 150% treatment, residue discarded from the 50% residue treatment was utilized, supplemented with additional discarded residue from the 0% residue treatment as needed. Pre- and post-emergence herbicides were used as appropriate each year to control weeds.

Ammonium nitrate was surface broadcast on all plots at 45 kg ha^{-1} N prior to planting. Although soya beans are not usually fertilized with nitrogen, ammonium nitrate was added in this experiment to treat crops uniformly and to introduce tagged N into the experiment. Previous soil tests indicated no need for P and K fertilizer. Plots were arranged in a randomized, complete block.

After planting with a no-till planter, aluminum access tubes were installed to 1.80 m in each plot, and soil water content was measured at approximately monthly intervals until harvest. Maximum and minimum soil temperatures were measured at the 50-mm soil depth with maximum—minimum thermometers in one replication of each crop, and readings were taken two

TABLE I

Maize stover and soya bean straw production (Mg ha^{-1}) as affected by crop residue rate on the soil surface

Crop/Year	Residue rate (%)				
	0	50	100	150	$LSD_{0.05}$
Maize					
1980	3.11	4.54	4.97	5.89	0.84
1981	3.06	4.27	5.34	5.87	0.85
1982	8.83	9.64	10.25	10.60	1.37
1983	3.97	7.27	7.16	8.75	0.97
Average	4.12	5.77	6.25	7.08	—
Soya bean					
1980	2.92	3.71	4.58	4.95	0.74
1981	2.36	4.07	4.71	5.38	0.99
1982	3.46	4.10	4.39	5.29	0.50
1983	3.18	3.60	4.54	4.81	0.57
Average	2.98	3.87	4.55	5.10	—

or three times weekly during the growing season. The experiment was repeated over 4 years (1980—1983).

In the first year of the experiment, ^{15}N-depleted ammonium nitrate was broadcast on half of each plot for both crops at 45 kg ha^{-1} N, with commercial ammonium nitrate applied to the other half. At maturity, 11.6 m of eight rows of each crop (0.76-m spacing) was combine-harvested for grain yield. Straw or stover from the entire area of each half-plot receiving ^{15}N-depleted fertilizer was collected and transferred to the corresponding half-plot that had not received the tagged fertilizer in spring 1980. Likewise, straw or stover from half-plots not receiving ^{15}N-depleted fertilizer in spring 1980 was transferred to half-plots that had received this fertilizer. In spring 1981, ^{15}N-depleted ammonium nitrate was again applied to half of each plot, but plots were split perpendicular to the split in 1980. This resulted in four quadrants for each plot, and the source of labeled-N uptake by the 1981 crop in each of the four quadrants could be identified (i.e. from crop residues, 1980 fertilizer residual, 1981 fertilizer and, by difference, mineralized soil organic N). At maturity, grain and straw or stover from each of the four quadrants of each plot were harvested separately. Each spring and autumn, two 42-mm diameter cores were collected per plot in 150-mm increments of 0.6 m, mixed and analyzed for inorganic N after extraction with 2 M KCl. Total nitrogen in plant samples was determined by standard Kjeldahl methods, ammonia was distilled and collected in HCl, and the isotope ratio was determined. In 1982 and 1983 only commercial ammonium nitrate fertilizer was applied and the studies with ^{15}N-depleted fertilizer were omitted. All nitrogen analyses of plants and soils were made using adaptations of procedures outlined in Black (1965).

All data were analyzed by analyses of variance, using appropriate statistical designs, and least significant differences between means were calculated.

RESULTS AND DISCUSSION

Between years, a wide variation in growing season temperatures and precipitation was observed (Table II), as is typical of a continental-type climate. Average precipitation and air temperature for the four growing seasons essentially equaled the long-term averages for this location. The 1982 growing season was relatively cool and moist, whereas, during the 1980 and 1983 growing seasons, a hot, dry period was experienced during July and early-August, when flowering and pollination of these crops occur. Except for a dry June, precipitation and air temperatures during the 1981 season were more normal.

Precipitation during the preceding season was reflected to some extent in available soil water storage at planting time the following spring (Table III). The effect of crop residue cover on soil water storage was also of great importance. This effect was most pronounced in the drier years when

TABLE II

Monthly precipitation and mean air temperature at Lincoln, Nebraska, U.S.A., during the growing season of 1980—1983

	April	May	June	July	Aug.	Sept.	Total (Average)
Precipitation (mm)							
1980	49	53	76	46	158	8	390
1981	48	101	22	82	129	64	446
1982	84	139	141	103	218	82	767
1983	28	127	196	9	30	66	456
Average	52	105	109	60	134	55	515
Long-term mean	64	97	108	91	87	76	523
Mean air temperature (°C)							
1980	11.1	17.1	23.5	27.9	26.0	19.4	20.8
1981	14.9	15.4	23.9	25.9	22.4	18.8	20.2
1982	9.1	17.4	19.3	26.1	23.4	18.4	18.9
1983	7.4	14.5	22.1	27.3	28.6	20.7	20.1
Average	10.6	16.1	22.2	26.8	25.1	19.3	20.0
Long-term mean	11.1	16.8	22.4	25.5	24.3	19.5	19.9

TABLE III

Available soil water (total minus that at -1.5 MPa; mm) to 1.52 m after planting as affected by crop residue rate on the soil surface

Crop/Year	Residue rate (%)				
	0	50	100	150	$LSD_{0.05}$
Maize					
1980	110	172	226	223	21
1981	195	168	180	208	18
1982	204	226	230	244	18
1983	203	226	257	252	19
Average	178	198	223	232	—
Soya bean					
1980	156	208	250	243	19
1981	119	124	166	188	16
1982	206	228	251	244	17
1983	206	254	260	220	18
Average	172	204	232	224	—

the extra water conserved by residue cover was more critical. In general, there was little difference between the effects of maize or soya bean residues. For both crops, soil water storage was about 30% greater for the 100 and

150% residue cover treatments compared with the 0% cover. In an earlier paper, using the data shown in Table III, Wilhelm et al. (1986) developed the following regression equations relating residue cover to soil water storage at planting:

Maize: $Y = 173 + 5X$ ($r^2 = 0.84$)

Soya bean: $Y = 175 + 8X$ ($r^2 = 0.71$)

where Y is the available soil water at planting (mm) and X is the quantity of surface residues applied after harvest of the previous crop (Mg ha^{-1}). Thus, each Mg ha^{-1} of maize residues left on the soil surface increased water storage at planting by 5 mm, and each Mg ha^{-1} soya bean residues increased soil water storage by 8 mm.

The additional soil water stored as a result of crop residues could be of critical importance during periods of extreme drought, such as during midsummer 1980. Available soil water to 1.52 m depth was always least for bare soil for both maize and soya beans throughout the entire 1980 growing season (Fig. 1). Available soil water declined for all treatments during a period of severe drought in July and early-August. For maize, essentially all available water was removed from the bare soil (0% residue) by early-August, whereas residue-covered plots still had 50—70 mm available

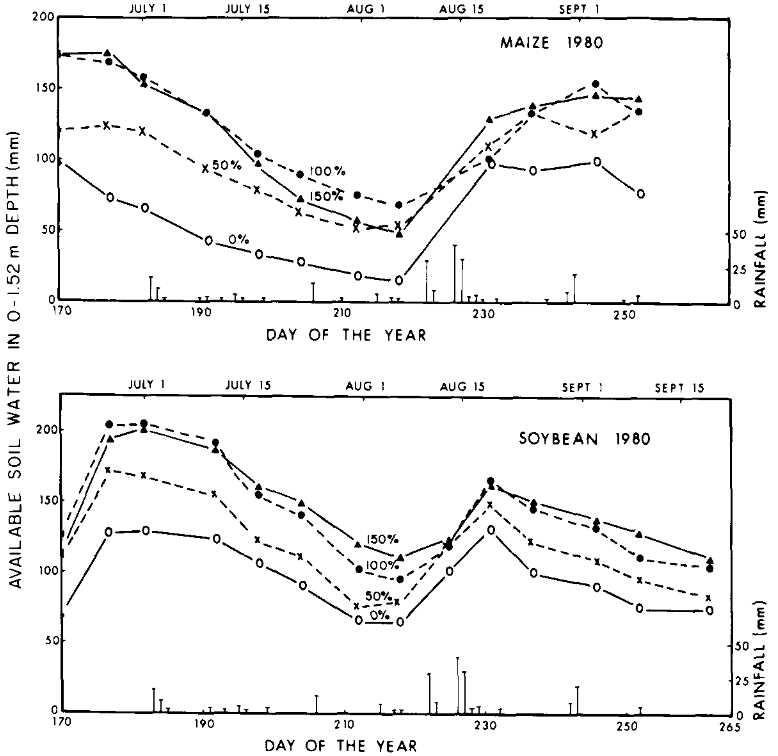

Fig. 1. Available soil water as affected by crop residue rate (0, 50, 100 and 150%).

water at that time. Appreciable precipitation in mid-August increased water storage for all soils, but water content of 0% residue plots still remained appreciably below that of residue-covered plots. Similar results were observed for soya beans, except that soya beans did not extract water as deeply as maize, leaving some unused water below 100 cm at all times for all treatments.

Crop residues on the soil surface also greatly reduced soil temperatures, especially at and near the soil surface. Effects of residues were especially pronounced during the midseason drought period experienced in 1980 (Fig. 2). Average maximum temperature at the soil surface reached about 57°C during this period for bare soil, compared to about 50°C for residue-covered soil. This difference of about 7°C between treatments was maintained throughout the remainder of the season. For most types of biological activity in temperate zone soils, optimum temperature is usually under 40°C, so it is apparent that the high surface soil temperatures found in midsummer on bare plots would result in stress to most biological systems.

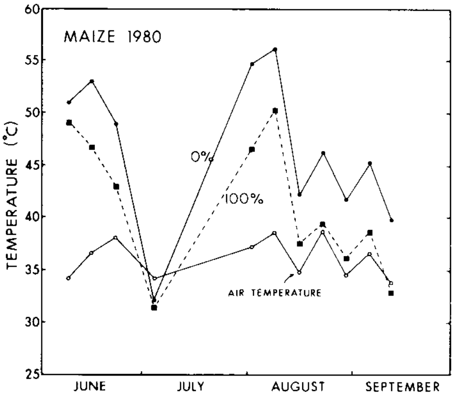

Fig. 2. Effect of crop residue rate (0 and 100%) on maximum surface soil temperatures.

Doran and co-workers (Doran, 1980a, b; Broder et al., 1984) have shown that leaving crop residues on the soil surface with no tillage, as compared to plowing residues under, generally results in increased populations of most classes of soil microorganisms in the upper 75 mm of soil. This increase in microbial biomass, observed at 7 sites from West Virginia to Oregon where long-term tillage comparisons were made, seemed to be rather universal regardless of soil, climate or crop. Generally, surface soil of no-till plots was cooler and more moist than that of plowed plots. Also, carbon in crop residues, needed as an energy source for most of the microbial biomass, is concentrated near the surface of no-till soils. These changes in no-till soil resulted in a habitat more conducive for microbial growth than was usually found in plowed soil.

The direct effects on plant growth of the altered soil environment re-

TABLE IV

Maize and soya bean grain yields (Mg ha^{-1}) as affected by crop residue rate on the soil surface

Crop/Year	Residue rate (%)				
	0	50	100	150	$LSD_{0.05}$
Maize					
1980	0.02	0.10	0.22	0.41	0.13
1981	3.36	4.18	4.97	5.76	0.53
1982	5.71	6.85	7.72	7.75	0.67
1983	1.49	2.23	1.78	1.80	0.48
Average	2.64	3.34	3.67	3.93	—
Soya bean					
1980	1.31	1.91	2.09	2.30	0.35
1981	1.47	2.09	2.59	2.80	0.38
1982	2.96	3.14	3.19	3.21	0.26
1983	0.90	1.00	1.04	1.12	0.22
Average	1.66	2.04	2.23	2.36	—

sulting from the presence of surface residues, as well as the indirect effects of soil environment on microbial activity and N transformation, both ultimately influenced crop yield (Table IV). For both crops, increasing crop residues on the soil surface increased grain yield. Using the yield data shown in Table IV, Wilhelm et al. (1986) found the following relations:

Maize: $Y = 2.90 + 0.12X$ ($r^2 = 0.81$)

Soya bean: $Y = 1.53 + 0.09X$ ($r^2 = 0.84$),

where Y is the grain yield (Mg ha^{-1}) and X is the crop residue (Mg ha^{-1}) left on the soil surface after harvest of the previous crop. Thus, on average, each Mg ha^{-1} of residues on the soil surface increased maize and soya bean grain yields by 0.12 and 0.09 Mg ha^{-1}, respectively.

The grain yield responses to increased surface residues were consistent from year to year, even though production level varied widely as a result of yearly variations in growing conditions. Little grain was produced by maize in 1980 because of the extreme drought at flowering time. On the other hand, 1982 growing conditions were near optimum, and near-record dryland yields were measured. Much the same variation existed for soya bean production, except that the period in which drought stress appeared in 1983 was more critical than in 1980 for flowering and seed development.

Maize stover and soya bean straw production were affected by residue cover to a greater extent than was grain production (Table I). Wilhelm et al. (1986) found that maize residue production increased by 0.27 Mg for each Mg maize residue left on the soil surface after harvest of the previous crop ($r^2 = 0.88$). Soya bean residue production increased by 0.30 Mg for each Mg soya bean residues left on the soil surface ($r^2 = 0.92$). As might be expected, stover and straw production were not as greatly affected by yearly variation in growing conditions as was grain production. For example, maize stover production in 1980 was comparable to that in 1981, compared to as much as 40-fold differences in grain production between these 2 years. However, the exceptionally favorable growing conditions in 1982 were reflected in greatly increased stover production.

The changes in soil environment resulting from crop residue cover altered biological activity, and so could be expected to alter N cycling and N availability to the growing crop. To study these changes in N cycling, ^{15}N-depleted fertilizer was applied in 1980 and 1981, as described earlier, to determine how much nitrogen was taken up by the 1981 crop from various sources (Power et al., 1986). Essentially none of the nitrogen contained in the maize stover which was left on the soil surface after harvest of the 1980 crop, was utilized by the 1981 crop (Table V), even though as much as 120 kg ha^{-1} N was returned in maize residues when applied at the 150% rate. About 5% of the nitrogen in the 1981 maize crop was derived from mineralization of the 1980 fertilizer N that had been immobilized in other organic forms (maize roots, microbial biomass and various forms of soil organic matter). Increasing rates of residue cover increased N uptake from current (1981) fertilizer treatment from about 4 to 11 kg ha^{-1}. However, by far the major effect of surface residues on N uptake by the 1981 maize occurred for uptake of the native soil N, which increased from 73 to 124 kg ha^{-1} as residue rate increased.

Soil sampling indicated that very little inorganic N remained in the soil by harvest time; therefore, most of the uptake of the native soil N resulted from mineralization of nitrogen in soil organic matter during the growing

TABLE V

Uptake of N (kg ha^{-1}) from various sources at 1981 harvest of maize and soya bean (whole plant) as affected by crop residue rate on the soil surface

Crop residue rate (%)	Source of N				
	Crop residues	Residual fertilizer	Current fertilizer	Native soil N	Total
Maize					
0	0	5	4	73	82
50	0	6	7	97	110
100	2	6	7	114	129
150	1	6	11	124	142
Soya bean					
0	0	2	14	84	100
50	1	2	21	124	148
100	38	7	16	116	177
150	63	6	20	106	195

season. These data indicate that microorganisms in the residue-covered soil were able to mineralize about 50 kg ha^{-1} N more than in the bare soil. Therefore, these data would indicate that the soil environment created by covering the soil surface with crop residues was more favorable for biological activity than that of the bare soil, especially biological activity involved in the N-mineralization process.

Over 95% of the nitrogen in the 1980 soya bean residues was taken up by the 1981 crop, except for the 50% residue rate (Table V). Although uptake of residual fertilizer N (1980) by soya bean generally increased with residue rate, only a few kg ha^{-1} N were involved (Power et al., 1986). Uptake of 1981 fertilizer varied from 14 to 21 kg ha^{-1} (31—47% of that applied), with higher values for residue-covered plots as well. As with maize, uptake of native N was appreciably greater from residue-covered than from bare plots. However, for soya bean, uptake of native soil N included nitrogen fixed by the legume nodules, and techniques used do not permit separation of fixed-N from uptake of mineralized soil N. Nevertheless, these results again show that residue on the soil surface created a soil environment that was more conducive to biological activity, whether that be *Rhizobia* activity in nitrogen fixation or mineralization of native soil N by numerous microorganisms.

CONCLUSIONS

Frequently, during a growing season, climatic events result in a crop being subjected to water and temperature stress. Adverse effects of stress on crop growth can be alleviated to some extent by proper selection of cultivar. This research shows that maintenance of crop residues on the soil surface is also an excellent management technique for reducing the impact of a stressful climate.

Data presented in this study indicate that crop residues on the soil surface reduce soil temperatures and reduce evaporation rates. These changes resulted in enhanced soil water content and more optimum conditions for microbiological activity, especially near the soil surface where the soluble carbon supply is most plentiful when residues are on the surface. One of the major effects of this increased microbial activity was increased mineralization, availability and uptake of indigenous soil N by the growing crop. In this experiment, for example, the presence of crop residues on the surface increased maize uptake of mineralized soil N by 70% compared to plots without surface residues. Thus, it appears that our initial hypothesis that, through management practices we can exercise some control over soil environment and subsequent biological activity, including crop growth, is substantiated by the results of this experiment.

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