Effects of Soybean and Corn Residue Decomposition on Soil Strength and Splash Detachment[1]

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ABSTRACT

Although field experiments have documented increased soil and water losses after soybeans (*Glycine max* L.) as compared with corn (*Zea mays* L.), a "soil effect" appears to be nondetectable by regular laboratory means. Because significant differences in quantity and quality of post-harvest residues occur between soybean and corn, a laboratory incubation experiment was designed to assess the effect of the plant materials on soil properties. Analysis shows that laboratory incubation of disturbed soil with and without corn and soybean residues at 20°C, with optimal water contents of 25% v/v, decreases splash detachment, increases shear strength and aggregate size after 7 to 14 d. Additions of corn or soybean residues increase soil strength and decrease soil splash in a log-linear fashion. The most pronounced effects were observed after 14 d. This corresponds to peak microbiological activity, indicating changes in stability are probably related to biological processes. Corn residue at typical field rates (20 Mg/ha) reduced soil splash by about one-third and increased strength about two times as compared to the check after 14 d of incubation. Incubation with soybean residue for a similar time caused slightly greater soil splash than incubation with the same amount of corn residue, suggesting that small changes in stability are related to residue quality. No difference in soil strength relative to residue quality was detected after 14 d of incubation, indicating a subtle difference between splash and strength as measures of surface-soil stability. Aggregate size measurements were less sensitive to plant residue treatment and time of incubation than splash or strength.

Additional Index Words: **fall cone shear strength, aggregate stability, water erosion, *Glycine max* L., *Zea mays* L., soil erosion.**

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ROW-CROP CULTURE OF SOYBEANS (*Glycine max* L.) generally increases soil and water losses when compared with row-crop culture of corn (*Zea mays* L.). Field evidence for increased soil loss has been provided by Laflen and Moldenhauer (1979) who found, in a 7-yr natural rainfall study on Grundy silt loam (Aquic Argiudolls), that average annual soil losses were about 40% higher ($P = 0.10$) when corn followed soybeans than when corn followed corn. The major difference in soil loss between these two conventionally tilled cropping rotations occurred during a period 30 to 60 d after planting (period P12). They speculated that this difference may indicate a "soil effect," since crop canopy and residue cover were nearly identical. More recently, however, Laflen and Colvin (1981) could not isolate the soil effect in data from a rainfall simulation study that examined the relationship between soybean and corn residue cover and soil loss. Alberts et al. (1985), who analyzed soil loss data from continuous, conventionally tilled soybeans and corn on natural rainfall plots of Mexico silt loam (Udollic Ochraqualfs), found average annual soil losses, from soybeans to be 3.4 times higher than that from corn.

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Much of the difference in soil loss between these crops occurred during seasonal period F (rough fallow), period 12 (30–60 d after planting) and period 4 (fall harvest to spring tillage). Measured universal soil loss equation C values (cover and management factor) were about twice as high for soybean cropping than that for corn cropping.

Because soybeans are thought to have a detrimental effect on soil structure, research has been conducted to evaluate the effects of soybean cropping on aggregate size and stability. Alberts and Wendt (1985) studied the mean-weight diameter (MWD) of dry- and wet-seived aggregates collected from Clarion clay loam and Monona silt loam (both are Typic Hapludolls) cropped continuously for 4 yr to soybeans and corn. They found that the MWD of dry-sieved aggregates was significantly lower for soybeans ($p < 0.05$) in October, but was similar in early June when differences would be expected to have the greatest influence on soil and water losses. No significant differences in the MWD of wet-sieved aggregates were found. Bathke and Blake (1984) found that aggregates were less water stable in the fall after soybeans. In spring, no consistent reductions in stability due to soybeans were found, but dry aggregates were smaller in size. Fahad et al. (1982), studying surface soil samples from a Sharpsburg silty clay loam (Typic Argiudolls) collected in September, were not able to find significant differences in water-stable aggregates between soybeans and corn.

Although field experiments have not found consistent soil effect differences between soybeans and corn, numerous laboratory studies have shown that the quantity and quality of organic material incorporated into the soil does influence aggregate size and stability. Highly significant positive regressions between the amount of plant material added and the amount of >0.25-mm aggregates were found after 30 d of incubation (Browning and Milam, 1946). Since then, other studies have yielded similar relationships between residue added to the soil and aggregate stability (McCracken, 1984; Chaney and Swift, 1984).

The effect of residue quality on aggregate size and stability also has been documented. Martin and Craggs (1946) found that readily decomposable substances like sucrose gave a fast, but short-lived increase in stability. Materials of higher resistance to microbial breakdown were more effective after longer incubation. Significantly greater amounts of large aggregates in corn compared with an equal amount of soybean residue amended soil were found by Schwartz et al. (1958) after 60 d of incubation of a silt loam soil. No other significant differences were found during the course of the 180-d study. McCracken (1984) also showed a significant increase of water-stable aggregates in corn as compared to soybeans after 128 d of incubation.

Because biological processes under laboratory conditions presumably occur much more rapidly than in the field due to the constant and optimal temperature and water content, incubation times for many of these experiments were unrealistically long. Incubation time is an important factor to consider because much of the average annual soil loss in the Corn Belt occurs during a 30-d period, from planting until 10% canopy cover. This critical period, which occurs immediately after residue incorporated by moldboard plowing is mixed with soil by disking, is when soil should be most carefully protected against raindrop and runoff forces. In some laboratory experiments, rates of plant residue amendments have also been too high.

The discrepancy between field and laboratory studies of soybean and corn cropping effects on soil stability underscores the importance of selecting laboratory methods which can estimate stability and relate it to soil and water losses in the field. Aggregate size has been commonly used to characterize a soil's resistance to slaking forces that are exerted on aggregates when wet and subjected to gently flowing water. However, soil splash detachment is mainly due to the forces of falling raindrops breaking down aggregates. The kinetic energy of raindrops falling at terminal velocity is from 1 to 2 orders of magnitude greater than the kinetic energy associated with gently flowing water (Hudson, 1981). Aggregates that may be water resistant and stable to breakdown due to wetting may not be stable when subjected to the impact of falling raindrops. For this reason, aggregate size and stability tests may not be the most suitable measurement for evaluating cropping effects on the soil. A more sensitive laboratory method, or set of methods, would help to reconcile the difference between field and laboratory studies and provide a consistent way to relate field and laboratory results. Such methods could also be used to estimate the effect of cropping and management on soil erodibility. Soil splash by single raindrop impact and shear strength as measured by the fall cone are two techniques recently used to study erosion that show much promise (Al-Durrah and Bradford, 1981).

Although some laboratory experiments cited above showed changes in soil stability with additions of organic materials, they did not isolate the effects of quantity or quality of specific amendments on subsequent soil stability. The objective of this laboratory experiment was to evaluate the effects of soybean and corn residue quantity and quality, and incubation duration on soil stability of packed cores as measured by: single drop splash detachment, fall-cone shear strength, and aggregate wet sieving. We based the addition rate of plant material on recent findings about post-harvest residues in cropland (Buyanovsky and Wagner, 1986). A short time duration for the experiment (7 weeks) was chosen because in laboratory incubation experiments with stable temperature and water content, most of the available energy sources are used in a short period (Chahal and Wagner, 1965).

MATERIALS AND METHODS

Soil was collected from within the upper 0.1 m of a Mexico silt loam (fine, montmorillonitic, mesic, Udollic Ochraqualfs) that had been maintained in continuous cultivated fallow for 2 yr at the McCredie Claypan Exp. Stn located about 35-km east of Columbia, MO. The soil was air-dried and sifted through a 2-mm sieve. Treatments evaluated were: (i) Check (Ck)—no plant materials added to soil; (ii) Soybean (Soy)—leaf, stem, and root mixture added at 0.47% by weight, which approximated the average annual input of soybean residue in the field (10 Mg/ha); (iii) Corn Low (CornL)—plant material added at the same rate as soybeans (10 Mg/ha), which is equal to half the average annual corn residue input in the field; and (iv) Corn High (CornH)—plant material added at 0.92% of soil, which is equivalent to the average annual field input of corn residue (20 Mg/ha). Plant materials, which consisted of 53% leaves and stems and 47% roots, were air-dried, ground, and sifted through an 849-μm (20-mesh) screen before being mixed with the soil using a rotating V-shell mixer. Soil-residue mixtures were pressed into an assembly of two white polyvinyl chloride (PVC) cylinders, 52.5-mm i.d. by 47.7-mm high to a bulk density of 1.2 Mg/m^3. The volumetric water content of the soil was adjusted to about 25% by adding deionized water to the soil surface of one end of the assembly, after which samples were placed in humidifiers and allowed to equilibrate for 18 h. Assemblies were cut in two using a thin spatula, which produced two separate samples. A small bottle brush was used to lightly sweep the cut surfaces to remove any smeared soil, after which a jet of compressed air (at 8 kPa) was directed through a 14-gauge needle at the surface to remove any loose soil particles. One group of samples was immediately prepared for measurement. Other samples were placed in sealed humidifiers and allowed to incubate for 1, 2, 4, and 7 weeks at a constant temperature of 20°C. Four replicate cores of each treatment-incubation time were prepared.

Dynamics of the decomposition process were estimated from CO_2 evolution determined by the alkali-absorption method (Anderson, 1982). Evaporation dishes with 1 *M* NaOH were placed into humidifiers with replicate cores from the same treatment. Dishes were removed for analysis every 3 to 4 d, titrated with HCl after CO_2 was precipitated with $BaCl_2$, and then replaced with fresh NaOH for future measurements. Results are expressed in milligrams of C evolved from 100 g of air-dried soil and represent an average evolution from at least four cores.

After selected incubation times, samples were slowly wet with a 0.05 mol/L $CaCl_2$–$MgCl_2$ solution, and allowed to equilibrate for 12 h. About 5 h before measurement, samples were transferred to a sand tension table maintained at a soil-water potential of −1 kPa. Measurement of soil splash detachment was conducted using the method of Gantzer et al. (1985). A single freefalling waterdrop was aimed at the soil surface causing soil splash to occur. Waterdrop characteristics consisted of a drop mass of 57.1 mg, a drop velocity of 8.4 m/s, and a kinetic energy of 2.01 mJ. Soil splash detachment was collected, oven-dried, and recorded for each of three determinations per sample core. Soil shear strength was estimated from three determinations per core immediately after splash measurement using a fall cone device (Hansbo, 1957). Statistical analysis was performed on logarithms of splash and strength in order to approximate the assumption of normality. These values were converted to geometric means for presentation. Aggregate size analysis was conducted using a method similar to that of Kemper and Chepil (1965). The method differed in that soil was not allowed to air-dry, but rather was analyzed directly from the wet samples after splash and strength were determined. This modification was done to insure a minimum breakage of bonds formed during incubation. These data are reported as geometric mean diameters.

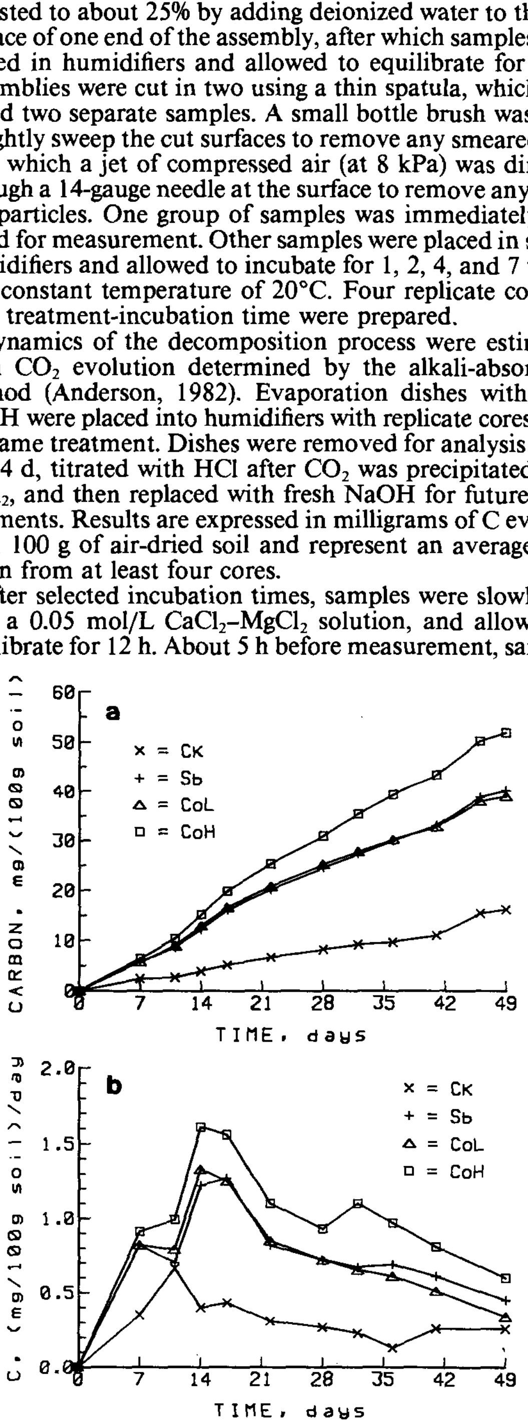

Fig. 1. Decomposition of plant residues in incubated cores as measured by CO_2 formation: (a) cumulative C evolution, (b) weekly dynamics of carbon evolution vs. incubation time: Ck, unamended; Soy, amended with 10 Mg/ha soybean material; CornL, amended with 10 Mg/ha corn material; and CornH, amended with 20 Mg/ha corn material.

RESULTS

Cumulative CO_2 evolution from the cores revealed no major difference in plant material availability between ground corn and soybean residues when applied at the same rate (Fig. 1a). By the end of the experiment, about 16% of the plant C from the Soy and the CornL treatments was released, compared to about 12% from the CornH treatment.

Carbon dioxide production from the residue treatments during the first 48 h of incubation was twice that from the Ck. After a short time during which CO_2 production stabilized, decay in the treatments with added residue accelerated rapidly and reached a maximum rate on the 14th d. Available C in the Ck samples could only provide 10 d of increased biological activity after which CO_2 production from the Ck samples started to decrease (Fig. 1b).

Residue quantity did not effect microbial activity during the initial stage of decomposition; but after the microbial population adjusted to the incubation environment, high residue rates (CornH) produced more CO_2 than other treatments. No direct relationship between CO_2 production and residue quantity, and no effect of quality of plant material (i.e., corn vs. soybean) on respiration dynamics were observed.

Soil splash detachment was influenced significantly by plant material ($P = 0.001$) and incubation time ($P < 0.001$) (Fig. 2a, Table 1). The interaction of these two factors was not statistically significant. Formal single degree of freedom tests were conducted to describe the nature of the main effects. The importance of residue quantity was assessed by testing the orthogonal contrast for the regression of soil splash on quantity of plant material. This contrast was highly significant ($P = 0.0002$). A second orthogonal contrast was tested to determine if residue quality (soybean vs. corn) had a significant effect on soil splash. This test was significant at the 5% level ($P = 0.026$). Although the analysis does indicate a relationship between soil splash and residue quality, the strength of the relationship is much less than that between soil splash and residue quantity.

Other contrasts used to test the effect of incubation time on soil splash showed that average splash at time zero of incubation was significantly greater than that for the average of all other times ($P < 0.001$). Soil splash decreased exponentially with incubation time to a minimum point around 14 to 28 d, after which splash was generally constant or increased slightly. No significant difference in splash occurred between weeks 4 vs. 7 or between week 2 vs. the average of weeks 4 and 7.

There is no indication that decomposition of soybean and corn material results in strengths significantly different at the same levels of residue (Fig. 2b, Table 1). There was an indication of a strength difference between CornL and CornH, whereas no difference in splash was observed between these two treatments (Fig. 2b). About 78% of the variation in mean soil splash from all cores was explained by mean soil strength (log transformed data).

Results from aggregate wet sieving were similar to those from the previous measurements (Fig. 2c, Table 1). One important difference, however, was that treatment effects on aggregate size were smaller than those on soil splash or soil strength. With the exception of time zero, treatment differences could not be detected visually by inspection of the graph (see Fig. 2c).

DISCUSSION

Biological activity in agricultural soils can be very intense after harvest when large amounts of C become available for the soil inhabitants. During such a flush, up to 40% of the total annual amount of CO_2 can be evolved in <60 d (Buyanovsky and Wagner, 1986). In our laboratory, where finely ground residue was incubated at optimum temperature and water content, intense decay began immediately, with maximum CO_2 evolution occurring between d 10 and 16 (Fig. 1b). All three methods of determining soil stability revealed a rapid increase in stability within this period, presumably due to biological processes.

Splash data indicate that the quality of plant material is significantly related to the logs of splash amount ($P = 0.02$), with soybean amended soil about 10% less stable than corn (Fig. 2a). Splash data also suggest no increase in soil stability with greater amounts of corn amendment. Conversely, strength data show that differences between soybean and corn amended soil at equal levels are not significant, and that differences between levels of corn amendment are relatively important (Table 1, Fig. 2b).

Table 1. Probability values for main effects and single degree of freedom tests for soil splash, soil strength, and soil aggregate size.

		Probability		
Source	df	Splash	Strength	GMD
Plant material	3	0.001	<0.001	0.017
Quantity-linear	(1)	<0.001	<0.001	0.002
Quality	(1)	0.026	0.185	0.948
Incubation time	4	<0.001	<0.001	<0.001
Week 4 vs. 7	(1)	0.416	0.879	0.413
Week 2 vs. 4 and 7	(1)	0.845	0.599	0.087
Week 0 vs. 2, 4, and 7	(1)	<0.001	<0.001	<0.001
Plant material × incubation time	12	0.700	0.690	0.526
Error	60			
		$R^2 = 0.47$	$R^2 = 0.82$	$R^2 = 0.50$

It has long been recognized that organic matter amendments influence soil stability due to increasing biological activity. Gilmour et al. (1948) showed that oat (*Avena sativa* L.) straw and alfalfa (*Medicago sativa* L.) were effective in the aggregation process only in the presence of common fungal species. Tisdall and Oades (1982), who have conducted investigations on the relation between aggregation and organic material, reported that plant roots and fungal hyphae were responsible for macroaggregate stabilization (aggregates >250 μm). Broder (1985) presented evidence showing that after corn cropping, a field soil has about 2.5 times as many fungi as soil after soybeans. Differences in soil splash between CornL and Soy (Fig. 2a) presumably should be related to the predominant microbial group (fungal in corn treatments, and bacterial in soybean treatments). In our experiment, these differences are only 5 to 10%.

Since the amount of residue was related to soil sta-

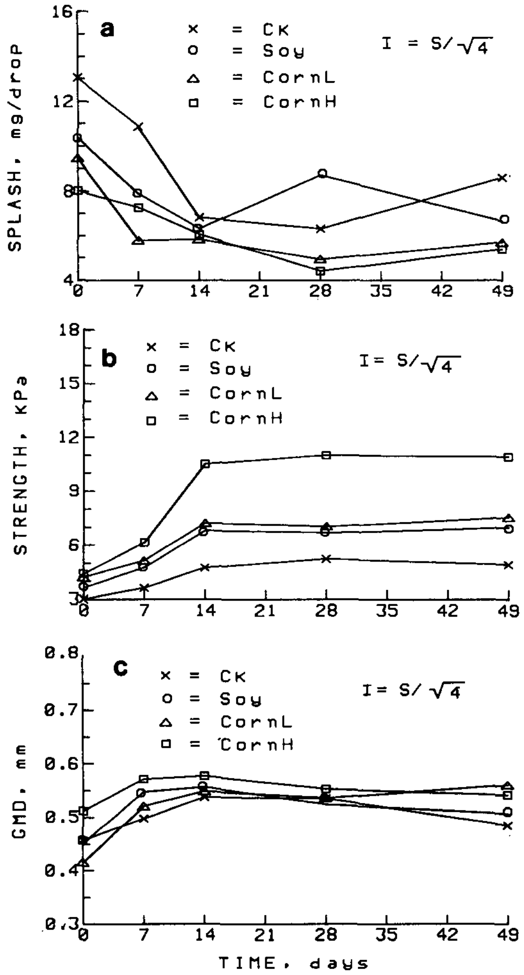

Fig. 2. Effects of incubation with crop residues on soil stability parameters: (a) geometric mean soil splash, (b) geometric mean soil strength, (c) geometric mean diameter of soil aggregates, from laboratory incubated cores vs. incubation time: Ck unamended; Soy amended with 10 Mg/ha soybean material; CornL, amended with 10 Mg/ha corn material; and CornH, amended with 20 Mg/ha corn material.

bility (Browning and Milam, 1946), and post-harvest residue after corn is about two times greater than that after soybeans (Buyanovsky and Wagner, 1986), it would be expected that greater differences in splash would be found between CornH and Soy. Our data did not show this; however, amounts of splash for both CornL and CornH were quite low. Soil strength differences (Fig. 2b) observed between treatments were also somewhat unexpected, in that there was a difference between CornH and CornL, while no difference between CornL and Soy was found. A soil strength difference between CornH and Soy may be explained by different amounts of residue within samples.

The interaction of treatment by soil splash/soil strength measurement may be explained partially by relating the level of kinetic energy applied to the samples for each measurement method. Inspection of splash data after 14 d (Fig. 2a) shows only 5 to 6 mg of soil splash for samples from the CornH and CornL treatments. Given the kinetic energy of one waterdrop (2.01 mJ), it may be that samples from both treatments were sufficiently strong to resist soil splash. Energy associated with a 100 g -30° fall-cone penetrating 10 mm, is equivalent to about 9.8 mJ, which is five times higher than that of a raindrop. The energy level of the fall cone apparently exceeded the critical energy necessary for soil failure to occur, which allowed differences between the corn treatments to be expressed. Failure of soil strength determinations to detect a difference between Soy and CornL, while soil splash determination revealed a difference, could be related to the mechanism of soil failure occurring with a raindrop vs. that with a cone. Splash would be more sensitive to near surface stability, since a single waterdrop disturbs only a small soil volume. A fall-cone that disturbs much greater soil volumes, would integrate soil properties to at least the depth of penetration.

Due to higher sensitivity of the splash test, certain differences were found between treatments at 0 time, which the other tests failed to reveal. Certain effects of the physical structure of the added plant material may be partly responsible. Though ground corn residue was passed through the same sieve as ground soybeans residue (840 μm, 20 mesh), it contained amounts of needle-shaped pieces, about 2 mm long. Soybean residues were more delicate and fragile, and gave a more uniform mass after grinding. Soil splash characteristics at 0 time showed a reinforcing effect from corn residue additions, presumably due to the presence of these long particles. Such an affect may also be important in the field.

The conclusions developed from this experiment are:

1. Incubation with soybean residue causes small (ca. 5–10%) but significantly greater soil splash than incubation with the same amount of corn residue, suggesting small differences in stability are related to residue quality. No difference in soil strength was detected, indicating a subtle difference between splash and strength as measures of surface-soil stability exist.
2. Aggregate wet sieving did not differentiate treatment effects on soil stability as well as soil splash or strength, and therefore techniques other than aggregate wet sieving should be used routinely to characterize cropping effects on soil stability.

REFERENCES

Alberts, E.E., and R.C. Wendt. 1985. Influences of soybean cropping on soil aggregate size and stability. Soil Sci. Soc. Am. J. 49:1534–1537.

Alberts, E.E., R.C. Wendt, and R.E. Burwell. 1985. Corn and soybean cropping effects on soil losses and *C* factors. Soil Sci. Soc. Am. J. 49:721–728.

Al-Durrah, M. and J.M. Bradford. 1981. New methods of studying soil detachment due to waterdrop impact. Soil Sci. Soc. Am. J. 45:949–953.

Anderson, J.P.E. 1982. Soil respiration. *In* A.L. Page et al. (ed.) Methods of soil analysis, Part 2. Agronomy 9:831–871.

Bathke, G.R., and G.R. Blake. 1984. Effects of soybeans on soil properties relating to soil erodibility. Soil Sci. Soc. Am. J. 48:1398–1401.

Broder, M.W. 1985. Changes in the chemical composition of and microbial population on corn, wheat, and soybean residue decomposing in Sanborn Field, Ph.D. diss. Univ. of Missouri, Columbia (86-07891).

Browning, G.M., and F.M. Milam. 1946. Rate of application of organic matter in relation to soil aggregation. Soil Sci. Soc. Am. Proc. 6:96–97.

Buyanovsky, G.A., and G.H. Wagner. 1986. Post-harvest residue input to cropland. Plant Soil 93:57–65.

Chahal, K.S., and G.H. Wagner. 1965. Decomposition of organic matter in Sanborn field soils amended with ^{14}C glucose. Soil Sci. 100:96–103.

Chaney, K., and R.S. Swift. 1984. The influence of organic matter on aggregate stability in some British soils. J. Soil Sci. 35:223–230.

Fahad, A.A., L.N. Mielke, A.D. Flowerday, and D. Swartzendruber. 1982. Soil physical properties as affected by soybean and other cropping sequences. Soil Sci. Soc. Am. J. 46:377–381.

Gantzer, C.J., E.E. Alberts, and W.H. Bennett. 1985. An electronic discriminator to eliminate the problem of horizontal raindrop drift. Soil Sci. Soc. Am. J. 49:211–215.

Gilmour, C.M., O.N. Allen, and E. Truog. 1948. Soil aggregation as influenced by the growth of mold species, kind of soil and organic matter. Soil Sci. Soc. Am. Proc. 13:292–296.

Hansbo, S. 1957. A new approach to the determination of the shear strength of clay by the fall-cone test. Royal Swedish Geotech. Inst. Proc. 14:1–47.

Hudson, N. 1981. Soil conservation. Cornell University Press. Ithaca, NY.

Kemper, W.D., and W.S. Chepil. 1965. Size distribution of aggregates. *In* C.A. Black et al. (ed.) Methods of soil analysis, Part 1. Agronomy 9:499–510.

Laflen, J.M., and W.C. Moldenhauer. 1979. Soil and water losses from corn-soybean rotations. Soil Sci. Soc. Am. J. 43:1213–1215.

Laflen, J.M., and T.S. Colvin. 1981. Effects of crop residues on soil loss from continuous row cropping. Trans. ASAE 24:605–609.

Martin, J.P., and B.A. Craggs. 1946. Influence of temperature and moisture on the soil-aggregating effect of organic residues. Agron. J. 38:332–339.

McCraken, D.V. 1984. Influence of corn and soybean residue decomposition on soil aggregate wet stability. M.S. thesis. Purdue Univ. West Lafayette, IN.

Schwartz, S.M., P.G. Freeman, and C.R. Russell. 1958. Soil-conditioning properties of modified agricultural residues and related materials: II. Persistence of soil-stabilizing activity as a function of type and extent of modification. Soil Sci. Soc. Am. Proc. 22:409–414.

Tisdall, J.M., and J.M. Oades. 1982. Organic matter and water-stable aggregates in soils. J. Soil Sci. 33:141–163.