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Research Letter

Corn Residue Particle Size Affects Soil Surface Properties

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Core Ideas

- Corn harvesting practices generate characteristic residue particle size distributions.
- Corn residue particle size influences its composition and decomposition.
- Residue particle composition and decomposition influence soil properties, i.e., soil C and N.
- Mechanical harvesting operations affect soil properties via residue size distributions.

Abstract: Field operations may differentially influence crop residue size distributions, altering residue decomposition rates and soil carbon (C) and nitrogen (N) dynamics. In a laboratory microcosm study modeling corn residue distributions observed in a no-till cropping system, microbial respiration was initially (first 30 d) inversely proportional to residue particle size across four size classes. Subsequently (30–60 d), respiration in the smallest particle size decreased in relation to the larger size classes. Residue particle size significantly increased soil C levels, with the smallest sizes producing the longest-lasting effects (150 d). Smaller residue size classes initially (30 d) immobilized more soil N compared with larger size classes; however, at 150 d, the smaller size classes had mobilized increasing amounts of N while the larger size classes had progressively immobilized more N. We conclude that crop residue management operations changed characteristic residue size distributions that moderate decomposition activities and result in unique soil C and N dynamics, possibly influencing soil properties, including nutrient availability.

The effects of differing levels of crop residue removal on soil properties has been vigorously studied to determine how much residue can be removed without degrading the soil and its productivity (Karlen and Johnson, 2014). However, soil properties may not respond linearly to increasing levels of crop residue removal (Lehman et al., 2014; Stetson et al., 2012; Wegner et al., 2018), suggesting an additional influence on soil properties beyond residue quantity. Mechanical operations during harvesting of grain and/or residues can influence the size distribution of residues remaining on the soil surface (Table 1). In no-till systems, residue particles remain on the surface to be decomposed and, depending on the particle size, may behave differently as they become part of the soil.

Previous studies have shown varying relationships between particle size and microbial respiration, depending on the plant residue type and particle size range (Angers and Recous, 1997; Bending and Turner, 1999; Sims and Frederick, 1970). None of these studies directly addressed the effect of corn (*Zea mays* L.) residue particle size on its decomposition and effect on soil parameters, particularly as it relates to no-till systems. Our study objectives were to determine the effect of corn residue particle size on microbial respiration and soil C and N dynamics in a laboratory-scale experiment modeling the 0- to 5-cm layer of soil in a no-till system.

Materials and Methods

Corn stalk and leaf residue were collected from a post-harvest bale, air dried at 80°C, chipped, and rotary-sieved to separate the residue into four size classes: class 1 = <0.4 mm, class 2 = 0.4–0.8 mm, class 3 = 0.8–6 mm, and class 4 = >6 mm, respectively. Fiber composition of each residue size class was determined by Ankom Fiber analysis.

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For each residue size class, 300 g of dried and sieved (2 mm) topsoil was mixed with 0, 2.1, or 4.2 g of residue and placed into a 2-cm-deep pot. Residue application rates were determined by bracketing the highest and lowest residue amounts observed in a field study (Table 1) and scaling these amounts to the surface area of the pots. Pots (six replicates per rate per size class) were maintained at field capacity soil moisture (daily gravimetric adjustment) in a growth chamber (75% humidity; 16 h daylight; 21/13°C day/night).

Soil respiration was determined by CO_2 flux at 17 occasions over a 60-d period. Ported lids were temporarily (0.5 h) applied, and headspace CO_2 was measured by gas chromatography (Lehman and Osborne, 2013). At 30 and 60 d, 4 g of soil was removed (1.5-cm-diam. cores) and dried, and visual residue was removed, fine ground, and sieved (0.5 mm). Total soil C and N were determined by combustion (TruSpec CHN analyzer, LECO Corporation) (Nelson and Sommers, 1996) and inorganic N species by 2 M KCl extraction and flow injection analysis (Lachet Instruments, 1989).

After 60 d, pots were transferred to a greenhouse (28/18°C day/night) and watered by a misting irrigator. After 150 d, soil was collected for total C and N analysis as described above. Statistical analyses were performed with a two-way ANOVA with residue amount and particle size as the fixed treatment factors and replication as a random factor, utilizing a mixed model (SAS Institute, 2007), α level of 0.05.

Results and Discussion

Residue amount (0 [none, no residue], 2.1 g [low], 4.2 g [high]) effect on respiration was significant ($p < 0.05$) at all sampling points (Table 2), except for the first 3 d, when respiration in the control (no residue) and low amount (2.1 g) were not significantly different. Thereafter, all residue rates had significantly different respiration (high > low > none). There was no interaction between the amount of residue and residue size, and therefore cumulative respiration is plotted for each residue size class as the average of high and low residue amounts (Supplemental Fig. S1). For the first 25 d, respiration from size classes 1 and 2 were not significantly different and both were significantly higher than size classes 3 and 4 and the no-residue control (Table 2). From 30 to 60 d, respiration from class 3 was equal to classes 1 and 2. From 45 to 60 d, class 2 respiration was significantly higher than class 1; otherwise, respiration was inversely proportional to particle size. The common expectation for respiration to be inversely proportional to residue particle size is based on the amount of surface area in contact with the soil. Even modest amounts of small particles produce large changes in active surface area (varying with square of particle diameter). This relationship has been borne out in studies with corn pith (Sims and Frederick, 1970) and wheat (*Triticum aestivum* L.) straw (Angers and Recous, 1997) but not confirmed in studies with potato (*Solanum tuberosum* L.) and brussels sprout (*Brassica oleracea* L. var. *gemmifera* DC.) shoots (Bending and Turner, 1999). Our smallest particle size (class 1) exhibited lower respiration than some larger particle sizes (class

Table 1. The amount of corn residue and its particle size distribution (by rotary sieve analyses) remaining on the soil surface of a no-till system measured under three harvesting conditions: (i) grain harvest only, (ii) grain plus baled stover, and (iii) silage removal. Field study details available in Stetson et al. (2012).

Residue removal level	Residue size class†						
	1	2	3	4	5	6	Total
	g kg^{-1}						kg ha^{-1}
Grain only	2.7	3.2	21.8	91.0	249.8	631.5	1231
Grain + stover	4.4	4.1	25.6	91.3	327.6	547.1	884
Silage	4.8	4.7	29.9	117.0	311.3	532.4	601

† Residue size classes: 1, <0.4 mm; 2, 0.4–0.8 mm; 3, 0.8–2 mm; 4, 2–6 mm; 5, 6–19 mm; 6, >19 mm.

Table 2. Cumulative CO_2 evolved (mg CO_2–C kg^{-1}) during incubation of soils with varied amounts and sizes of corn residue added. Differing letters indicate statistical differences at $p < 0.05$. Low and high rates were pooled for residue particle size class analysis. All size classes within a rate were pooled for residue application rate analysis.

	CO_2 evolved				
	Day 1	Day 15	Day 30	Day 45	Day 60
	mg CO_2–C kg^{-1}				
Residue particle size class†					
None	59 a	607 a	1219 a	1618 a	2136 a
Class 1	97 c	1041 c	1830 c	2326 c	2903 c
Class 2	95 c	1074 c	1934 c	2484 c	3104 c
Class 3	75 b	948 c	1815 c	2393 c	3006 c
Class 4	70 b	736 b	1500 b	2031 b	2627 b
Residue application rate‡					
None	59 a	607 a	1219 a	1618 a	2136 a
Low	71 a	841 b	1641 b	2159 b	2717 b
High	97 b	1059 c	1899 c	2457 c	3091 c

† Residue size classes: 0, no residue; Class 1, < 0.4 mm; Class 2, 0.4–0.8 mm; Class 3, 0.8–6 mm; Class 4, > 6 mm.

‡ Residue application rates: none, no residue; low, 2.1 g residue per 300 g of soil in a pot; high, 4.2 g residue per 300 g of soil in a pot.

2, 3) during the last 15 d of the study. The ultimately lower respiration in this small particle size fraction could be due to its relatively high lignin content (Supplemental Table S1) or because smaller particles are more prone to physical protection of the surface, as previously suggested (Ambus and Jensen, 1997; Sims and Frederick, 1970).

Residue amount (0, 2.1, 4.2 g) significantly ($p < 0.05$) increased the amount of soil C at all sampling points for all residue size classes except class 4, where there was no effect (data not shown). Averaging the two rates of residue application for clarity, we found a significant effect of residue size class on soil C (Table 3). At 30 d, size classes 1 and 2 had higher soil C than classes 3 and 4; at 60 d, size class 1 had higher C than the other classes. At 150 d, classes 1 and 2 had more soil C than the initial soil C level and both remained significantly higher than the no-residue control.

In moderating respiration and soil C, residue particle size appears to be an additional factor (besides residue quantity and quality) for soil priming, where added substances alter soil organic matter dynamics (Blagodatskaya and Kuzyakov, 2008). Residue size may also influence soil organic matter stabilization, which has been reported to be independent of molecular structure under many conditions and is associated with microbial activities (Schmidt et al., 2011).

There was no effect of residue rate on total soil N or interaction between residue rate and size for any of the three sampling days (data not shown). The only significant residue size effect was observed at 150 d, where residue size class 4 had lower soil N than the other treatments (Table 3).

All residue size classes had significantly lower soil nitrate values than the no-residue control at all sampling dates (Table 4), demonstrating net N immobilization as previously observed (Sims and Frederick, 1970). At 30 and 60 d, size classes 3 and 4 had significantly higher soil nitrate than the smaller size classes 1 and 2. At 150 d, the results were mixed, with size class 2 having the highest soil nitrate among the residue treatments. At 30 d, size class 1 had significantly higher ammonium concentrations compared with the other size classes (Table 4). Between 60 and 150 d, soil ammonium concentrations declined by approximately 0.5 mg kg^{-1} for all residue treatments with the larger particle size classes 3 and 4 having significantly lower soil ammonium than size class 1 on Day 150.

In conclusion, the mechanical procedures used for harvesting and handling grain and crop residues may produce characteristic residue particle size distributions that can affect soil properties, including soil C and N dynamics and microbial activities. Consideration of residue particle size distributions will promote more accurate interpretation of studies examining the effects of harvesting operations on soil properties and enhance the predictive value of these studies.

References

Ambus, P., and E.S. Jensen. 1997. Nitrogen mineralization and denitrification as influenced by crop residue particle size. Plant Soil 197:261–270. doi:10.1023/A:1004276631914

Angers, D.A., and S. Recous. 1997. Decomposition of wheat straw and rye residues as affected by particle size. Plant Soil 189:197–203. doi:10.1023/A:1004207219678

Bending, G.D., and M.K. Turner. 1999. Interaction of biochemical quality and particle size of crop residues and its effect on the microbial biomass and nitrogen dynamics following incorporation into soil. Biol. Fertil. Soils 29:319–327. doi:10.1007/s003740050559

Blagodatskaya, E., and Y. Kuzyakov. 2008. Mechanisms of real and apparent priming effects and their dependence on soil microbial biomass and community structure: Critical review. Biol. Fertil. Soils 45:115–131. doi:10.1007/s00374-008-0334-y

Karlen, D.L., and J.M. Johnson. 2014. Crop residue considerations for sustainable bioenergy feedstock supplies. BioEnergy Res. 7:465–467. doi:10.1007/s12155-014-9407-y

Table 3. Soil C and N by residue size class for the 30, 60, and 150 d sampling dates. The initial soil C and N were 21.0 g C kg^{-1} 1.87 g N kg^{-1}, respectively.

Residue size class†	Soil C			Soil N		
	30 d	60 d	150 d	30 d	60 d	150 d
	g C kg^{-1}			g N kg^{-1}		
0	20.6 a	20.7 a	20.9 a	1.93	1.90	1.84 b
1	22.9 c	22.3 c	22.9 b	1.91	1.98	1.83 b
2	22.5 c	21.9 b	22.5 b	1.89	1.95	1.87 b
3	22.1 b	22.0 bc	21.9 ab	1.86	1.90	1.88 b
4	21.7 b	21.7 b	21.3 ab	1.89	1.94	1.67 a
Prob > *F*	0.0001	0.0017	0.0066	0.5190	0.2201	0.0406

† Residue size classes: 0, no residue; 1, <0.4 mm; 2, 0.4–0.8 mm; 3, 0.8–6 mm; 4, >6 mm.

Table 4. Soil NO_3 and NH_3 by residue size class for the 30, 60, and 150 d sampling dates.

Residue size class†	Soil NO_3			Soil NH_3		
	30 d	60 d	150 d	30 d	60 d	150 d
	mg NO_3 kg^{-1}			mg NH_3 kg^{-1}		
0	10.73 d	6.97 c	11.43 c	2.27 a	2.25	1.98 b
1	1.45 a	1.12 a	5.08 b	2.37 b	2.48	1.88 b
2	1.34 a	1.33 a	3.22 ab	2.26 a	2.48	1.79 ab
3	3.32 b	2.34 b	2.95 a	2.16 a	2.43	1.58 a
4	7.07 c	3.58 b	4.62 b	2.20 a	2.35	1.65 a
Prob > *F*	0.0001	0.0002	0.0001	0.0333	0.2489	0.0341

† Residue size classes: 0, no residue; 1, <0.4 mm; 2, 0.4–0.8 mm; 3, 0.8–6 mm; 4, >6 mm.

Lachet Instruments. 1989. Quickchem method 12-107-041-B. Lachet Instruments, Milwaukee, WI.

Lehman, R.M., T.F. Ducey, V.L. Jin, V. Acosta-Martinez, C.M. Ahlschwede, E.S. Jeske, R.A. Drijber, K.B. Cantrell, J.R. Frederick, and D.M. Fink. 2014. Soil microbial community response to corn stover harvesting under rain-fed, no-till conditions at multiple US locations. BioEnergy Res. 7:540–550. doi:10.1007/s12155-014-9417-9

Lehman, R.M., and S.L. Osborne. 2013. Greenhouse gas fluxes from no-till rotated corn in the upper Midwest. Agric. Ecosyst. Environ. 170:1–9. doi:10.1016/j.agee.2013.02.009

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In: D.L. Sparks, et al., editors, Methods of soil analysis. Part 3. Chemical methods. Vol. 5. SSSA, Madison. p. 961–1010.

SAS Institute. 2007. SAS user's guide: Statistics. SAS Inst., Cary, NC.

Schmidt, M.W., M.S. Torn, S. Abiven, T. Dittmar, G. Guggenberger, I.A. Janssens, M. Kleber, I. Kögel-Knabner, J. Lehmann, and D.A. Manning. 2011. Persistence of soil organic matter as an ecosystem property. Nature 478:49–56. doi:10.1038/nature10386

Sims, J.L., and L.R. Frederick. 1970. Nitrogen immobilization and decomposition of corn residue in soil and sand as affected by residue particle size. Soil Sci. Soc. Am. J. 109:355–361. doi:10.1097/00010694-197006000-00005

Stetson, S.J., S.L. Osborne, T.E. Schumacher, A. Eynard, G. Chilom, J. Rice, K.A. Nichols, and J.L. Pikul. 2012. Corn residue removal impact on topsoil organic carbon in a corn–soybean rotation. Soil Sci. Soc. Am. J. 76:1399–1406. doi:10.2136/sssaj2011.0420

Wegner, B.R., S.L. Osborne, R.M. Lehman, and S. Kumar. 2018. Seven-year impact of cover crops on soil health when residue is removed. BioEnergy Res. doi:10.1007/s12155-017-9891-y