Water retention properties of maize stem residue as affected by particle size and decomposition in soil

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Abstract

The aim of this study was to investigate the effects of crop residue particle size and decomposition on water retention properties. Two pieces of 0.5 and 5 cm length of intact maize stem were chosen as experimental model. Maize particles were incubated in soil during 49 days at 24°C to alter the characteristics of stem particles by decomposition. Maximum water retention and residual humidity of particles were established by immersing the particles at three decomposition stages (undecomposed, decomposed after 14 days and after 49 days) for different duration of time until stable weight. We observed that 0.5 cm particles absorbed the same amount of water per g of residue as 5 cm particles. Decomposed particles absorbed more water than undecomposed ones for both particle sizes. Similar trends were obtained for residual water. We hypothesized that higher maximum water absorption and lower residual water retention in decomposed particles were due to an increase in residue porosity during decomposition. Particle size affected C mineralization with significant higher mineralization for 0.5 cm particles (29% of added C) than for 5 cm particles (21% of added C). The consequences of water retention properties on residue mulches are discussed in the context of conservation agriculture.

Key Words

Crop residue management, Physical properties, Granulometry, Specific surface, C dynamics

Introduction

For integrated and sustainable agricultural management, it is crucial to understand the processes involved in decomposition of crop residues. The dynamics of decomposition is controlled by many factors. Among these factors, physical characteristics and location in soil determine the contact between soil and residue. Some studies showed that decreasing the residue particle size and incorporating residue into soil, increase area in contact with soil and make degradable components more accessible to decomposer micro organisms (Anger and Recous 1997). Conversely leaving crop residues in mulch at the soil surface such as in no tilled systems greatly affect the dynamics of water in and below the mulch, and the decomposition of the mulch itself becomes highly dependent on environmental conditions, particularly moisture (Coppens *et al.* 2007). To understand and model residue mulch decomposition and associated C and N dynamics, it is necessary to determine residue physical properties, particularly those related to water dynamics and their relation to decomposition. To answer these questions, we selected maize stem as experimental model because it is frequently involved in rotations, particularly in conservation agriculture.

Materials and Methods

Characterization of crop residues

The maize stems were collected at the INRA experimental station in Mons (80) on 10 July 2006. We eliminated the nodes of stems because nodes have very different chemical and physical features compared to internodes. The maize internodes were then cut into two different particle sizes: 5 cm length (T5 treatment) and 0.5 cm length (T0.5 treatment). The shape and geometry of the 5 cm and 0.5 cm particles are presented in Figure 1.

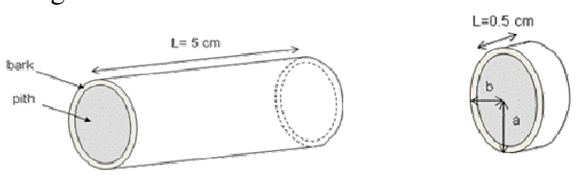


Figure 1 Schematic diagram of two particle sizes, 5 cm and 0.5 cm.

Physical and chemical properties of residue
The particles were characterized by their geometry, specific surface, potentially available contact surface and volume. For characterizing the geometry of the particles, we designed the shape of the residue as close as possible to their exact shape (Figure 1), in order to estimate the volume and specific surface of the two sizes. The geometrical shape of maize stem was not exactly a cylinder, because both ends of the stem particles are of elliptical shape. Van Soest (1963) analysis indicated that maize stem was composed of 24% soluble, 26% hemicelluloses, 43% cellulose and 7% lignin components. While soluble C at 20°C was 25% of dry matter and C/N was 183.

Maximum water retention and residual humidity
To our knowledge, there is no standardized and published protocol to examine water retention and residual humidity for crop residue, so, the first step was to set up a protocol before using it for particles at different stages of decomposition. The strategy was to immerse particles in 1200 ml deionized water for different time durations (t) and note their weight after removal from water. The water absorption by each particle size was calculated using difference between initial weight and weight after immersion, the maximal water retention being the maximal difference obtained at a given time. Once the protocol was established, then it was applied to all stages of decomposition for the two sizes.

To assess the residual humidity of particles, the previous particles having maximal water retention were placed sequentially at 40°C until constant weight, 80°C until constant weight and 120°C until constant weight. The protocol for residual humidity measurements was deduced from this experiment. It was calculated as the difference in water content of particles at 40°C and 120°C. The duration of drying was selected as 48 hours at both temperatures (40°C and 120°C) for 0.5 cm particles. While this duration for 5 cm particles was 96 hours at 40°C and 144 hours at 120°C to determine residual water content.

Incubation Experiment
The soil was also collected at the INRA experimental station in Mons, France. The main characteristics of the soil were: 16.8% clay, 76.3% silt, and 3.8% sand. Organic carbon content was 8.70 mg C g^{-1} of soil and soil pH (H_2O) was 7.6. Incubation experiment was conducted during 49 days at 24 ± 1°C by mixing soil samples and maize internodes added to soil in amount equivalent to 4 g C kg^{-1} of dry soil. A control soil without residue added was included. The dynamics of C mineralization was followed at 3, 7, 10, 14, 21, 28, 36, 42 and 49 days after the beginning of the incubation by replacing CO_2 traps periodically. The concentrations of CO_2 trapped in NaOH solution were measured by continuous auto- analyzer (TRAACS 2000, Bran and Luebbe).

Results
Physical characteristics of particles
Several physical characteristics changed with decomposition stage as particle mass decreased with decomposition. The average mass of particles decreases rapidly from t=0 to t=14 and more slowly from t=14 to t=49. The volume of particles was almost same at the different decomposition stages. The density of particles decreased with time (Table 1).

Table 1. Physical characteristics for two sizes of particles (T0.5 and T5) at three stages of decomposition (t=0, t=14 days and t=49 days): the mass of particles (M), the volume of particles (V) the density of particles (D), the degraded mass (md), the volume of created pore (Vp), the supplement volume of water absorbed (Vw) and the residual humidity (wR).Values are mean of 10 replicates (± SE). Symbol nr means "Not relevant".

	Decomposition stage					
	t=0		t=14 days		t=49 days	
Treatment	T0.5	T5	T0.5	T5	T0.5	T5
M (g)	0.13±0.03	0.88±0.15	0.09±0.01	1.05±0.06	0.08±0.01	0.83±0.08
V (cm3)	0.82±0.09	6.75±1.05	0.84±0.09	10.42±1.01	0.83±0.17	8.58±0.84
D (g/ cm3)	0.16±0.02	0.13±0.01	0.11±0.01	0.10±0.01	0.09±0.01	0.10±0.01
md (g)	nr	nr	0.03±0.0	(-)0.17±0.2	0.05±0.0	0.05±0.2
Vp (cm3)	nr	nr	0.20±0.2	(-)0.97±1.2	0.29±0.2	0.30±1.3
Vw (cm3)	nr	nr	0.23±0.2	2.57±0.9	0.02±0.2	2.88±1.8
wR %	5.18±1.16	7.71±0.48	2.36±0.85	4.27±0.14	3.73±0.43	4.55±0.13

Effect of decomposition stage on water retention properties
Preliminary experiment showed that the maximal water retention was obtained at different durations of immersion, depending on the particle size, i.e. 2 hours for 0.5cm particles and 30 hours for 5cm particles. We applied the experimental procedure set up above to particles removed from soils at different stages of decomposition (t=0, t=14 and t=49). Undecomposed 5 cm particles (t=0) absorbed 0.37 g of water/cm^3 of residue, particles at t=14 absorbed 0.49 g of water/cm^3 of residue and at t=49, particles absorbed 0.63 g of water/cm^3 of residue, i.e. 23 % (t=14) and 40% (t=49) more water than undecomposed particles (Figure 2). We observed that undecomposed residue particles (t=0) absorbed less water than decomposed particles. The same trend was obtained whether results were expressed by mass or by volume. Conversely, for the 0.5cm length particles, undecomposed particles (t=0) absorbed 0.40 g of water/cm^3 of residue, decomposed particles (t=14) absorbed 0.67 g /cm^3 of residue and decomposed particles (t=49) absorbed 0.42 g water/cm^3 of residue (Figure 2). Therefore the increase in water retention at t=49 was not similar to the pattern observed for the 5 cm length particles.

Residual water content decreased with decomposition, from 8 % (g H_2O/100 g DM) at t=0 to 5% at t=49 for T5; from 5% at t=0 to 4% at t=49 for T0.5. The hypothesis is that the increase in porosity with decomposition allowed the water contained in the residue to be evaporated (Table 1).

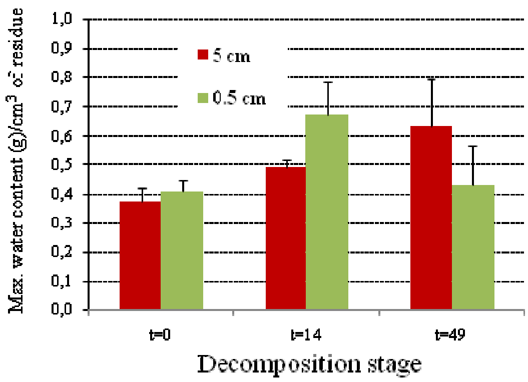
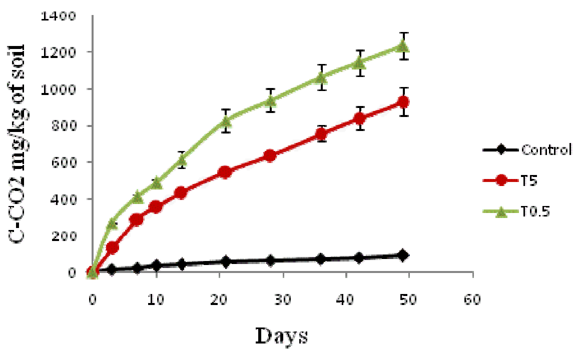
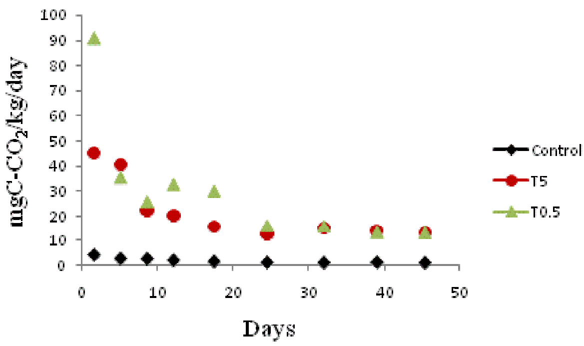


Figure 2 Maximum water absorption for 5 cm and 0.5 cm particles at different stages of decomposition measured after 30 hours and two hours of immersion respectively.

Carbon mineralization
The C-CO_2 mineralized from control soil was regular with a mean rate of 2.0 mg C per kg soil per day. After 49 days a total of 87.5 mg / kg of soil organic C were mineralized to CO_2 (Figure 3a). When maize residues were added to the soil, we observed a large increase in C mineralization (Figure 3a). The maximal rates of C mineralization peaked already at day 3 for the two amended treatments with the highest rate being obtained with the smaller size. The rates of C mineralization decreased continuously over time until the end of incubation and there were no significant differences in rates between the two residue treatments over the 20-49 day period. They remained significantly higher than the control soil (Figure 3b).



(a)
Figure 3a: Cumulative C mineralization. Each treatment has 4 replicates.



(b)
Figure 3b: Rate of C mineralization. Each treatment has 4 replicates.

Conclusion

According to literature (Findeling *et al.* 2007; Coppens *et al.* 2007), both physical processes that drive mulch decomposition are first the contact between the soil and the residue particle to be decomposed and secondly the water content of mulch in relation to rainfall. Our results confirmed that the particle size of crop residues has an important effect on residue decomposition as it increases the effective contact between the particle and the soil.

The absorbed water content of residue was found to depend on the particle size and on the stage of decomposition. The particle size affected the kinetic of absorption: the larger was the particle, the longer was the time to reach the maximum water content. The maximum water absorbed per volume unit was constant for different size of particles and it increased with decomposition stage. This can be qualitatively explained by the creation of new pores during decomposition process. This study shows that the effects of particle size on retention properties are determined by the quantity of vegetal material (volume or mass). This feature differs from the effects of particle size on decomposition which are essentially determined by the contact interface between the soil and the residues to be decomposed. The difference in amount of water retained between different sized particles at different decomposition stages implies that size, decomposition stage and rate of mulch cover per surface area will have a significant effect on the interception of rain. This amount of water received to the mulch plays an important role in determining the decomposition and mode of N release (Seneviratne *et al.* 1997).

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