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Estimation of optimum moisture levels for biodegradation of compost bulking materials

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Abstract

Moisture affects the physical and biological properties of compost and other solid state fermentation matrices. Aerobic microbial systems experience different respiration rates (oxygen uptake and CO2 evolution) as a function of moisture content and material type. In this study the microbial respiration rates of 13 compost-bulking materials were measured by a pressure sensor method at 6 different moisture levels. The experimentally determined respiration quotient (RQ) values were used to calculate CO2 respiration rates from O2 consumption. The RQ values of all materials were around 1.0 except for silage, oat straw and leaves which were about 1.5. A wide range of respiration and heat production rates were observed for different materials, with alfalfa hay, silage, oat straw, and turkey litter having the highest values. These four compost-bulking agents may be particularly suitable for improving internal temperature and pathogen destruction rates for disease-related mortality composting. Optimum moisture content was determined based on measurements across a range that spans the maximum respiration rate. A mechanistic model of moisture kinetics was also used to predict the optimum moisture levels. There was good agreement between experimental observations and modeled optimum moisture content. The optimum moisture content of each material was observed near WHC, which ranged from near 65 to over 85% on a wet basis for all materials except a highly stabilized yard waste compost (optimum around 30% w.b.). This study demonstrates the importance of moisture content on the biodegradability of organic materials and specific respiration rates of each material. The results can be used to develop moisture management and process control strategies to maintain compost and cover materials in an acceptable range.

Keywords

moisture content, respiration rates, respiration quotient, mechanistic model, compostbulking materials, mortality composting

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***Abstract*.** Moisture affects the physical and biological properties of compost and other solid state fermentation matrices. Aerobic microbial systems experience different respiration rates (oxygen uptake and CO_2 evolution) as a function of moisture content and material type. In this study the microbial respiration rates of 13 compost-bulking materials were measured by a pressure sensor method at 6 different moisture levels. The experimentally determined respiration quotient (RQ) values were used to calculate CO_2 respiration rates from O_2 consumption. The RQ values of all materials were around 1.0 except for silage, oat straw and leaves which were about 1.5. A wide range of respiration and heat production rates were observed for different materials, with alfalfa hay, silage, oat straw, and turkey litter having the highest values. These four compost-bulking agents may be particularly suitable for improving internal temperature and pathogen destruction rates for disease-related mortality composting. Optimum moisture content was determined based on measurements across a range that spans the maximum respiration rate. A mechanistic model of moisture kinetics was also used to predict the optimum moisture levels. There was good agreement between experimental observations and modeled optimum moisture content. The optimum moisture content of each material was observed near WHC, which ranged from near 65 to over 85% on a wet basis for all materials except a highly stabilized yard waste compost (optimum around 30% w.b.). This study demonstrates the importance of moisture content on the biodegradability of organic materials and specific respiration rates of each material. The results can be used to develop moisture management and process control strategies to maintain compost and cover materials in an acceptable range.

Keywords. moisture content, respiration rates, respiration quotient, mechanistic model, compost-bulking materials, mortality composting

Introduction

Composting has long been recognized as an environmentally acceptable method for treating industrial and agricultural organic wastes. Because it provides for pathogen destruction as well as volume and mass reduction, it has more recently been accepted as an option for dead animal management in many regions of the world (Blake and Donald, 1992; Sims et al., 1992; Cummins et al., 1994; Stanford et al., 2000; Fonstad, 2003).

Keener et al. (1993) enumerated more than 20 factors which affect the decomposition of organic matter in the composting process. Since the composting process is very intricate, it is not easy to estimate the effect of a single factor on the rate of organic matter decomposition. Temperature, moisture content, oxygen concentration in the airspace, and C/N ratio are generally recognized as the primary factors affecting the composting process (Haug, 1993; Keener et al., 1993; Ekinci et al., 2001; Ekinci et al., 2002). In a typical organic waste composting process these factors are controlled by varying ingredient mix ratios, aeration, turning frequency, and occasionally by moisture addition. However, it is much more difficult to control these factors in mortality composting piles, especially when bio-security constraints call for zero pile-turning.

One of the few options available to control moisture, oxygen concentration, and C/N ratio in mortality composting is by changing the type and thickness of cover and base materials. The material in these layers, supplemented by fluids hydrolyzed from the carcasses, comprise the active composting substrate during the initial stages of decomposition when the carcasses themselves are anaerobic. Microbial activity in this region significantly impacts carcass biodegradability and pathogen control. Internal temperatures, carcass degradation rates, and pathogen destruction in the early stages of composting can be improved with the use of highly biodegradable and appropriately permeable cover materials.

Moisture content affects microbial activity as well as the physical structure in the composting process, and thus has a central influence on the biodegradation of organic materials. Because it is relatively easy to measure, moisture content often serves as a proxy for other critical factors: water availability, which limits microbial activity in the low moisture range; and particle size, porosity, and permeability, all of which limit oxygen transport in the high moisture range (Miller et al., 1996; Richard et al., 2002; Richard et al., 2004). Because of its importance to the composting process, the effect of moisture content on the decomposition rate has been investigated by many researchers. Previously reported optimum moisture contents for composting range from 25 to 80% on a wet basis (w.b.), with generally recommended values in the 50 to 70% range (Bishop et al., 1983; Haug, 1993; Imbeah, 1997; Richard et al., 2002; Conjé et al., 2004). As is evident from this relatively wide range of reported values, there is no universally applicable optimum moisture content for composting materials. Each material has unique physical, chemical and biological characteristics, and these affect the relationship between moisture content and its corollary factors water availability, particle size, porosity, and permeability.

In order to consistently ensure successful mortality composting, it is important that guidelines for potential cover materials, including recommended moisture levels, facilitate rapid biodegradability in the early stages of the composting process. In this study, optimum moisture levels were estimated for thirteen potential cover materials, all widely available in Iowa: corn stalks, oat straw, silage, wood shavings, alfalfa hay, soybean straw, wheat straw, leaves-large, leaves-small, turkey litter, yard waste compost, beef manure, and sawdust.

The microbial respiration rate (oxygen uptake and CO_2 evolution) is a widely accepted indicator of the decomposition rate of organic materials (Hamelers and Richard, 2001; Richard et al., 2002; Conjé et al., 2004). Respiration rate is a function of the biodegradable material mass, its stability, and environmental conditions, such as temperature, moisture content, matrix bulk density, and air-filled porosity (Haug, 1993; Ekinci et al., 2002; Richard et al., 2002; Conjé et al., 2004). In this study, the respiration rate of each cover material was estimated as a function of moisture content at a constant temperature of 30˚C. Optimum moisture content was modeled based on measurements across a moisture range that spans the maximum respiration rates.

A number of models have been introduced to describe the effect of various factors on the decomposition rate, including moisture content, temperature, free airspace, oxygen content and C: N ratio (Murwira et al., 1990; Haug 1993; Richard and Walker, 1998; Richard et al., 1999; Ekinci et al., 2002; and Conjé et al., 2004). The models developed by the above researchers have limitations, because the data underlying the models were typically based on experiments with a specific material, and developed by considering a single factor in isolation. Since several factors interact with each other during the composting process, understanding interrelationships between factors and their effect on decomposition rate is important to improving the accuracy of the models.

Hamelers and Richard (2001) developed a mechanistic model of Oxygen Uptake Rate (OUR) based on fundamental physical properties and biological mechanisms associated with the interactions of water during the composting process. This mechanistic model of the moisture effect (Equations 1 and 2) includes the significant relationships between water potential, air-filled pore size and length, and the effective particle size. Hamelers and Richard (2001) and Richard et al. (2002) found good agreement between experimental observations and this model's results.

$$OUR_m(\theta_w) = \frac{f(\theta_w, \varepsilon_s)}{f(\theta_{w,\max}, \varepsilon_{s,\max})} \times OUR_{\max} \quad (1)$$

The moisture effect function $f(\theta_w)$ can be written:

$$f(\theta_w) = \left[\frac{1-\varepsilon_s(1+\theta_w)}{\theta_w(1-\varepsilon_s)}\right]^n \left[\frac{\theta_w}{1+\theta_w}\right]^m \quad (2)$$

Where

$OUR_m(\theta_w)$ = Maximum Oxygen uptake rate at specific water content [mol O_2 $kg^{-1}h^{-1}$]

$OUR_{\max}$ = Maximum Oxygen uptake rate in the water content range [mol O_2 $kg^{-1}h^{-1}$]

$\theta_{w,\max}$ = Volumetric water content at which the OUR_{max} occurs [m^3/m^3]

$\varepsilon_{s,\max}$ = Volumetric solids content at which the OUR_{max} occurs [m^3/m^3]

n = Exponent accounting for variable pore diameters and particle size ($0<n<1$)

m = Exponent accounting for moisture and matrix effects on oxygen transport and microbial growth (*m* is typically between 1.5 and 4 in soil matrices)

The present study investigates the characteristics of biodegradability and heat production of 13 compost-bulking materials by monitoring respiration rates at a range of moisture contents. The respiration rate results are intended to help generate guidelines for selecting and arranging composting bulking materials, as one of the few options available to manage the mortality composting process. Hamelers and Richard's (2001) mechanistic model of moisture kinetics was used to predict the optimum moisture level for each material. This modeling approach also predicted respiration rates under non-optimal moisture conditions, and can be used to develop moisture management strategies for maintaining compost and cover materials in an acceptable range.

Materials and Methods

Sample preparation

The 13 compost-bulking materials were collected from locations in central Iowa, and included: corn stalks, oat straw, silage, wood shavings, alfalfa hay, soybean straw, wheat straw, leaves-large, leaves-small, turkey litter, yard waste compost, beef manure, and sawdust. The five materials with long stems (corn stalks, oat straw, alfalfa hay, soybean straw, and wheat straw) were chopped to approximately 10 cm lengths.

Moisture content (MC) and Volatile solids (VS)

Moisture contents throughout this study were measured by drying at 105°C for approximately 24 hours, while volatile solids were measured by combustion at 550°C for 8 hours.

Water holding capacity (WHC)

A wet sample of known initial moisture content was weighed (W_I : g, wet basis) placed in a beaker. After soaking in water for 1-2 days and draining excess water overnight through Whatman #2 filter paper, the saturated sample is weighed again (W_S : g, w.b.). This nearly saturated state was used to define the water holding capacity (WHC), similar to the definition of field capacity in soils. For samples less than WHC, the percent is calculated as:

$$WHC(\%) = \frac{\{(W_S - W_I) + MC_I \times M\}}{W_S} \times 100 \qquad (3)$$

Where MC_I = Initial moisture content of sample (decimal);

M = Initial mass of the sample (g, w.b.).

Bulk density and Air-filled porosity

Bulk density was measured using an approximately 22-liter volume container. The container was filled with material, and then the material was slightly compacted to ensure absence of large void spaces. The bulk density can be calculated by dividing the weight of the material by the volume of container.

If the moisture content (MC), volatile solids (VS) and bulk density of a sample are known, the air-filled porosity values can be calculated using equation 4 instead of direct measurement (Richard et al. 2002; 2004).

$$\varepsilon_a = 1 - \rho_{wb} \cdot \left(\frac{MC}{\rho_w} + \frac{DM \cdot OM}{\rho_{om}} + \frac{DM \cdot (1 - VS)}{\rho_{ash}} \right) \qquad (4)$$

Where VS=Volatile solids (decimal)

The air-filled porosity values were calculated using the known density of water (ρ_w ; 1000kg/m^{-3}) and estimated densities of volatile solids (ρ_{vs} ;1600kgm^{-3}), and ash (ρ_{ash} ; 2500kgm^{-3}), as well as the moisture content and bulk densities of the sample (Rahman 1995; Van Ginkel et al. 1999; Richard et al. 2002; Ahn et al. 2004).

Respiration test

The microbial respiration rate was measured by a pressure sensor method (OxiTop system, Sadaka et al., 2004) at 5 different moisture levels (20, 50, 80, 90, 98% of water holding capacity). Each unit of the OxiTop system consists of a 1 liter jar, a pressure sensor – data logger head (OxiTop-C WTW, Weiheim, Germany), and a rubber capsule for NaOH pellets. As oxygen is consumed, any CO_2 produced is absorbed on the NaOH pellets, leading to a pressure drop that is directly related to the oxygen utilization. A controller (OxiTop OC 110 WTW, Weiheim, Germany) is used to collect data from the pressure sensor data loggers. Company supported Software (Achat OC, PC communication software version 2.03) is used to download the data from the controller to a spreadsheet.

Moisture adjusted samples were incubated at 30°C for 2 days in order to acclimate the microbial community prior to each test. 5-20g of sample was then placed in the jar and incubated for 2 days at 30°C. Pressure in the jar initially increases during the first hour or two, due to the difference between room and incubator temperatures. After the temperature has equilibrated in the incubator, subsequent carbon dioxide absorption by sodium hydroxide pellets creates a pressure drop measured by the sensor several times each hour. The oxygen consumption can be calculated from the pressure difference:

$$O_2 = \frac{\Delta P\,(hPa)\times 100\left(\frac{Pa}{hPa}\right)\times 1\left(\frac{\frac{N}{m^2}}{Pa}\right)\times V\,(m^3)\times 32\left(\frac{g}{mole}\right)\times 1000\left(\frac{mg}{g}\right)}{8.314\left(\frac{J}{mole.K}\right)\times 1\left(\frac{N.m}{J}\right)\times T\,(K)\times \frac{t(h)}{24\left(\frac{h}{d}\right)}\times W\,(g)\times(1-MC)\times VS_{decimal}} \tag{5}$$

Where:

O_2 = the consumed oxygen [mg/g_{vs}.d]

ΔP = the difference between the maximum and final pressure (hPa)

V = the jar volume (m^3)

T = the incubation temperature (^{o}K)

t = the incubation time (h)

Respiration Quotient (RQ)

The respiration quotient (RQ) was evaluated at 5 different moisture levels (20, 50, 80, 90, 98% of water holding capacity). 5-10g of moisture-adjusted and pre-incubated sample was placed in a 1 L volume bottle and incubated for 2 days at 30°C. Each moisture content for each sample material was incubated in triplicate. CO_2 and O_2 were measured before and after incubation using CO_2 and O_2 sensors (CO_2 sensor: Model GMT221, VAISALA, Helsinki, Finland; O_2

sensor: Handy atmosphere, Oxyguard, Birkerod, Denmark). The RQ value was evaluated from equation 6.

$$RQ = \frac{Volume\ of\ CO_2\ produced}{Volume\ of\ O_2\ consumed} = \frac{(\%CO_{2\ final} - \%CO_{2\ initial})}{(\%O_{2\ initial} - \%O_{2\ final})} \quad (6)$$

Where:

$\%CO_{2\ final}$, $\%O_{2\ final}$ = Final gas concentrations (volume basis) of CO_2 and O_2

$\%CO_{2\ initial}$, $\%O_{2\ initial}$ = Initial gas concentrations (Volume basis) of CO_2 and O_2

Software and program

The parameters *n* and *m* in the mechanistic OUR model were optimized by fitting the model to measured respiration data using the complex-Box constrained search method (Richard et al., 2002). The complex-Box constrained search parameter estimation procedure was run in Visual Basic (Microsoft Office Excel 2003, Microsoft Corp., Redmond, Washington). The model was forced to zero at the predicted saturated water content, on the premise that oxygen transport would be negligible in a large, fully saturated pile, and therefore oxygen utilization would necessarily go to zero.

Results and Discussion

Volatile solids and water holding capacity

The volatile solids and water holding capacity of all 13 compost-bulking materials are shown in table 1. The moisture content listed in the first data column of table 1 was for the material as collected, while adjusted moisture levels for the RQ and respiration rate experiments were set based on a percentage the water holding capacity in the last data column.

Table 1. General characteristics of 13 compost-bulking materials (N=3 for all tests).

Cover materials	MC[1] (w.b.,%)	VS[2] (d.b.,%)	BD[3] (kg/m^3)	WHC[4] (w.b.,%)
Corn stalks	29.2±0.8	91.5±0.4	56.9±8.5	82.4±1
Silage	74.2±0.8	93.3±0.6	342.3±5.6	80.2±0.3
Oat straw	17.3±0.6	91.8±0.1	38.1±1.9	79.3±1.4
Wood shavings	9.4±0.0	99.4±0.0	99.8±3.7	76.8±1.8
Alfalfa hay	10.0±0.1	89.7±0.1	49.8±3.1	78.9±0.4
Soybean straw	10.8±0.3	91.3±0.5	31.6±0.5	82.1±0.1
Wheat straw	9.1±0.2	91.9±0.2	22.6±0.5	82.6±0.3
Leaves-large	40.5±0.8	87.3±1.3	40.2±2.4	73.2±1.2
Leaves-small	48.1±1.7	80.6±0.8	86.7±0.9	77.1±0.6
Turkey litter	48.2±0.5	72.1±2.9	542.2±20.2	68.9±2.4
Yard waste compost	15.1±0.5	21.5±0.7	891.1±31.2	32.5±0.8
Beef manure	67.9±1.1	64.9±7.2	627.4±27.7	75.8±0.0
Sawdust	8.0±0.0	98.9±0.0	241.3±3.6	77.7±0.7

[1] Moisture content (as collected), [2] Volatile solids, [3] Bulk density, [4] Water holding capacity

Respiration Quotient (RQ)

Respiration quotient (RQ) allows the conversion of respiration rates between O_2 consumed and CO_2 produced. RQ is approximately equal to 1 under aerobic conditions (Cronjé et al., 2004; Gea et al., 2004; Smårs et al., 2001; Gea et al., 2005; Sadaka et al., 2004) and is greater than 1 under anaerobic conditions, when CO_2 is produced without consuming O_2. Several parameters have been shown to affect the RQ value, including organic composition, temperature, and state of oxidation, all of which can vary during the decomposition process (Weppen, 2001; Nakasaki et al., 1985; Nakasaki et al., 1987; Cronjé et al., 2004).

The RQ values of all materials were quite stable across most of the tested moisture levels, with the exception of extremely low moisture conditions (20% of WHC). At these low moisture levels respiration rates were also low, and values were sometimes below sensor detection limits. The net respiration rates of wood shavings and yard waste compost were low across all moisture levels, presumably because of nitrogen limitations and/or carbon availability constraints. To reduce the influence of any error caused by detection limits of sensors (CO_2:±0.02%, O_2:±0.5%), measurements with concentration differences of either CO_2 or O_2 less than 0.5% were eliminated from the analysis. The resulting RQ values of the tested compost-bulking materials are show in table 2.

Table 2. Respiration quotient (RQ) of 13 compost-bulking materials.

Cover materials	RQ	N
Corn stalks	1.2±0.2	12
Silage	1.5±0.1	12
Oat straw	1.5±0.1	12
Wood shavings	ND	-
Alfalfa hay	0.9±0.1	12
Soybean straw	1.2±0.1	12
Wheat straw	1.2±0.3	10
Leaves-large	0.9±0.1	12
Leaves-small	1.5±0.2	12
Turkey litter	0.7±0.3	10
Yard waste compost	ND	-
Beef manure	1.1±0.1	12
Sawdust	1.1±0.2	12

The mean RQ value of all materials was around 1.0 except for silage, oat straw and leaves-small, each of which had RQ values around 1.5. Higher RQ values for some materials may reflect oxygen transport limitations, resulting in anaerobic degradation within the interior of particles or aggregates, in water filled pores, and on water coated organic surfaces.

Degradation and heat production rate

Temperature is an important parameter for controlling biodegradation rate in the composting process. Its role also is essential in terms of pathogen destruction. The mortality composting pile heats up due to the aerobic degradation of cover materials, with minor energy contributions from anaerobic degradation within and at the surface of carcasses during the initial composting period. A controlled quantity of water is sometimes added to improve heat generation and biodegradation in mortality composting piles (Stanford et al., 2000). Fluids contributed by the carcasses can contribute substrate and nutrients, as well as moisture, but this will only occur in lower regions of the pile. Internal temperatures, carcass degradation rates, and pathogen destruction are all improved when the cover material itself is capable of degrading and hence producing heat. Increased understanding of the biodegradation rate and heat release capability of compost-bulking materials across a wide range of moisture levels will help in the design of the mortality composting process.

The oxygen uptake data from the respiration experiments was used to calculate the energy production from each material. Cooney et al. (1968) reported that the energy generated per gram of oxygen used by thermophilic bacteria is 14.4kJ/g O_2. Energy production rates in figures 1 through 3 result from a simple multiplication of the Cooney's value with the oxygen uptake rate.

The 13 materials are grouped into 3 sets in accordance with their respiration and energy production rates. Alfalfa hay, silage, oat straw, and turkey litter had the highest respiration and energy production rates (figure 1). Yard waste compost, sawdust, and wood shavings exhibited the lowest respiration and heat production values (figure 3), and the remaining materials were intermediate between these groups (figure 2).

Comparison of measured and modeled respiration rate

The measured (data points) and modeled (continuous line) oxygen uptake rates of 13 materials are illustrated in Figures 4 and 5. The measured oxygen uptake rates were divided by the maximum measured rate of each sample to get normalized rates. The oxygen uptake rate curves increase to a peak as moisture increases from low levels to near the optimum, and return sharply down to zero at the saturation moisture content. On the whole, the measured and modeled results match well.

The measured and modeled optimum moisture conditions for 13 materials are tabulated in Table 3. In general, the optimum moisture content shows good agreement between measured and modeled results. As in previous investigations, a wide range of optimum moisture content observed for different materials. The optimum moisture content of each material was generally quite near to its water holding capacity. This optimum ranges from near 65 to over 85% moisture (w.b.) for all materials except yard waste compost (around 30% w.b.).

Compost-bulking agent selection and moisture management strategies

Respiration and energy measurements for 13 potential cover materials highlight significant differences in their potential to produce heat and high temperatures. Based on these data, alfalfa hay, silage, oat straw, and turkey litter can be expected to improve internal temperatures and pathogen destruction rates, which is especially important for disease-related mortality composting. The rest of materials can be used as moisture amendments and bulking agents in general purpose composting or mortality composting where pathogen destruction is less critical. The yard waste compost tested in this study was not a good moisture amendment because of its low WHC, and was not a good bulking agent because of its small particle size and high bulk density. Yard waste composts vary widely, and some such composts might perform well, but based on these results a well stabilized, fine, or soil-like compost should be viewed cautiously.

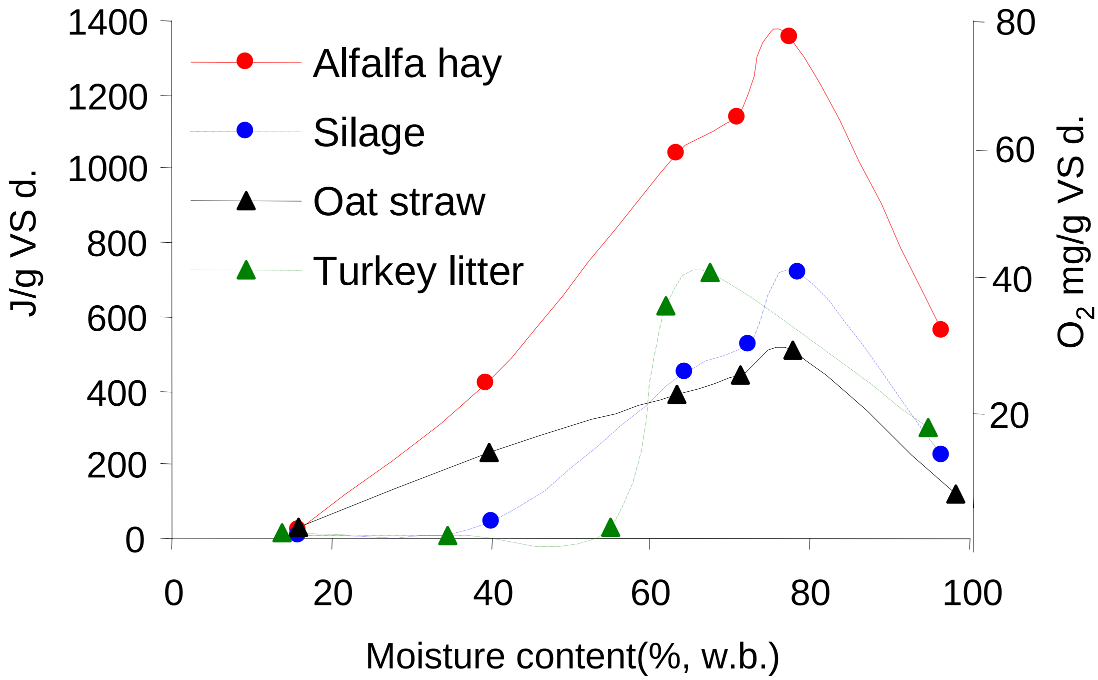

Figure 1. Energy production and oxygen uptake rate vs moisture content for the most rapidly degrading cover materials in this study: alfalfa hay, silage, oat straw, and turkey litter.

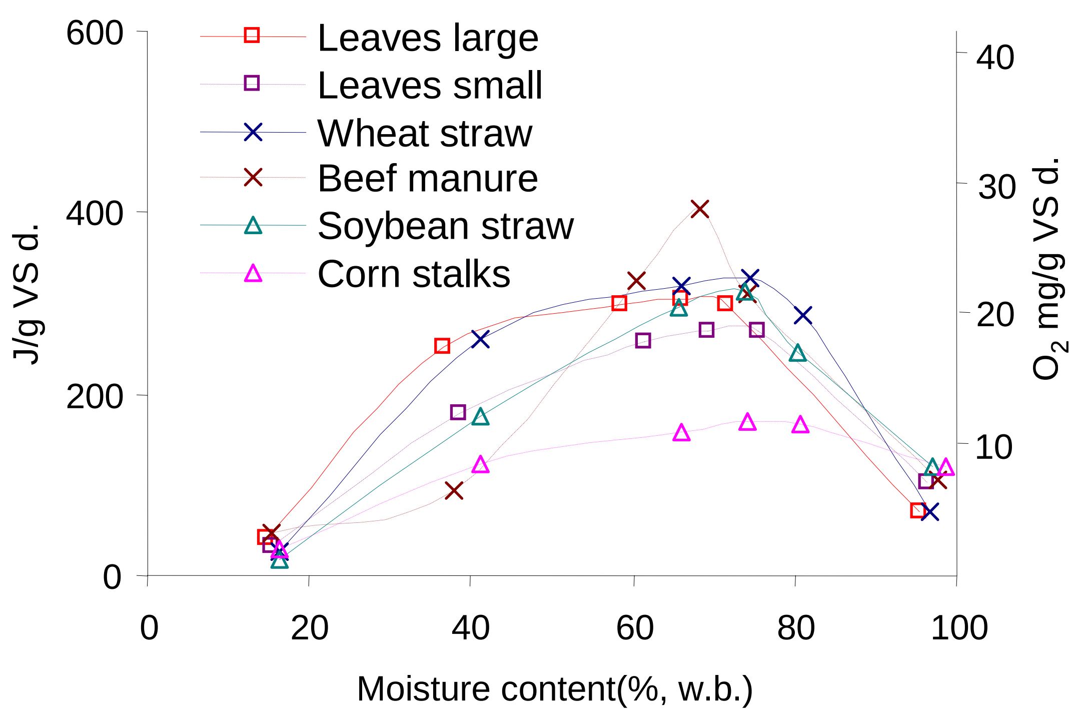

Figure 2. Energy production and oxygen uptake rate vs moisture content for leaves (large and small), wheat straw, beef manure, soybean straw, and corn stalks.

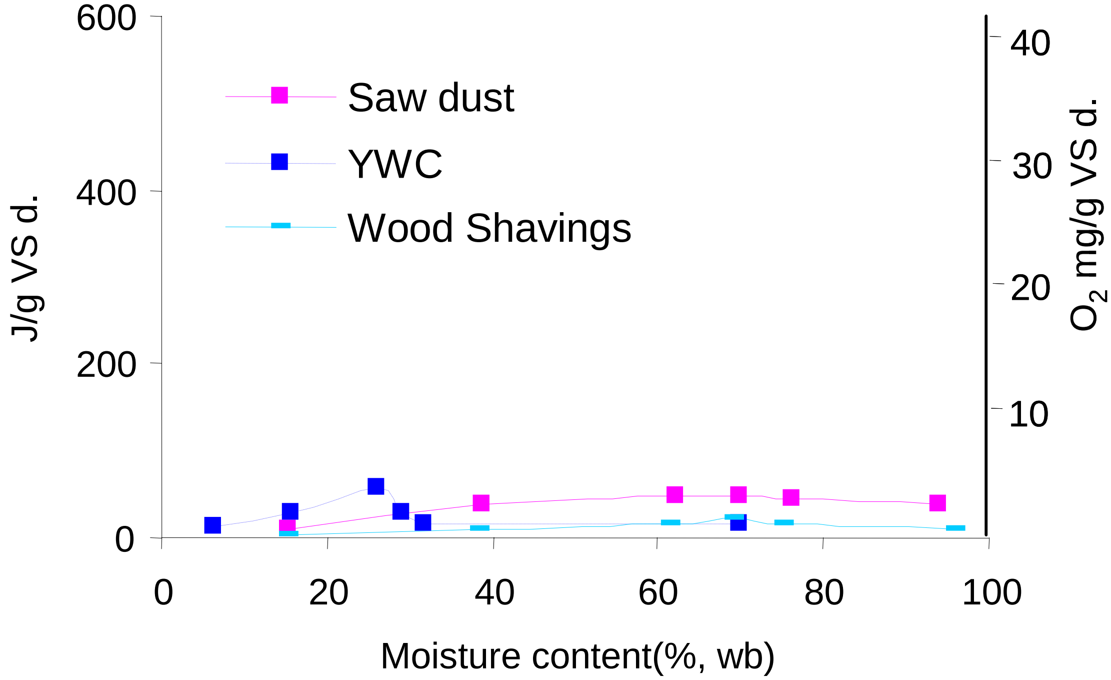

Figure 3. Energy production and oxygen uptake rate vs moisture content for the least rapidly degrading materials in this study: sawdust, yard waste compost (YWC) and wood shavings.

The optimum moisture content of each material was observed near its water holding capacity (WHC). Artificially adjusting moisture content to values just below WHC will improve biodegradation and energy production rate in the initial composting period. However, adding such water directly to a completed mortality composting pile is not a good strategy because adsorption is not instantaneous or homogeneous, and the leachate generated may facilitate pathogen transport. Instead, water should be incorporated prior to building the pile, and some bulking material should be kept dry for the lower center of the pile. Amendments placed directly beneath a carcass will need additional reserves of WHC to absorb fluids as the carcass hydrolyses and begins to decompose. These fluids must be absorbed within the pile to prevent pathogen transport into runoff or soil. High moisture material in the bottom of a pile is likely to become compacted under significant compressive force, with both overburden and carcass weight contributing to increased bulk density, reduced porosity and reduced permeability. All these factors can encourage anaerobic conditions, odors, and leachate contamination.

There is plenty of time to adjust moisture content at general composting operations prior to pile construction. The case is somewhat different for mortality composting in an emergency situation, as then the operator only has one day to moisten and prepare materials, since the dead animal need to be disposed within 24 hours of death by law (IAC, 2002).

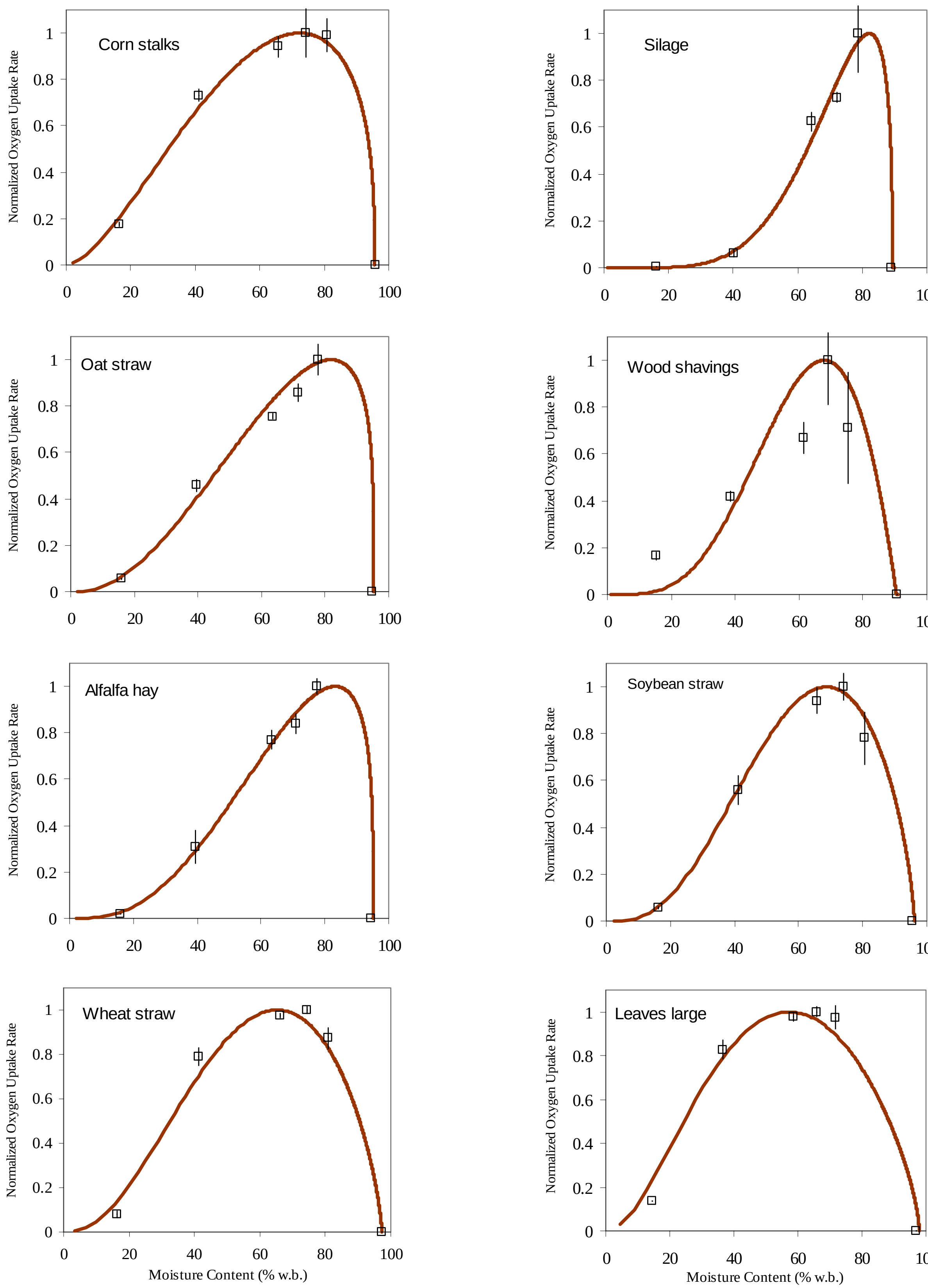

Figure 4. Measured and modeled normalized oxygen uptake rates as functions of moisture.

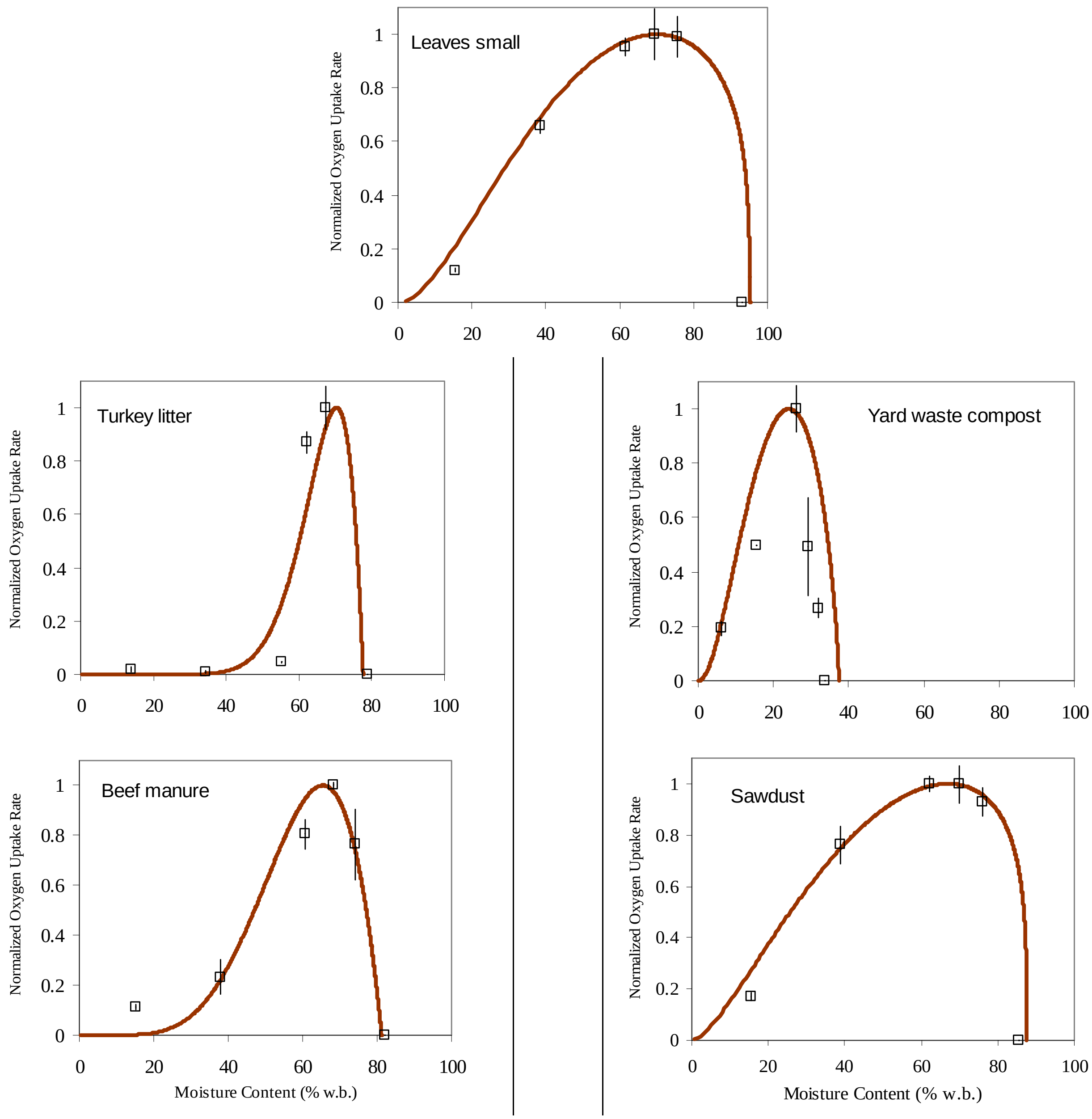

Figure 5. Measured and modeled normalized oxygen uptake rates as functions of moisture. Measured data is presented as means and standard deviations in box plots, with the model fit to the data is presented as a solid line.

Table 3. Measured and modeled optimum moisture conditions

	Measured				Modeled						
	$\varepsilon_{a,\max}$ (%)	$\theta_{w,\max}$ (%)	$\varepsilon_{s,\max}$ (%)	MC(%)	n	m	$\varepsilon_{a,\max}$ (%)	$\theta_{w,\max}$ (%)	$\varepsilon_{s,\max}$ (%)	MC(%)	r^2
Corn stalks	85.1	4.75	2.6	74	0.350	2.10	85.5	4.29	2.8	85	0.99
Silage	50.0	6.02	7.1	79	0.371	7.12	42.1	7.37	6.9	82	0.99
Oat straw	78.8	5.75	3.2	78	0.256	2.81	75.2	7.46	2.9	82	0.98
Wood shavings	65.1	4.86	5.9	75	0.999*	5.58	73.0	3.36	6.2	68	0.88
Alfalfa hay	76.7	5.69	3.5	77	0.295	3.70	72.6	8.2	3.0	83	0.99
Soybean straw	78.0	6.82	2.8	81	0.807	4.29	89.3	3.8	2.2	69	0.99
Wheat straw	90.2	4.79	1.7	74	0.758	3.32	93.3	3.16	1.6	65	0.99
Leaves-large	90.5	4.25	1.8	72	0.811	2.94	96.1	2.56	1.1	58	0.99
Leaves-small	73.7	5.3	4.2	76	0.375	2.38	86.2	4.51	2.5	70	0.99
Turkey litter	37.9	3.69	13.2	68	0.999*	15.89	27.1	4.36	13.6	70	0.91
Yard waste compost	46.6	0.78	29.9	26	0.764	3.00	32.6	0.72	39.1	24	0.99
Beef manure	43.9	3.93	11.4	68	0.999*	7.94	49.9	3.46	11.2	65	0.98
Saw dust	40.8	5.11	9.7	76	0.295	1.90	66.5	3.4	7.6	67	0.99

Curve fit constrained by parameter at theoretical upper limit for n.

Conclusions

Several conclusions can be drawn from this investigation of the biodegradability of 13 mortality compost cover materials. While not a comprehensive assessment of the full range of bulking amendments, the study did assess a diverse set of the most common carbon amendments available in much of the US.

Measuring the respiration quotient (RQ) and oxygen uptake rates provided important insight on the effects of moisture content on respiration and heat production rates. The experimentally determined RQ values were consistent across a range of moisture contents, with the exception of extremely low moisture conditions where respiration rates were low and sensor detection limits were encountered. The RQ values of all materials were around 1.0 except for silage, oat straw and leaves, which had RQ values about 1.5. It was not possible with our apparatus and instruments to reliably measure RQ for materials containing small amounts of biodegradable materials (wood shavings and yard waste compost) or at extremely low moisture conditions (20% of WHC).

The respiration rates measured by the OxiTop pressure sensor method varied across the range of moisture content tested, with low values at low moisture levels and peak values near the measured water holding capacity of the material. These results were converted to heat generation rates based on Cooney et al.'s (1968) conversion factor. The highest values were observed for alfalfa hay, silage, oat straw, and turkey litter in descending order. These appear to be excellent compost-bulking materials to improve internal temperature and pathogen destruction rates for disease-related mortality composting. Most of the remaining materials can be used as carbon amendments and bulking agents in general composting or composting of non-contagious mortalities, although they may be less likely to achieve pathogen time-temperature goals. Yard waste compost requires careful use because of its poor physical (small particle size, high bulk density, low WHC) and biological (biodegradability) characteristics. Sawdust and wood shavings had even lower respiration rates than our stabilized yard waste compost across much of the moisture range, but should not be discounted as amendments. Although their respiration rates are low as a pure material, this is widely recognized as a function of their high C:N ratio and lignin content. Supplemental nitrogen from manure or degrading carcasses can address the nutrient limitation, and stimulate higher decomposition rates. Woody materials also have a great deal of structural strength, and their ability to maintain porosity and permeability under conditions of high moisture and compressive stress is an important benefit (Richard and Kim, 2003). Data on the mechanical strength, porosity and permeability of all 13 cover materials is currently being analyzed.

The optimum moisture content was modeled with a mechanistic function that considers pore and particle characteristics, air-filled porosity, and matrix water potential.. There was good agreement between experimental observations and modeled optimum moisture content. The optimum moisture content of each material occurred near its measured water holding capacity (WHC), which ranged from near 65 to over 85% (w.b.) for all materials except yard waste compost. For the highly stabilized and high ash content yard waste compost tested in this study, WHC and optimum moisture were both around 30% (w.b.).

This study demonstrates the importance of moisture content on the biodegradability of organic materials and predicts optimum moisture content and respiration rates for each material across a wide moisture range. The results will be useful to develop moisture management strategies and process designs for maintaining compost and cover materials in an acceptable range.

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