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Chemical and Physical Properties of Processed Newspaper Compared to Wheat Straw and Wood Shavings as Animal Bedding¹

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ABSTRACT

Because of continuing concerns about the safety and the suitability of recycled newspaper as an animal bedding material, municipal curbside-collected newspaper was processed into chopped and pelleted forms for comparison studies with wheat straw and kiln-dried pine-wood shavings. Measurements included nutrient, heavy metal, dioxin and furan content, particle size distribution, density, combustion potential, and water-holding capacity. Recycled newspaper, straw, and wood shavings tested below or equivalent to National Research Council dietary tolerance levels and US Environmental Protection Agency toxic equivalent levels. Small particle size distribution was shavings > straw > all forms of newspaper. The density of pelleted newspaper was 50-fold greater than that of chopped newspaper and straw and 15-fold greater than shavings. In simulated flash burns, chopped newspaper, straw, and shavings ignited, and flames spread rapidly in newspaper and shavings and lasted the longest in shavings. Pelleted newspaper did not ignite. Chopped and pelleted forms of newspaper and wood shavings had higher water holding capacities (>400%) than did straw (200%). Animal industries can, in confidence, utilize recycled newspaper as an animal bedding material, providing that sources of low toxicity are identified, and suitable processed forms are produced.

(Key words: pelleted recycled newspaper, animal bedding materials, wheat straw, wood shavings)

Abbreviation key: ICPMS = inductively coupled plasma mass spectrometry, NIST = National Institute

of Standards and Technology, PCDD = polychlorinated dibenzo-p-dioxin, PCDF = polychlorinated dibenzo furan, PN = pelleted newspaper, RN = recycled newspaper, S = wheat straw, TEF = toxic equivalent factor, TEQ = toxic equivalent, WHC = water-holding capacity, WS = wood shavings.

INTRODUCTION

Traditionally, animal bedding materials have been inexpensive by-products of local cereal grain and lumber production. A combination of popular press and cooperative extension publications have encouraged the use of waste paper, primarily recycled newspaper (RN) as an animal bedding alternative, particularly for dairy cattle and poultry (18, 23). The recycling industry views the use of RN by animal industries as a viable economic alternative when recycled paper markets are weak.

Documentation by cooperative extension and peer-reviewed research addressed specific concerns regarding how traditional materials such as straws, wood products, and sand compared to newspaper in terms of heavy metal content (6, 23), absorption capacity (3, 8), and some nutrient constituents (12, 17). Perceptions and concerns still persist regarding the management and safety of RN when used for animal bedding (11, 18), although no single or collective research effort has concluded the contrary.

Although large and small animal industries have used various forms of paper bedding, a variety of animal management complaints have been expressed over the use of shredded and chopped paper (2). Some of the objections include caking when wet; clogging of gutters and equipment; littering of facilities; high dust production when processed, and risk of fire when processed or stored.

Historically, petrochemical carriers for ink production along with high metal content pigments contributed greatly to the toxicity of printed paper products (6, 23). Although vegetable oil ink carriers have been substituted for petrochemical carriers, the effects of

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long-term metal, and dioxin and furan loading remains a concern after wastes have been land applied (4). The FDA still does not sanction the use of RN or other waste paper, pending assurances that no harmful residues will be detectable in milk and meat products if bedding materials are eaten (12).

No peer-reviewed data compare the combustion potential of newspaper bedding material products to traditional materials. A complete evaluation of the chemical and physical properties of RN is required before recommendations can be made for the use of newspaper and other waste paper for agriculture.

This study provides an evaluation of the chemical and physical properties of RN in chopped and pelleted (PN) forms in comparison to wheat straw (S) and kiln-dried, pinewood shavings (WS). Properties measured included: nutrient, heavy metal, dioxin and furan content; density, particle size distribution, combustion potential, and water-holding capacity (WHC).

MATERIALS AND METHODS

Source, Preparation, and Sampling of Materials

Three types of bedding materials were procured for this study and for future in vivo studies. Materials consisted of: 1) straw produced from Dynasty Seed Wheat (Hoffmann Seed Co., Milan, OH) cut at the boot stage and harvested as square bales (200 count), average weight 15.5 kg (Brook Hollow Farm, Sergeantsville, NJ), 2) kiln-dried pine WS in 0.92-m³ bags (225 count), average weight, 11.5 kg (Emerald Peak Wood, Kingston, ON, Canada), and 3) municipally collected, bundled curbside RN (12.7 metric tonnes) provided through the courtesy of Hunterdon County Utilities Authority, Division of Solid Waste and Recycling, Flemington, New Jersey. Contaminants in the RN were estimated as: <2% nonnewsprint materials, e.g., magazine, cardboard, and mail stock, or <5% moisture due to weather exposure (by personal communication with Alan Johnson February, 1996, describing the contamination by moisture and foreign materials of RN collected by Hunterdon County, NJ, Office of Solid Waste Recycling).

The RN was further processed into chopped bits averaging 2.54 cm² with a bale chopper (Goossen Industries, Beatrice, NE), and three PN forms measuring 2.54 cm long with diameters of 0.32, 0.64, 1.27 cm, respectively (Andritz Sprout-Bauer, Muncy, PA).

Pooled samples were produced for each type of clean bedding material by collecting core samples randomly from 15% of the entire stock of each material procured. Sampling method and preparation differed for specific analyses. Sampling and preparation for nutrient, dioxin, and furan analyses consisted of: 1) baled S coring by Penn State forage sampler and ground through a

Wiley mill (1-mm screen, A. H. Thomas, Philadelphia, PA); 2) bagged WS grab sample and ground through a Wiley mill; 3) curbside RN grab sample after processing through a hammer mill (2 mm screen) prior to pelleting.

The treatment of samples prepared for heavy metal analysis changed slightly, although the collection process remained the same. Because of the sensitivity ng/kg of the analytical methods used in quantifying trace metals, metal contamination by grinding equipment was unavoidable. Therefore, newspaper materials were processed as previously described because they would otherwise be exposed to steel processing equipment. However, S and WS would be used directly as delivered and not further processed through steel component equipment such as a grinder, so S and WS were ground in a marble mortar and pestle before acid digestion to avoid any uncharacteristic metal concentrations.

Measurements of density, combustion potential, particle size distribution, and WHC required that samples of each material be intact and reflect their intended use as a bedding material. Thus, grab samples were taken from bales of S, WS, chopped RN, and pelleted forms of RN, and analyses were performed directly on pooled samples.

Nutrient Analyses

Pooled samples of bedding materials (hammer-milled RN, ground S, and WS) were assayed for moisture by oven drying at 100°C (1); CP by the Kjeldahl procedure (1); C and N by Carlo Erba NA-1500 analysis (26); ether extract by Soxhlet methods (1); ADF, NDF, cellulose, hemicellulose, and lignin by Fibertec I (Tecator, Herndon, VA) (22), total ash by ignition at 550°C in a muffle furnace for 8 h (1); Ca, Mg, Fe, and Mn by atomic absorption (16); P by Harris and Popat (7); and Si by methods of Goering and Van Soest (5). Bedding materials were acid and microwave oven digested, and Cu and Zn were measured by inductively coupled plasma mass spectrometry (ICPMS), according to the procedures performed for heavy metal analysis described below.

Heavy Metal Analyses

Cadmium, Cr, and Pb were measured by a modification of procedures described by Wu et al. (28). One-tenth gram samples of each bedding material (ground RN, S, and WS), and each of two National Institute of Standards and Technology (NIST) standard reference materials (No. 1575 Pine Needles and No. 1573 Tomato Leaves) were assayed in replicates. Two-milliliter high purity, concentrated HNO₃ were added to the samples and cold digested for 24 h, after which 100- μ l of high-purity HF was added to each sample. Samples were

further digested in closed vessels with an MDS 2000 microwave oven equipped with pressure sensor (600 psi maximum pressure, 0 to 60 watts \pm 50 in 1% increments, 2450 MHz at full power, CEM Corp., Matthews, NC) set at 80% power for 30 min with maximum pressure of 100 psi. After cooling, samples were diluted with 10 ml of 3% HNO₃ trace metal grade water and stored in high-density polyethylene plastic bottles (Nalgene, Sybron Corp., Rochester, NY). Prior to analysis, samples were diluted further (100- μ l sample in 900 μ l of 3% HNO₃), and each standardized at 4 mg/kg of Ga, In, Sc, and Tl drift monitor, to be measured within instrument sensitivity parameters. A Finnigan, MAT (ELEMENT, Bremen, Germany) ICPMS was used to measure Cd, Cr, Pb, Cu, and Zn. Mercury was digested by the cold vapor technique, then measured by Fisher Mercury Analyzer IV atomic absorption (24). Blind duplicates, NIST, and industrial standards were used for confirmation. Recoveries of Zn in standard reference materials ranged from 71 to 100%. The average of recovery of all other elements was 90.2% \pm individual element standard deviation (27).

Dioxin and Furan Analyses

Dioxin and furan analyses were performed by Triangle Laboratories (RTP, Inc., Durham, NC). Samples were prepared by Environmental Protection Agency method 8290 (Rev. 12/92 LLW-7). All samples were fortified with 2 ng of the tetra- through heptachlorinated internal surrogate and alternate standards and 4 ng of the octachlorinated dibenzodioxin internal standard. High-resolution gas chromatography and mass spectrometry were used to measure 17 2,3,7,8-substituted polychlorinated-para-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF). International toxic equivalent factors (TEF) were calculated (10) and reported as toxic equivalent concentrations (TEQ) for detectable dioxins and furans. Spiked standards and blind duplicates were used to validate methods.

Physical Properties

Geometric mean particle size distribution was measured by dry sieving 200 g of unprocessed bedding samples and reported as percent retained on four 21.5-cm diameter mesh screens with 5-, 3-, 2-, and 1-mm diameter openings, respectively, and as percent that passed. Samples that weighed 200 g were placed on the top (5 mm) of the stacked screens and were shaken five times in two directions along a 70-cm long grid distance in even strokes. Bedding retained by each screen was weighed, and the percentage of particle distribution was calculated.

Density (kg/m³) of each bedding material was measured as compressed bulk (simulating storage) and loose (as distributed bedding in a 9.3-m² stall). Compressed bulk measurements were taken by measuring a randomly sampled unit (n = 12) of each material (S = bales, WS = bag, RN = bundles, PN = box) for its length, width, height, and weight. Measurements for each type of material were calculated as kilograms per cubic meter and averaged. Weights of loose material were recorded (n = 12/type), then measured for length, width, and depth, calculated as kilograms per cubic meter, and averaged per material type.

Each loose form of bedding material (0.32-, 0.64-, and 1.27-cm RN pellets; chopped RN, S, and WS) was assessed for combustion potential with two types of ignition: 1) representing an ash or smoldering burn (by lighted cigarette), and 2) representing an intense flash burn (by methenamine pill). Duration(s) and timed migration or extent (cm/s) of flame were measured by American Society for Testing Materials methods 16 CFR part 1630, FF 1-70 (SGS U.S. Testing Co., Inc., Fairfield, NJ). Blind duplicates and industrial standards were used as controls.

Methods used to measure WHC reflected two possible bedding conditions and were modified from methods used by Colucci et al. (3): 1) hypersaturation by dousing or submersion in deionized H₂O, 2) contact with but nonsubmerged in dH₂O for capillary redistribution. Hypersaturation by submersion was tested by placing 20 g of bedding material into a 2-L container; 400 ml of dH₂O was added to insure that all bedding material was covered. Each material was submerged in dH₂O for 1, 5, 15, and 30 min and 1, 24, and 48 h. Materials were then drained of dH₂O and reweighed to measure WHC with the formula: gain in weight \div original weight \times 100 = %.

Nonsubmerged absorption was similarly assessed; however, only 10 g of bedding was exposed to 100 ml of dH₂O, for 1, 2, 4, 8, 12, 24, and 48 h. No attempt was made to submerge the bedding materials below water. Materials were drained of dH₂O and immediately reweighed to measure WHC as described.

Statistical Analyses

ANOVA (20) was performed with three models to assess the effects on WHC: model 1) type of loose bedding (S, WS, chopped RN, PN measuring 2.54 cm \times 0.32, 0.64, 1.27 cm), time (1, 5, 15, 30 min and 1, 24, and 48 h) and type \times time interaction for WHC measured on submerged samples; model 2) type of loose bedding, time (1, 2, 4, 8, 12, 24, 48 h), type \times time interaction for WHC measured on nonsubmerged samples; model 3) method of measuring WHC (submerged or nonsub-

Table 1. Moisture, pH, nutrient, and heavy metal toxicant content of recycled newspaper (RN)¹, wheat straw (S)² and wood shavings (WS)³.

	RN	S	WS
Moisture as received, %	2.7	7.0	5.7
pH	6.4	5.9	3.9
DM, %			
Crude protein	1.4	8.6	0.7
Ether extract	1.9	2.4	3.4
Neutral detergent fiber	92.1	64.9	90.5
Acid detergent fiber	77.6	41.4	79.8
Hemicellulose	14.5	23.6	10.7
Cellulose	54.3	34.8	49.5
Lignin	23.7	5.6	29.0
Ash	3.4	5.6	0.5
C	44.1	42.2	46.9
Ca	0.15	0.36	0.06
Mg	0.02	0.21	0.02
N	0.11	1.61	0.09
P	0.03	0.24	0.01
Si	2.09	1.80	0.40
Fe	0.01	0.01	0.01
Mn	ND ⁴	0.01	0.01
Cu	<0.01	<0.01	<0.01
Zn	<0.01	<0.01	<0.01
Toxicant metals, mg/kg			
Cd	0.12	0.01	0.16
Cr	4.35	0.72	1.78
Hg	ND ⁵	ND	ND
Pb	0.89	0.13	0.17

¹Curbside collection from Hunterdon County Utilities Authority, Division of Solid Waste and Recycling, Flemington, NJ.

²Dynasty Seed Wheat (Hoffmann Seed Co., Milan, OH) cut in boot stage and harvested as straw in square bales (average weight 15.5 kg), Brook Hollow Farm, Sergeantsville, NJ.

³Kiln-dried in bags, Emerald Peak Wood Co., Kingston, ON, Canada.

⁴Nondetectable concentrations.

⁵All pelleted newspaper materials had ND Hg, however, curbside RN (unprocessed) contained 0.068 mg/kg of Hg.

merged), type of loose bedding, type × method, time (1, 24, 48 h) × method, and type × time × method interactions.

RESULTS AND DISCUSSION

Nutrient Composition

At acquisition, all forms of bedding materials contained 3 to 7% moisture (Table 1). The pH of materials varied; S and RN had a higher pH, 5.9 and 6.4, respectively, than WS, which was more acidic, pH 3.9. Moisture and pH content can influence microbial presence and growth in bedding materials (9).

Wheat straw contained more CP and N than RN or WS (Table 1). If field-spread, clean S would return 14 to 18 times more N to soil than clean RN or WS. The clean S harvested at the boot stage had a C:N of 26:1, ideal (30:1) for microbial support (9, 19, 21). Because of high C and low N contents, the C:N in clean WS

(519:1) and PN (414:1) provide a poor growth medium for microorganisms when land applied without additional nitrogen sources. Ether extractables were present in all materials (Table 1). The amounts were attributable to the presence of waxes in S, resins and tars in WS, and ink carrier in RN. Both WS and RN contained 38% more NDF than S due to a higher cellulose and lignin content (Table 1).

Recycled newspaper contained either nondetectable or low quantities of macro and micro minerals in comparison to S and WS (Table 1). Silica comprised 61% of the total ash in RN. Samples of New Jersey municipally collected RN representing the New York to Philadelphia corridor, contained 10 mg/kg of Cu and 14 mg/kg of Zn, or <0.01% Cu and Zn quantified by ICPMS technique. Earlier studies in the United States by Temple (23) in 1989 and by Richard (18) in 1991, reported newspaper containing 2 and 14 mg/kg of Cu and 9 and 14 mg/kg of Zn, respectively. O'Connell and Meaney (14) reported 2 and 12 mg/kg for Cu and Zn, respectively, in Ireland by acid digestion and ICPMS analysis.

Toxicity: Metals

Recycled newspaper, S, and WS contained detectable levels of Cd, Cr, and Pb (Table 1). Cadmium and Pb were present at <1 mg/kg, the highest level was Pb in RN. Concentrations of Cr were higher than Cd and Pb being 4, 2, and 1 mg/kg in RN, WS, and S, respectively. These data agree with previous reports (13, 14, 18).

Temple (23) and Richard (18) evaluated and compared black and white newsprint (Cd 0.17, Cr 0.66, Pb 3.6 mg/kg; Cd 1.5, Cr 0.9, and Pb 1.1 mg/kg, respectively) to a number of paper and agricultural substances, including sawdust (Cd 0.8, Cr 4, and Pb 12 mg/kg). No detection limit was provided in either earlier study. O'Connell and Meaney (14) evaluated newspaper, and found Cd = nondetectable, Cr = 1.4 mg/kg, and Pb = 0.5 mg/kg. Detection limits and the reported values differed between the analytical methods used here and the O'Connell study (ng/kg vs. mg/kg-μg/kg sensitivity, respectively). Differences could be due to either sensitivity in detection equipment, contamination in digestion procedures, or more probably, differences in newspaper stock. The sawdust evaluated by Richard was not as clearly characterized as WS in this study. Differences could be attributable to detection methods or more likely the difference between nonspecified woods in sawdust and kiln-dried pine WS.

Concentrations of Hg in S, WS, and all PN products were <0.0002 mg/kg, the detectable limit; the exception was RN, which contained 0.068 mg/kg of Hg. Recycled newspaper likely differed from PN products because

heat generated during the pelleting process vaporized the Hg present in RN.

Maximum tolerance of dietary Cd, Cr, Pb, and Hg for domestic animals including horses, cattle, poultry, swine, rabbit, and sheep recommended by NRC (13) are 0.5, 1000, 30, and 2 mg/kg, respectively. Thus, the traditional bedding materials and the paper products evaluated in this study would be safe if they were consumed incidentally or otherwise. Eventual land application of clean RN, S, and WS would also not be a concern (25). Currently, EPA guidelines for sewage sludge application are 39, <1200, 57, and 300 mg/kg, respectively dry weight monthly average concentration for Cd, Cr, Hg, and Pb.

Toxicity: Dioxin and Furan

The only dioxin or dibenzofuran congener detected in RN was 2, 3, 7, 8 tetrachlorodibenzofuran at 3.7 ppt (Table 2). Other chlorinated dioxins and furans were present at very low concentrations in S and WS. Congeners (chlorinated, 2-ringed, planar benzene molecules joined by 2 O atoms PCDD, or a C-O-C and C-C bond PCDF; congeners can have the same number of chlorine atoms placed in different positions or may have differing numbers of chlorine atoms) were present in WS: 1, 2, 3, 4, 6, 7, 8 HpCDD (9.0 ng/kg), 1, 2, 3, 4, 6, 7, 8, 9-OCDD (67.2 ng/kg), 1, 2, 3, 4, 7, 8 HxCDF (2.5 ng/kg), 1, 2, 3, 4, 6, 7, 8-HpCDF (3.6 ng/kg), 1, 2, 3, 4, 6, 7, 8, 9, OCDF (6.1 ng/kg) and S: 2, 3, 7, 8-TCDD (0.57 mg/kg), 1, 2, 3, 4, 6, 7, 8 HpCDD (0.99 ng/kg), 1, 2, 3, 4, 6, 7, 8, 9-OCDD (5.7 ng/kg), 1, 2, 3, 4, 6, 7, 8, 9-OCDF (4.9 ng/kg).

Dioxin and furan compounds are carcinogenic, particularly 2-3-7-8 tetrachlorodibenzofuran, and bioaccumulate in the food chain. In addition to their accidental occurrence caused by combustion processes, these polychlorinated dioxins and furans are otherwise ubiquitous in the environment and naturally occurring at ultratrace levels (10). Since the materials evaluated are eventually land applied and no standards have been set for their dioxin and furan content, values were compared to those set for sewage sludge. The TEQ reported fall far below international averages for unrestricted use (<5 ng/kg). Although dioxins and furans are a concern, all TEQ levels of materials tested in this study were consistent with established background concentrations (<1 ng/kg) (Table 2). Recycled newspaper contained fewer detected concentrations of individual PCDD and PCDF congeners compared to S or WS, and total TEQ of RN were comparable to S and WS (S < RN < WS) (Table 2). If used bedding materials are to be land applied, allowed tonnage for land application will not be affected by the PCDD and PCDF according to

current recommendations (Centers for Disease Control guidance value for residential use: 1 ng/kg TEQ land applied) (15).

Particle Size Distribution

Wood shavings contained the largest distribution of small particles with 15% passing 3- and 2-mm screen openings, and 6% as fines passing the 1-mm screen (Table 3). The next highest amount of fines was present in S, probably because of chaff. Pelleted newspaper had >99% of volume retained by the 5- or 3-mm screen. A significant percentage (11.3%) of PN measuring 0.32 cm in diameter passed the 5-mm screen opening but was retained by the 3-mm screen. This high rate of passage could be because the 0.32-cm pellet was inherently narrow and not fully retained by the 5-mm screen. Amounts of fines in PN decreased as pellet diameter increased (Table 3). Particles of PN, S, and WS passing a 1-mm screen are of concern as fines measuring <10 μm and particularly <2.5 μm have been reported to irritate and even cause hyperreactive airway disease conditions in both humans and horses (2). It is even more important to avoid bedding materials that contain large amounts of fines when ventilation or fresh air exchange is restricted.

Density

Square bales of S and compressed bags of WS had similar bulk storage densities (Table 3), 100 kg of DM/ m^3 . Bundled curbside RN, the bulk storage form of chopped RN, was similar in density to PN. All bulk storage forms of RN, bundled or pelleted, were 3.5 to 5.5 times as dense as bulk storage forms of S and WS. Variations in densities were even greater in loose forms of bedding materials. Wheat straw and chopped newspaper were 30 and 2% as dense as WS and PN, respectively.

Costs associated with transportation and storage would be lower for a denser material. Usage of a material as animal bedding would also depend on the material's density. To determine their functional value as bedding, loose materials must be compared in usage studies, where the initial volume plus additions with use over time are measured.

Combustion Potential

No loose bedding materials of any type ignited when tested by lighted cigarette. This test simulated a slow, smoldering burn by ASTM methods (eight replicates per material investigated). That nothing ignited should not be interpreted to mean that the careless use of a

Table 2. Polychlorinated dibenzo-p-dioxin (PCDD) and polychlorinated dibenzofuran (PCDF)¹ content (ng/kg) of recycled newspaper (RN)², wheat straw (S)³ and wood shavings (WS)⁴.

Congener ⁵ , ng/kg	RN	(DL) ⁶	S	(DL)	WS	(DL)	International TEF ⁷
2,3,7,8-TCDD	ND ⁸	(0.7)	ND	(0.6)	ND	(0.8)	1.0
1,2,3,7,8-PeCDD	ND	(2.5)	ND	(1.1)	ND	(2.0)	0.5
1,2,3,4,7,8-HxCDD	ND	(5.2)	ND	(1.6)	ND	(1.8)	0.1
1,2,3,6,7,8-HxCDD	ND	(5.1)	ND	(1.3)	ND	(1.5)	0.1
1,2,3,7,8,9-HxCDD	ND	(4.8)	ND	(1.4)	ND	(1.6)	0.1
1,2,3,4,6,7,8-HpCDD	ND	(7.3)	1.0		9.0		0.01
1,2,3,4,6,7,8,9-OCDD	ND	(9.1)	5.7		67.0		0.001
2,3,7,8-TCDF	3.7		ND	(0.6)	ND	(0.9)	0.1
1,2,3,7,8-PeCDF	ND	(1.5)	ND	(0.6)	ND	(1.5)	0.5
2,3,4,7,8-PeCDF	ND	(1.4)	ND	(0.6)	ND	(1.4)	0.05
1,2,3,4,7,8-HxCDF	ND	(4.0)	0.8		2.5		0.1
1,2,3,6,7,8-HxCDF	ND	(2.9)	ND	(0.6)	ND	(0.9)	0.1
2,3,4,6,7,8-HxCDF	ND	(3.6)	ND	(0.7)	ND	(1.1)	0.1
1,2,3,7,8,9-HxCDF	ND	(3.9)	ND	(0.8)	ND	(1.2)	0.1
1,2,3,4,6,7,8-HpCDF	ND	(3.5)	1.4		3.6		0.01
1,2,3,4,7,8,9-HpCDF	ND	(5.0)	ND	(1.1)	ND	(1.5)	0.01
1,2,3,4,6,7,8,9-OCDF	ND	(7.2)	4.9		6.1		0.001
TEQ (detectable) ⁹ , ng/kg	0.37		0.12		0.45		
TEQ (1/2 DL), ng/kg	0.19		0.06		0.23		

¹PCDD, PCDF testing performed by Triangle Laboratories, Inc., Durham, NC.

²Curbside collection from Hunterdon County Utilities Authority, Division of Solid Waste and Recycling, Flemington, NJ.

³Dynasty Seed Wheat (Hoffmann Seed Co., Milan, OH) cut in boot stage and harvested as straw in square bales (average weight 15.5 kg), Brook Hollow Farm, Sergeantsville, NJ.

⁴Kiln-dried in bags, Emerald Peak Wood Co., Kington, ON, Canada.

⁵Congener - following compounds of chlorinated, 2 ringed, planar, benzene molecules joined by 2 oxygen atoms PCDD, or a C-O-C and C-C bond PCDF. The following congeners range from 4 through 8 carbon positions occupied. Congeners can have the same number of chlorine atoms placed in different positions, or may have differing numbers of chlorine atoms.

⁶Detectable limit.

⁷International toxic equivalent factor, NATO/CCMS 1-TEF system.

⁸Nondetectable concentrations.

⁹Toxic equivalent (TEQ): = concentration (ng/kg) × toxic equivalent factor.

lighted cigarette would never result in ignition of loose bedding materials. There are far too many reports where loss of property and life has occurred in such circumstances.

Ignition by methenamine pill simulated a flash burn by intense heat and resulted in flame propagation in S, WS, and chopped newspaper, but not in PN products (Table 3). Once ignited, flames spread rapidly in chopped newspaper and WS compared to S. The flame lasted twice as long in WS.

Fire in agricultural production systems is of great concern and a constant threat. The amount of fire damage incurred depends on the quickness with which flames spread and their duration. Chopped paper, although popular for its price, availability, and ease of on-site preparation, is highly flammable and has been the fuel for many accidental farm fires. Data from this study suggest that PN products show the least threat of accidental combustion.

Water-Holding Capacity

The WHC of bedding materials was less ($P < 0.01$) when nonsubmerged (Figure 1A) versus being submerged (Figure 1B) in H₂O (357 vs. 378%, respectively). This difference was because S had a lower WHC when nonsubmerged versus being submerged (211 vs. 344%, $P < 0.05$). The WHC of all other materials was similar whether nonsubmerged or submerged. The comparison of WHC by nonsubmerging or submerging may simulate and be useful to assess the WHC of bedding materials in vivo, especially after an animal has urinated and bedding materials are submerged or floating in urine until the moisture is redistributed.

Water-holding capacity depended ($P < 0.01$) on type of material and time the materials were submerged or nonsubmerged in water. The type of bedding material × time interaction was significant ($P < 0.01$), regardless of whether materials were submerged or nonsubmerged

when measuring WHC. However, the WHC \times time interaction was not significant.

In the first minute or hour, WS and chopped newspaper immediately absorbed a maximum WHC of 400% whether submerged or nonsubmerged with dH₂O (Figure 1). Wheat straw exhibited the next immediate high WHC (200% at 1 min) by both methods. Lower cellulose content and the cutin to waxy coating of plant stems may be contributing to the lower WHC of S in comparison to WS and chopped newspaper. The immediate (1 min) dH₂O uptake (50%) of PN products was low in comparison to the other materials (Figure 1). This lower initial WHC could be the result of limited water initially penetrating the surface area of a pellet; but, as water did penetrate and the compressed fibers expanded (pop-corning), WHC increased. Size of the pellet was also a factor influencing WHC. Surface area to unit mass was greatest for the 0.32-cm diameter pellet versus 0.64- and 1.27-cm diameter pellets and, therefore, had the

initially greater WHC when compared to the other PN materials.

Maximal WHC occurred at 24 h when materials were either nonsubmerged or submerged in water. Materials could be ranked into groupings related to their low to high WHC: S < 1.27-cm PN < 0.32- and 0.64-cm PN, chopped newspaper, and WS. Focusing on 24 h for comparing WHC of potential bedding materials is appropriate because box and tie stalls are generally cleaned approximately every 24 h.

CONCLUSIONS

Sources of RN that possess low toxicity risks are available and when processed are comparable and in some physical properties superior to S and WS for use as animal bedding materials. Products of RN and WS had high WHC compared to S. Although WS and S contained greater quantities of small particles (diameter

Table 3. Physical properties: geometric mean particle size distribution, density of stored and loose bedding, combustion potential¹ of recycled newspaper (RN)² in chopped and pelleted forms³, wheat straw (S)⁴ and wood shavings (WS)⁵.

	RN				S	WS
	Chopped	Pellets, cm				
		0.32	0.64	1.27		
	%					
Particles retained by dry sieving						
Screen openings, mm						
5	99.83	88.15	99.74	99.81	98.12	80.13
3	0.08	11.29	0.08	0.05	0.52	4.40
2	0.00	0.13	0.02	0.05	0.07	5.57
1	0.04	0.07	0.02	0.0	0.09	3.90
<1	0.05	0.36	0.14	0.04	1.20	6.00
	kg of DM/m ³					
Density						
Bulk storage ⁶	432.9	540.4	476.9	608.0	97.9	125.1
Loose bedding ⁷	11.2	542.9	475.0	647.2	12.7	36.6
	Time (sec)					
Flame propagation ⁸						
Length	118.4	0	0	0	99.5	191.3
Extent	21.7	0	0	0	53.6	24.0

¹Combustion testing performed at SGS U.S. Testing Co., Inc., Fairfield, NJ.

²Curbside collection from Hunterdon County Utilities Authority, Division of Solid Waste and Recycling, Flemington, NJ.

³Pelleted at Andritz Sprout Bauer Co., Inc., Muncy, PA.

⁴Dynasty Seed Wheat (Hoffmann Seed Co., Milan, OH) cut in boot stage and harvested as straw in square bales (average weight 15.5 kg), Brook Hollow Farm, Sergeantsville, NJ.

⁵Kiln-dried in bags, Emerald Peak Wood Co., Kingston, ON, Canada.

⁶Materials stored as individual units of bulk forms: square baled S (15.4 kg/0.189 m³), bagged kiln-dried pine WS (11.51 kg/0.092 m³), and curbside bundled RN (0.066 kg/0.057 m³).

⁷Materials were distributed in 9.3 m² stalls at depths of: S, 18 cm; WS, 6.4 cm; chopped newspaper, 7 cm; 0.32 cm PN, 1.8 cm; 0.64 cm PN, 4 cm; 1.27 cm PN, 4 cm.

⁸Bedding materials were ignited by methenamine pills. Measurements included the length of time propagation existed and the length of time flame covered a distance of 11.4 cm in each bedding having a depth of 2.54 cm.

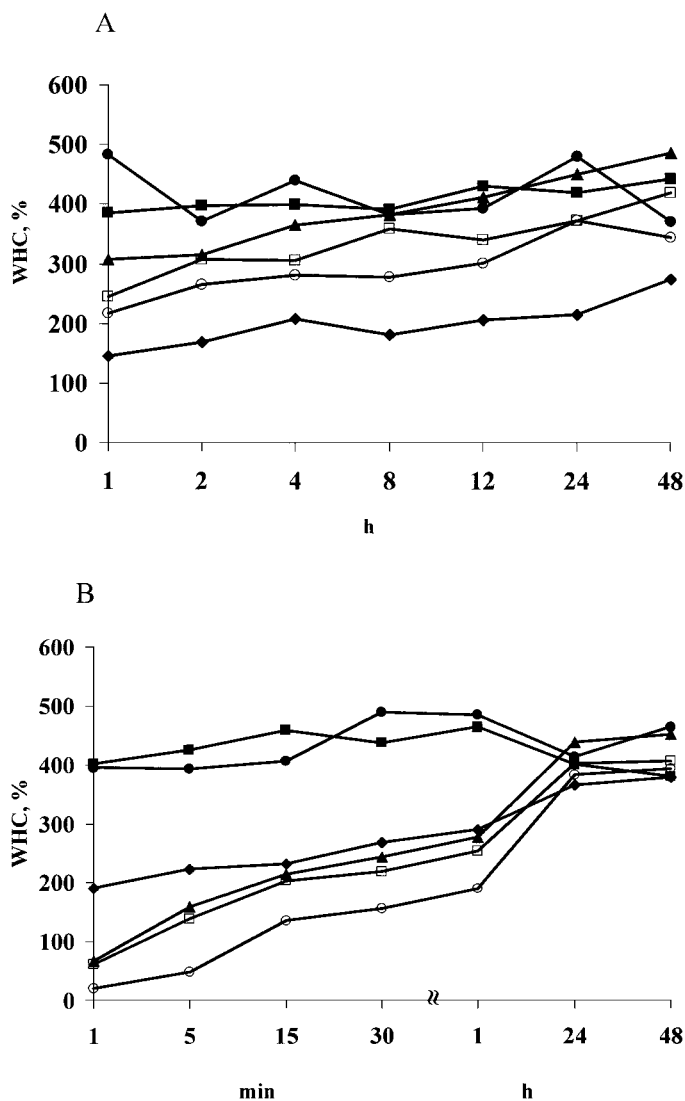


Figure 1. Changes in water-holding capacity of chopped RN (●), 0.32-cm pelleted newspaper (PN) (▲), 0.64-cm PN (□), 1.27-cm PN (○), S (◆), and wood shavings (■) measured by nonsubmersion (A), or submersion (B).

ter <1 mm) than processed RN, further studies must establish differences in respirable dust. Pelleting of RN increased density and reduced the danger of combustion in comparison to chopped RN, WS, and S. Thus animal industries can, in confidence, utilize RN as an animal bedding material, providing sources of low toxicity are identified and suitable processed forms produced.

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REFERENCES

- 1 Association of Official Analytical Chemists. 1984. Official Methods of Analysis. 14th ed. AOAC, Washington, DC.
- 2 Clarke, A. F., and T. Madelin. 1987. Technique for assessing respiratory health hazards from hay and other source materials. *Equine Vet. J.* 19:442-447.
- 3 Colucci, P., Y. Dong, J. G. Buchanan-Smith, and S. Leeson. 1992. Phone book paper as a source of bedding for domestic livestock. *J. Anim. Sci.* 70(Suppl. 1):284.(Abstr.)
- 4 Edwards, J. H., E. C. Burt, and R. L. Raper, 1995. Issues affecting application of noncomposted organic waste to agricultural land. Pages 230-232 in *Agricultural Utilization of Urban and Industrial By-Products*. ASA Special Publication no. 58. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI.
- 5 Goering, H. K. and P. J. Van Soest. 1975. Forage fiber analysis (apparatus, reagents, procedures, and some applications). *Agric. Handbook 379*. USDA, Washington, DC.
- 6 Goodrich, P. R., B. D. Backus, and D. D. Schroeder. 1988. Limiting the land—application of mixed paper based on metal content. *Biol. Wastes* 24:81-94.
- 7 Harris, W. D., and P. Papat. 1954. Determination of the phosphorus content of lipids. *Am. Oil Chem. Soc. J.* 31:124.
- 8 Heimlich, J. E., and S. Howard. 1990. Absorbency of Newsprint. CDFS 125, Ohio Coop. Ext. Serv., Ohio State University 2 pp.
- 9 Hogan, J. S., and K. L. Smith. 1997. Bacteria counts in sawdust bedding. *J. Dairy Sci.* 80:1600-1605.
- 10 Jones, K. C., and A. P. Sewart. 1997. Dioxins and furans in sewer sludges: a review of their occurrence and sources in sludge and of their environmental fate, behavior, and significance in sludge-amended agricultural systems. *Crit. Rev. Environ. Sci. Technol.* 27:1-85.
- 11 McChesney, D. G. 1996. FDA's view on the use of non-traditional products as sources for animal feed ingredients. Pages 14-19 in *Proc. Food Waste Recycling Symposium*, NJ Dept. Agric., Trenton, NJ.
- 12 Munn, D. A., 1992. Comparisons of shredded newspaper and wheat straw as crop mulches. *Hort Technology* 2:361-366.
- 13 National Research Council. Subcommittee on Mineral Toxicity in Animals. 1980. Mineral tolerance of domestic animals/Subcommittee on Mineral Toxicity in Animals, Committee on Animal Nutrition, Board on Agriculture and Renewable Resources, Commission on Natural Resources, National Research Council. Washington, DC: National Academy of Sciences.
- 14 O'Connell, J. M., and W. J. Meaney. 1997. Short-term fate of heavy metals/trace elements, naphthalene and polychlorinated biphenyls in lactating cows fed newspaper. *Ir. Vet. J./Times* 50:171-173.
- 15 Paustenbach, D. J., H. P. Shu, and F. J. Murray. 1986. A critical examination of assumptions used in risk assessments of dioxin contaminated soil. *Regul. Toxicol. Pharmacol.* 6:284-307.
- 16 Perkin-Elmer. 1971. Analytical methods for atomic absorption spectrophotometry. Perkin-Elmer Corp., Norwalk, CT.
- 17 Rechcigl, J. E., and H. C. MacKinnon, 1997. Agricultural uses of by-products and wastes. ACS Symposium Series 668, American Chemical Society, Washington, DC.
- 18 Richard, T. 1991. Livestock bedding: A new market for old news? *In Newspaper as a Livestock Bedding. A Resource Guide to Available Extension Information for Farmers, Recyclers, and Community Groups*. Cooperative Extension Service, Michigan State Univ., East Lansing, MI.

- 19 Rynk, R. 1992. On-Farm Composting Handbook. Northeast Regional Agricultural Engineering Service, Ithaca, NY.
- 20 SAS Institute. 1997. SAS Users Guide: Statistics. Version 6.12 Edition. SAS Institute Inc., Cary, NC.
- 21 Swinker, A. M., M. K. Tanner, D. E. Johnson, and L. Benner. 1998. Composting characteristics of three bedding materials. *J. Equine Vet. Sci.* 18:462–466.
- 22 Tecator. 1978. Appendix to Fibertec Manual. Tecator, Hogänäs, Sweden.
- 23 Temple, G. 1989. Potential uses and problems of using shredded paper for animal bedding. Pennsylvania Recycling Conference April/May 1989, Penn State University, University Park, PA, PENpages No. 08801720.
- 24 US Environmental Protection Agency. 1988. Method of chemical and wastewater analysis. Revise USEPA/600-479-020.
- 25 US Environmental Protection Agency. 1995. Standards for the use or disposal of sewage sludge; final rule and proposed rule. 40 CFR Parts 403 and 503, Federal Register, Vol. 60 No. 206:54773.
- 26 Verado, D. J., P. N. Froelich, and A. McIntyre. 1990. Determination of organic carbon and nitrogen in marine sediments using the Carlo Erba NA-1500 Analyser. *Deep-Sea Res.* 37:157–165.
- 27 Ward, P. L. 1998. Recycled newspaper's potential as an agricultural resource: chemical and physical properties; in vivo animal bedding properties; usage and market acceptability when compared to wheat straw and wood shavings. Ph.D. Dissertation, Rutgers, The State University of NJ, New Brunswick.
- 28 Wu, S., X. Feng, and A. Wittmeier, 1997. Microwave digestion of plant and grain reference materials in nitric acid and hydrogen peroxide for the determination of multi-elements by inductively coupled plasma mass spectrometry. *J. Anal. At. Spectrom.* 12:797–806.