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...
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 kilndried, 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), and harvested as square bales (200 count), average weight, 11.5 kg (Emerald Peak Wood, Kingsdon, 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 John- son 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, Hern- don, 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-µl 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 ± 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-µl sample in 900 µl of 3% HNO₃), and each standardized at 4 mg/kg of Ga.

Microwave oven equipped with pressure sensor (600 psi ± 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. Prior to analysis, samples were diluted further (100-µl sample in 900 µl of 3% HNO₃) and each standardized at 4 mg/kg of Ga, In, Sc, and Tl.

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 + original weight × 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 × 0.32, 0.64, 1.27 cm), time (1, 5, 15, 30 min and 1, 24, and 48 h) and type × time interaction for WHC measured on submerged samples; model 2) type of loose bedding, time (1, 2, 4, 8, 12, 24, 48 h), type × 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), wheat straw (S), and wood shavings (WS).

<table>
<thead>
<tr>
<th></th>
<th>RN</th>
<th>S</th>
<th>WS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture as received, %</td>
<td>2.7</td>
<td>7.0</td>
<td>5.7</td>
</tr>
<tr>
<td>pH</td>
<td>6.4</td>
<td>5.9</td>
<td>3.9</td>
</tr>
<tr>
<td>DM, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude protein</td>
<td>1.4</td>
<td>8.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Ether extract</td>
<td>1.9</td>
<td>2.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Neutral detergent fiber</td>
<td>92.1</td>
<td>64.9</td>
<td>90.5</td>
</tr>
<tr>
<td>Acid detergent fiber</td>
<td>77.6</td>
<td>41.4</td>
<td>79.8</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>14.5</td>
<td>23.6</td>
<td>10.7</td>
</tr>
<tr>
<td>Cellulose</td>
<td>54.3</td>
<td>34.8</td>
<td>49.5</td>
</tr>
<tr>
<td>Lignin</td>
<td>23.7</td>
<td>5.6</td>
<td>29.0</td>
</tr>
<tr>
<td>Ash</td>
<td>3.4</td>
<td>5.6</td>
<td>0.5</td>
</tr>
<tr>
<td>C</td>
<td>44.1</td>
<td>42.2</td>
<td>46.9</td>
</tr>
<tr>
<td>Ca</td>
<td>0.15</td>
<td>0.36</td>
<td>0.06</td>
</tr>
<tr>
<td>Mg</td>
<td>0.02</td>
<td>0.21</td>
<td>0.02</td>
</tr>
<tr>
<td>N</td>
<td>0.11</td>
<td>1.61</td>
<td>0.09</td>
</tr>
<tr>
<td>P</td>
<td>0.03</td>
<td>0.24</td>
<td>0.01</td>
</tr>
<tr>
<td>Si</td>
<td>2.09</td>
<td>1.80</td>
<td>0.40</td>
</tr>
<tr>
<td>Fe</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Mn</td>
<td>ND^8</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Cu</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Zn</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Toxicant metals, mg/kg</td>
<td>0.12</td>
<td>0.01</td>
<td>0.16</td>
</tr>
<tr>
<td>Cd</td>
<td>0.12</td>
<td>0.01</td>
<td>0.16</td>
</tr>
<tr>
<td>Cr</td>
<td>4.35</td>
<td>0.72</td>
<td>1.78</td>
</tr>
<tr>
<td>Hg</td>
<td>ND^5</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Pb</td>
<td>0.89</td>
<td>0.13</td>
<td>0.17</td>
</tr>
</tbody>
</table>

^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.
^4Non-detectable concentrations.
^5All pelleted newspaper materials had ND Hg, however, curbside RN (unprocessed) contained 0.068 mg/kg of Hg.

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 newprint (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⁻¹ 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 con-
sumed incidentally or otherwise. Eventual land appli-
cation 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 tetrachlorodibenzo-p-dioxin at 3.7 ppt
(Table 2). Other chlorinated dioxins and furans were
present at very low concentrations in S and WS. Conge-
ers (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 dif-
fering 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 (0.99
ng/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, partic-
ularly 2-3-7-8 tetrachlorodibenzo-furan, and bioaccumu-
late in the food chain. In addition to their accidental
occurrence caused by combustion processes, these poly-
chlorinated dioxins and furans are otherwise ubiqui-
utous in the environment and naturally occurring at ul-
tratrace levels (10). Since the materials evaluated are
eventually land applied and no standards have been
set for their dioxin and furan content, values were com-
pared 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 con-
cern, all TEQ levels of materials tested in this study
were consistent with established background concen-
trations (<1 ng/kg) (Table 2). Recycled newspaper con-
tained 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 inher-
ently 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/
m³. 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 newspa-
per were 30 and 2% as dense as WS and PN, respec-
tively.

Costs associated with transportation and storage
would be lower for a denser material. Usage of a mate-
rial as animal bedding would also depend on the materi-
al’s density. To determine their functional value as bed-
ding, loose materials must be compared in usage stud-
ies, 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) content (ng/kg) of recycled newspaper (RN), wheat straw (S), and wood shavings (WS).

<table>
<thead>
<tr>
<th>Congener 5, ng/kg</th>
<th>RN (DL) 6</th>
<th>S (DL)</th>
<th>WS (DL)</th>
<th>International TEF 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,3,7,8-TCDD</td>
<td>ND (0.7)</td>
<td>ND (0.6)</td>
<td>ND (0.8)</td>
<td>1.0</td>
</tr>
<tr>
<td>1,2,3,7,8-TeCDD</td>
<td>ND (2.5)</td>
<td>ND (1.1)</td>
<td>ND (2.0)</td>
<td>0.5</td>
</tr>
<tr>
<td>1,2,3,6,7,8-HxCDD</td>
<td>ND (5.2)</td>
<td>ND (1.6)</td>
<td>ND (1.8)</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,7,8,9-HxCDD</td>
<td>ND (4.8)</td>
<td>ND (1.4)</td>
<td>ND (1.5)</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8-HpCDD</td>
<td>ND (7.3)</td>
<td>ND (1.0)</td>
<td>ND (1.6)</td>
<td>0.1</td>
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<tr>
<td>1,2,3,4,6,7,8,9-OCDD</td>
<td>ND (9.1)</td>
<td>5.7</td>
<td>67.0</td>
<td>0.001</td>
</tr>
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<td>2,3,7,8-TCDF</td>
<td>3.7</td>
<td>ND (0.6)</td>
<td>ND (0.9)</td>
<td>0.1</td>
</tr>
<tr>
<td>1,2,3,7,8-TeCDF</td>
<td>ND (1.5)</td>
<td>ND (0.6)</td>
<td>ND (1.5)</td>
<td>0.5</td>
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<tr>
<td>2,3,4,7,8-TeCDF</td>
<td>ND (1.4)</td>
<td>ND (0.6)</td>
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<td>ND (0.6)</td>
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<td>ND (0.7)</td>
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<td>ND (0.8)</td>
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<td>1,2,3,4,7,8,9-HpCDF</td>
<td>ND (5.0)</td>
<td>ND (1.1)</td>
<td>ND (1.5)</td>
<td>0.01</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8,9-OCDF</td>
<td>ND (7.2)</td>
<td>4.9</td>
<td>6.1</td>
<td>0.001</td>
</tr>
<tr>
<td>TEQ (detectable) 8, ng/kg</td>
<td>0.37</td>
<td>0.12</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>TEQ (1/2 DL), ng/kg</td>
<td>0.19</td>
<td>0.06</td>
<td>0.23</td>
<td></td>
</tr>
</tbody>
</table>

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., Kingston, 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 × 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 (popcorning), 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 (diameters...
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.

ACKNOWLEDGMENTS

The authors would like to thank Tania Otero, who as a masters student assisted greatly in sample management and analysis; Gene Hall who assisted with the help of his analytical lab and ICPMS equipment to measure heavy metals; Rob Sherrell and Paul Field who helped to develop new procedures specific to the test materials for the analysis of heavy metals; Charlotte Fuller and Gary Taghon for assistance in additional carbon and nitrogen quantification.

REFERENCES