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Short Communication

Root-zone water quality as affected by incorporation of shredded newsprint

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Abstract

Experiments to examine the effects on root-zone water quality by deep trenching disposal of municipal shredded newsprint in agricultural production soils were conducted in Alabama, USA. Three treatments were examined during the study. In two treatments, a 25:1 carbon/nitrogen (C:N) ratio was examined by mixing poultry litter or liquid ammonium nitrate (NH_4NO_3) with the shredded newsprint. The third treatment examined cellulose (125:1 C:N) only. The water quality data from two depths (0.6 and 1.2 m) adjacent to the trenches (within 5 cm) and from a no trench area (> 1.5 m from the trenches) suggest that there is no leaching of P and K. Nitrogen, as measured by total Kjeldahl (TKN) and nitrate (NO_3^-), showed mobility next to the trenches. Nitrate movement below the 1.2 m depth occurred using cellulose only. The poultry litter/cellulose mixture showed little NO_3^--N vertical movement and the NH_4NO_3/cellulose mixture showed some NO_3^--N movement next to the trenches.

Keywords: Water quality, Waste utilization; Recycling; Nutrient leacting

1. Introduction

Disposal of solid wastes in the U.S. is becoming increasingly challenging. Over 5400 landfills are filling up at an alarming rate and few new ones are being approved (Rathje, 1991). The nation's annual trash bill now exceeds 15 billion

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dollars and new and innovative methods of handling waste materials will be required for the future.

According to Rathje (1991), misperceptions must be dealt with before a reduction in trash can be achieved. Rathje reports that most people believe that landfills are filled with fast-food packing, polystyrene foam and disposable diapers. However, Rathje's research has shown that these components add up to only about 2% of the total solid waste while the largest component is paper. Waste paper now occupies some 50% of the waste stream, and newspapers themselves occupy between 10–15%, even though many are now being recycled or exported. Rathje (1991) reports that paper does not decompose as rapidly as once believed and he has found legible copies that have been buried for 40 years. Alternative methods for disposal of waste paper should be investigated before expensive landfill space is filled to capacity.

An alternative paper recycling method being investigated at the USDA-ARS National Soil Dynamics Laboratory is to use shredded newspaper as a soil amendment for crop production (Edwards et al., 1992, 1993). Experiments have been conducted on both surface incorporation and burial in vertical trenches. Preliminary results have indicated that increased cotton yields have resulted when the waste paper was applied in a vertical trench between plant rows. The trenches alleviated the shallow rooting problems associated with a hardpan and the shredded paper may help decrease the rate at which the hardpan reconsolidates.

Vertical mulching of agricultural crop residue was investigated as a method of alleviating heavy straw concentrations left on the soil surface after large yields (Spain and McCune, 1956). In earlier times, before researchers and farmers realized the full benefits of surface residues for erosion control, and how to conduct field operations in heavy residue cover, heavy straw concentration was perceived to interfere with planting operations and prevent timely field operations. Curley et al. (1958) investigated burial of organic materials, including hay and corn cobs, as a method of increasing soil-water availability and deepening the plant root zone. They found that, in the first year of the experiment, large differences in crop yield using the organic materials were achieved due to the benefits afforded by vertical mulching. In later years, however, yield results were confounded by heavy winter rains which provided adequate moisture for all plots. A Canadian experiment (Clark and Hore, 1965) found that vertical mulching had little effect on crop yields, soil moisture distribution, unit draft or watertable levels.

Despite marked successes by researchers in the vertical trenching of crop residues, commercialization of this process has not been successful. Apparently, the potential yield increases have been insufficient to overcome the significant machinery and tillage energy costs. If waste cellulose materials are applied, these machinery and energy costs may be offset by potential payments from municipalities to farmers for disposal of a portion of their solid waste. Burt et al. (1992) have calculated these potential payments to be in the $1100 per ha per year range.

Because of these promising economics, an experiment to investigate vertical trenching of shredded newspaper was conducted near Shorter, AL, at the Auburn University E.V. Smith Agricultural Research Center. One of the objectives of this experiment was to determine the effect on water quality, in the root zone (0.6 m) and in the deep seepage (1.2 m), of placing a mixture of shredded newspaper and various nitrogen sources in vertical trenches between crop rows.

2. Methods and materials

Shredded newspaper was obtained from CEL-PAK [1] (Decatur, AL) which recycled it for insulation. This material was passed through a 9.5-mm size screen before being packaged into 11.4-kg bundles. A carbon/nitrogen analysis of the shredded newspaper showed it to contain 48% carbon and approximately 0.2% nitrogen (125 : 1 C : N).

This experiment used an implement developed at the USDA-ARS National Soil Dynamics Laboratory (NSDL) for digging a trench and applying the shredded newspaper in the trench. This implement consisted of a 15-cm wide shank which was used to subsoil to a depth of 61 cm. A large hopper mounted above the shank held the shredded newspaper until it was placed into the trench. The shredded newspaper was dispensed directly behind the shank to allow some of the cellulose material to fall to the bottom of the trench. Excavations performed during initial trials showed that a uniform shredded paper/soil mixture was being obtained along the 61-cm depth of the trench.

The field plots for this experiment were 18.3 × 6.1 m and were located on a soil of type Cahaba-Wickham-Bassfield sandy loam (Typic Hapludult). The site had a well-developed hardpan 8- to 15-cm thick located at a depth of 20 to 30 cm. The cation exchange capacity of this soil averaged 6.3 meq/100 g over the plot area and contained 1.2% organic matter in the surface layer. The hydraulic conductivity for this soil averaged 9.3 cm/h over the plot area for the layer above the hardpan. All plots were planted to grain sorghum (*Sorghum bicolor* (L.) Moench), and were fertilized with 14.6 kg N/ha, as determined by soil tests prior to the experiment, using two broadcast applications. The crop was planted on June 10, 1993 simultaneous to a starter fertilizer application of 3.1 kg N/ha supplied from a 17–17–17 fertilizer mixture. On June 21, another 11.5 kg N/ha was added using ammonium nitrate (34–0–0).

Three treatments were applied to the trench area of the plots. All three of these treatments received 7.4 Mg C/ha in the form of shredded newsprint. The first of these treatments (A) was achieved by applying only newsprint directly into the trench. In the other two treatments (B and C), nitrogen was mixed with the shredded material to adjust its C : N ratio to 25 : 1. The nitrogen added was to help optimize crop yields and minimize the effects of the large quantities of carbon being placed into the soil. The first of these nitrogen treatments (B, 0.3 Mg N/ha) consisted of mixing a 33% liquid ammonium nitrate solution with the shredded

[1] The use of tradenames or company names does not constitute endorsement by the USDA-ARS or Auburn University.

newspaper prior to applying it in the trench. The second treatment (C) consisted of mixing poultry litter with the shredded newspaper to achieve the same 25 : 1 C : N ratio. The poultry litter contained 21.8% C and 3.05% N. Irrigation was used on all plots early in the growing season to establish the crop. Each treatment was replicated four times.

Two lysimeters (Soil Moisture Equip. Corp.,[1] 1992) consisting of a length of 3.8 cm (ID) PVC pipe with a ceramic cup fitted on the end were placed at depths of 0.6 m and 1.2 m adjacent to the trench (within 5 cm) in each of the three treatments. Lysimeters were also placed in an area adjacent to the plots (> 1.5 m from the trenches). These lysimeters were sampled to give data to which comparison of the treatments can be made and are designated as the "no trench" treatment in the results. Beginning in July, 1993, all lysimeters were sampled once a month by placing a vacuum on them three days prior to extracting the liquid sample.

Water samples extracted from the lysimeters were immediately iced and transported to the Agricultural Engineering waste management laboratory for analysis. Total Kjeldahl nitrogen (TKN) was determined by the micro-Kjeldahl technique of AOAC (1984) and NO_3^--N was determined by Orion [1] specific-ion electrode. Total phosphorus was determined by the colorimetric (spectrophotometer) method of *Standard Methods for the Examination of Water and Wastewater* (APHA, 1992) and potassium was determined by specific-ion electrode (Orion [1]).

Statistical analyses were performed on the data using the computer software of Cohort (1990). Because the sample size was not equal (from 4 to 16), a typical analysis of variance (ANOVA) of the data would be questionable, however, a one-way completely randomized ANOVA was performed. The results of this analysis are included in Table 2. The ANOVA test showed significant differences between treatments at the 5% level for all sample constituents, except K at the 0.6 m depth. The data were also analyzed statistically using a Duncan's multiple range test to detect differences between the means of the treatment data.

3. Results and discussion

The data from this study are summarized in Table 1. These data represent a varying number of liquid samples since all lysimeters did not yield samples every month. Samples were taken on July 6, August 12, September 15, October 15, November 15 and December 9, 1993. The values in Table 1 represent the means and standard deviations of the four replications for each treatment for these sampling dates with the minimum number of samples being four. Treatments are: (A) cellulose only, (B) liquid fertilizer/cellulose mixture (25 : 1 C : N), and (C) poultry litter/cellulose mixture (25 : 1 C : N), respectively. These data should be compared to the "no trench" data.

The Duncan's range test results showed significant differences ($P = 0.05$) for the phosphorus data as noted in Table 1. At the 0.6 m depth, the phosphorus concentration was statistically the same for treatment C and the "no trench"

Table 1
Lysimeter data for nitrogen, phosphorus, and potassium for the treatments studied [b,c]

Treatment [a]	Depth (m)	No. of samples	TKN-N (mg N/l)	NO_3-N (mg N/l)	P (mg P/l)	K (mg K/l)
A	0.6	16	1.54a (0.26)	15.28a (1.35)	0.16b (0.02)	0.40ab (0.02)
	1.2	8	0.76b (0.07)	11.56a (1.76)	0.16c (0.02)	0.20b (0.02)
B	0.6	12	1.50c (0.21)	11.61c (1.22)	0.15b (0.02)	0.41ab (0.03)
	1.2	7	1.37a (0.08)	8.00b (1.01)	0.24a (0.01)	0.37a (0.02)
C	0.6	13	2.55b (0.35)	13.74b (1.27)	0.25a (0.03)	0.43a (0.02)
	1.2	6	1.38a (0.13)	3.68c (0.76)	0.21ab (0.05)	0.37a (0.05)
No trench	0.6	12	1.45c (0.20)	12.67bc (1.36)	0.22a (0.07)	0.39b (0.04)
	1.2	4	1.43a (0.18)	2.32c (0.26)	0.19bc (0.02)	0.23b (0.04)

[a] Treatments: A – cellulose only, 125:1 C:N ratio; B – liquid ammonium nitrate fertilizer with cellulose, 25:1 C:N ratio; C – poultry litter with cellulose, 25:1 C:N ratio.
[b] Values in parentheses are standard deviations.
[c] Similar means are indicated by like letters (Duncan's multiple range test).

results while different for treatments A and B. At the 1.2 m depth, the results are even more varied. This result was most likely caused by the varying sampling numbers. From an environmental viewpoint, however, the data for phosphorus and potassium show no great movement down the cellulose trench as evidenced by sample depth. The data show a "no trench" concentration of 0.22 mg/l and 0.19 mg/l for phosphorus at the 0.6 and 1.2 m depths, respectively. These results compare to values of 0.16, 0.15 and 0.25 and 0.16, 0.24 and 0.21 mg/l at the 0.6 and 1.2 m depth for treatments A, B, and C, respectively. Similar trends can be seen for the potassium data with no great movement occurring next to the cellulose trenches.

Nitrogen was analyzed to evaluate TKN and NO_3^--N data separately to indicate the biological processes occurring in the soil. TKN includes the ammonia (NH_3) and organic nitrogen (ON) fractions. These forms of nitrogen are not completely oxidized and are the major forms in the poultry litter. NO_3^--N represents a highly

Table 2
One-way completely randomized analysis of variance

Source	Depth	Variable	Significance level [a]
Cellulose treatments [b]	0.6 m	P	0.003
		K	0.156
		NO_3^--N	0.002
		TKN	0.002
Cellulose treatments	1.2 m	P	0.003
		K	0.0001
		NO_3^--N	0.0001
		TKN	0.0001

[a] Signifies a significant difference at this probability level.
[b] Cellulose treatments: A – cellulose only (125:1 C:N ratio); B – cellulose with liquid NH_4NO_3 (25:1 C:N ratio); C – cellulose with poultry litter (25:1 C:N ratio).

oxidized and mobile form of nitrogen. By examining these forms independently, one can determine if biological oxidation is a major process occurring in the soil.

Examining the TKN data, there is an elevated value (2.55 mg TKN-N/l) for the poultry litter when compared to the "no trench" value (1.45 mg TKN-N/l) at the 0.6 m depth. This is expected since the nitrogen in the poultry litter is initially mainly in the TKN form. Indeed, this is confirmed by the Duncan's multiple range test which shows the poultry litter results to be different from the "no trench" results. The treatments without litter (A and B) show no great numerical difference when compared to the "no trench" at the 0.6 m depth. The values at the 1.2 m depth (0.76, 1.37, 1.38 and 1.43 mg TKN-N/l for treatments A, B, C and the "no trench") are all relatively the same with the Duncan's test showing the cellulose only treatment (A) to be statistically different. Thus, the TKN data show an elevated value at the 0.6 m depth using poultry litter, but no great increase at the 1.2 m depth. This suggests that the extra TKN in the poultry litter has been biologically released as NH_3 or has been oxidized to NO_3^--N before it gets to the 1.2 m depth.

Some concern should be expressed from examination of the nitrate data. The nitrate values at the 0.6 m depth for all treatments and the "no trench" are above the USEPA drinking water standard (10.0 mg NO_3-N/l; USEPA, 1976). This perhaps reflects the use of the broadcast fertilizer at the beginning of the study. The value at the 1.2 m depth, well below the rooting zone of the crop, is also above this standard for the cellulose only application (treatment A). This means that NO_3^--N movement below this depth (1.2 m) can be assumed to ultimately enter the groundwater supply. The data for the treatments containing an extra nitrogen source (B and C) show much reduced nitrate levels at the 1.2 m depth, with the poultry litter mixture being less that the liquid fertilizer mixture. Both of these mixtures had the 25:1 C:N ratio.

One possible explanation of the elevated nitrate levels at the 1.2 m depth next to the trench containing cellulose only (treatment A) is that the pores in this trench remained open, which may have allowed rapid movement of the fertilizer in the trench such that no microbial action occurred. This is different from treatments B and C where mixing of the cellulose and the nitrogen source occurred before placement in the trench. Treatments B and C, thus, possibly enhanced conditions for microbial activity from the beginning of the experiment and thus, allowed microbial use of the nitrogen fraction in degrading the cellulose in the trench. Statistically, treatment B is different from treatment C and the control at the 1.2 m depth.

These data suggest that mixing poultry litter with cellulose (treatment C) produces a facultative microflora that, in degrading the high carbon cellulose fraction of the mixture, converts the ON fraction to ammonia which, in turn, volatilizes to the atmosphere. Also, C:N ratios of 20 to 25:1 using poultry litter has been shown to cause major immobilization (microbial assimilation) on land-applied poultry litter (Chescheir et al., 1986; Gale and Gilmore, 1986). This might also explain why the NO_3^- ion in the NH_4NO_3/cellulose mixture (treatment B) moved to the 1.2 m depth (i.e., NO_3^--N is already oxidized and unaffected by the facultative microflora). The NO_3^--N concentrations at the 1.2 m depth are 8.0 and 3.68 mg NO_3-N/l for the B and C treatments, respectively. In fact, the 3.68 mg NO_3-N/l at the 1.2 m depth for treatment C is statistically equal to the "no trench" data. Thus, it appears that the addition of a nitrogen source may actually help control the conversion of N to the NO_3^--N form, and, in turn, may aid in reducing the potential movement of nitrate below the root zone. Also, the poultry litter/cellulose mixture may have enhanced bacterial growth even beyond that of the ammonium nitrate/cellulose mixture. Thus, the potential for nitrate movement into the groundwater may be reduced and is an apparent highly desirable attribute of adjusting the C:N ratio to 25:1 in these cellulose tillage systems.

4. Conclusions

This study was based on a limited number of water quality samples collected during an extremely dry growing season, however, some preliminary conclusions are appropriate:

1. The vertical movement of phosphorus and potassium adjacent to the cellulose trench does not appear to be a major water quality concern.
2. The use of cellulose in mixtures with either liquid fertilizer or poultry litter appears to either temporarily immobilize nitrogen or release it as ammonia during the degradation of the cellulose fraction.
3. The use of cellulose alone appears to cause direct vertical movement of NO_3^--N adjacent to the trench to below the rooting zone. This allows nitrate from fertilizer to become a potential ground water contaminant.
4. Of the three treatments studied, the use of a poultry litter/cellulose mixture appears to offer the best control of NO_3^--N formation and, thus, best controls nitrate movement in the soil. This could be possible because of a microbial growth factor supplied in the poultry litter.

From the above conclusions, it appears that when disposing of shredded newsprint in this manner (i.e. cropland trenching), mixing the cellulose with poultry litter to attain a 25:1 C:N ratio is preferable to mixing it with inorganic fertilizer to obtain the same 25:1 C:N ratio. This is because the poultry litter/cellulose mixture actually helped prevent groundwater contamination from the deep seepage of nitrate when compared to the inorganic fertilizer mixture. Finally, because of the limited amount of data, further work is needed to assess the environmental impact of this practice on the water quality in and near the plant root zone.

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