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Nitrogen Leaching in Paper-Amended Soil Columns

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ABSTRACT

In the southeastern United States, productivity of sandy, poorly structured soils could be improved by increasing organic matter content. Organic matter can be increased by adding waste paper with either nitrogen (N) fertilizer or poultry litter (PL) to adjust the carbon (C) to nitrogen ratio. Our objective was to compare N leached when ammonium nitrate (AN) or PL was added to 30-cm-deep, 20-cm-diameter soil columns amended with waste paper. We established soil columns with three treatments in the Ap horizon over three treatments in the E horizon in nine treatment combinations. No plants were grown. The Ap horizon treatments were AN plus waste paper, PL plus waste paper, and nothing added. Additions were balanced to a 20:1 C to N ratio. The E horizon treatments were waste paper mixed, waste paper on the column axis (not mixed), and nothing added. The experiment was run in 1993 and 1994. Columns were leached with 500 ml (1.5 cm) of deionized water two or three times a week. For both trials of the experiment, more N leached from AN plus paper (2.39 g) than from PL plus paper (0.36 g) or the nothing-added (0.24 g) Ap treatments. This result reflects more N available for leaching from the AN treatment. Increased leaching of N can limit growth and deteriorate groundwater quality. In 1994, we measured 0.48, 0.30, and 0.97 g of N in the effluent from paper mixed, not mixed, and no paper added to the E horizon, respectively. Less N leached from columns with paper in the E horizon. For E horizons with paper, less leaching of N and higher N contents at the end of the experiment suggest that paper held some N preventing it from leaching.

INTRODUCTION

Many southeastern Coastal Plain soils have a sandy loam or loamy sand Ap texture and low organic matter (~1%). The E horizon, just below the Ap, also contains sandy loam or loamy sand with about 0.5% organic matter. Adding crop residues can increase organic matter (Wood et al., 1991), increase cation exchange capacity (Blevins et al., 1977), decrease bulk density (Tester, 1990), and decrease penetrometer resistance (Thompson et al., 1987). Addition of carbon (C) from paper balanced with nitrogen (N) from poultry litter (PL) or fertilizer has the potential of increasing soil organic matter and reducing the demand for municipal landfill space (Edwards et al., 1993a, 1993b).

Mixtures of N and waste paper, as a soil amendment, improved the growth of cotton [*Gossypium hirsutum* L.], maize [*Zea Mays* L.], and soybeans [*Glycine max* (L.) Merr.] (Edwards et al., 1992; Lu et al., 1995). If ammonium nitrate (AN) was used as the N source, plants were stunted for 4 to 6 weeks at the beginning of the growing season possibly due to leaching or immobilization of N. Treatments with PL and waste paper did not stunt plants and yielded 40% more maize grain than the treatment with PL alone (Lu et al., 1995).

The objectives of this study were (1) to compare N leached from AN plus waste paper with N leached from PL plus waste paper when these treatments are added to the surface layer of a Coastal Plain soil and (2) to find out if waste paper added to the soil below the N source could reduce N leaching from the soil.

MATERIALS AND METHODS

Soil used in the study was a Norfolk loamy sand (structureless to weakly structured, fine loamy, siliceous, thermic, Typic Kandiudult) obtained from a field near Florence, SC. Each year of the study, the top two horizons, the Ap and E, were collected in separate containers and sieved through a 0.64-cm-opening screen to remove debris and destroy any large structural blocks. Both horizons had a loamy sand texture. As determined by the dry combustion method (Nelson and Sommers, 1982), the Ap horizon had a 0.94% organic matter content in 1993 and 0.72% in 1994; the E horizon had a 0.41% organic matter content in 1993 and 0.39% in 1994.

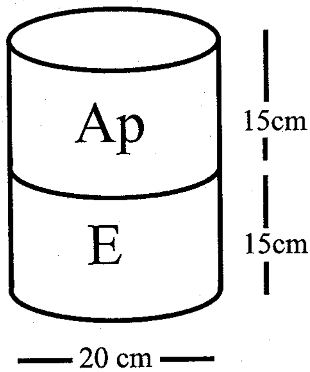

FIGURE 1. The experimental setup. Soil was packed to 1.2 g cm^{-3}.

The paper used in the experiment was waste paper obtained from a commercial insulation company. It did not have fire retardant added. The paper consisted of materials difficult to recycle including telephone books and other ad inserts with heavy clay coatings. It had been ground by the supplier using a hammer mill equipped with three screens, the smallest of which had 0.63-cm openings. The PL was obtained from a northern Alabama poultry house. It contained wood shavings and poultry excreta.

Using a wooden disk fitted to the columns, 5.93 kg (dry weight) of each soil horizon was compacted into 20-cm diameter polyvinylchloride cylinders with a force of approximately 110 N. For each horizon, half of the soil was poured into the column and compacted by pushing on the wooden disk. Then the other half of the soil was added into the column and compacted. Soil horizons were compacted to a depth of 15 cm each and a resultant bulk density of 1.2 g m^{-3}. Thermocouples were embedded at mid-depth near the axis of the column. The E horizon was compacted in the bottom of the cylinder and the Ap on top (Figure 1).

There were three treatments in the Ap horizon factored with three treatments in the E horizon for a total of nine treatment combinations (3 treatments in Ap x 3 treatments in E). For the Ap horizon, treatment 1 was a mixture of the soil with 134 g of waste paper and 9.3 g of AN. This treatment simulated paper added at a rate of 41 Mg ha^{-1} and N from AN added at a rate of 0.95 Mg ha^{-1}. Paper was analyzed at 0.61% N and 61% C (Edwards et al., 1995); therefore, additions to this treatment included 81.5 g of C and 4.07 g of N for a 20:1 C to N ratio. Because PL was 2.75% N and 41% C, treatment 2 was a mixture of the soil with 40 g of waste paper and 157.5 g of PL. This treatment simulated paper added at a rate of 12 Mg ha^{-1} and N from PL added at a rate of 1.3 Mg ha^{-1}. Treatments 1 and 2 had equal amounts of C and N added to the Ap. Treatment 3 had nothing added to the Ap horizon.

The three E horizon treatments were made up by (1) mixing 40 g of waste paper uniformly into the horizon, (2) adding 40 g of waste paper (not mixed) as a loosely packed ball in the middle of the horizon along the axis of the column, and (3) adding nothing to the E horizon. The second treatment, paper on the axis, simulated insertion of waste paper down the shank of a plow. This treatment was included because thorough mixing of the first treatment would probably capture N better, but be economically unfeasible, whereas a plow injection method that would add paper similar to the second treatment already exists (Raper et al., 1996). Additions to the E horizons of the first and second treatments simulated another 12 Mg ha^{-1} paper added deeper into the soil than the Ap.

The experiment was run in the spring of 1993 and repeated in the spring of 1994. It was located in a room that was continuously and positively ventilated with outside air. Nothing was grown in the columns. Weeds were removed as they germinated.

For both years, we obtained soil from the edge of the same field. In 1994, soil was gathered from a site that was 6 to 10 m east of the 1993 site. Depth of the Ap at the first site was ~30 cm; at the second site, it was ~22 cm. Thickness of the E at the first site was ~15 cm; at the second site, it was ~8 cm. The Ap and E were distinct horizons; there were abrupt changes at the Ap to E and the E to Bt horizons at both sites. In 1993, the Ap horizon had field soil water contents ranging from 6.0 to 6.2% and the E had water contents ranging from 5.6 to 6.1% on a dry weight basis. In 1994, the Ap horizon had water contents ranging from 12.4 to 14.2% and the E from 10.8 to 11.4%. After packing soils into the cylinders, water contents were adjusted to 15% (33% of the pore volume) for all treatments for both years. In 1993, extra water (five times the mass of the waste paper in a column) was added when wetting the columns to wet the paper. The extra water made paper-amended columns wetter than non-amended columns and was not done in 1994.

After water was added to the columns, they were covered with plastic wrap to prevent evaporation for 3 to 5 days while they came to equilibrium. The covers were removed and kept off the columns for the remainder of the experiment. A temporary covering of screen wire wrapped in cheese cloth was placed on column surfaces to protect them from compaction while water was added. Columns were leached by pouring 500 ml (1.5 cm) of deionized water onto the surface 2 or 3 times a week. The effluent was captured as it came out of the bottom of the E horizon; its volume was recorded; and it was subsampled. Subsamples were analyzed for NO_3-N and NH_4-N using ion chromatography (Greenberg et al., 1992).

Temperatures were measured in both horizons four or five times a week. In 1993, temperatures measurements were taken with a microvoltmeter (Taylor and Jackson, 1965). In 1994, temperature measurements were automated with a commercially available eight-channel, microvolt data logger for easier data collection. Temperature measurements were always taken before leaching with water to eliminate the effect of water temperature. Water was at room temperature.

In 1993, we measured respiration weekly using a stainless steel, 1-liter chamber attached to a portable carbon dioxide gas analyzer. The chamber was placed on the soil surface at the center of the column. The increase in carbon dioxide in the chamber was monitored at 1 s intervals for 30 s. Respiration was measured as evolution of CO_2 from the soil.

At the end of the experiment, we analyzed the soil for total N and C. Total soil N was determined by the Kjeldahl digestion and steam distillation procedure of Bremner and Mulvaney (1982). Total C was determined on air-dry soil by a dry combustion method of Nelson and Sommers (1982).

The experimental design was randomized complete block with four replicates. Data were analyzed using the general linear models procedure (SAS Institute, 1990) with LSD as a mean separation procedure. Treatments in the Ap and E were analyzed as a three-by-three factorial. Since N and temperature interactions with date were significant, they were analyzed by date. Unless otherwise specified, all statistical tests were evaluated for significance at $P \leq 0.05$.

RESULTS AND DISCUSSION

Nitrogen for the Ap Horizon Treatments

NO_3-N and NH_4-N

Averaged over all treatments, 342 mg of NO_3-N leached through the columns in 1993 and 393 mg in 1994. In both trials of the experiment, more NO_3-N leached from treatment AN than the treatments with either PL or nothing added (Tables 1 and 2). The greater amount of NO_3-N leached from treatment AN came from the higher amounts of NO_3-N in that treatment originally (1.63 g, 50% of the AN-N added). This contrasts with the PL treatment where approximately 70% of its N is organic and approximately 5% (0.19 g, 0.05 times 3.83 g of N in the PL added) is NO_3-N (Edwards et al., 1995). The amount of NO_3-N leached through the PL treatment did not differ from the treatment with nothing added.

Greater leaching in the AN treatment agrees with the work of Wood et al. (1996) and Sexton et al. (1996) where they noted higher amounts of NO_3-N leached in fertilized plots than in manured plots. It also agrees with the work of Edwards et al. (1992) who found concentrations of soil NO_3-N$\geq$9 mg kg^{-1} at 2-m depth 8 months after AN and waste paper were applied to the soil surface. In contrast, when PL was the N source, Edwards et al. (1992) found $\leq$5 mg kg^{-1} soil NO_3-N at the 2-m depth.

Averaged over all treatments, 63 mg of NH_4-N leached through the columns in 1993 and 204 mg in 1994. The overall high rate of NH_4-N leaching was indicative of the wet conditions of the columns (3 to 4.5 cm of water leached per week), as also seen by Wang and Bettany (1995). In both trials of the experiment, more

TABLE 1. The NO_3-N in the effluent of the treatments for the sampling period in 1993.

	Additions to Ap horizon			Additions to E horizon		
Day†	AN and paper	PL and paper	Nothing	Paper on the axis	Paper mixed	Nothing
	mg of NO_3-N					
7	264a‡	--††	4.82b	134a	130a	139a
8	105a	0.85b	5.74b	49.8a	21.2b	27.3b
12	278a	4.80b	9.40b	107a	97.5ab	53.8b
15	231a	0.02b	5.19b	83.7a	68.7a	84.3a
20	63.6a	0.01b	3.02b	24.1ab	11.3b	31.2a
22	32.6a	<0.01b	3.12b	14.1a	1.55b	20.0a
29	13.8a	<0.01a	0.55a	0.14a	<0.01a	14.2a
36	0.36a	<0.01b	0.15ab	0.07b	<0.01b	0.44a
Total	988a	5.69b	32.0b	413a	330a	370a

†Days after the beginning of the experiment.
‡Means with the same letter in rows for each horizon are not different by the LSD test.
††No data.

TABLE 2. The NO_3-N in the effluent of the treatments for the sampling period in 1994.

Day†	Additions to Ap Horizon			Additions to E Horizon		
	AN and paper	PL and paper	Nothing	Paper on the axis	Paper mixed	Nothing
	mg of NO_3-N					
7	21.3a‡	10.0b	21.8a	20.0b	0.22c	33.3a
9	68.7a	2.85b	43.6a	42.0a	10.6b	62.7a
13	153a	0.46c	76.9b	52.5b	35.7b	134a
16	230a	<0.01b	36.6b	52.5b	38.8b	160a
20	115a	<0.01b	10.0b	30.2b	19.5b	75.1a
23	126a	<0.01b	2.30b	35.5ab	17.4b	75.3a
27	100a	<0.01b	<0.01b	20.7b	9.32b	70.4a
30	77.6a	<0.01b	0.16b	19.5b	8.44b	42.0a
34	83.0a	<0.01b	0.14b	18.8a	5.93a	50.3a
Total	975a	13.3b	192b	292b	146b	703a

†Days after the beginning of the experiment.
‡Means with the same letter in rows for each horizon are not different by the LSD test.

NH_4-N leached from the treatment with added AN (Tables 3 and 4) than the treatment with nothing added. In 1993, and at times in 1994, the treatment with added AN leached more NH_4-N than the treatment with PL added. Greater leaching of NH_4-N from the AN treatment came from the greater amount of NH_4-N added to that treatment originally (1.63 g, 50% of the AN-N added) than to the PL treatment where approximately 25% of the N came from NH_4 [0.96 g, 0.25 times 3.83 g of N in the PL added (Lu et al., 1995)] or to the treatment with nothing added.

Total N

Both the AN and PL plus paper treatments had 4.07 g N added. For these two treatments, 3.26 g N came from AN and 3.83 g came from PL; the rest came from the paper. More N leached out of the AN treatment than either of the other treatments. A total of 34% of the N leached from treatment AN in 1993 and 39% in 1994 (Table 5). Because treatment AN had more N leached and more or equivalent C than the other treatments at the end of the experiments, treatment AN had the highest C to N ratio at the end of the experiments (Table 5). The higher ratio implies lower N availability because of higher immobility (Vanluawe et al., 1996). Greater leaching from the AN treatment resulting in less available N than when PL was added helps explain why Lu et al. (1995) saw stunting of maize growth in field treatments when AN and paper were added, but not when PL and paper were added.

Nitrogen for the E Horizon Treatments

For the analysis of the treatments of the E horizons, in 1993, no differences were found among treatments for either NO_3-N, NH_4-N, or total N leached (Tables 1, 3, and 5). In 1993, a mean of 0.44 g of N was measured in the soil at the end of the experiment with no differences among treatments. In 1994, the highest NO_3-N and NH_4-N concentrations were found in the effluent of the treatment with nothing added to the E horizon (Tables 2 and 4). Not surprisingly, the most total N was also leached through the E horizon with nothing added, and less was leached through the treatments with paper added (Table 5). In 1994, paper, as a C source, captured N leached into the E horizon. We verified this by measuring the total N remaining in the soil at the end of the experiment. The treatment with nothing added had the least N; treatments with paper added to the E horizon had more N (Table 5). The treatment with paper mixed throughout the horizon captured more N than the paper-on-the-axis treatment. The mixed treatment had a lower amount leached and a higher N content at the end of the experiment. It also had a higher C and a higher C to N ratio (Table 5), which implies that more N could still be captured there. The treatment with paper on the axis had equivalent C content and C to N ratio to the treatment with nothing added. However, this analysis used soil outside the ball of paper. Including the paper would increase both.

TABLE 3. The NH_4-N in the effluent of the treatments for the sampling period in 1993.

Day†	Additions to Ap Horizon			Additions to E Horizon		
	AN and paper	PL and paper	Nothing	Paper on the axis	Paper mixed	Nothing
	mg of NH_4-N					
7	47.8a‡	--††	0.02b	19.4a	25.2a	27.1a
8	27.6a	4.94b	0.02b	16.9a	6.73b	5.34b
12	16.9a	9.22b	0.10c	9.91a	9.80a	4.88b
15	19.9a	13.1b	<0.01c	11.2ab	12.7a	9.01b
20	9.42a	9.22a	<0.01b	5.96a	6.47a	6.22a
22	8.84b	12.3a	0.01c	6.81a	7.87a	5.98a
29	3.25a	1.48b	<0.01b	0.97a	1.85a	1.90a
36	1.13a	0.88a	<0.01b	0.52a	0.90a	0.56a
Total	135a	51.1b	0.16c	71.7a	71.5a	61.0a

†Days after the beginning of the experiment.

‡Means with the same letter in rows for each horizon are not different by the LSD test.

††No data.

TABLE 4. The NH_4-N in the effluent of the treatments for the sampling period in 1994.

Day†	Additions to Ap Horizon			Additions to E Horizon		
	AN and paper	PL and paper	Nothing	Paper on the axis	Paper mixed	Nothing
	mg of NH_4-N					
7	2.81a‡	0.92b	0.98b	2.53a	1.44ab	0.75b
9	4.48a	2.89a	6.30a	2.73b	3.14ab	7.80a
13	14.3a	21.0a	5.56b	8.35b	10.2b	21.7a
16	28.9b	46.0a	1.70c	18.8b	17.7b	39.2a
20	37.9a	42.7a	1.83b	26.3a	20.7a	35.5a
23	47.7a	36.7a	1.83b	33.6a	17.7b	34.9a
27	58.5a	39.6b	1.84c	28.6b	27.1b	44.3a
30	50.6a	51.7a	1.12b	35.1ab	27.1b	41.2a
34	55.1a	50.0a	0.39b	36.2ab	26.5b	42.8a
Total	300a	292a	21.6b	192b	152b	268a

†Days after the beginning of the experiment.

‡Means with the same letter in rows for each horizon are not different by the LSD test.

TABLE 5. Conditions at the end of the experiment.

	Additions to Ap Horizon			Additions to E Horizon		
Treatment	AN and paper	PL and paper	Nothing	Paper on the Axis	Paper mixed	Nothing
Year	Total N measured in the effluent (g)					
1993	1.12a†	0.06b	0.03b	0.48a	0.40a	0.43a
1994	1.27a	0.30b	0.21b	0.48b	0.30b	0.97a
	C to N ratio for each horizon					
1993‡	11a	9.1b	7.8b	6.5b	8.2a	6.7b
1994‡	11a	9.0b	8.3b	5.0b	7.0a	5.4b
	Total N (g kg^{-1})					
1993‡	0.77b	0.96a	0.63c	0.43a	0.45a	0.39a
1994‡	0.68b	0.83a	0.54c	0.40b	0.43a	0.36c
	Total C (g kg^{-1})					
1993‡	8.32a	8.76a	4.88b	2.73b	3.68a	2.43b
1994‡	7.45a	7.52a	4.51b	1.96b	2.98a	1.90b

†Means with the same letter in rows for each horizon are not different by the LSD test.

‡ Original conditions for Ap, E horizons: 1993 C/N=7.7, 12, N=0.70, 0.20 g kg^{-1}, and C=5.4, 2.4 g kg^{-1}; 1994 C/N=7.4, 8.7, N=0.56, 0.25 g kg^{-1}, and C=4.1, 2.2 g kg^{-1}.

Because the addition of paper would have added a C source for microbial use in capturing or immobilizing N, capture of N in the E horizon was expected, as seen by Schoenau and Campbell (1996) when they added residues to the soil. Differences among treatments may not have been significant in 1993 because the E horizon had a high C to N ratio at the beginning of the experiment (Table 5). This high initial C to N ratio (relatively high initial C) may have caused the treatment with nothing added to capture or immobilize N as well as the paper-amended treatments. In 1993 even the treatment with nothing added had significantly more N at the end of the experiment than at the beginning.

Temperature

Table 6 shows selected temperature readings for the Ap horizon. Mean temperatures were 20.8°C for 1993 and 24.6°C for 1994. Since the room that housed the experiment was ventilated but not air conditioned or heated, mean temperatures of the columns generally reflect the outside temperatures.

For the Ap horizons, treatments with AN and PL had higher temperatures than the treatment with nothing added (Table 6). Temperature differences were small

TABLE 6. Mean temperature readings for 1993 and 1994.

Year	AN and paper	PL and paper	Nothing
		°C	
1993	20.9a	20.9a	20.7b
1994	24.7a	24.7a	24.5b

†Means with the same letter in rows are not different by the LSD test.

but consistent across replicates and significant for most dates of measurement. Neither treatment with additions to the Ap had consistently higher temperatures than the other.

For the E horizons, in 1993, temperatures were not different among treatments. In 1993, mean temperatures for the E horizon treatments were 20.8°C. In 1994, mean temperatures for the E horizon treatments were 24.6°C. In 1994, temperatures of the two E horizon treatments with paper were slightly higher, 0.05°C, than the horizons with nothing added. Over the duration of the experiment, this small difference was significant and consistent. Higher temperatures could indicate microbial activity, suggesting immobilization of N in the Ap and E horizons (Flynn and Wood, 1996; Schoenau and Campbell, 1996) that had additions of paper.

For the first 7 days of measurement in 1993 and the first 12 days in 1994, Ap horizon temperatures were higher than E horizon temperatures. This result agrees with Winkler et al. (1996) who reported higher initial respiration rates in the Ap vs. the E horizon. After this time, the trend reversed; temperatures in the E horizon were higher than in the Ap for 36 days in 1993 (the end of the experiment) and for 24 days in 1994. After these 24 days in 1994, there was no consistent trend. Temperature differences between horizons were small, ranging from 0.1 to 0.7°C, with most differences being ~0.2°C. However, these differences were often significant and consistent across replicates. Since treatments with N and paper can support greater microbial activity than unamended soil (Robertson et al., 1993), the change of higher temperatures from Ap to E horizon may reflect a migration of N down the column and an increase of respiration by microbial activity lower in the column later in the experiment.

Respiration

Carbon dioxide evolution was initially greater from treatments with AN or PL and paper additions in the Ap horizon than from the treatment with nothing added (Table 7). After three weeks, CO_2 evolution from only the PL treatment was greater than the treatment with nothing added.

TABLE 7. Carbon dioxide evolution in 1993 for the treatments of the Ap horizon.

Day	AN and paper	PL and paper	Nothing
	------- μ moles CO_2 m^{-2} sec^{-1} -------		
13	6.96a†	4.46a	1.67b
21	2.34a	2.27a	0.69b
27	4.02ab	5.78a	2.61b
34	3.04b	4.15a	2.88b
41	2.83b	9.59a	2.88b
Mean	3.48b	5.32a	2.88c

†Means with the same letter in rows are not different by the LSD test.

The decrease in CO_2 evolution for treatment AN paralleled the leaching of NO_3-N. While the NO_3-N concentration in the effluent was high, CO_2 evolution was high. When the NO_3-N concentration in the effluent diminished, CO_2 evolution dropped to the level of the treatment with no additions. The drop in CO_2 evolution was likely caused by a reduction of available N as it was leached or as it was immobilized by microbes. After respiration dropped in the AN and paper treatment, it remained high in the PL and paper treatment because of the relatively slow mineralization of PL (Smith and Peterson, 1982). Since most N in PL is organic (Wood and Hall, 1991; Cummins et al., 1993) and must be converted to the inorganic form, conversion becomes the limiting step in N availability for microorganisms. The rate of mineralization is also governed largely by microbially mediated processes (Stevenson, 1986).

CONCLUSIONS

In 1993 and 1994, the Ap horizon treatment with AN and waste paper leached more N (32 and 39% of the AN-N added, respectively) than either of the other treatments. This increased leaching was a result of more N being in leachable form (NO_3-N or NH_4-N). In 1993, after 2 to 3 weeks, respiration of the AN treatment measured at the surface of the column decreased to the level of the treatment with no additions. At the same time, the N level in the effluent of the AN and waste paper treatment decreased because of N loss and immobilization.

In 1994, waste paper in the E horizon captured or immobilized some of the N that was leached into it. Treatments with paper in the E horizon had lower amounts of N in their effluent and higher N contents remaining in the soil at the end of the experiment. The treatment with paper mixed throughout the horizon captured more N than the treatment with paper on the axis.

At the beginning of the experiment, temperatures were higher in the Ap horizon. After 7 to 12 days, temperatures were higher in the E horizon. This result helped confirm that the paper in the E horizon was effective in capturing N (perhaps by an increase of microbial respiration in the E horizon as the experiment progressed).

If growing plants cannot take up N fast enough, additions of PL and paper to the soil allow slower leaching of N than AN plus paper additions to the soil and pose less of an environmental threat. These results suggest that wastes with high N content, such as confined animal manures, are a better source of N for C to N adjustment of waste paper than soluble commercial fertilizers. The mixture of PL and waste paper is also a way to combine two wastes beneficially.

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