UTILIZATION OF ORGANIC BYPRODUCTS TO REDUCE SOIL EXTRACTABLE P FROM REPEATED APPLICATION OF MANURES

J. H. Edwards*, L. D. Norton**, G. E. Aiken***, and T. R. Way*

*USDA-ARS, Auburn, AL; **USDA-ARS, West Lafayette, IN; ***USDA-ARS, Booneville, AR

ABSTRACT

Long-term application of animal manures to agricultural land can result in build-up of soil P. As a result, states are limiting the quantity of animal manure or commercial fertilizer P that can be applied to agricultural land when soil extractable P exceeds predetermined limits. Alternative uses of animal manure are being developed in cases where land utilization will cause significant environmental risk. Products are being developed by mixing, blending, or co-composting organic wastes including waste paper to reduce volume or to overcome chemical problems associated with the byproduct or to overcome soil problems from repeated applications. We determined the effectiveness of blending different organic wastes to remediate soil with extractable soil P levels > 200 mg ha^{-1}. One experiment included a series of forage systems as well as the soil amendments. A soil amendment was developed that blended waste paper with $(NH_4)_2SO_4$. The C:N ratio of the soil amendment was adjusted to 20:1. All soil amendments were incorporated into the top 10 cm of soil (Zulch fine sandy loam). Initial soil samples were collected in the spring by horizon prior to amendment application to a depth of 90 cm. Soil samples were collected in the Ap horizon five months after application of organic soil amendments. Significant differences in Mehlich-3 soil extractable P were found only in the 0-6.5 and 6.5-15 cm soil depths. Using $(NH_4)_2SO_4$ to adjust the C:N ratio was the most effective waste paper treatment to reduce soil extractable P. Water soluble P was significantly affected in both the 0-6.5 and 6.5-15 soil zone by the application of waste paper blended with $(NH_4)_2SO_4$.

INTRODUCTION

Confined animal agriculture,(i.e., beef cattle, dairy, poultry, and swine) are the major sources of animal manure by-products in the USA. Manure management from animal production facilities has emerged because in recent years animal and crop production units are largely separated. Manures generated from the confinement of animals can result in significant degradation of soil, water, and air quality if not properly managed.

Environmental concerns associated with the land application of manures encompass many aspects of nonpoint source pollution, i.e., pollution of surface water with soluble and/or particulate P (Sharpley et al. 1998; US EPA 1993), leaching loses of P and NO_3-N in subsurface drainage and to ground water (Sims et al. 1998), reduced air quality by emission of volatile organic compounds (Hatfield et al. 1998), excess salt contamination from over application (Moore 1998) and increased eutrophication in estuary waters (Sharpley et al. 1998). Thus, maintaining the quality of the environment is a major consideration when developing management practices to effectively use animal manures as a nutrient resource in agricultural production systems (Edwards and Someshwar 2000; Sharpley et al. 1994; Sharpley and Tunney 2000; Daniel et al. 1994; Sims 1997; and Eck and Stewart 1995).

In the northeast U.S., much of the soil analyzed for plant-available P exceeded P levels needed for agricultural production, i.e., Delaware 64%, Ohio 68%, and Pennsylvania 56% (Sims 1992; Sharpley et al. 1994; Stout et al. 1998). In Arkansas, Mehlich-3 extractant soil tests showed that in 1992 more than 63% of soil samples from counties with high intensity poultry production were high in soil test P (STP) and 28% were very high (Snyder et al. 1993).

Many states are putting limits on the quantity of manure or commercial fertilizer P that can be applied to agricultural land. In Texas, the Texas Natural Resource Conservation Commission (TNRCC) has set limits that when STP levels reach 200 mg ha^{-1} extractable P (400 lb/ acre) then P application is limited to plant removal (TNRCC

1998). If the STP is greater than 200 mg ha^{-1} extractable P, commercial or manure P cannot be applied until the STP level is below the 200 mg ha^{-1} extractable P limit.

The waste paper fraction of municipal solid waste (MSW), as collected by municipalities, is not suited for direct land application because it is very resistant to decomposition by soil microorganisms and creates barriers that emerging seedlings are not able to penetrate. A processing step is required that may include grinding, chopping, or shredding the paper; however, it becomes very light and can be easily blown about, and storage and transportation may become difficult. Some properties of ground waste paper, (i.e., low bulk density), make it very difficult to use on a large scale because specialized land application equipment is required (Chen et al. 1989; Giusquiani et al.1995; Lu et al. 1995).

The elemental composition of waste paper that was used as a raw material for the soil amendments is given in Table 1. The table also includes some of the limits of heavy metals that can be applied to agricultural land where sewage sludge has been applied (US EPA 1993; 1995). When several different waste paper products were evaluated for their chemical composition (i.e., telephone books, old newsprint, old food containers, advertisement inserts, and junk mail) Al contents ranged from 4,525 to 10,120 mg kg^{-1}.

In previous studies (Edwards et al. 1995; Edwards 1997; Lu et al. 1995; 1997) when an inorganic source of N (i.e., anhydrous ammonia) was used to adjust the C:N ratio of the waste paper, a toxic concentration of Al was released from the waste paper into the soil solution. This released Al resulted in N, Ca, Mg, and P foliar deficiency symptoms in corn seedlings. The N deficiency was due to by immobilization of N by the soil microorganisms during the decomposition process. The Ca and Mg deficiency was caused by damaged root systems of young corn induced by excess Al. The P deficiency was caused by precipitation of P from soil solution due to excess the Al.

In the evaluation of waste paper as a source of Al, the ionic strength of the soil solution where waste paper was applied at 2.44 kg m^{-2} was determined to be14.83 mmol L^{-1}. The ionic strength was influenced more by Na concentration than either Ca, Mg, or K concentration (the $\sum$total concentration of the three ions were 0.05 mmol L^{-1}). At pH 7.85, the major P species in the soil solution were HPO$_4^{-2}$ (0.16 mmol L^{-1}) and H$_2$PO$_4^{-1}$ (0.025). Total Al ionic activity was 0.23 mmol L^{-1}, and the major Al specie in the water solution from waste paper was Al(OH)$_3$°, with an ionic activity of 0.228 mmol L^{-1} at pH 7.85 (Lu et al. 1997).

For waste paper amendments to effectively reduce soil extractable P, the release of Al from the waste paper must be controlled. To determine Al release rate waste paper was extracted with NH$_4^+$ ion for 24 hours. The solution pH of the waste paper increased from 7.6 to 10.3 when the concentration of NH$_4^+$-N was increased from 0.01 to 1.0 M. The Al concentration increased from 1.02 to 10.19 mg L^{-1} as the concentration of NH$_4^+$-N increased (Lu et al. 1997). The soluble anion species of Al(OH)$_4^-$ would be formed from Al(OH)$_3$. The ionic activity of Al(OH)$_4^-$ ranged from $\leq$ 0.001 mmol L^{-1} at pH 7.6 to 2 mmol L^{-1} at pH 10.3 in the NH$_4^+$-N extracting solution. Thus, the release of Al, or different Al species from waste paper, could be potentially controlled by the NH$_4^+$-N ion. Mixing the ground waste paper with (NH$_4$)$_2$SO$_4$ before land application was the means used to insure that the surface of waste paper was reduced and that the adsorbed Al was released to the soil solution.

It is important to note that the high levels of monomeric Al in soil solution caused severe Al toxicity symptoms to plants only in the treatments in which the C:N ratio was adjusted with inorganic forms of N. When poultry litter was used, Al toxicity to plants was eliminated. This suggested that the relatively high percentage of water soluble organic C (18%), in addition to high levels of P in poultry litter, played an important role in chelation of the monomeric Al species. Binding of Al with organic acids or P eliminates toxicity associated with monomeric Al. In fact, P is currently being added to a nonchemical weed control product developed from recycled paper to reduce the toxic effects of Al contained in the paper (Smith et al. 1997; 1998).

What is needed is a form of waste paper that can be applied to land using existing, easily modifiable, or readily available equipment. Several companies use a process step that involves pelletization (i.e. a pressurized extrusion process). This added step increases the cost of using waste paper and thus

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prohibits its use for general land application. In the current experiments, a waste paper recycling company has agreed to manufacture the waste paper soil amendments per our specifications to be evaluated on field sites with high extractable soil P. Thus, the objectives of our current research are to utilized soil amendments made from blending waste paper with $(NH_4)_2SO_4$, the N source for C:N adjustment to remediate soil with extractable soil P levels > 200 mg ha^{-1}.

MATERIALS AND METHODS

History of the Egg Laying Facility for the on-Farm Study

The experimental site is a confined animal egg laying operation with 500,000 birds that produce approximately 400,000 eggs a day and generate about 38 tons of wet (70% moisture) manure a day with approximately 4% N and 2% P. The manure is removed from the 10 houses by a flush system and washed into a primary lagoon. The facility has a primary and secondary lagoon with about six months' storage capacity. The egg laying operation has been land applying manure for 20 years. The manure was applied close to the sites of the egg laying as a matter of convenience. Consequently, soil test P levels on 200 acres of land close to the egg-laying operation have soil extractable P levels above 200 mg L^{-1}.

On-Farm Experiments

A series on-the-farm field studies were established in 1999 where the initial soil extractable P was greater than 200 mg kg^{-1}. They include an organic and inorganic soil amendment experiment to reduce the soil extractable P and an experiment to determine the maximum of P amount that can be removed by forage systems during a growing season.

The soil is a Zulch fine sandy loam (Thermic Udertic, Paleustalfs). The soil is moderately deep to weathered shale (76 to 102 cm), moderately well drained, very slowly permeable soil that was formed from alkaline clayed loamy deltaic sediments, with a slope of 1 to 3%.

Before the application of the soil amendments, soil samples were collected from the experimental areas in 15 cm increments to a depth of 180 cm to establish initial chemical and physical properties. Chemical properties include cation exchange capacity (CEC), pH, organic C, total N, KCl extractable nitrate and ammonium, Mehlich-3 extractable P and waster soluble P. Only the Mehlich-3 and water soluble P will be presented in this paper.

Manufactured Organic and Inorganic Soil Amendments

The organic and inorganic soil amendments were manufactured by Tascon Inc, Houston, TX per Dr. J.H. Edwards'(USDA-ARS) specifications and they contained both waste paper and $(NH_4)_2SO_4$ as a N source to adjust the C:N ratio of the soil amendment to 20:1.

Application of Soil Amendments

The manufactured soil amendments were applied annually in the spring and incorporated into the top 15 cm of soil with a vertical-action tiller. When adjusted for ash and moisture content each soil amendment was applied at rates a rate of 2.44 kg m^{-2} (0.5 lbs ft^2). This resulted in 14,148 kg ha^{-1} of total carbon for each soil amendment that was land applied. The C:N ratio of the soil amendments was adjusted to 20:1 with $(NH_4)_2SO_4$ before it was applied.

Forage Systems for Maximum P removal

Treatments for the forage systems include: 1) bermudagrass (soil amendment), 2) bermudagrass (control-soil amendment), 3) bermudagrass (fall rye-soil amendment), 4) bermudagrass-fall rye and arrowleaf clover-soil amendment), 5) bermudagrass (fall-rye and arrowleaf clover-spring Kobe annual lespedeza- spring- soil amendment). The soil amendment used in this experiment was waste paper where the C:N ratio was adjusted with $(NH_4)_2SO_4$ (20:1).

Experimental Design

The experimental design was a randomize complete block of five organic soil amendment treatments with four replications. Elemental concentrations of the waste paper and soil extracts were determined by a dry-ashing method (Hue and Evans 1986). The concentrations of Ca Mg, K, P, Mn Fe, Cu, Fe, Zn, Pb, Al, Na, Cd, and Cr were

measured by inductively coupled argon plasma (ICAP) spectrophotometry. Soil samples were extracted with Mehlich-3 solution (Mehlich 1984) and with water and the elemental concentrations of both were measured by ICAP spectrophotometry.

Statistical Analyses

Statistical analyses were performed using the Statistical Analysis System (SAS 1988) for the field and laboratory experiments. Orthogonal polynomial contrasts were used to determine whether the response to treatments was linear, quadratic, or both. The general linear models (GLM) procedure of regression was used to estimate the correlation between Mehlich-3 soil extractable P and water extractable P. Unless otherwise noted, all statistical tests were reported at $P \leq 0.05$.

RESULTS

Initial Labile Extractable Al from Waste Paper

In a lab study, to determine if waste paper could be used as a source of Al, waste paper samples were extracted with H_2O and 0.1 M NH_4Cl to determine how much of the Al was removed from the waste paper (Table 2). Waste paper extracted with 10 m L^{-1} of deionized water for two hours on a reciprocating shaker resulted in a labile Al fraction less than 0.1 mg L^{-1}. When an additional waste paper sample was extracted with 0.1 M NH_4Cl and handled the same way as the water extract, the labile Al fraction ranged from 2.41 to 2.47 mg L^{-1} with different forms of waste paper and a control of pine bark. These water and 0.1 M NH_4Cl extractions were conducted without trying to control the pH of the surface of the waste paper or pine bark. When the pH of the surface of waste paper was adjusted with 0.1 N HCl and then extracted with 0.1 M NH_4Cl, and 0.1 M NH_4Cl that had been brought to volume with 0.1 N HCl, the labile Al concentration is given in Table 3. By using this method to decrease the surface pH of the waste paper, labile Al ranged from 1.47 to 5.66 mg L^{-1} with the different forms of waste paper and pine bark.

The potential for exploiting the interactions of P (associated with excess poultry litter) and Al (associated with waste paper) to reduce nutrient imbalances in soils clearly exists. The aluminum in waste paper that is toxic to plants can be detoxified by complexing with organic acids and P contained in poultry litter. Through both the direct binding of P with Al, and the indirect effects on soil solution P resulting from a reduction in free organic acids, Al may also reduce problems associated with excessive soil P.

Initial Mehlich-3 and Water Soluble Soil Extractable P Levels

To establish the soil extractable P level and depth of leaching of P from long-term manure application, 20 initial composite soil samples were collected over the experimental area. In order to follow the guidelines established by TNRCC for soil test P level (greater than 200 mg kg^{-1}), soil samples were collected by 15-cm depth increments to a final depth of 180 cm and by horizons zone greater than 90 cm. The Mehlich-3 soil extractable P levels are given in Fig. 1. The Ap soil horizon was further divided into the surface 0-6.5 cm and lower 6.5-15 cm. The Mehlich-3 soil extractable P level in the surface 0-6.5 zone averaged approximately 1488 mg P kg^{-1} while the soil 6.5-15 cm surface zone averaged 1369 mg P kg^{-1}. Another indication that the soil P levels were not leaching in this soil was the concentration of water soluble P that was maintained in the surface 0-15 cm zone (Fig. 2). However, P concentration from each soil zone suggests that there may be a problem with P deficiency conditions. To determine the extent that remedation had occurred with the application of organic amendments, soil samples were collected only from the 0-15 cm soil zone in July 1999, four months after the first application of soil amendments.

Forage Systems for Maximum Mehlich-3 Extractable P Removal

In the forage utilization study established for maximum removal of soil extractable P, a soil organic amendment was included to separate the P that was removed by the forage system and the P removed by the soil amendment. Soil samples were collected four months after the application of the waste paper adjusted with $(NH_4)_2SO_4$. The evaluation of the waste paper amendment to remove soil extractable P was restricted to the surface soil (Fig. 3). In the top 0 to 6.5 cm Ap soil horizon, the waste paper amendment reduced soil extractable P by 14 % and in the 6.5 to 15 cm Ap soil horizon, soil extractable P was reduced by 18%

within the first four months after application.

Water Soluble P from Experimental Area with P > 200 mg ha⁻¹

Measurement and prediction of P concentration in runoff waters is a key factor in determining mobility and transport of solution P and suspended solid P from fields, pastures, and woodland. In order to determine the mobility of the Mehlich-3 soil extractable P and water soluble P from long-term manure application, water soluble extractable P was determined on the forage utilization experimental sites. The surface horizon (0-6.5 cm and 6.5-15 cm Ap horizon) water soluble P concentration are shown in Fig 4.

In the forage system site for maximum P removal, a blended waste paper and $(NH_4)_2 SO_4$ soil amendment was applied at 6.1 metric tons ha⁻¹. The surface horizon (0-15 cm) was divide into two soil zone (0-6.5 cm and 6.5 -15 cm). The water soluble extractable P was increased by 1.13 mg P in the 0-6.5 cm zone and was decreased by 0.55 mg P in the 6.5-15 cm zone four months after the application of the blended waste paper and $(NH_4)_2 SO_4$ when compared to the non-amendment control.

DISCUSSION

The National Research Council (1993) has suggested that reducing nutrient loading from animal manures on agricultural land will be difficult to achieve unless alternative methods are developed or improvement in the efficiency in feed conversion to animal protein are made. Economic restrictions will result in application of manures on inappropriate sites, namely those with elevated levels of N and P from repeated application or sites that are susceptible to runoff and leaching losses of nutrients. Thus, the potential for environmental contamination is high based on content method of disposal on agricultural land (Eck and Stewart 1995; Sims and Wolf 1994).

Nitrogen is the nutrient most susceptible to loss (i.e., ammonia volatilization) during storage, transport, and land application. Because of N losses, N:P ratios in manure are generally lower than crop requirements, resulting in buildup of excess P in soil especially with repeated application. Mixing these high nutrient manures with other organic wastes of inferior quality could enhance their value for agricultural and horticultural uses, especially in areas where land application of these manures can cause significant environmental risk. A goal of this research is to develop best management practices that will improve the nutrient efficiency of manure by-products when applied to agricultural land as a nutrient source. Current manure management practices are not designed to effectively conserve and use nutrients from animal manure.

Nutrient imbalances in corn seedlings were observed when ground waste paper (GWP) was surface-applied in the spring and the C:N ratio was adjusted to ≤ 30:1 with three inorganic N sources(i.e., urea, NH_3, and NH_4NO_3, and one organic source, poultry litter). The inorganic N sources gave rise to P, Ca and S imbalances (Lu et al. 1994; 1995; 1997; Edwards et al. 1995). Nutrients needed by the plants (N, K, P, etc.) for growth were supplied in addition to N needed to adjust the C:N ratio of GWP. When compared to poultry litter, all inorganic N sources stunted corn growth during the first 4 to 6 weeks after emergence. When the N supply for the corn crop was from urea or NH_4NO_3, the induced nutrient imbalances were reduced compared to a GWP control where the C:N ratio was not adjusted; however, the corn plants were stunted, delayed in maturity, and had lower grain yield than when poultry litter was the N source. Corn plants receiving anhydrous ammonia as the N source did not recover and no grain yield was obtained.

Soil solution Al was ten times greater when anhydrous ammonia was the N source compared to the control using standard cultural practices (Lu et al. 1994). Whole corn plant (above ground) tissue samples were collected for chemical analyses 40 days after emergence. The normal Al concentration in plant tissue is below 0.4 mg kg⁻¹; however, Al concentrations were 1.08, 0.89, and 0.77 mg kg⁻¹, respectively, when NH_3, NH_4NO_3, and urea were used to adjust C:N ratio of GWP, and was below 0.4 mg kg⁻¹ when poultry litter was used. Corn roots exhibited signs of Al toxicity, i.e., severe stunting and thickening at the root apex due to the inhibition of cell division.

The effects of GWP and N source on soil solution ionic activities were determined at 40 days after planting in a field study; seed germination and extractable Al for GWP in laboratory studies were

also evaluated to determine their effects on corn seedling stunting and nutrient imbalances during early growth stages (Lu et al. 1995). The Al extracted from GWP increased as the NH_4OH concentration in the extracting solution increased which was characteristic as a quadratic relationship with an r^2 of 0.90. The $\Sigma\alpha_{ca}/\Sigma\alpha_{cation}$ ratio in soil solution for all N sources was greater than the 0.15 reported by Bennett and Adams (1970), where incipient NH_3 phytotoxicity can occur.

At 40 days after planting, a two-fold increase in soil monomeric Al ($\Sigma Al\alpha_{mon}$) ionic activity and a five-fold increase in soil P ($\Sigma P\alpha$) ionic activity were measured in GWP treatments as compared to no N GWP treatments. When NH_3 was the N source used to adjust the C:N ratio of GWP, the $\Sigma Al\alpha_{mon}$ ionic activities were increased by a factor of five as compared to NH_3 applied alone. When PL was the N source, the Al_T ($\Sigma Al\alpha_{species}$) ionic activity was 119 mmol L^{-1} compared to the $\Sigma Al\alpha_{mon}$ ionic activity of 0.53 mmol L^{-1}. It appears that $\Sigma Al\alpha_{mon}$ ionic activity induce nutrient disorder and caused severe stunting of corn seedlings during early season growth. The relatively high water-soluble organic carbon in PL (18 %) may have acted as a chelating agent to reduce the $\Sigma Al\alpha_{mon}$ ionic activities in the GWP, or as a soluble carbon source for increasing microbial utilization of all the N, thus slowing the formation and accumulation of phytotoxic levels of byproducts (Lu et al. 1997).

In addition to the Al in paper there are other industrial waste by-products that have chemical properties, i.e., high pH or Ca content, that can be used to amend soil with nutrient excesses or imbalances. In laboratory studies, two coal combustion by-products, i.e., fluidized bed combustion flyash and flue gas desulfurization products were effective in reducing Mehlich-3 P by 45%, Bray-1 P by 50%, water extractable P by 72%, and equilibrium P concentration by 37% (Stout et al. 1998). These reductions resulted in the conversion of ready desorbable soil P to less soluble Ca-bound or Al and Fe-bound pools.

In lab studies where organics were applied, increasing the rate of manure or alfalfa residue additions to soil increased soil pH, P in equilibrium solution, extractable P, and decreased exchangeable Al (Iyamuremye et al., 1996a). The application of manure or alfalfa residue increased resin P_i, $NaHCO_3$-P_i (biologically available) and $NaHCO_3$-P_o (readily mineralizable), and $NAOH$-P_i (chemisorbed) in all five soils with high P fixation characteristics (Iyamuremye et al., 1996b). In a P speciation study, the addition of manure decreased total soluble Al and Fe in soil solution and increased base cation and SO_4 while increasing total P in soil solution (Iyamuremye et al. 1996c).

Two mechanisms have been proposed for the role that organics play in increasing P concentration in soil solution, i.e., 1) organic acids which replace P sorbed on metal hydroxides, and 2) the dissolution of P sorbed at the metal-oxide surface (Iyamuremye and Dick 1996).

In another study, addition of manure decreased total soluble Al and Fe in soil solution but increased basic cation and SO_4 concentrations as well as total P in soil solution (Iyamuremye et al. 1996c). Manures are high in P and also contain many organic acids, both of which contribute to excess soil P. Organic acids in soil are thought to indirectly increase P concentrations in soil solution by either replacing P sorbed on metal hydroxides, or by causing dissolution of P sorbed at the metal oxide surface (Iyamuremye and Dick 1996).

CONCLUSION

While chemical complexation of Al with P may result in detoxification of Al, as discussed earlier, it may also function by detoxifying excessive P in soil. Recently, the idea of using Al to bind with P has been suggested to reduce the toxic effects of P. In fact, in some states, consideration is being given to treating poultry litter with Al amendments to precipitate P, thereby reducing the risk of P contamination before the manure is applied to land.

The potential for exploiting the interactions of P (associated with excess poultry litter) and Al (associated with waste paper) to reduce nutrient imbalances in soils clearly exists. The aluminum in waste paper that is toxic to plants can be detoxified by complexing with organic acids and P contained in poultry litter. Through both the direct binding of P with Al, and the indirect effects on soil solution P resulting from a reduction in free organic acids, Al may also reduce problems associated with excessive soil P. In light of the potentially beneficial effects of poultry litter on Al contained within waste paper, and the beneficial effects of waste paper in reducing P associated with poultry litter, further

research in this area is warranted.

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Table 1. The chemical composition of the waste paper used to blend the organic and inorganic soil amendments along with the US EPA limits.

Elemental Content	EnviroGuard Plus®				US EPA[3]
	Subsample	Subsample	Subsample	X	Limits (mg kg^{-1})
	Macronutrients, (mg kg^{-1})			mg kg^{-1}	
P[1]	7,560	7,860	7,340	7,587	
K[1]	11,510	13,270	13,660	12,813	
Ca[1]	41,310	48,150	52,970	47,477	
Mg[1]	1,430	1,790	1,950	1,723	
	Micronutrients, (mg kg^{-1})				
Cu[1]	165	134	193	164	4,300
Fe[1]	456	466	534	485	
Mn[1]	86	106	130	107	
Zn[1]	142	169	194	168	7,500
B[1]	36	40	38	38	
Mo[1]	7.5	7.0	7.0	7.2	75
	Non-essential nutrients, (mg kg^{-1})				
Al[1]	4,870	4,260	4,350	4,493	
Na[1]	5,552	5,874	5,220	5,548	
Ba[1]	18.5	15.5	14.5	16.2	
Si[1]	4,720	4,500	4,360	4,526	
	Heavy Metals, (mg kg^{-1})				
As[2]	ND[4]	ND	ND	ND	75
Cd[2]	ND	ND	ND	ND	85
Co[2]	ND	ND	ND	ND	
Cr[1]	10.0	9.5	10.5	10.0	3000
Se[2]	ND	ND	ND	ND	100
Ni[2]	ND	ND	ND	ND	420
Hg[2]	ND	ND	ND	ND	57
Pb[1]	9.0	12.0	9.0	10.3	840

[1] Elemental concentration of the EnviroGuard Plus® were determined by a dry-ashing method of Hue and Evans, 1986. The concentrations of Ca, Mg, K, P, Mn Fe, Cu, Fe, Zn, Pb, Al, Na, Si and Cr were measured by inductively coupled argon plasma (ICAP) spectrophotometry.

[2] Elemental concentration of the EnviroGuard Plus® were determined by a dry-ashing method of Hue and Evans, 1986 using 5 grams samples. The concentrations of As, Cd, Co, Cr, Se, Ni were measured by Atomic Absorption spectrophotometry. The concentration of these were below the detection limits of the instrument.

[3] Federal Register vol. 58, No. 32 p. 9382, Table 1 of 503.13 - ceiling concentrations of pollutants.

[4]ND - Non-determined

Table 2. Extractable labile Al from waste paper and pine bark.

Waste Byproducts	Forms of Aluminum	
	Labile Al (mg L^{-1})	Total Al (mg kg^{-1})
Water extractant[1]		
Pine Bark	0.11	592.85
Pellet waste paper	0.11	2042.25
Crumble waste paper	0.09	1295.20
0.1 M NH$_4$Cl extractant[2]		
Pine Bark	2.46	684.4
Pellet waste paper	2.47	2644.45
Crumble waste paper	2.41	2127.4

[1] A one gram subsample of waste paper was extracted with10 mL of deionized water.

[2] A one gram subsample of waste paper was extracted with10 mL of 0.1 M NH$_4$Cl that was made in deionized water.

Table 3. Extractable labile Al from waste paper and pine bark when the pH of the surface of the waste was altered with HCl.

Waste Byproducts	Forms of Aluminum	
	Labile (mg L^{-1})	Total Al (mg kg^{-1})
0.1 N HCl extractant[1]		
Pine Bark	1.58	947.25
Pellet waste paper	1.47	3194.50
Crumble waste paper	1.98	2402.97
0.1 M NH$_4$Cl extractant[2]		
Pine Bark	2.62	331.30
Pellet waste paper	2.67	1343.15
Crumble waste paper	3.36	840.52
0.1 M NH$_4$Cl extractant[3]		
Pine Bark	5.29	757.70
Pellet waste paper	5.09	1632.6
Crumble waste paper	5.66	378.45

[1] A one gram subsample of waste paper was extracted with10 mL of 0.1 N HCl.

[2] A one gram subsample of waste paper was extracted with10 mL of 0.1 M NH$_4$Cl that was made in deionized water.

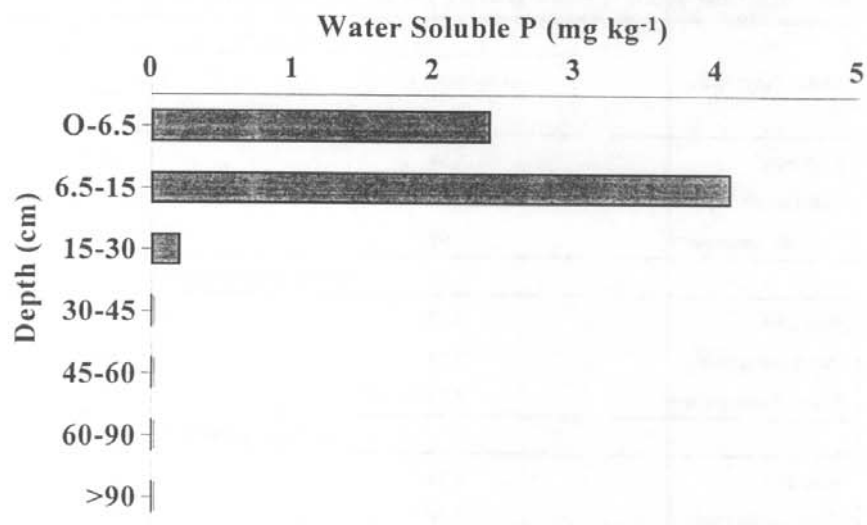[3] A one gram subsample of waste paper was extracted with10 mL of 0.1 M NH$_4$Cl that was made in 0.1 N HCl.

Water Soluble P (mg kg⁻¹)

Figure 1. Initial water soluble soil extractable P from the experimental area by 15 cm increments to 90 cm.
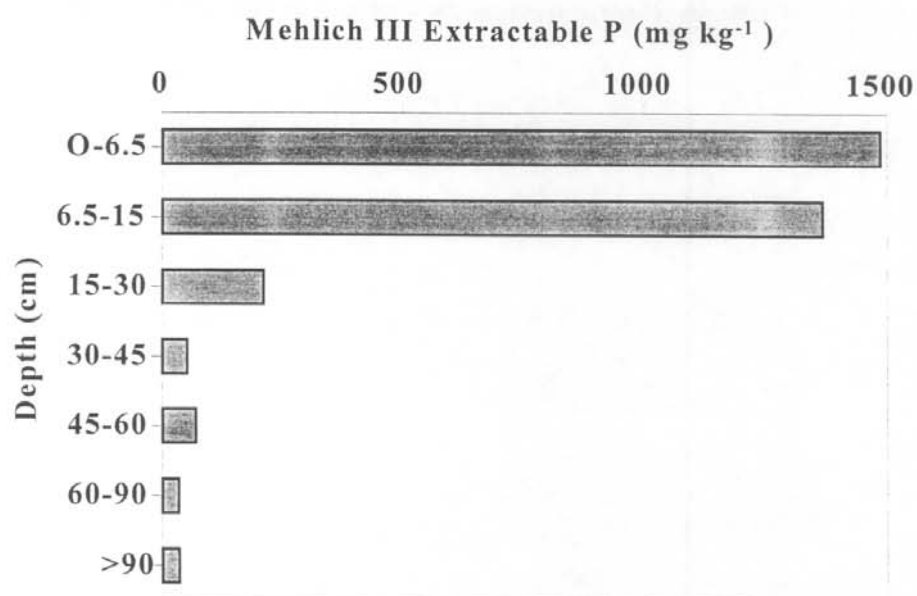
Mehlich III Extractable P (mg kg⁻¹)

Figure 2. Initial Mehlich III soil extractable P from the experimental area by 15 cm increments to 90 cm.
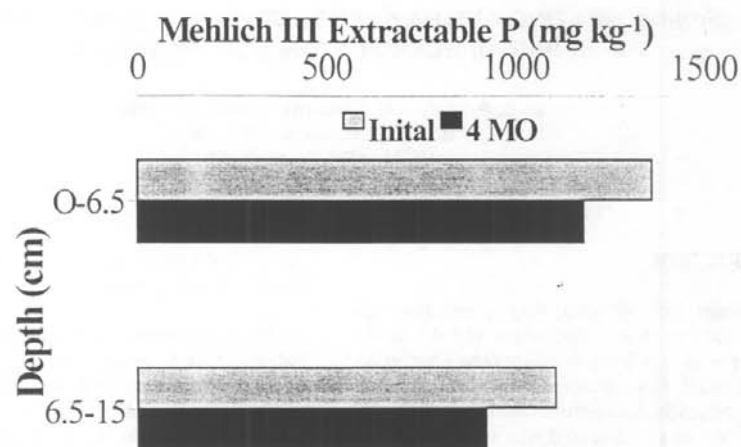
Mehlich III Extractable P (mg kg⁻¹)

Figure 3. Mehlich III soil extractable P four months after soil amendment application to land area with soil extractable P > 200 mg ha⁻¹.

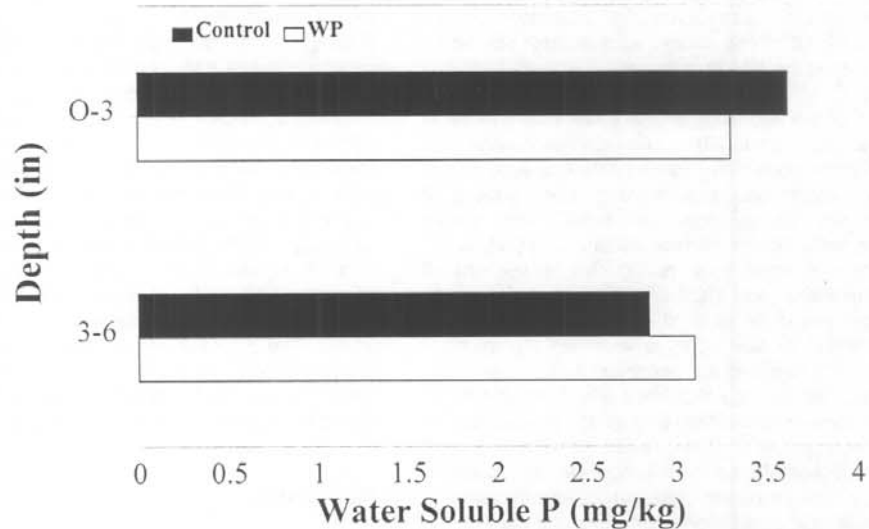**Figure 4.** Water soluble P four months after application of waste paper soil amendment adjusted to C:N 20:1 with $(NH_4)_2SO_4$ in the experimental with P > 200 mg ha⁻¹.