Scientific Research and Essays Vol. 5 (11), pp. 1302-1306, 4 June, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 © 2010 Academic Journals

Full Length Research Paper

Effect of paper mill lime sludge as an acid soil amendment

A. Mohammadi Torkashvand[1]*, N. Haghighat[2] and V. Shadparvar[2]

[1]Young Researchers Club Rasht Branch, Islamic Azad University-Rasht Branch, Rasht, Iran.
[2]Islamic Azad University-Rasht Branch, Rasht, Iran.

Accepted 29 April, 2010

The possibility of using paper mill lime sludge as a soil amendment in an acid soil was investigated. Sludge used contained 58.4% calcium carbonates plus a small amount of heavy metals. A pot experiment was conducted with an acid soil and *Sorghum vulgaris variety speed seed* as test plant. Treatments with three replicates consisted of 0, 0.5 and 1, 2 and 4% paper mill lime sludge (L_0, $L_{0.5}$, L_1, L_2 and L_4, respectively). Shoot were harvested after 60 days and dry matter yield was determined after drying of the harvested shoots at 70°C for 48h. Subsamples of dry shoots were ground and then dry-ashed in a furnace at 550°C and then extracted with 2N HCl. The concentrations of P, K, Fe, Mn and Zn were measured in the extracts. Results showed that paper mill sludge significantly increased pH, which was proportional to the application rate of paper mill sludge. The application of 2% sludge (based on soil dry mass) remarkably increased shoot dry matter and P, K, Fe, Mn, K and P uptake.

Key words: Acid soil, paper mill lime sludge, soil amendment.

INTRODUCTION

About 30% of the world's arable soils are acidic (VonUexkull and Mutert, 1995) characterized by an excess of H^+, Al^{3+} and Mn^{2+} and lack (deficiencies or unavailabilities) of certain mineral elements, particularly calcium (Ca), magnesium (Mg) and phosphorus (P). Acid soils are deleterious to plant growth (Foy, 1992). The most common management practice to ameliorate acid soils is the surface application of lime and other calcareous materials (Bolan et al., 2003). The main aim of soil liming is to neutralize acidic inputs and recovering the buffering capacity to the soil (Ulrich, 1983).

Applications of industrial wastes as fertilizer and soil amendment have become popular in agriculture. Paper mill sludge is produced as a by-product of paper production that disposal of this material presents a problem for the mill (Battaglia et al., 2007; Calace et al., 2005; Mahmood and Elliot, 2006). Disposal by land filling, the most common disposal method, is costly and faces increasingly stringent environmental regulations (Feldkinchner et al., 2003). Lime sludge is the solid waste produced as part of the process that turns wood chips into pulp for paper. The major component of lime mud is calcium carbonate ($CaCO_3$) and it is estimated that about 0.47 m^3 of lime mud is generated to produce 1 ton of pulp (Wirojanagud et al., 2004).

Land application is one of the several limited methods available to manage solid waste (Schoof and Houkal, 2005) and is more economically and ecologically sound than landfill practice (Zule et al., 2007). For land application of sludges produced from pulp mills, Simpson et al. (1982) reported that combined Kraft paper mill secondary sludge-fly ash applied at a rate of 108 metric dry ton ha^{-1} significantly increased the yield of fescue and corn. The high alkalinity of lime mud has been utilized to precipitate heavy metals in tanning wastewater (Wirojanagud et al., 2004), remove phosphorus from piggery effluent (Weaver and Ritchie, 1987), stabilize sewage sludge (Fang and Wong, 1999) and immobilize heavy metals (Little et al., 1991; Fang and Wong, 1999). Mcbride and Spiers (2001) demonstrated that lime mud has heavy metal concentrations comparable to or lower than those of agricultural lime. Battaglia et al. (2007) reported the addition of paper mill sludge to a soil contaminated by lead and zinc induces a decrease in the mobile forms of both metals. Calacea et al. (2005) by leaching experiments showed that the addition of a paper

*Corresponding author. E-mail: m.torkashvand54@yahoo.com. Tel: 0098-131-4247058, 09125137128. Fax: 0098-131-4223621.

mill sludge, consisting mainly of carbonates, silicates and organic matter to a heavy-metal polluted soil produces a decrease of available metal forms. Gaskin and Morris (2004) indicated that lime mud has potential to be used as an agricultural liming material because of its capability to neutralize soil acidity (increase soil pH) and add calcium and magnesium to the soil. Although high moisture content of lime mud creates more shipping and handling difficulties than typical dry agricultural liming materials (Mahmoudkhani et al., 2004), this obstacle can be overcome as sludge dewatering technology improves (Chen et al., 2002; Yin et al., 2004). The objectives of the present study were then to evaluate the value of the waste as an agricultural lime material. However, it should be noted that results from this controlled laboratory experiment can be different to actual field trials since actual field practice. Also, actual field conditions are under influence from consistently changing weather condition which is dramatically different than this laboratory experiment.

MATERIALS AND METHODS

The paper mill sludge was obtained from Pars and Chocka factories, Khoozestan and Guilan province, Iran. Total concentrations of some elements in the paper mill sludge were determined in the extract after digestion of samples with HNO_3 and HCl (Hossner, 1996) for elemental analysis. The amounts in the digests were determined using inductively coupled plasma atomic emission spectrometry (ICP-AES, LEEMAN LABs, Inc.). The sludge pH and EC (Rhoads, 1996) were determined in a 1:2.5 paper mill sludge/water suspension using a Metrohm 320 pH meter and Metrohm 644 conductometer, respectively.

A pot experiment was conducted in the greenhouse with a soil collected from the fields around Lahijan, Iran. Some physical and chemical properties of the soils are shown in (Table 1). Soils were air-dried and crushed to pass a 6 mm sieve. Treatments with three replicates consisted of 0, 0.5 and 1, 2 and 4% paper mill lime sludge (L_0, $L_{0.5}$, L_1, L_2 and L_4, respectively). *Sorghum vulgaris variety speed seed* was used as the test plant. Six seeds were sown in each pot. Seedlings were thinned to 3 when they were about 10 cm high. During the growth period, pots were irrigated with distilled water as needed. All pots received 50 mgN/kg as ammonium nitrate 1 week after germination. Shoot were harvested after 60 days and dry matter yield was determined after drying of the harvested shoots at 70°C for 48 h. Sub samples of dry shoots were ground and then dry-ashed in a furnace at 550°C and then extracted with 2N HCl. The concentrations of Fe, Mn and Zn were measured in the extracts by atomic absorption spectrophotometry, K by flame photometry and P by spectrophotometry. Soil samples from each pot were analyzed for AB-DTPA extractable Fe, Mn, Zn, K and P. Data were analyzed by standard ANOVA procedures using MSTATC and SAS software and significant differences was determined based on $P < 0.05$ level for the least significant difference Test.

RESULTS AND DISCUSSION

The chemical composition of the paper mill sludge showed that this compound contained about 58.4% calcium carbonates equivalent and a pH of about 13.2 (pH of 1:2.5 dry paper mill sludge/water suspension) and small amounts of Zn, Cu, Cr, Cd and Pb respectively 4.12, 2.35, 7.54, 3.25 and 28.6 $mg.kg^{-1}$.

Soil pH and EC

(Table 2) shows the effect of added paper mill sludge on soil pH. Paper mill sludge significantly increased pH, which was proportional to the application rate of paper mill sludge. Increase in pH was 0.76 units for $L_{0.5}$, 1.09 units for L_1, 1.76 units for L_2 and 2.68 units for L_4 compared to the control (L_0). Increase in soil pH indicates the usefulness of paper mill sludge as a liming agent for amelioration of acid soils. Similar results was obtained by He et al. (2009) for the use of paper mill lime mud as a liming agent and its effect on soil pH and ryegrass growth. It is indicated that the added lime mud increased soil pH to a range of from 6.5 to 10.2 and L_2 and L_3 brought initial soil pH to 7.6 - 8.3 higher than the recommended level of 6.0 – 7.0 for ryegrass (Hall, 1992). In an 84-d incubation study, boiler ash and lime by-products of paper industry applied to an acid (pH = 5.2) Marvyn loamy sand (fine-loamy, siliceous, thermic, Typic Kanhapludults) at equivalent rates based on CCE resuited in mean pH values significantly higher than values achieved with agricultural lime **(**Muse and Mitchel, 1995). Paper mill lime sludge increased EC, significantly in L_2 and L_4 treatments compared with control treatments. It should be regarded that the amount of soil electrical conductivity in treatments creates any problem for plant growth.

Dry matter yield

Dry matter yield increased significantly ($P \leq 0.05$) in 1% and 2% paper mill sludge treatments (L_1 and L_2) compared to the control (Figures 1 and 2). Yield was 1.37 and 1.9 times higher than control (L_0). Many studies have shown that the liming improved the growth of many crops cultivated on acid soils such as red clover (Steiner and Alderman, 2003), wheat and barley (Tang et al., 2003), peanut (Chang and Sung, 2004) and cotton (Pearson et al., 1973). Moustakas et al. (1999) reported significant yield increases of flue-cured tobacco cultivars in an acid soil, after the addition of 4 t ha^{-1} (MgO + CaO) which resulted in a pH increase from 4.8 to 6.1. A 4year field study in Alberta (Macyk, 1996) recommended an agronomically sound decomposed pulp mill sludge application rate of 40 – 80 dry ton ha^{-1} for brome grass. Rengel (1996) reported that retardation of root growth in acid soils was mainly due to aluminium toxicity. Therefore, increase in yield can be due to the reclamation of soil acidity and decrease in aluminum toxicity. Thus, increase of soil pH as the result of utilization paper mill sludge and subsequent increase in some nutrients availability may be reason for increase in yield. Increase

Table 1. Some properties of the used soil.

pH	5.8
EC (dS/m)	0.95
Total N (%)	0.06
P (mg/kg)	11.5
K (mg/kg)	113.0
Organic matter (%)	1.2
Texture	Sandy loam

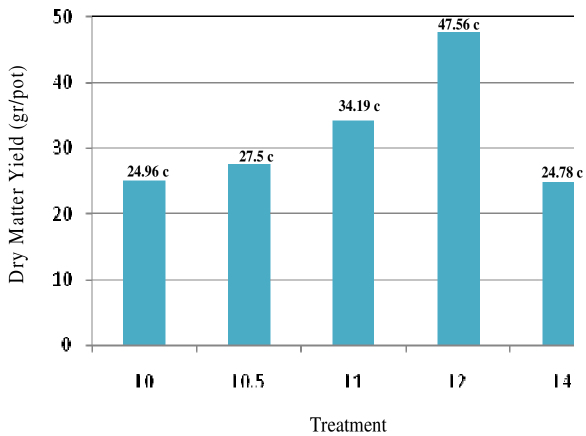

Figure 1. The effect of paper mill sludge on dry matter yield.

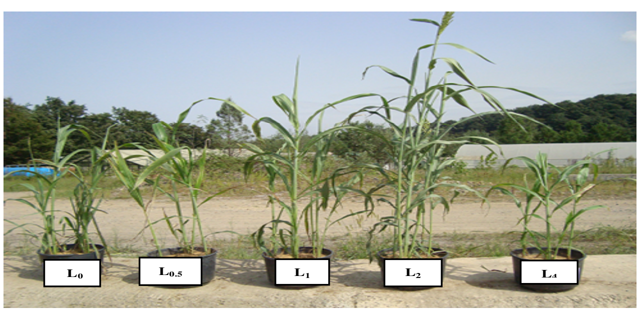

Figure 2. Sorghum growth in treated soil by paper mill sludge.

in plant yield as the result of utilizing calcareous by-products of other industries such as converter slag has also been reported in other studies (Ogutoinbo et al., 1996; Abou seeda et al., 2002; Prado et al., 2003; Barbosa Filho et al., 2004).

Phosphorus

The effect of treatments on P uptake is observed in (Table 3). Paper mill sludge increased P uptake by $L_{0.5}$ and L_1 treatments, but not significant. Utilizing 2% paper mill sludge remarkably ($P \leq 0.05$) increased P uptake that is due to the higher dry matter yield of this treatment compared with control, $L_{0.5}$ and L_1 treatments. Of course, the effect of treatments on leaf P concentration was not significant (Table 4). This can be due to soil P concentration, because the use of paper mill sludge did not affect soil phosphorus, significantly (Table 2). Phosphorus is an essential plant nutrient, it is indispensable for phospholipids, ATP and nucleic acids synthesis and therefore a deficiency can limit plant growth (Schachtman et al., 1998).

High pH values associated with high quantities of Ca probably facilitate precipitation of P as calcium phosphates, thus, limiting the availability of P to the plant. In contrast a similar increase in pH due to lime application, as happened in the present study, may cause some solubilization of P from Fe–P and Al–P complexes, thus, increasing P availability as was suggested by McCants and Woltz (1967). It seems that soil P concentration has not changed as the results of an interaction between precipitation and solubilization of P by liming.

Potassium

Based on (Table 3), paper mill sludge increased K uptake remarkably ($P \leq 0.05$) in L_1 and L_2 treatments that is due to the higher dry matter yield compared with control. Taking consideration into (Table 4), while the largest K uptake is related to L_2 treatment, but the lowest leaf K consideration is also related to this treatment. Karaivazoglou et al. (2007) reported that liming reduced leaf K concentration ($P \leq 0.05$) on average from 18.7 to 16.4 g kg^{-1} d.m. (12% reduction). The lower K content of leaves in limed treatments could be explained by the competition between K and Ca in their uptake by plants (Flower, 1999).

Therefore, liming may intensify K deficiency if low or no K fertilizer is applied. Mohammadi Torkashvand and Sedaghathoor (2007) reported that the use of a calcareous by-product of steel industry as a liming agent reduced K content in an acid soil. They stated that this decrease in soil K might be due to the potassium fixation. Al and Fe hydroxides polymers decline in clays interlayer or insoluble compounds, as K alominosilicates are formed consequently increasing K fixation (Malakouti and Afkhami, 1999).

Iron

Application of paper mill sludge significantly ($P \leq 0.05$) increased Fe uptake in L_2 treatment that is due to the higher yield compared with control (Table 3). (Table 4) shows that leaf Fe concentration has reduced in 1, 2 and 4% treatments of paper mill sludge, but this decrease is significant in 4% treatment. Decreasing leaf Fe Paper mill sludge increased Mn uptake in $L_{0.5}$, L_1 and L_2 concent-

Table 2. The effect of Paper mill sludge on some soil characteristics.

Treatment	pH	EC (dS/m)	P	K	Fe	Mn	Zn
			mg/kg				
Control	5.56 e	0.85 c	9.9 a	106.3 a	113.1 a	12.1 a	1.43 a
$L_{0.5}$	6.32 d	0.91 c	9.3 a	106.5 a	116.0 b	11.4 a	1.76 a
L_1	6.65 c	1.05 c	10.3 a	85.4 ab	104.6 a	11.7 a	1.66 a
L_2	7.32 b	1.28 b	10.3 a	73.6 b	92.4 ab	11.4 a	1.83 a
L_4	8.24 a	1.35ab	10.9 a	66.4 b	76.6 b	10.8 a	1.86 a

LSD (least significant difference) shows the significant difference (ρ = 0.05) among the different treatments.
Values followed by the same letters in each column are not significantly different at the 0.05 level (least significant difference).

Table 3. The effect of paper mill sludge on some nutrients uptake by plant.

Treatment	P	K	Fe	Mn	Zn
	mg/pot				
Control	60.86 b	285.2 c	3.56 bc	5.15 d	1.05 b
$L_{0.5}$	90.96 b	336.9 bc	4.02 b	7.64 bc	1.06 b
L_1	80.83 b	423.1 ab	4.16 b	9.00 ab	1.46 b
L_2	147.9 a	449.4 a	5.9 a	10.54 a	2.38 a
L_4	67.4 b	284.1 c	2.6 c	6.40 cd	1.00 b

Table 4. The effect of paper mill sludge on some nutrients concentration of leaf.

Treatment	Fe	Mn	Zn	K	P
		(mg/kg)			(%)
Control	a 141.6	b 207.3	ab 42.4	a 1.14	b 0.24
$L_{0.5}$	a 145.6	a 279.0	b 38.6	a 1.22	a 0.33
L_1	ab 122.3	a 265.0	ab 42.7	a 1.24	b 0.23
L_2	ab 123.6	b 221.0	a 49.7	b 0.94	ab 0.31
L_4	b 105.3	a 259.0	b 40.0	a 1.15	ab 0.27

ration might be due to the soil Fe concentration. Extractable Fe decreased proportional to the application rate of paper mill sludge. Extractable Fe concentration depends on initial pH of soil. Increase in soil pH to the range of 7.4 - 8.5 decreased Fe level. It was found that Fe was precipitated as $Fe(OH)_3$ due to the increased pH (Norvell and Lindsay, 1982). Similar results were found by Mohammadi Torkashvand and sedaghathoor (2007) with the use of calcareous converter slag in acid soils.

Manganese and zinc

Paper mill sludge increased Mn uptake in L0.5, L1 and L2 treatments than in the control, significantly (P ≤ 0.05) that is due to the higher yield of sludge treatments. Zn uptake only in L_2 treatments is significant as compared with control. Paper mill sludge had not a considerable effect on leaf Mn and Zn concentration and also soil available with Mn and Zn.

Conclusions

Treatments of acid soils with increasing rates from 0.25 to 16% of paper mill sludge increased soil pH. Application of paper mill sludge to pots increased the dry matter yield and P, K and micronutrients uptake for sorghum with the rate 2% being more effective. Results indicate a promising potential for paper mill sludge to be used as an inexpensive source of available lime for correction of soil acidity. This, however, needs further studies in the field and with various crops to determine the correct rates and to study the residual and environmental impact of application of this material to the soil.

REFERENCES

Abou Seeda M, El-Aila HI, El-Ashry S (2002). Assessment of basic slag as soil amelioration and their effects on the uptake of some nutrient elements by radish plants. Bull. Nat. Res. Cent. (Cairo), 27(4): 491-506.

Barbosa Filho MP, Zimmwrmann FJP, da Silva (2004). Influence of calcium silicate slag on soil acidity and upland rice grain yield. Cienciae Agrotechnol, 28 (2): 323-331.

Battaglia A, Calace N, Nardi E, Petronio BM, Pietroletti M (2007). Reduction of Pb and Zn bioavailable forms in metal polluted soils due to paper mill sludge addition Effects on Pb and Zn transferability to barley. Biores. Technol., 98: 2993-2999.

Bolan NS, Adriano DC, Curtin D (2003). Soil acidification and liming interactions with nutrient and heavy metal transformation and bioavailability. Adv. Agron., 78: 215-272.

Calacea N, Campisib T, Iacondinib A, Leonia M, Petronioa BM, Pietroletti M (2005). Metal-contaminated soil remediation by means of paper mill sludges addition: chemical and ecotoxicological evaluation. Environ. Poll., 136: 485-492.

Chang CS, Sung JM (2004). Nutrient uptake and yield responses of peanuts and rice to lime and fused magnesium phosphate in an acid soil. Field Crops Res., 89: 319-325.

Chen G, Yue PL, Mujumdar AS (2002). Sludge dewatering and drying. Drying Technol., 20(4): 883-916.

Fang M, Wong JWC (1999). Effects of lime amendment on availability of heavy metals and maturation in sewage sludge composting. Environ. Poll., 106(1): 83-89.

Feldkinchner D, Wang C, Gower S, Kruger E, Ferris J (2003). Effects of nutrient and paper mill biosolids amendment on growth and nutrient status of hardwood forest. Forest Ecol. Manage., 177: 95-116.

Flower KC (1999). Agronomy and physiology, 4C field practices. In: Davis DL, Nielsen MT (Eds.), Tobacco: Production, Chemistry and Technology. CORESTA. Blackwell Science, Great Britain, pp. 76–103.

Foy CD (1992). Soil chemical factors limiting plant root growth. Adv. Soil Sci., 19: 97-131.

Gaskin J, Morris L (2004). Land Application of Pulp Mill Lime Mud. Res. Bull. (Agricultural Experiment Station, College of Agricultural and Environmental Science, University of Georgia).

Hall MH (1992). Ryegrass. (Pennsylvania State College of Agricultural Sciences Research, Extension, and Resident Education Programs, Pennsylvania State University).

He J, Lange CR, Dougherty M (2009). Laboratory study using paper mill lime mud for agronomic benefit. Process Safety Environ. Protect, 87: 401-405.

Hossner LR (1996). Dissolution for total elemental analysis. In Methods of Soils Analysis. Part 3. Chemical Methods; Sparks DL, Ed.; Soil Soc. Amer. Mad., pp. 49-64.

Karaivazoglou NA, Tsotsolis NC, Tsadilas CD (2007). Influence of liming and form of nitrogen fertilizer on nutrient uptake, growth, yield, and quality of Virginia (flue-cured) tobacco. Field. Crops. Res., 100: 52-60.

Little DA, Reneau RB, Martens DC (1991). Lime-stabilized and chemically-fixed sewage sludges as lime amendments. Biores. Technol., 37(1): 93-102.

Macyk TM (1996). Research relative to land application of pulp mill wastes in Alberta. Pulp and Paper-Canada, 97(3): 48-52.

Mahmood T, Elliot A (2006). A review of secondary sludge reduction technology for the pulp and paper industry. Water Res., 40(11): 2093-2112.

Mahmoudkhani M, Richards T, Theliander H (2004). Recycling of solid residues to the forest: experimental and theoretical study of the release of sodium from lime mud and green liquor dregs aggregates. Process Safety Environ. Protect. Clean Technol. Waste Minimiz., 82(3): 230-237.

Malakouti MJ, Afkhami M (1999). The necessity to prevent potassium depletion in rice fields of northern regions. Soil and Water Research Institute. Tech. pub. No. 62, Tehran, Iran.

Mcbride MB, Spiers G (2001). Trace element content of selected fertilizers and dairy manures as determined by ICP-MS. Communicat. Soil Sci. Plant Analy., 32: 139-156.

McCants CB, Woltz WG (1967). Growth and mineral nutrition of tobacco. Adv. Agron., 19: 211-265.

Mohammadi Torkashvand A, Sedaghat Hoor Sh (2007). Converter Slag as a Liming Agent in Acidic Soils. Intern. J. Agri. Biol., 9(5): 715-720.

Moustakas NK, Ntzanis H, Pangos E, Kosmas S (1999). Soil properties, yields and chemical characteristics of flue-cured tobacco as affected by liming. Agric. Mediterr., 129: 25-35.

Muse JK, Mitchell CC (1995). Paper mill boiler ash and lime by-products as soil liming materials. Agron. J., 87(3): 432-438.

Norvell WA, Lindsay WL (1982). Effect of ferric chloride aditions on the solubility of ferric iron a near-neutral soil. J. Plant Nutr., 5: 1285-1295.

Oguntoynbo FI, Aduay EA, Sobulo RA (1996) Effectiveness of some local liming materials in Nigeria as ameliorants of soil acidity. J. Plant Nutr., 19(7): 999-1016.

Pearson RW, Childs J, Lund ZE (1973). Uniformity of limestone mixing in acid subsoil as a factor in cotton penetration. Soil Sci. Soc. Am. Proc. 37: 727–732.

Prado RM, Fernandes FM, Natale W (2003). Residual effect on calcium silicate slag as soil acidity corrective in sugar cane rattoon. Revista Brasileria de Ciencia do Solo., 27(2): 287-296.

Rengel Z (1996). Uptake of aluminium by plant cells. N. Phytol., 134: 389-406.

Rhoads JD (1996). Salinity: Electrical conductivity and total dissolved solids. In Methods of Soils Analysis. Part 3. Chemical Methods; Sparks DL, Ed.; Soil Society of American: Madison, WI, pp. 417-435.

Schachtman DP, Reid RJ, Ayling SM (1998). Phosphorus uptake by plants: from soil to cell. Plant Physiol., 116: 447-453.

Schoof RA, Houkal D (2005). The evolving science of chemical risk assessment for land-applied biosolids. J. Environ. Quality, 34(1): 114-121.

Simpson GG, King LD, Carlile BL (1982). Land application of kraft paper mill sludges, In Proceedings of the Fifth Annual Conference of Applied Research and Practices on Municipal and Industrial Waste Madison, USA, pp. 634-646.

Steiner JJ, Alderman SC (2003). Red clover seed production. VI. Effect and economics of soil pH adjusted by lime application. Crop Sci. 43: 624-630.

Tang C, Rengel Z, Diatloff E, Gazey C (2003). Responses of wheat and barley to liming on a sandy soil with subsoil acidity. Field Crops Res., 80: 235-244.

Ulrich BA (982). concept of ecosystem stability and of acid deposition as driving force for destabilisation, in: B. Ulrich, J. Pankrath (Eds.), Effects of Accumulation of Air Pollutants in Forest Ecosystems, Proceedings of a Workshop held at Go¨ ttingen, West Germany, 16-18, D. Reidel Publisher Company, Dordrecht, Boston, London, pp.1-29.

Von Uexkull HP, Mutert E (1995). Global extent, development and economic impact of acid soils. Plant Soil, 171: 1-15.

Weaver DM, Ritchie GSP (1987). The effectiveness of lime-based amendments and bauxite residues at removing phosphorus from piggery effluent. Environ. Poll., 46(3): 163-175.

Wirojanagud W, Tantemsapya N, Tantriratna P (2004). Precipitation of heavy metals by lime mud waste of pulp and paper mill. Songklanakarin J. Sci. Technol. 26: 45–53.

Yin X, Han P, Lu X, Wang Y (2004). A review on the dewaterability of bio-sludge and ultrasound pretreatment. Ultrasonics Sonochem., 11(6): 337-348.

Zule J, Cernec F, Likon M (2007). Chemical properties and biodegradability of waste paper mill sludges to be used for landfill covering. Waste Manage. Res., 25(6): 538-546.