JASEM ISSN 1119-8362

Full-text Available Online at
www.ajol.info and
www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage. *March 2013*
Vol. 17 (1) 105-110

Soil Contamination from Cassava Wastewater Discharges in a Rural Community in the Niger Delta, Nigeria

***[1]IZONFUO, W-AL; BARIWENI; PA, GEORGE; DMC**

Department of Chemical Sciences
Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria
E-mail: welfordabbey@yahoo.com Phone: +2348033124303
Department of Geography & Environmental Management
Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria
E-mail: pbariweni@yahoo.com Phone: +2348035085317
Department of Chemistry, Rivers State University of Science & Technology, Nkpolu – Port Harcourt, Nigeria
E-mail: dayegeorge@yahoo.com Phone: +2348037048976

*Corresponding Author: Izonfuo, W-AL

KEY WORDS: Soil contamination; cassava wastewater; physico-chemical characteristics; cassava processing.

ABSTRACT: Ten soil samples were collected with a 9mm Dutch auger along two transects for six months for the purposes of investigating the effects of cassava wastewater on the physico-chemical characteristics of soils around a cassava processing plant in a rural community in the Niger Delta. It was observed that the addition of cassava wastewater to the soil resulted to changes in the parameters. Mean Mg level of the soil samples was lower than the mean in the control soil samples. Correlation analysis shows that soil pH influenced CN^- (r = 0.18); K (r = 0.17); Ca (r = 0.97); Mg (r = 0.13); Na (r = 0.03); P (r = 0.08); N (r = 0.40); Organic Carbon (r = 0.08) and organic matter (r = 0.06). The cyanide levels in the soils were found to be higher than the recommended limits for agriculture and other purposes. Also, amongst the exchangeable bases, Mg was significantly influenced by cassava wastewater discharges. The implications of these variations on agriculture and other activities have been appraised. © JASEM

One of the greatest threats to sustainable development is environmental degradation. Environmental degradation, which is the gradual lowering of environmental quality, is due to human activity and natural causes. Natural causes such as soil erosion, leaching, volcanic activities, forest fires are common features and constitute a threat to the natural environment but these are usually mitigated by other natural processes. Human causes of environmental degradation include industrialization, urbanization, logging, agriculture, agricultural products processing, etc. The extent of the threat from these activities is usually associated with the degree of the activity and absence of mitigating measures.

One common human activity that may result to environmental degradation is cassava processing. Cassava processing activities are now extensively carried out in many rural and urban centres in Nigeria and elsewhere. Cassava (*Manihot esculenta)* and its wastewater have been reported to be toxic and poisonous (Okezie and Kosikowski, 1983; Akintowa and Tunwashe 1992; Hans, 1994; Adeyemo, 2005). The toxicity of cassava and its wastewater is basically associated with its pH and cyanide content. Cassava wastewater has been observed to be highly acidic, with pH as low as 2.6 (ESCAP, 1992). Also, Nok and Ikediobi (1990) reported the pH of fermenting cassava to be between 5.5 and 6.3. Cassava wastewater may therefore influence the acidity of soils when large amounts are added to the soil. It is reported that when soil pH is too acidic, plants cannot utilize N.P.K and other nutrients (Spector, 2001). In acidic soils, plants are also likely to take up toxic metals, which may lead to their eventual death.

Cyanide in cassava wastewater is another major cause for concern. According to Bengtsson and Triet (1994), the cyanide content of untreated cassava wastewater ranges between 3.2 to 3.5mg CN^-/L. Balagopalan and Rajalekshmy (1998) observed that the concentration of total cyanoglucosides in cassava wastewater samples ranged between 10.4 – 274mg/L. When cyanide interacts with (soil) water, it produces a weak acid (Shape, 1976). Another effect of cyanide in the soil is its strong bonding with cations to form complexes such as potassium hexacyanoferrate (II) ($K_4Fe[CN]_6$) (Shape, 1976). Cyanide in soils has also

**Corresponding E-Mail: : welfordabbey@yahoo.com*

been reported to be herbicidal (Ogundola and Liasu, 2007).

No doubt, the presence of varying amounts of cyanogenic glucosides and their breakdown products in cassava food products have been a cause of concern, because of their possible effect on health, as well as the increasing importance of cassava in food security. In recent times, cassava has become more important, because almost all parts of the crop are now known to be useful. Large-scale cultivation and processing of the crop are now being encouraged. In spite of the reported potential deleterious effects of cassava wastewater and other components of cassava breakdown to alter soil chemistry, data regarding the effects of cassava wastewater on soil physico-chemical properties are limited. Since there is a high level of cassava processing activity in Nigeria and elsewhere, there is a compelling need to provide data regarding the effects of these activities on the physico-chemical properties of soils.

MATERIALS AND METHODS

The study was carried out in a rural community in the Niger Delta area of Nigeria where the indigenous people are mainly farmers cultivating banana, cocoyam and cassava. In order to assist farmers to easily process their cassava into garri and other edible products, a cassava processing plant is established in the community. About 30 – 40 metric tonnes of cassava tubers are processed daily generating about 15000 to 20000 liters of wastewater which is discharged into the immediate environment without any form of treatment.

Soil samples were collected with a 9mm Dutch auger from five points each along two transects (A & B) near the cassava processing plant for six months. Three auger borings were collected from each point and bulked together to obtain a representative soil sample for each unit/point. The soil samples (A1 – A5, B1 – B5) were collected in the direction of the surface flow from the topsoil (0 – 10cm) and (a1-a5, b1-b5) from the sub-soil (11 – 20cm), placed in labeled polythene bags and transported to the laboratory for analyses. Soil samples were also collected upslope the processing plant as control. All samples were analyzed by standard methods of USDA-NRCS (1996) for their pH, electrical conductivity, % total nitrogen, available phosphorus, cyanide, organic carbon, exchangeable bases/cations (Na^+, K^+, Ca^{++}, Mg^{++}) and cation exchange capacity (CEC). The pH of the soil samples (in a ratio of soil to water of 1:1) was measured with a pH meter, OORNING pH meter (Model 7). The CN^- content in the soil samples was determined by titrimetry using two procedures. The first procedure used $AgNO_3$ as titrant with potassium iodide indicator (detection limit = 0.33mg/kg; ICMI, 2006) and the other procedure used $NiSO_4$ as titrant with silver iodide indicator. Results obtained from the two procedures were agreeable. The cation exchange capacity was measured at pH 7 & by ammonia acetate extraction. Exchangeable bases (Na, Mg, K and Ca) were determined by AAS. Exchangeable acidity was assessed by extraction with $BaCl_2^-$triethanolamine solution buffered at pH 8.2 and back titrated. Total N was measured by dry combustion while available P was determined by the Bray P-1 procedure using the ascorbic acid – potassium antimonyl – tartrate – molybdate method. Organic matter content of the soil samples was estimated by multiplying organic carbon levels by a factor of 1.724 as prescribed by Odu *et al* (*1985*).

RESULTS AND DISCUSSION

The results of the study are presented in Table 1. From the results, pH for the topsoil ranged from 6.30 to 6.90 while that for the subsoil ranged from 3.30 to 6.80. The mean pH levels were 6.62±0.21 in the topsoil and 6.02±0.99 in the subsoil downstream the processing plant, while it was 6.20±0.20 and 6.10±0.10 in the top- and sub soils respectively in the control. Variation in mean pH for topsoil and subsoil was wider downstream the processing plant than upstream. The soil pH was found to be generally acidic. This is in agreement with the pH of soils of the area (Odu *et al,* 1985). The mean soil pH (6.32±0.76) was found to be higher than that of the control (6.13±0.15). Cyanohydrins are relatively stable in acid environments but rapidly decompose at a neutral or higher pH into to ketones and the toxic hydrogen cyanide (Cooke 1978, cited in Essers, 1994). Even though cassava wastewater is known to be acidic, it appears not to have lowered the soil pH but rather increased it. This may be due to the non decomposition of cyanohydrins into ketones and free HCN. The addition of cassava wastewater therefore appears to have brought about the dilution of hydrogen ion concentration resulting in the higher pH values obtained. In fact, such pH levels may enhance the stability of cyanohydrins in the soil and encourage their accumulation in the soil. According to Evanylo and McGuinn (2000), if the pH of soil is above 5.50, nitrogen (in the form of nitrate) is made available to plants. Also phosphorus is available to plants when soil pH is between 6.00 and 7.00

(Spector, 2001). The observed pH levels are adequate to make nutrients available to plants in the study area.

Electrical conductivity varied from 40.00 to 72.00µs/cm in the topsoil and from 24.00 to 64.00µs/cm in the subsoil. Mean electrical conductivity was 60.50±10.12µs/cm in the topsoil and 41.70±11.80µs/cm in the subsoil. The mean electrical conductivity of the soil downstream the processing plant (51.10±14.41µs/cm) was found to be higher than that of the control (42.25±13.82µs/cm).

Results for the exchangeable bases show that Na levels in the soil ranged between 0.19 and 0.27cmol/kg in the topsoil and between 0.19 and 0.38cmol/kg in the subsoil; K levels varied from 0.06 to 0.17cmol/kg in the topsoil and from 0.05 to 0.14cmol/kg in the subsoil; Ca levels hovered between 2.80 and 6.90cmol/kg in the topsoil and between 1.30 and 4.50cmol/kg in the subsoil; Mg levels varied from 0.60 to 3.80cmol/kg in the topsoil and from 0.10 to 7.40cmol/kg in the subsoil. The mean of the exchangeable bases were 0.23±0.06cmol/kg for Na; 0.09±0.03cmol/kg for K; 3.72±1.63cmol/kg for Ca and 1.82±1.66cmol/kg for Mg downstream the processing plant. Although the soil means for Na (0.23±0.06cmol/kg) and K (0.09±0.03cmol/kg) were comparable to those of the control (0.23±0.02cmol/kg for Na and 0.09±0.03cmol/kg for K), the means for Ca (3.72±1.63cmol/kg) and Mg (1.82±1.66cmol/kg) were lower than those of the control (4.15±2.10cmol/kg for Ca and 2.30±0.27cmol/kg for Mg). The mean Mg levels in the control (2.30±0.27cmol/kg), which is adequate for agriculture was reduced to levels not adequate (1.82±1.66cmol/kg) for agriculture downstream the processing plant. Exchangeable bases' distribution gives an indication of the relative abundance and availability of some major nutrient elements. A cation content of about 2meq/100g soil is considered adequate for Ca and Mg, while for K, 0.2 meq/100g soil and above is considered adequate for agriculture (Odu *et al.,* 1985). The soil means for K were generally found to be lower than the required values for certain crops such as plantain, banana etc.

Results also indicated that CN^- content in the topsoil ranged between 186.58 and 263.12mg/kg and from 167.44 to 310.96mg/kg in the subsoil. The mean cyanide levels, 221.50±28.08 mg/kg in the topsoil and 220.54±48.02 mg/kg in the subsoil, were higher than those of the control (148.31±6.77mg/kg). The observed cyanide levels in the soil samples which are unusually high compare with the concentrations of total cyanoglucosides in cassava wastewater which ranged between 10.4 to 274mg/L (Balagopalan & Rajalekshmy, 1998). Given the high level of CN^- in the soil, it may be suggested that the CN^- in the soil are speciated as salts of the Group II elements. High CN^- levels in the control are indicative of previous activities in the area hitherto the establishment of the cassava processing plant. It also suggests the ability of CN^- to remain recalcitrant in the environment for long without being degraded. Cyanide is known to remain in the soil at negligible levels when it is added to soil as demonstrated by Ogudola and Liasu (2007), who treated soil with cassava wastewater to determine the use of wastewater as an inorganic herbicide. Analysis of treated soils showed cyanide residues of 0.04mg/kg. These results agree with the findings of Delang *et al* (1982 cited in Ogundola and Liasu, 2007) about the formation of free cyanide, which is associated with cyanohydrins hydroxyl-nitrates that have been stabilized by glycosylation. As stated by Ogundola and Liasu (2007), at high concentrations cyanide becomes toxic to soil microorganism which, can no longer change cyanide to other chemical forms. It is therefore possible that the observed high levels of cyanide in the soil samples in this study are a direct effect of the large volumes of cassava wastewater that are added to the soil on a daily basis. The CN^- levels in the soil were found to be higher than the recommended levels of 11.00mg/kg for soil for habitat and agriculture and 55.00mg/kg for other purposes (National Environmental Board, 2004).

Total nitrogen ranged between 0.01 to 0.02% in the subsoil but remain constant (0.02%) in the topsoil. The mean % total Nitrogen values, which were 0.02±0.00 in the topsoil and 0.02±0.01 in the subsoil, were not significantly different from those of the control (0.02±0.00). Total and mineral nitrogen give an indication of the reserves of organic nitrogen capable of undergoing mineralization under suitable conditions. A total nitrogen level below 0.10% in soil is considered low for agricultural activities (Odu *et al.,* 1985). Low nitrate levels are indicative of low nitrification and could be due to the acidic pH of the soils, which may have influenced the activities of nitrifying bacteria in the soil.

The organic carbon levels of the soil samples ranged between 0.03 and 0.80% in the topsoil and from 0.02 to 0.21% in the subsoil. Mean organic carbon levels, which were 0.15±0.18% downstream the processing unit, were lower than those of the control

0.48±0.57%. Soil containing <1.00% of carbon are considered low in organic carbon (Odu *et al.,* 1985).

Organic matter levels ranged between 0.05 to 1.38% in the topsoil and from 0.01 to 0.36% in the subsoil. Mean organic matter levels, which were 0.41±0.40% in the topsoil and 0.11±0.11% in the subsoil, were found to be generally low. The mean organic matter levels (0.26±0.32%) downstream the processing plant, which were also found to be lower than those of the control 0.78±1.03% were attributed to the influence of cassava wastewater on the soil. Low organic matter levels were related to changes in the physico-chemical characteristics of the soil, which can distort bacterial activities vis-à-vis decomposition of organic matter.

Exchangeable acidity ranged between 1.64 and 2.00cmol/kg in the topsoil and from 1.64 to 2.08cmol/kg in the subsoil downstream the processing plant. The mean exchangeable acidity downstream (1.78±0.13cmol/kg) was found to be lower than that of the control (1.86±0.12cmol/kg).

Available P varied between 16.84 and 54.03ppm in the topsoil and from 8.42 to 51.22ppm in the subsoil. Mean P levels was 27.44±10.16ppm in the topsoil and 30.94±14.98ppm in the subsoil downstream the processing plant. Available P levels were found to be higher downstream than upstream the processing plant. A value of 10ppm and below is considered low; 20ppm moderate and 50ppm high (Odu *et al.,* 1985).

Conclusion: It can be concluded from the results of this study that cassava wastewater alters the physico-chemical characteristics of soils. All the parameters assessed had higher values in the topsoil than the subsoil downstream the processing plant except Na, Mg, exchangeable acidity and available Phosphorus, which had higher values in the subsoil than the topsoil, and for % N which remained unchanged. The results obtained downstream the processing plant were observed to be reversed upstream the plant except for pH, %N, Mg and CEC, which maintained the same trend both upstream and downstream the processing plant. The pH of the soils in the area, which were generally acidic were slightly decreased in acidity. This may have distorted the activities of soil bacteria which can trigger off a number of reactions, which may deleteriously impact the physico-chemical characteristics of the soil. Results from correlation analyses reveal that soil pH influence the CN (r = 0.18), K (r = 0.17), Ca (r = 0.47) Mg (r = 0.13), Na (r = 0.03), P (r=0.08), N (r=0.40), organic carbon (r=0.08) and organic matter (r=0.06). Results from correlation analysis also reveals that electrical conductivity of the soil is related to the Ca (r = 0.2) and Mg (r = 0.1) levels. The trends observed suggest varying degrees of binding of CN and Na (r = 0.15); K (r = 0.19);

Ca (r = 0.06) and Mg (r = 0.18), which invariably influenced the electrical conductivity. Major cause for concern is the high cyanide levels in the soils, which were found to be higher than the safe levels for agriculture and other purposes. There is therefore a dire need for enlightenment on the deleterious effects of indiscriminate dumping of untreated cassava wastewater on arable lands. It is therefore hereby recommended that all cassava wastewaters be subjected to some form of treatment before they are discharged to surroundings where large scale cassava processing activities take place.

Table 1: Mean physico-chemical characteristics of soil samples receiving cassava wastewater.

Sample description	pH	Elect Cond µs/cm	CN^- mg/kg	% ORG C	% TOTAL N	% ORG MATTER	Exchangeable Bases Cmol/kg				Cmol/kg EXCH … ACIDITY	AVAIL P ppm	CEC Cmol/ Kg
							Na^+	K^+	Ca^+	Mg^+			
A1	6.50	40.00	239.20	0.03	0.02	0.05	0.19	0.08	6.90	1.10	2.00	54.03	10.27
A2	6.70	55.00	191.36	0.05	0.02	0.09	0.23	0.11	3.20	1.40	1.80	28.07	6.74
A3	6.40	54.00	239.20	0.07	0.02	0.12	0.23	0.07	3.50	3.80	1.76	25.26	9.36
A4	6.90	58.00	263.12	0.12	0.02	0.21	0.21	0.06	5.70	0.70	1.80	25.26	8.47
A5	6.90	72.00	239.20	0.21	0.02	0.36	0.27	0.06	6.50	1.60	1.64	16.84	10.07
B1	6.70	68.00	239.20	0.19	0.02	0.33	0.27	0.13	4.90	0.60	1.72	18.94	7.62
B2	6.80	58.00	191.36	0.17	0.02	0.29	0.2	0.1	5.10	2.90	1.64	23.15	9.94
B3	6.30	70.00	234.42	0.35	0.02	0.60	0.25	0.17	3.40	0.10	1.80	28.77	6.62
B4	6.40	72.00	191.36	0.80	0.02	1.38	0.22	0.09	2.80	1.90	1.76	25.26	6.77
B5	6.60	58.00	186.58	0.38	0.02	0.66	0.022	0.08	5.70	0.70	1.76	28.77	8.46
a1	6.40	30.00	191.36	0.02	0.01	0.03	0.26	0.05	4.50	2.10	1.84	8.42	8.75
a2	6.00	24.00	243.98	0.21	0.02	0.36	0.19	0.08	3.50	0.40	1.92	51.22	6.09
a3	6.10	45.00	239.20	0.02	0.02	0.03	0.22	0.14	2.40	1.20	1.64	33.68	3.96
a4	6.80	62.00	287.04	0.09	0.01	0.01	0.29	0.06	1.40	7.40	1.64	49.12	10.79
a5	3.30	46.00	191.36	0.09	0.01	0.16	0.22	0.05	1.30	1.50	1.72	18.94	4.79
b1	6.10	47.00	310.96	0.10	0.01	0.17	0.24	0.11	2.80	1.20	1.72	43.50	6.07
b2	6.50	28.00	200.93	0.02	0.02	0.03	0.22	0.10	3.00	3.20	2.08	42.10	8.60
b3	6.00	44.00	167.44	0.07	0.02	0.12	0.22	0.06	3.30	2.50	1.68	25.26	7.76
b4	6.60	53.00	191.36	0.05	0.02	0.07	0.22	0.06	2.50	1.90	1.64	18.24	6.32
b5	6.40	38.00	181.79	0.05	0.01	0.09	0.38	0.08	1.90	0.10	1.96	18.94	4.42
Topsoil mean	6.62	60.50	221.50	0.24	0.02	0.41	0.21	0.10	4.77	1.48	1.77	27.44	8.43
Stdev	0.21	10.12	28.08	0.23	0.00	0.40	0.07	0.03	1.46	1.14	0.10	10.16	1.44
Subsoil mean	6.02	41.70	220.54	0.07	0.02	0.11	0.25	0.08	2.66	2.15	1.78	30.94	6.76
Stdev	0.99	11.80	48.02	0.06	0.01	0.11	0.05	0.03	0.99	2.06	0.16	14.98	2.18
Soil mean	6.32	51.10	221.02	0.15	0.02	0.26	0.23	0.09	3.72	1.82	1.78	29.19	7.59
Stdev	0.76	14.41	38.29	0.18	0.00	0.32	0.06	0.03	1.63	1.66	0.13	12.59	2.00
C1	6.30	38.00	143.52	0.14	0.02	0.24	0.26	0.11	1.40	2.20	1.92	33.68	5.89
C2	6.00	28.00	143.52	0.35	0.01	0.60	0.24	0.06	4.10	2.20	2.00	35.08	8.60
c1	6.20	61.00	153.09	1.32	0.02	2.28	0.21	0.12	6.50	2.70	1.76	28.07	11.29
c2	6.00	42.00	162.66	0.09	0.02	0.01	0.21	0.06	4.60	2.10	1.76	16.84	8.74
Topsoil mean	6.15	33.00	143.52	0.25	0.02	0.42	0.25	0.09	2.75	2.20	1.96	34.38	7.25
Stdev	0.21	7.07	0.00	0.15	0.01	0.25	0.01	0.04	1.91	0.00	0.06	0.99	1.92
Subsoil mean	6.10	51.50	157.88	0.71	0.02	1.15	0.21	0.09	5.55	2.40	1.76	22.46	10.02
Stdev	0.14	13.44	6.77	0.87	0.00	1.61	0.00	0.04	1.34	0.42	0.00	7.94	1.80
Soil mean	6.13	42.25	150.70	0.48	0.02	0.78	0.23	0.09	4.15	2.30	1.86	28.42	8.63
STDEV	0.15	13.82	9.16	0.57	0.00	1.03	0.02	0.03	2.10	0.27	0.12	8.29	2.21

REFERENCES

Adeyemo, OK (2005): Haematological and histopathological effects of cassava mill effluents in *clarias gariepinus*. *African Journal of Biomedical Research*, vol. 8 (2005):179 – 183. Retrieved April 2, 2008 from http://www.bioline.org.br/md

Akintowa, A Tunwashe, OL (1992);: Fatal cyanide poisoning from cassava-based meal. *Human and Experimental Toxicology*, 11:47-49.

Balagopalan C Rajalekshmy, L (1998): cyanogens accumulation in the environment during processing of cassava (*Manihot esculenta Crantz)* for starch and sago. *Water, Air and Solid Pollution,* 102: 407 – 413.

Bengtsson, B Triet, T. (1994); Tapioca –starch wastewater toxicity characterized by microtox and Duckweed Tests. *Ambio* vol 23 No 8, 473 - 477.

ESCAP (Economic and Social Commission for Asia and the pacific) (1982): *Industrial pollution control Guidelines* Vol. V: Tapioca industry. United Nations, Bangkok, Thailand, 17p.

Essers, AJA (1994); Further improving the enzymatic assay for cyanogens in cassava products, *Acta Horticulturae*. Cassava safety No 375, p. 97-104.

Evanylo, G McGuinn, R (2000); *Agricultural Management practices and soil quality; measuring, assessing and comparing laboratory and field test kit indicators of soil quality attributes*. Publication number 452 – 400.

http://www.ext.vt.edu/pubs/compost/452-400/5452-400.html

Hans Rosling (1994); Measuring effects in humans of dietary cyanide exposure from cassava. *Acta Horticulturae*. Cassava safety No 375, p. 271-283.

International Cyanide Management Institute (ICMI) (2006): *cyanide facts: sampling and analysis ofcyanide in gold mining operations*. International Cyanide Management Institute. Retrieved April 21, 2008 from http://www.cyanidecode.org/cyanide_sampling.php

National Environment Board (2004): Soil quality standards. Notification of national environmental board No. 25 BE *Royal govt. gazette* No. 121 special part 119D. http://www.pcd.go.th.info serv/en reg std soil01.html

Nok, AJ; Ikediobi CD (1990); Purification and some properties of linamarase from cassava(Manihot esculenta). *J. Food Biochem* 14(6), 447 - 489.

Odu, CTI, Esuruoso, OF, Nwobosho, LC; Ogunwale, JA (1985); *Environmental Study of the Nigerian Agip Oil Company Operational areas – soils and freshwater vegetation*.niongraf – Italy.

Ogundola AF & Liasu MO (2007): herbicidal effects of effluent from processed cassava on growth performances of *Chromolaena odorota* weeds population. *African Journal of Biotechnology,* Vol. 6(6), pp. 685 – 690. Retrieved April 2, 2008 from http://www.academicjournals.org/AJB

Okezie BO; Kosikowski, FV (1983); Cassava as food. CRC Crit. Rev. *Food Sci Nutr*. 17, 259 – 275.

USDA – Natural Resources Conservation service (1996): *Soil Survey Laboratory Methods Manual*. Soil survey investigations Rep. 42, Ver. 3.0. National Soil Survey Center, Lincoln, NE.

Shape, AG (1976); *The chemistry of cyano-complexes of the transition metals*. Academic press, London.

Spector, Christy (2001); About soil pH. Retrieved March 12, 2008 fromhttp://soil.gsfc.nasa.gor/soilpH/plant pH.htm