JASEM ISSN 1119-8362

Full-text Avalable On-line at
www.bioline.org.br/ja
J. Appl. Sci. Environ. Mgt. *March*, 2006
Vol. 10 (1) 9 - 14

Impact of Yamoussoukro Lakes Water on Lettuce Quality

ASSIDJO N. EMMANUEL[1*], YESSOH M. JEAN-MARIE[2], ATTE D. NOGUES[1], MESSOUM FRANCIS[3]

1- *Laboratoire de Nutrition et de Technologie Alimentaire, Dépt Génie Chimique et Agro-Alimentaire, Institut National Polytechnique Houphouët-Boigny, BP 1313 Yamoussoukro, Côte d'Ivoire ; assidjo@yahoo.fr*

2- *Laboratoire de Modélisation de l'Information et des processus, Institut National Polytechnique Houphouët-Boigny, BP 1313 Yamoussoukro, Côte d'Ivoire*

3- *Direction de la Recherche, Ministère de l'Enseignement Supérieur et de la Recherche Scientifique, BP V 151 Abidjan, Côte d'Ivoire*

ABSTRACT: Waters from lakes, in Yamoussoukro city (Cote d'Ivoire), are usually used for legumes irrigation. However, these lakes were found to be polluted in previous works, inducing probably legume toxicity. The purpose of this work is to draw the relationship between water quality and legume (lettuce) one via their respective physical and chemical characteristics. This study pointed out that, even if lakes were polluted, their characteristics are in the limit of the irrigation water quality standard. In addition, lettuce samples, drawn from the surroundings of lake, respect also FAO quality standard. They are, therefore, good for consumption, and no strong relationship is found to exist between irrigation water quality and lettuce one. Moreover, we found that this water does not constitute a negative factor for environment. @JASEM

After its independence, the Côte d'Ivoire gave a priority to the development of perennial cultures which have known a considerable rise since then. This political choice makes it a world agricultural leader of coffee-cocoa production. But, this country is not less conscious that in the current context of economic entities proliferation and increased markets competition, the diversification of its cultures is needed. Thus during these last years, a broad interest was carried to the market gardening in order to, on the one hand, balance people nutrition and, on the other hand, export the eventual production surplus. However, the potential environmental pollution and more particularly that of water sources used for the irrigation of these cultures, leads to questions about their quality and innocuousness. Indeed, the increase of people and their activities creates significant quantities of undesirable substances which are poured in the rivers (Ryding and Rast, 1993). Former studies (Lhote, 2000; Mama, 1995) undertaken on the artificial lakes of Yamoussoukro city showed that they do not respect the quality standards and are thus polluted. The consequences of this fact (pollution) are numerous. The most significant of them are: the unaesthetic aspect of water, the health risks, difficulties for water treatment and biodiversity deterioration (Allard, 1986). The preponderant use of water from these lakes is the irrigation of the market gardening cultivated around the lakes (Lhote, 2000; Mama, 1995); what constitutes a concern due the fact that these vegetables are consumed by people. They also participate to the financial autonomy of producers (FAO, 2000). So, is it relevant to suspend the gardening production? What is the real degree of water pollution? Are the vegetables also contaminated? This work aims to answer to these questions.

MATERIALS AND METHODS

Water samples: Yamoussoukro city possess a hydrous network of ten artificial lakes (ANADER, 1993). In the surrounds of some of them (4), market-gardenings are intensively cultivated (lettuce, tomato, parsley…) (Lhote, 2000; Mama, 1995; ANADER, 1993). Water from these 4 lakes is frequently used for irrigation and was consequently retained for study. In addition, certain market-gardeners use, instead of water from the lakes, wells one for the irrigation. These wells are dug approximately at 1 m of the lake (Mama, 1995). Water from them was also drawn for analysis. Thus, 3 or 4 samples of 1 litre were drawn, in polyethylene bottles, from each lake and the eventual wells. Certain parameters, taking into account their great variability in time, were measured in situ (Pauwels, 1992):

- temperature thanks to a mercury thermometer (precision 1/10) (AFNOR, 1997a; AFNOR, 1997b)
- pH and potential redox using the pH-meter WTW pH 90 (WTW, Weilheim, Germany) which in the last case is equipped with a redox electrode Melter Toledo Pt 4808-S7 combined with silver chloride (AFNOR, 1997a; AFNOR, 1997b)

* Corresponding author: E-mail: assidjo@yahoo.fr

- dissolved oxygen was determined using an oxymeter WTW OXI 320 (WTW, Weilheim, Germany) (AFNOR, 1997a; AFNOR, 1997b)
- conductivity enabling to appreciate the quantity of dissolved salts was measured with a conductimeter WTW LF 330 (WTW, Weilheim, Germany) (AFNOR, 1997a; AFNOR, 1997b). After these analyses, samples were preserved in cool box and transported immediately to laboratory for analyses. On each sample, 17 physico-chemical parameters were determined according to AFNOR standards (AFNOR, 1997a; AFNOR, 1997b). While the suspended matter rate (SM) was obtained by gravimetry, the ammoniacal nitrogen and nitrate, orthophosphate and total phosphorus rates were determined by spectrophotometry using UV-Visible spectrophotometer KONTRON UVIKON 810 (Kontron S.A., St Quentin, France). On the other hand, the permanganate index, that permits the appreciation of water organic matter content, was obtained using AFNOR NF T 90-050 standard (AFNOR, 1997a). The total nitrogen rate was appreciated using Kjedahl method (AFNOR, 1997a; AFNOR, 1997b). The proportioning of chlorine was done according to AFNOR NF T 90-114 standard (AFNOR, 1997a). Moreover, the water content in various minerals (sodium, potassium, calcium, magnesium, iron, zinc, copper, chromium and lead) was determined by atomic absorption spectrometer SpectrAA-20 (Perkin-Elmer, Australia) (AFNOR, 1997a; AFNOR, 1997b).

Lettuce samples: The test vegetable used in this study was lettuce (*Lactuca sativa*) (Chaux and Foury, 1994; Ministère de la coopération française, 1993). In the surround of selected lakes, vegetable sampling was performed in three points: upstream, medium and downstream of the culture board. In each point, three lettuce plants were taken and this at different vegetative stages. This operation was repeated three times on the same site. The samples, bagged and labelled were also transported in cool box to laboratory for analyses. On each sample, 11 parameters were regularly analyzed. Prior any analysis, plants were preliminarily washed, dried, crushed and incinerated. Like water samples, total nitrogen content was determined by Kjedahl method (IITA, 1981) and minerals (phosphorus, calcium, potassium, sodium, magnesium, iron, zinc, copper, and chromium, lead) by atomic absorption spectrometric method (AFNOR, 1997a AFNOR, 1997b; IITA, 1981).

RESULTS AND DISCUSSIONS

Water quality: To evaluate the quality of water samples, physicochemical parameters were regularly determined and the mean values of the results obtained are consigned in Table 1. Analysing this table, it appears that lakes water is globally slightly alkaline (pH 7.0 – 8.0), excepted for lake B whose pH value is 9.1. Moreover, the lakes temperatures vary from 25.2 to 27.2°C. The content of dissolved oxygen obtained for all samples varies from 2.3 to 9.7 mg/l. If one compares the values obtained for lake A to the associated well (A_p) one, on the one hand, and for lake C to well C_p one, on the other hand, we note that in both cases the dissolved oxygen contents are higher in wells (6.5 and 5.9 mg/l for wells A_p and C_p respectively) than in lakes (5.0 and 4.2 mg/l for respectively lakes A and C).

Table 1: Water samples physicochemical characteristics

Parameters	A	Ap	B	C	Cp	D	Max. conc.
pH	7.30	7.10	9.10	8.00	7.00	7.40	6.50..8.50
Temperature (°C)	26.50	27.10	27.20	26.50	26.80	25.20	< 25.0
O_2 (mg/l)	5.00	6.70	9.70	4.20	5.90	2.30	-
Redox Potential (mV)	342.20	395.40	401.00	330.60	336.60	166.00	-
Conductivity (µS/cm)	520.80	554.00	315.80	251.40	307.20	230.20	< 750
Cl^- (mg/l)	30.80	40.80	30.60	25.80	28.00	24.80	< 300
Na^+ (mg/l)	30.40	33.94	19.27	13.81	15.04	15.83	< 70
K^+ (mg/l)	28.22	31.55	16.08	10.58	11.75	11.47	-
Ca^{2+} (mg/l)	23.21	25.34	18.43	19.82	22.42	18.72	> 20
Mg^{2+} (mg/l)	6.40	7.37	5.40	4.07	4.42	4.16	< 300
N (mg/l)	7.23	4.73	3.24	2.34	1.42	2.86	< 10
NH_4 (mg/l)	0.50	0.34	0.25	0.19	0.16	0.27	< 5
NO_3 (mg/l)	0.09	0.07	0.08	0.16	0.15	0.04	< 3
P (mg/l)	0.81	0.66	0.32	0.19	0.15	0.36	< 10
P_2O_5 (mg/l)	0.13	0.19	0.04	0.03	0.05	0.06	< 5.0
SM (mg/l)	34.03	26.87	28.66	9.30	8.33	11.83	< 1500
Permanganate index (mg/l)	11.58	9.69	07.79	3.43	2.88	04.42	< 50

Max. conc. : Maximal admitted concentration

This mismatch ranging between 23.0 and 28.8 % could be explained by the presence of macrophytes in lakes and their absence in wells (Lhote, 2000). Indeed, due to a phenomenon of eutrophisation noted on Yamoussoukro lakes (Mama, 1995; Lhote, 2000) macrophytes overgrown some lakes of the hydrous network. Thus, by their presence, they reduce contact surface between water and air, constituting consequently, a barrier to atmospheric oxygen dissolution. This fact is in addition confirmed by higher dissolved oxygen content in lake B (9.7 mg/l), which is devoid of macrophytes (Mama, 1995). Moreover, as oxygen is the principal medium oxidizing, less there is oxygen more the medium is reduced. Thus, it appears that richer is the medium in dissolved oxygen (lake B), higher is its redox potential (401.0 mV). Furthermore, if there is less dissolved oxygen (lake D) its potential redox is lower (166.0 mV). The electric conductivity which expresses the quantity of dissolved salts in a solution varies, for these samples of water, from 230.2 µS/cm (lake D) to 554.0 µS/cm (well A_p). These results indicate a relatively weak mineralization in this water. Moreover, it should be noted that conductivities are higher in the wells of 6.37 and 22.19 per cent than in lakes A and C respectively. The content of suspended matter (SM) in lake and wells ranges from 8.33 to 34.03 mg/l. In addition, while the nitrogen content varies from 1.42 to 7.23 mg/l, the phosphorus one goes from 0.03 to 0.19 mg/l. Values obtained for studied salts (Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}) are all largely lower than the required standard. This fact enables to forecast that the use of this water for the irrigation is not a danger of salinity, sodicity and alkalinity for soils. Moreover, among the revealing indices of irrigation water pollution, there are ammonia and nitrates contents which are lower. The permanganate index which gives an indication of the organic matter quantity in the medium varies from 2.88 to 11.58 mg/l.

Table 2: Irrigation quality indexes

Evaluation criteria	A	Ap	B	C	Cp	D
Mojeïko and Varotnik $\frac{100 \times Na^+}{Ca^{2+} + Mg^{2+} + Na^+} \leq 60\%$	43.89	43.89	37.89	31.08	30.51	34.90
$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} < 8$	1.44	1.52	1.01	0.73	0.76	0.86
$\frac{100 \times Mg^{2+}}{Ca^{2+} + Mg^{2+}} < 50\%$	31.57	32.64	32.81	25.89	24.71	27.04
Sodicity coefficient $\frac{Na^+}{Ca^{2+}} < 1$	1.14	1.16	0.91	0.61	0.58	0.73
Sovolev $\frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+}} \leq 2$	1.20	1.21	0.91	0.65	0.64	0.76

The results obtained herein are very close to those obtained by Lhote (2000) and Mama (1995). These authors have shown in their respective works that physicochemical parameters concentration varies from one season to another. But, in all cases, water from the Yamoussoukro city lakes is polluted. This assertion was drawn comparing their results to human consumption standards. Therefore, one can conclude as they did that water from the lakes is polluted. But, as the main use of this water is to irrigate vegetable, it is necessary to analyse the results obtained according to irrigation standards. Then, if one compares these results to standard presented in Table 1, it appears that pH values respected the standard maximum value (pH 8.5), except samples from lake B (9.1). Temperatures are all higher than the standard (25.0°C). Concerning conductivity, suspended matter, nitrogen and phosphorus, all samples values remain lower than the standard ones (750.0 µS/cm, 1500 mg/l, 10 mg/l and 10 mg/l respectively) (Ayers and Westcot, 1988). Consequently, this water can be use in association with fertilizing elements, because it is poor in nutritive ones. Whereas permanganate indexes are 4 to 14 times lower than the standard, thus indicating a rather low content of organic matter, ammonia and nitrates are 10 to 100 fold inferior to

* Corresponding author: E-mail: assidjo@yahoo.fr

irrigation quality index of the lake (Ayers and Westcot, 1988). Therefore, the water samples drawn for analysis are suitable for irrigation (Ayers and Westcot, 1988; FAO, 1990). In order to confirm this assertion, various coefficients were calculated and presented in Table 2.

These criteria define each one a significant parameter either for the plant (magnesium ratio) or for soil (alkalinity: Mojeïko and Varotnik, SAR; sodicity: Sovolev) (Paliwal and Gandi, 1976; Suarez, 1981; FAO, 1976). According to the allowed standard, the rate of sodium absorption (Sodium Absorption Ratio: SAR) and the ratio suggested by Mojeïko and Varotnik must be lower respectively than 8 and 60 % (Paliwal and Gandi, 1976; Suarez, 1981). When Table 2 is analyzed, it is noted that while the SAR of the various water samples varies from 0.73 to 1.52 and is thus lower than 8, the Mojeïko and Varotnik ratio ranges from 30.51 to 43.89 %. This last ratio is also lower than 60 % in all cases. Consequently, water used is far from creating soil alkalinity (FAO, 1976; Ayers and Tanji 1981). In the same mood, it appears that the magnesium and Sovolev ratios are all lower than 50 % and 2, respectively, leading to conclude that water samples are neither toxic for plant nor create any soil salinity (FAO, 1976). Moreover, sodicity ratio, excepted for water from lake A (1.14) and from well A_p (1.16), is lower than the acceptable limit (1.00), for all other water samples (from 0.58 to 0.73). Thus, only lake A and its related well can create a sodicity problem to soil, and reduce consequently the capacity for mineral absorption for plants growing on these soils. Globally, the results obtained point out the good quality of studied water samples for irrigation (Ayers and Westcot, 1988; FAO, 1990).

Table 3: Water samples heavy metal content (mg/l)

Elements	A	Ap	B	C	Cp	D	Maximal admitted concentration[1]
Iron (Fe)	0.35	0.22	0.38	0.17	0.08	0.23	5.00
Zinc (Zn)	0.56	0.14	0.35	0.27	0.08	0.17	2.00
Copper (Cu)	0.55	0.34	0.29	0.23	0.12	0.21	0.20
Lead (Pb)	0.95	0.52	0.49	0.40	0.10	0.20	5.00
Chrome (Cr)	0.30	0.10	0.21	0.14	0.05	0.13	0.10

[1]National academy of sciences (1972)

Nevertheless, water can also contain organic substances, heavy metals and micronutrients which can reduce its aptitude for irrigation. Thus, certain heavy metals were determined and the values obtained are summarized in Table 3. This table shows that water samples contain heavy metals. While iron varies from 0.008 to 0.350 mg/l, zinc, copper, lead and chromium range respectively from 0.08 to 0.56 mg/l, from 0.12 to 0.55 mg/l, from 0.10 to 0.95 mg/l and from 0.05 to 0.30 mg/l. This presence of heavy metals results in most of cases from human activities, in particular from domestic wastewater (Mama, 1995; Lhote, 2000). When comparing water samples each other, it appears that lake A is the most contaminated. In addition, the heavy metals values obtained are in all cases lower in well samples than in lakes ones. Indeed, the iron content in the well A_p is 1.59 times lower than that of lake A. It is the same case for well C_p which presents a content of this same compound 2.12 times lower than in the lake C. This phenomenon is also observed for zinc whose content in wells (A_p and C_p) is 4.00 and 3.38 times lower than in lakes A and C respectively. Copper, lead and chromium values are 1.91 to 4.00 times lower in wells than in lakes. However, though these values are different to zero, they are inferior to the admitted maximum values, excepted for copper. Indeed, this last heavy metal presents values superior to National Academy of Sciences of the United States standards (0.20 mg/l) (National Academy of Sciences, 1972), excepted for samples from well C_p (0.12 mg/l). But in regards to Russian standards (Paliwal and Gandi, 1976; Suarez, 1981; FAO, 1976; Boudanov, 1969) that are more flexible, all samples respect the maximum limit (2 mg/l). We can consequently conclude that wells are less contaminated than lakes. Furthermore, well C_p shows the best ecological characteristics. The use of wells is thus justified, because through soil most of heavy metals are filtered and purified water presents consequently less pollution danger. The quality of lettuce: The various lettuce samples were studied. The results of this study are depicted in Table 4. This table shows that nitrogen rate varies from 2.21 to 3.07 mg/l. In addition, the other studied macronutrients present variable values from one sampling site to the other. Indeed, for instance, when the sodium rate varies from 21.20 to 26.60 mg/l, magnesium one goes from 2.25 to 2.98 mg/l. Moreover, it is noticed the significant absorption of potassium (from 21.60 to 34.30 mg/l) in comparison to calcium one (from 10.38 to 13.60 mg/l). This result can be explained by the presence of magnesium which would reduce the calcium rate according to the antagonism phenomenon and increase the potassium rate according to the synergy phenomenon (Callot, 1982). However, all these values are largely inferior to the maximum limit. In addition, Table 4 points out the presence of heavy metals in lettuce. Although their content is lower than the admitted maximum value, the iron concentration (from 0.25 to 0.63 mg/l) is 4 times higher than other metals one. This fact can be explained by the composition of the soil which is ferralitic type (ANADER, 1993).

Table 4: Lettuce physicochemical characteristics

Elements	A	Ap	B	C	Cp	D	Maximal admitted concentration
Azote (N)	2.410	2.210	3.070	2.440	2.220	2.500	-
Phosphate (P_2O_5)	0.210	0.190	0.170	0.190	0.160	0.190	-
Potassium (K)	30.880	27.900	21.600	30.200	28.200	34.300	-
Sodium (Na)	25.800	22.400	21.200	25.700	23.100	26.600	-
Calcium (Ca)	10.380	10.400	10.860	13.520	13.300	13.600	-
Magnesium (Mg)	2.440	2.350	2.980	2.450	2.250	2.650	-
Iron (Fe)	0.620	0.600	0.630	0.420	0.250	0.370	< 2.000
Zinc (Zn)	0.015	0.014	0.120	0.004	0.002	0.010	< 0.200
Copper (Cu)	0.006	0.005	0.004	0.002	0.001	0.001	< 0.050
Lead (Pb)	0.012	0.010	0.010	0.002	0.001	0.001	< 0.080
Chrome (Cr)	0.003	0.003	0.002	0.002	0.001	0.001	< 0.009

Thus, we can conclude that these metals, in trace in the samples do not constitute a danger for consumers' health. Consequently, the lettuces cultivated in these conditions are suited to consumption (Derache, 1986). A question seems however significant: does exist a correlation between the irrigation water quality and the lettuce one? To answer to such a question, a statistical study based on the determination of correlation coefficients (r) was made. Calculations were performed using the Microsoft Excel 2000 software (Paris, France). The results obtained are presented in Table 5. One can noticed that excepted for the correlation coefficient of lead (0.77), copper (0.51) and phosphate (0.63), all other coefficients are inferior to 0.50, relating to weak relation between the water quality and the lettuce one for the element considered. By taking account all the parameters at once, one obtains a total correlation coefficient of 0.21. This value lower than 0.50, indicates the weak relationship between lettuce and irrigation water qualities. This established fact can be due to the fact that water is not committed in a direct relationship with the lettuce (Heller, 1993). This result confirms the essential role of soil in water-plant relations.

Conclusion: According to former studies, water from lakes in Yamoussoukro city, used for the irrigation of the market gardening, is polluted. However, our study shows that, although polluted, this water respects the irrigation water standards. The presence of heavy metals remains very limited, because of the weak industrialization of the city. In addition, the studied lettuces show characteristics which are within the limits of FAO standard and are consequently good for human consumption. Moreover, the weak correlation existing between the water characteristics and those of vegetables (lettuces) show the essential role of soil in the water-plant relation. This fact is furthermore positive because if we extrapolate, whatever the water quality, it could be utilised for lettuces irrigation without affecting this later quality. But, the strong correlation observed particularly for lead and copper induce to be circumspect. The good ecological characteristics observed for wells samples show the interest to vulgarise their use.

Table 5: Correlation coefficient (r) between irrigation water and lettuce characteristics

	N	P_2O_5	K	Na	Ca	Mg	Fe	Zn	Cu	Pb	Cr
r	-0.23	0.63	-0.18	-0.18	-0.01	-0.02	0.35	0.22	0.51	0.77	-0.09

REFERENCES

AFNOR, (1997a). Qualité de l'eau : Méthodes d'analyse 1 Tome 2°. AFNOR, Paris.

AFNOR, (1997b). Qualité de l'eau : Méthodes d'analyses des eaux 2. Eléments majeurs, autres éléments et composés minéraux, Tome 3. AFNOR, Paris.

ANADER, (1993). Bulletin interne. Agence Nationale d'Appui au Développement Rural, Yamoussoukro

Allard, L (1986). Les matières organiques produites par l'eutrophisation en eau douce. Agence Financière de Bassin « Seine Normandie », Paris.

Ayers, R S; Tanji, K K (1981). Agronomic aspects of crop irrigation with wastewater. Proc. Spec. Conf., Water Forum, 81(1):578-586.

Ayers, R S; Westcot, D W (1988). La qualité de l'eau en agriculture, Bulletin FAO d'irrigation et de drainage n° 29. FAO, Rome.

Boudanov, J.M (1964). Exigence de la qualité des eaux de source et des effluents industriels et domestiques utilisées pour l'irrigation des parcelles agricoles. Kiev Ed., Kiev

Callot, G (1982). Mieux comprendre les interactions sol-racines : Incidence sur la nutrition minérale. I.N.R.A., Paris.

Chaux, C ; Foury, C (1994). Productions légumières, Légumes, Feuilles, Tiges, Fleurs, Racines, Bulbes. Technique et Documentation Lavoisier, Paris.

Derache, R (1986). Toxicité et sécurité des aliments. Technique et documentation Lavoisier, Paris.

FAO, (1976). Prognosis of salinity and alkalinity, Soils bulletin n°31. FAO, Rome.

FAO, (1990). Etude et propositions pédologiques en vue de l'irrigation. Bulletin pédologique n° 42, FAO, Rome

FAO, (2000). L'agriculture urbaine et périurbaine, la santé et l'environnement urbain. Document de discussion pour la conférence électronique de FAO sur l'agriculture urbaine et périurbaine. FAO, Rome.

Heller, R (1993). Physologie végétale. 1-nutrition. Masson, Paris.

IITA, (1981), Analyses prélèvements pédologiques et végétaux. International Institute of Tropical Agriculture, Ibadan.

Lhote, A (2000). Critères d'évaluation de la qualité de l'eau d'un système lacustre tropical. Approche statistique : cas de la ville Yamoussoukro. Thèse Ecole Supérieure d'Ingénieur de Poitiers (ESIP), Poitiers.

Mama, D (1995). Etude dynamique des processus conduisant à l'eutrophisation du système lacustre de Yamoussoukro. DEA. Université de Cocody, Abidjan.

Ministère de la coopération française, (1993). Mémento de l'Agronome Collection « Techniques rurales en Afrique », 4ème édition. Paris.

National Academy of Sciences, (1972). Water quality criteria. United States Environmental Protection Agency, Washington DC, Report n° EPA-R373-033

Paliwal, K V; Gandhi, A P (1976). Effect of salinity, SAR, Ca: Mg ratio in irrigation water and soil texture on predictability of exchangeable sodium percentage. Soil Sci. 122:85-90.

Pauwels, J M (1992). Méthodes d'analyses de sols et de plantes, équipement, gestion de stocks de verrerie et de produits chimiques. Manuel de laboratoire de pédologie. Dschang & Bruxelles, Bruxelles.

Ryding, S O; Rast, W (1993). Le contrôle de l'eutrophisation des lacs et réservoirs, Sciences de l'environnement 9, Masson, Paris.

Suarez, D L (1981). Relationship between pHc and SAR and an alternative method for estimating SAR of soil or drainage water. Soil Sci. Soc. Am. J. 45:469-475.