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ALUMINUM CONTENT OF TEA LEAVES AND FACTORS AFFECTING THE UPTAKE OF ALUMINUM FROM SOIL INTO TEA LEAVES

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ABSTRACT: Numerous studies indicated that aluminum, the most abundant metallic element within the lithosphere, was considered to be related to some human diseases especially the Alzheimer' s disease. Tea, economically an important beverage in the world, has been found to contain higher concentration of aluminum than many other drinks and foods. Therefore, tea would be a potentially important source of dietary aluminum. In order to understand the sources of aluminum in tea leaves and factors related with aluminum content of tea leaves, an experiment was designed to investigate the relationships of aluminum in tea leaves with leaf age, soil properties and forms of aluminum in soils. The results showed that there were great distinctions in the concentration of aluminum in tea leaves with different leaf age ($Al_{old\ leaf} > Al_{mature\ leaf} > Al_{young\ leaf}$). Moreover, soil pH was the major factor controlling the uptake of aluminum from soil into tea leaves. Furthermore, the content of aluminum in tea leaves was better predicated by the soluble aluminum extracted by 0.02mol/L $CaCl_2$.

KEY WORDS: aluminum; tea leaf; soil properties

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1 INTRODUCTION

Aluminum, the most abundant metallic element within the lithosphere (7% – 8% by weight), occurs generally only in combined form: as an oxide in bauxite, the primary ore, and in complex aluminosilicates such as micas and feldspars (HEM, 1986; LINDSAY, 1979). These compounds of Al, nearly unavailable to plants, dissolve to form the hydrated ion $Al(H_2O)_6^{3+}$ (written Al^{3+} for simplicity) or hydrolysis products of this ion under acidic conditions. The Al ions bind to cation-exchange sites on soil particles or exist in soil solution and thus accessible for plants (ROSSELAND *et al.*, 1990). Tea plants, an important beverage in the world, have been found to contain higher concentration of Al than many other plants, up to more than 5 000 mg/kg of Al in its old leaves (CHENERY, 1955; MATSUMOTO *et al.*, 1976; OWOUR *et al.*, 1 989). Commercially-available tea also contains higher concentrations of Al than many other drink and foods, whose 30% – 40% of Al would be solved into infusions. Therefore, tea would be a potentially important source of dietary aluminum. Aluminum has long been considered a non-toxic element for humans, except in the relatively unusual circumstances of industrial exposure. Aluminum toxicity to

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humans has, in recent years, been implicated in the pathogenesis of a number of clinical disorders in patients with chronic renal failure on long-term intermittent haemodialysis treatment (JONES *et al.*, 1986). Moreover, numurous studies has indicted that some neuropathy especially Alzheimer's disease, a very common form of senile dementia, may be related to the content of Al in human's body (MARTYN 1990; MARTYN *et al.*, 1989; WISNIEWSKI *et al.*, 1990;). Consequently, there will be of theoretical and practical significance to study the aluminum content of tea leaves and the factors controlling the uptake of Al from soils into tea leaves for improving tea garden soil and decreasing contents of Al in tea leaves.

2 MATERIALS AND METHODS

In order to investigate the aluminum content of tea leaves and the factors controlling the uptake of Al from soil into tea leaves, duplicate samples for both soils (depth of 0 – 20cm) and tea leaves with different leaf age (old leaf of one-year age, mature leaf of two-month age and young leaf of half-month age) were collected from thirteen tea gardens located main tea production areas in east China (situation of the tea gardens refer to Table 1). These areas have subtropical wet monsoon climate with mean annual temperatures of 15℃ and mean rainfall of 800mm to 1800mm. The soil samples were air-dried, sifted to pass 2mm sieve and stored in small plastic containers prior to analysis. The tea leaves were rinsed thoroughly with deionized water to reduce surface contamination, dried in an oven at 50℃, then ground with a mill to pass 2mm sieve and stored in a dessicator.

Soil pH and organic matter(OM) content were determined by the methods described by AVERY and BASCOMB(1974). The method used to estimate cation exchange capacity (CEC) was based on that of HESSE (1971) with sodium (NaOAc) used as the exchange ion. The procedure of determining soil texture has been give by DONG (1993).

The forms of labile Al in soils were evaluated by extracting the soils using a number of selected extractants. The various forms of Al, i. e. water soluble-Al, exchangeable-Al, organic Al complex and sorbed inorganic-Al, were obtained with 0.02 mol/L $CaCl_2$ (HOYT *et al.*, 1972), 1mol/L KCl, 0.1 mol/L $CuCl_2$ and 1mol/L NH_4OAc at pH 4.0 (SOON, 1993) in the sequential extraction procedure.

To determine the "total" Al content of soil and tea leaves were digested with a mixture of nitric and perchloric acid (RAMSEY *et al.*, 1991). The amount of Al in all extracts was determined by Inductivity Coupled Plasma Atomic Emission Spectrometry (ICP – AES) at 308.2nm.

3 RESULTS AND DISCUSSION

3.1 Contents of Aluminum in the Tea Leaves

The contents of aluminum in the tea leaves from different tea gardens varied obviously, ranging from

Table 1 Situation of the tea gardens

Tea gardens	Parent material	Total Al /(mg/kg)	pH	OM(%)	Clay(%)	CEC(cmol/kg)
1	Fluvio-marine deposit	22686	5.10	2.02	13.2	10.4
2	Argillo-arenaceous	44570	4.16	5.06	29.8	19.9
3	Quaternay-red clay	45776	4.67	3.28	26.9	21.3
4	Grit stone	36005	4.34	3.84	3.7	14.2
5	Grit stone	45601	4.70	4.39	38.0	18.6
6	Loess	61695	6.02	4.22	35.8	33.0
7	Loess	63225	5.45	2.24	21.7	26.2
8	Loess	59170	5.69	2.76	22.1	21.4
9	Loess	54032	4.95	3.04	23.2	22.6
10	Loess	40405	4.05	5.34	10.5	19.3
11	Loess	54182	4.51	7.06	17.8	23.6
12	Loess	42004	4.33	3.83	6.9	15.5
13	Purple Sandstone	37914	4.48	4.35	10.0	17.5

156 to 596 mg/kg for the young leaves, 873 to 3637 mg/kg for the mature leaves and 1790 to 4381 mg/kg for the old leaves (Table 2). Although there were great distinctions in the concentration of aluminum in the tea leaves for different tea gardens, the distribution law of aluminum in the tea leaves with different age was the same for the same tea garden, i. e. $Al_{old\ leaf} > Al_{mature\ leaf} > Al_{young}$ leaf. The concentration of aluminum in the old leaves were 1.1 – 3.3 times higher than that in the mature leaves and 5.2 – 17.8 times higher than that in the young leaves. MATSUMOTO *et al.*, (1976) reported that the Al content in tea leaves growing in cultural solution of 0.001mol/L $AlCl_3$ depended on the leaf age, 3% Al in older leaves and only 0.01% Al in young ones, a 300-fold difference. That the content of Al in tea leaves increased sharply with the increasing of leaf age indicates that tea leaves is of the characteristic of accumulating aluminum.

3.2 Effects of Soil Properties on the Aluminum Contents of Tea Leaves

The variation in the Al levels of tea leaves from different origins reflects different soil conditions and hence Al uptake by tea leaves in different soils (KLAUS *et al.*, 1989). The correlation of Al contents in the tea leaves with all of the soil properties, except soil pH, were not or weakly significant (Table 3). Aluminum in the tea leaves was as a function of soil pH. It shows that there were strong significant increases of Al in the leaves with decreasing soil pH with correlation coefficients of –0.54 ($p = 0.1$), –0.78 ($p = 0.01$) and –0.69 ($p = 0.05$) for the young, mature and old leaves, respectively (Table 3). This is probably the reason that the increases of mobility of Al promotes the bio-availability of Al to tea plants at lower soil pH. The Al concentration of old leaves linearly increased with of Al in the old leaves (Fig. 1). However, the relationship between aluminum contents of the young and mature leaves and soil pH was non-linear with a marked in-

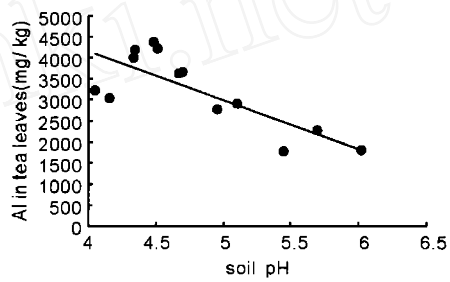

Fig. 1 Relationship of aluminum in the old leaves with soil pH

Table 2 Concentrations of labile forms of Al in the soils, and Al content in the tea leaves (mg/kg)

Tea gardens	Soluble Al	Exchangeable Al	Organic Al complexes	Sorbed inorganic Al	Old leaves	Mature leaves	Young leaves
1	31	195	90	115	2892	873	168
2	53	218	258	155	3030	1247	284
3	30	361	177	157	3634	1916	346
4	136	326	154	31	4187	3122	596
5	59	376	185	162	3652	2256	402
6	2.5	460	70	82	1826	1027	227
7	2.3	327	119	196	1790	1322	344
8	6.1	261	120	194	2279	1273	168
9	17	118	142	146	2784	1208	156
10	33	306	148	85	3228	2828	274
11	60	328	211	122	4212	3637	336
12	63	318	152	140	4010	3475	594
13	50	201	198	154	4381	2853	375
Mean	42	292	156	134	3223	1906	320
Range	2.3 – 136	118 – 460	70 – 258	31 – 196	1790 – 4381	873 – 3637	156 – 596

crease with soil pH below 5.0 (Fig. 2 and Fig. 3). Higher accumulation of Al in the old leaves as compared to the young and mature leaves is the result of a longer growing period (CHENERY, 1955; MATSUMOTO *et al.*, 1976).

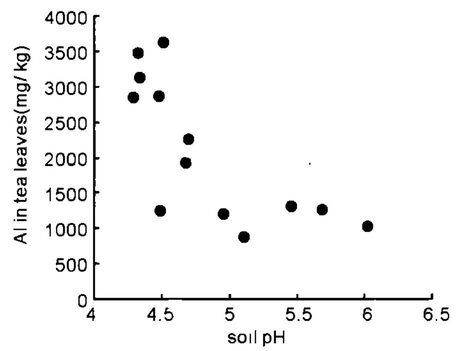

Fig. 2 Relationship of aluminum in the mature leaves with soil pH

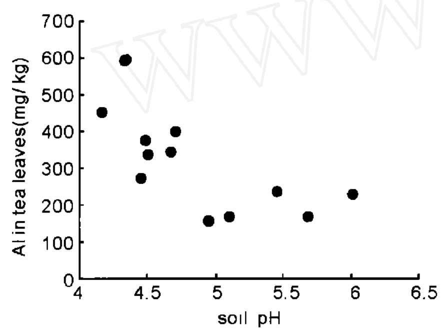

Fig. 3 Relationship of aluminum in the young leaves with soil pH

KUBOTA (1983) indicated that soil pH was a factor that strongly influences release and forms of mineral elements to plants. The availability of soil Al in tea gardens and the uptake of Al by tea plants should be considred closely with the soil pH.

3.3 Relationship of Forms of Al in the Soils with Al Contents of Tea Leaves

Different forms of Al in the soils extracted by chemical reagents were usually assessed for their availability to plant tissues based on the correlation between Al concentrations in the plant tissue and different forms of Al in the soils. In the present study, the results showed that the concentrations of Al in the tea leaves were best predicted by the amount of soluble Al in the soils extracted by 0.02mol/L $CaCl_2$, followed by that of organic Al complexes extracted by 0.1mol/L $CuCl_2$ for the mature leaves (Table 3). The correlation coefficients for the relationship between the concentrations of Al in the tea leaves and the amount of soluble Al in the soils extracted by 0.02mol/L $CaCl_2$ were 0.77 ($p = 0.01$) for the young and old leaves and 0.66 ($p = 0.05$) for the mature leaves (Table 3). The results may demonstrate that soluble Al in the soils extracted by 0.02mol/L $CaCl_2$ is only easily assimilated by tea plants. Comparison of this result with the relationship between soluble Al in the soils extracted by 0.02mol/L $CaCl_2$ and soil pH (DONG *et al.*, 1999), suggests that the species of Al taken up by tea plants

Table 3 Correlation coefficients for the relationships between Al in the tea leaves and soil properties/Al forms in the soils

	Al in the old leaves	Al in the mature leaves	Al in the young leaves
pH	-0.69**	-0.78***	-0.54*
OM	0.52*	0.56**	NS
CEC	-0.58*	-0.49*	NS
Clay	-0.49*	-0.48*	-0.50*
Soluble Al	0.77***	0.66**	0.77***
Exchangeable Al	NS	NS	NS
Organic Al complexes	0.62**	NS	NS
Sorbed inorganic Al	NS	NS	NS*

*Significant at $p = 0.1$; **Significant at $p = 0.05$; ***Significant at $p = 0.01$; NS means not significant was the Al^{3+} ion.

Organic Al complexes may contribute to the Al^{3+} ion in soil solution through the removing of equilibrium between forms of Al in the soils. Other two forms of Al may be too stable to be taken up by the tea plants.

If the Al uptake by tea leaves was expressed by the concentration of soluble Al in the soils, the equations obtained from linear regression for the relationships are given as follows:

$$[Al]_{young\ leaf} = 200.02^{**} + 3.07^{**}[Al]_{soil}$$

$$[Al]_{mature\ leaf} = 1306.2^{*} + 18.5^{*}[Al]_{soil}$$

$$[Al]_{old\ leaf} = 2428.2^{**} + 19.0^{**}[Al]_{soil}$$

($*$, $**$coefficients statistically significant at $p = 0.05$ and 0.01, respectively)

The result shows that $CaCl_2$-extractable Al in the soils can be regarded as "tea available Al".

4 CONCLUSION AND SUGGESTION

The results of this study have shown that: 1) the levels of aluminum in the tea leaves with different leaf age were great distinct, the distribution law is $Al_{old\ leaf} > Al_{mature\ leaf} > Al_{youngleaf}$; 2) soil pH was the major factor controlling the uptake of aluminum from soil into tea leaves; 3) the contents of aluminum in the tea leaves were better predicted by the soluble aluminum the soils extracted by 0.02mol/L $CaCl_2$.

REFERENCES

AVERY B W, BASCOMB C L, 1974. *Soil Survey Laboratory Methods. Tech. Monogr*[M]. No. 6, Soil Survey, Harpenden.

CHENERY E A, 1955. A preliminary study of aluminum and the tea bush[J]. *Plant and Soil*, 6: 174 – 200.

DONG D, 1993. *Influence of soil geochemistry on the uptake of Al from soil into the soybean plant*[D]. Unpubl. Ph. D. Thesis, Univ. London.

DONG De-ming, XIE Zong-lei, DU Yao-guo, LIU Chun-ming and WANG Sheng-tian, 1999. Influence of soil pH on aluminum availability in the soil and aluminum in tea leaves [J]. *Commun. Soil Sci. Plant Anal.* 30(5 + 6): 873 – 883.

HEM J D, 1986. Geochemistry and aqueous chemistry of aluminum[A]. In: J. W. COBURN and A. C. ALFREY (eds.). *Kidney Inernational*[M], Springer-Verlag, NY. S3 – S7.

HESSE P R, 1971. *A text Book of Soil Chemical Analysis*[M]. London: John Murray Publ. Ltd.

HOYT P B, NYBORG M, 1972. Use of dilute calcium chloride for the extraction of plant-available aluminum and manganese from acid soil[J]. *Can. J. Soil Sci.*, 52: 163 – 167.

KUBOTA J, 1983. Soils and plants and the geochemical environment[A]. In: I. THORNTON(ed.). *Applied Environmental Geocheminstry*[M]. London: Academic Press, 103 – 122.

JONES K C, BENNETT B G, 1986. Exposure of man to environmental aluminum — an exposure commitment assessment [J]. *The Science of the Total Environment*, 52: 65 – 82.

KLAUS R, KOCH M A, PRRUNO P, VILLIERS S De, 1989. Determination of aluminum levels in tea and coffee by inductively coupled plasma optical emission spectrometry and graphite furnace atomic absorption spectrometry[J]. *Analyst*, 114: 911 – 913.

LINDSAY W L, 1979. *Chemical Equilibria in Soils*[M]. New York: John Wiley and Sons, 34 – 39.

MARTYN C N, 1990. Aluminum and Alzheimer's disease: an epidemiological approach[J]. *Environmental Geochemistry and Health*, 12(1 + 2): 169 – 172.

MARTYN C N, OSMOND C, EDWARDSON J A, BARKER D J P, HARRIS E C, LACEY R E, 1989. Geographical relation between Alzheimer's disease and aluminum in drink water[J]. *Lancet*, i, 59 – 62.

MATSUMOTO H, HIRASWA E, MORIMURA S, TAKAHASHI E, 1976. Localization of aluminum in tea leaves[J]. *Plant Cell Physiol*, 17: 627 – 631.

OWOUR P O, CHERUIYOT D K A, 1989. Effects of nitrogen fertilizers on the aluminum contents of mature tea leaf and extractable aluminum in the soil[J]. *Plant and Soil*, 119: 342 – 345.

RAMSEY M H, DONG D, THORNTON I, WATT J, GIDDENS R, 1991. Discrimination between Al held within vegetationand that contributed by soil contamination using a combination of Electron Probe Micro-Analysis (EMPA) and Inductively Coupled Plasma Atomic Emission Spectrometry (ICP – AES) [J]. *Environ. Geochem. Health*, 13(2): 114 – 118.

ROSSELAND B O, ELDHUSET T D and STAURNES M, 1990. Environmental effects of aluminum[J]. *Environmental Geochemistry and Health*, 12(1 + 2): 17 – 27.

SOON Y K, 1993. Fractionation of aluminum acid soils: A review and a proposed procedure[J]. *Comm. In Soil Sci. Plant Anal*, 24(13 + 14): 1683 – 1708.

WISNIEWSKI H M, MORETZ R C, STURMAN J A, WEN G Y, SHEK J W, 1990. Aluminum neurotoxicity in mammals [J]. *Environmental Geochemistry and Health*, 12(1 + 2): 115 – 120.