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## WATER-SAVING IRRIGATION REGIMES FOR VEGETABLE CROP PRODUCTION UNDER CONDITIONS OF VOLGA-DON INTERFLUVE

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**Abstract.** Soils of the southern region of Chad are developed on wind-drawn sand and colluvio-alluvium deposits of two main rivers Logone and Chari. This region of Chad is principal agricultural zone of Chad. Evaluation of physical and chemical properties of sandy soils and their fertility in this region revealed that some soils have very high content of strontium. With aim to locate areas with high content of strontium in soil, and to study its dependence on physical properties of soil and translocation of strontium in soil profile nine pedons were dug on different fields intensively used for agricultural production. Using X-ray spectrometric analysis and radiometric measuring of soil samples it has been revealed that Sr content in soil samples varies from 10 to 270 mg/kg of soil depending on type of soil, depth of soil layers, clay and organic content. Strontium content negatively correlates with total content of calcium and phosphorus in layers of soil. Low CEC of soil may be a reason of translocation of strontium from higher to lower layers of soils. Strontium content in soils do not relates with level of radioactivity of soils under study. The highest content of strontium has been found in soils developed on colluvio-alluviumdeposits. Very wide Ca/St ratioin soil samples of alluvial hydromorphic soils may cause increase of Sr content in vegetable food and drinking water. This may be one of etiological factors which directly or indirectly may cause misbalance in mineral nutrition and severe diseases of a man. It worth of considering necessity of further studies of Sr dynamic in soils under different crop production systems and how to mitigate negative effect of natural pollution of soils with this element.

**Keywords:** strontium, Ca/Sr ratio, sandy soil, eolian/alluvial deposits, Kashin-Beck disease, osteoarthritis

### INTRODUCTION

Analyzing physical, chemical composition and level of fertility of sandy soils on agricultural fields in Southern part of Republic of Chad we found that some soils have extremely high content of strontium. Soils of this area have very specific physical and chemical properties for they are have been formed on eolian and colluvio-alluvium deposits. These deposits are historically very young and time to time are covered by new wind and flood-drawn deposits. In some low places along the rivers there are clay soils of hydromorphic type. On sandy soils at higher places farmers usually grow corn, peanut, cassava, and taro. On lower places along the river they cultivate rice, root vegetables, banana, and green vegetables. Commercial produce of these crops compose main part of people’s diet.

General information known on etiological factors which may cause Kashin-Beck disease and other diseases, mostly bone abnormalities [1, 2], led us to analyze more deeply strontium status of sandy soils in mentioned area.

Chemical properties of strontium are very similar to those of barium, calcium, as they may form same salts and basis, but being heavier strontium forms less mobile hydroxide, what causes its accumulation in soils, plant and live organism tissue. The origin of Sr in soils in fact is soil-forming material usually brought by wind and floods from areas where contemporary Earth surface was an ocean bottom at Pleistocene epoch. Ocean sediments at Tibetsy area where usually strong wind is born contain the rests of sea acantarium (radiolarium) which is mainly composed of  $\text{SrSO}_4$ . Even the present sea weeds in oceans contain 26—140 mg per 100 g of dry matter, whereas grasses contain only around 2—3 mg/100 g d.m. Main forms of strontium salts in sea sediments are carbonate and phosphate. In all geochemical and biochemical processes calcium and strontium accompanies each other. The ratio Ca/Sr in soils formed on mother rock of eolian and alluvial sediments unavoidably determines content of strontium in soils and plants. Of course, it worth mentioning that soils and plants may be polluted by radioactive  $^{90}\text{Sr}$  precipitated after nuclear explosions or accidents at nuclear objects, but this is a special case.

In any case, while evaluating qualities of soil, as an agricultural object, it worth paying attention to total content of strontium and its ratio to calcium. It will be helpful in finding coincidence with such diseases as Kashin-Beck and other bone abnormalities and finding means of its prevention [2—5].

## MATERIALS AND METHODS

City Moundou is a capital of the southern province in Chad. All fields around the city are allocated for crop production and pastures. Soils may be considered as very young as they are formed by periodic wind-driven and alluvial deposits. With aim to study geographical distribution of strontium in soils nine pedons up to 1...1.2 m depth were dug. Locations of pedons excavated (see table 1) were purposely chosen to study influence of height above sea level, hydrology, mode of soil use (arable, pasture, crops cultivated). Having in mind to do further study on soil fertility management in this area all pedons were GPS fixed. As there are no distinguished genetic horizons of soil profile, samples were taken from regular layers 0...30, 30...50 and 50...100 cm. All agrochemical properties such as pH of water and salt extractions, cation-exchange capacity (CEC), content of total and exchangeable phosphate, calcium, magnesium, potassium in soil samples were determined by appropriate techniques [4]. Total content of P, Ca, Sr, Fe, Mn, Mg, K was determined using by X-ray spectrometer `Spectroscan Max G`.

## RESULTS AND DISCUSSION

According to Atlas Cartographique of Chad main part of in the province belong to three main groups, Arenosols, Ferrasols, Flivisols. Soils in pedons: # 1, 3, 4, 5, 6, 7 pertain to sandy ferritique and ferrallitic groups. Upper layers of sandy ferrallitic soils have light brown or gray-brown color. Soils, which suffer periodic but prolong flooding, have some hydromorphic features and dark gray color (pedons # 2, 8, 9). All soils have sandy granulometric composition. Clay content in soils is in the range 2...3%, cation exchange capacity varies from 1 to 2 meq/100g.

Table 1

**Geographical location and average content of Ca and Sr  
in main soils studied in province of Moundou (Chad)**

№ Pedon	Geographical location	Height Above sea level <i>m</i>	Total content in 0—30 cm layer <i>mg/kg</i>		Ca/Sr ratio	
			Sr	Ca	mass	atomic
1	8° 37' 26.94" N 15° 59' 33.28" W	474	15	469	31	69
2	8° 35' 57.96" N 16° 03' 33.34" W	400	235	827	4	7.7
3	8° 35' 22.52" N 16° 06' 20.28" W	389	16	714	45	99
4	8° 37' 49.24" N 16° 05' 51.60" W	411	14	851	61	125
5	8° 33' 58.79" N 16° 00' 18.10" W	412	11	422	38	82
6	8° 39' 52.64" N 16° 01' 38.36" W	481	8	500	63	139
7	8° 34' 30.40" N 16° 00' 38.06" W	409	12	347	29	63
8	8° 32' 59.59" N 16° 05' 49.36" W	396	9	381	42	95
9	8° 36' 14.68" N 16° 04' 46.58" W	396	273	2 310	9	19

NB: Level of water above sea level in the river = 380 m.

Soil acidity measured in KCL extraction was in the range 3.9...5.2. Content of exchangeable aluminum was very low (0.2...0.5 meq/100 g). Organic matter (OM) content in soils on higher places was in the range 0.6—0.8%. In hydromorphic soils OM content was in the range 1.1...1.3%. Granulometric composition and content of OM, phosphorus, calcium and strontium is represented in Table 2.

Table 2

**Content of OM, clay, sand and selected elements in soil layers of different pedons**

Pedon	Layer, <i>cm</i>	OM,%	Sand,%	Clay,%	Silt,%	pH		P	Ca	Sr
						H <sub>2</sub> O	KCl			
						content, mg/kg				
1	0—30	0.79	98.67	0.8	0.6	5.3	4.8	0.075	469	75
	30—50	1.18	96.6	1.6	1.8	5.3	5.0	0.067	664	105
	>100	0.99	95.8	3.2	1.0	4.8	4.8	0.063	796	125
2	0—30	1.13	943.0	2.6	3.4	4.8	4.5	0.086	827	1175
	30—50	0.78	97.2	1.4	1.4	4.8	4.1	0.095	510	1170
	>100	0.45	96.6	1.6	1.8	4.6	4.2	0.068	880	1035
3	0—30	1.43	99.2	0.4	0.4	5.3	5.2	0.066	714	80
	30—50	0.53	98.6	0.6	0.8	5.0	5.4	0.078	246	65
	>100	0.59	96.2	1.6	2.2	4.8	4.1	0.074	389	105
4	0—30	0.84	97.6	1.0	1.4	5.2	4.9	0.109	851	70
	30—50	0.64	97.6	0.8	1.6	4.9	4.5	0.104	536	105
	>100	0.96	99.2	0.6	0.2	4.8	4.0	0.081	263	130
5	0—30	0.58	98.6	0.4	1.0	5.1	4.6	0.096	422	55
	30—50	0.71	98.2	0.8	1.0	4.6	4.0	0.080	274	85
	>100	0.51	99.2	0.6	0.2	4.3	3.9	0.083	137	130
6	0—30	0.65	99.6	0.2	0.2	5.4	4.9	0.064	499	40
	30—50	0.51	99.0	0.2	0.8	5.3	4.7	0.080	370	55
	>100	0.72	98.2	0.4	0.6	4.8	4.2	0.080	290	75

End of the Table 2

Pedon	Layer, cm	OM,%	Sand,%	Clay,%	Silt,%	pH		P	Ca	Sr
						H <sub>2</sub> O	KCl			
7	0—30	0.85	97.8	0.8	1.4	5.3	4.5	0.087	347	60
	30—50	0.45	97.8	1.2	1.0	5.1	4.2	0.076	312	75
	>100	0.26	97.2	2.2	0.6	4.7	3.9	0.044	279	145
8	0—30	1.04	99.4	0.4	0.2	5.6	5.0	0.084	381	45
	30—50	0.45	98.3	0.6	1.2	5.1	4.3	0.072	187	50
	>100	0.52	98.0	1.2	0.8	4.8	4.0	0.068	470	95
9	0—30	1.54	95.0	2.2	2.8	5.5	4.8	0.136	2 310	1 365
	30—50	0.84	98.0	1.2	0.8	5.3	4.3	0.075	1 322	1 260
	>100	0.51	94.3	2.7	3.1	5.0	4.1	0.101	1 249	1 185

As other researchers found mobility of strontium very much depends on granulometric composition of soil, OM content, soil acidity, calcium and phosphate content [3, 5—7].

Eolian nature of soil formation at the area and very high content of sand allow us to expect high risk of mobility of strontium in soil profiles and high content of strontium in ground water.

The main goal pursued in our research was to evaluate dependence of strontium content on physical, chemical, hydrological properties of soils used for crop production in the province Moundou in Chad. Data presented in the Table 2 shows that the range of strontium content in soils varies very much: from very low (8...12 mg/kg) to extremely high (235...273 mg/kg). Low content of native strontium prevails in upper layers of most soils on fields located on higher elevations, and which are used for production of corn, peanut and cassava. It's worth mentioning that in some soils lower layers have higher content of strontium, what may be explained by (a) different content of strontium in wind-brought material in previous times, and (b) by lixiviation of strontium together with silt into lower layers of soil. But, as it has been suggested by soil scientists [1, 7], abundance of strontium is to be compared to that of its homologous element which is calcium. Statistical analysis of the data obtained confirms close correlation between strontium and calcium content in soils. Content of both elements positively correlates with amount of clay and silt in soils. But very low CEC of soils (less than 2 meq/100 g) suggests that larger amount of these elements is in form of poorly weathered material than in the form of extractable salts. This fact is also confirmed by absence of any correlation between acidity of soils and contents of Ca and Sr in soils (Table 3).

Table 3

The Pearson's correlation matrix among measured levels of OM, clay and selected elements (n = 27)

Parameter	OM, %	Sand,%	Clay,%	Silt,%	pH		Total content, mg/kg			
					H <sub>2</sub> O	KCl	P	Ca	Sr	
OM, %	1									
Sand, %	0.2397	1								
Clay, %	0.1511	0.3455	1							
Silt, %	0.2065	0.0118	0.6737	1						
pH-H <sub>2</sub> O	0.0600	-0.0384	-0.0878	0.0469	1					
pH-KCl	0.5074	0.0118	-0.1815	-0.0668	0.0104	1				
P	0.3669	0.0516	0.0434	0.4845	0.0654	0.1132	1			
Ca	0.5484	0.0975	0.5260	0.5851	-0.1074	0.1914	0.5556	1		
Sr	0.2512	0.3501	0.5556	0.6445	-0.1143	-0.190	0.4085	0.7481	1	

Soil exchangeable acidity varies in the range from 4 to 5 units providing average coefficient of variation around 9.6%, which is very low for the territory under study. Calcium content in soils correlates positively with organic matter and phosphorus content in soils, whereas content of strontium does not show such interrelation. As other researchers suggest, it can be governed by lesser activity of this element in biotic system [5, 6, 8].

Nowadays it is recognized that high accumulation of strontium in human body may cause Kashin-Beck disease, osteoarthritis and different metabolic disorders [1—4, 9—12]. That is why it is a reason of big concern for researchers, pathologists and administration in the area. Here we do not mention negative effect of radioactive strontium and other radio nuclides on wild life and human beings, as it is a specific case in quite ordinary situations.

Data presented in Tables 1 and 2 shows, that high content of Sr in soils and its high mobility along the profile of soils should be of big concern as cultivation of food crops may bring problems with health of people living there. Higher content of strontium in low layers of some soils may be explained at least by two obvious factors. Firstly, it may be caused by downward movement of strontium in sandy soils during rainy season. Sandy soils with low content of clay and silt and, as consequence, with low CEC are not able to hold basic elements in upper layers of soil. Wind-translocation of weathered material from northern part of the country (Tibetsy area) is the second factor. That area is rich in strontium-containing material originated from ocean deposits of Pleistocene period. Lowest layers of soil may be formed from sandy deposits brought by the North-West wind centuries before, whereas upper layers of soils have been formed later from sand and dust delivered by wind from other directions.

Russian researchers have accumulated much information on nature of strontium content in soils and biological tissues, its mobility in different conditions, and its influence on health of people. They classified soils on basis of strontium content and established level of Ca/Sr ratio in soils which may be dangerous for human being, and find the way for soil remediation. Moreover, on basis of this data a special State regulation has been adopted which classifies soils and water on basis of strontium content. Having this information we are trying to evaluate data obtained on strontium content in sandy soils of the province Moundou in Chad.

It has been found, that mobility of strontium depends highly on mass or atomic Ca/Sr ratio [1, 3, 5, 6, 10]. Value of these ratios matters for assessment of strontium status of the soils, and this value have been used in Russia for classifying soils and drinkable water usability. For example, water which contains more than 7 mg of water soluble strontium per one liter is not portable, and not to be used in kitchen [1, 11]. Soils which have very low ratio total amount of Ca and Sr are not to be used for production of food crops. In Russia and Ukraine it has been approved that soils which have Ca/Sr ratio of extractable form is less than 140 are not suitable for agricultural production [5, 11, 13]. The reason is much recognized: such levels of strontium in water and wide ratio Ca/Sr may cause Kashin-Beck disease, osteoarthritis, 'strontium-caused rachitis', other physiological abnormalities [3, 4, 8, 10, 12, 14]. It is accepted that these diseases are a consequence of misbalance between Ca and Sr in water and food diet, that causes displacement of Ca by Sr [2, 10, 12, 14, 15].

Very high total content of strontium in sandy soils may be the cause of exhaustible supply of it by winds and floods. Furthermore, its mobility in sandy soils is very high. Strontium translocation along the soil profile and sorption of this element by soil depend on prevailing chemical composition of soil salts (sulphate, carbonate, chloride, and phosphate; OM, clay and silt content). All these factors suggest possible measures of soil remediation. Such measures may include enrichment of soil with organic material [5, 6, 9], use of phosphate fertilizers [3, 6, 9, 10]. These measures may reduce transfer factor of strontium from 0.2...0.3 to as low as 0.01...0.008 [5, 16, 17].

## CONCLUSIONS

Vast majority of soils in Moundou province in Chad pertain to light sandy Arenosols, Ferralsols, and Fluvisols, which are of low fertility. Some soils have high content of strontium and calcium due to their formation from wind-brought materials originated from ocean deposits of Pleistocene period. Such soils have mostly low Ca/Sr ratio what may cause higher translocation of strontium from soil to plant and ground water, and consequently to human nutrition chain.

Future many-side and versatile research in Chad is needed to establish correlation between strontium content in soils, rate of transfer of this element to plant produce, and frequency and severity of diseases thought to be caused by high accumulation of strontium in human body.

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## СОДЕРЖАНИЕ СТРОНЦИЯ В ПЕСЧАНЫХ ПОЧВАХ ЮЖНОЙ ПРОВИНЦИИ ЧАДА

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Почвы южной провинции Чада сформированы на вековых наносах песка, привнесенного из пустынной северной части страны — Сахели, и на отложениях двух основных рек Чада — Логон и Чари. Эта провинция является основной сельскохозяйственной зоной Чада. Оценка физических и химических свойств отдельных образцов почв этой провинции выявила очень высокое содержание стронция в некоторых из них. С целью локализации мест с высоким содержанием стронция в почве

и изучения зависимости распределения этого элемента в профиле почв было открыто 9 почвенных разрезов на различных полях, интенсивно используемых в сельском хозяйстве. Данные анализов почв, полученные с использованием рентгеновского спектрометра и радиометра, свидетельствуют о широком варьировании содержания стронция в почвенных образцах от 10 до 270 мг/кг в зависимости от типа почв, глубины почвенного слоя, содержания глины и органического вещества. Содержание стронция отрицательно коррелировало с общим количеством кальция и фосфора в почвенных образцах. Низкий уровень катионного обмена в верхних слоях почвы может быть одной из причин перемещения стронция из верхних горизонтов в нижние. Содержание стронция в почвах не зависело от уровня общей радиоактивности изучаемых почв. Наиболее высокое содержание стронция было выявлено на почвах, сформированных на аллювиальных отложениях. Сделано предположение, что очень широкое отношение Ca/Sr в образцах гидроморфных почв может быть причиной повышенного содержания стронция в растительных продуктах и питьевой воде. Это может быть одним из факторов, прямо или косвенно вызывающим дисбаланс в минеральном питании, вызывающим тяжелые заболевания человека. Сделан вывод о необходимости дальнейшего изучения динамики стронция в почвах, используемых в различных системах земледелия, и снижения отрицательного эффекта естественного загрязнения почв этим элементом.

**Ключевые слова:** стронций, отношение Ca/Sr, песчаные почвы, ветровые и аллювиальные отложения, болезнь Кашина, остеоартрит

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