

COCA COLA® IS IT! THE UBIQUITOUS EXTRACTANT FOR MICRONUTRIENTS IN SOIL¹

Ewald Schnug, Juergen Fleckenstein, and Silvia Haneklaus

Institute of Plant Nutrition and Soil Science, Federal Agricultural Research Centre Braunschweig-Völkenrode, Bundesallee 50, D-38116 Braunschweig, Germany

ABSTRACT: Coca Cola® has been found to be an excellent extractant for micronutrients in soils, particular for manganese (Mn). The main ingredients of Coca Cola®, phosphoric acid, reducing sugar and carbon dioxide are well proven in common extraction recipes. The overall extraction force of Coca Cola® was similar to that of commonly used phosphoric acid methods. Compared to DTPA, Coca Cola® extracted only 27% of iron (Fe), 38 % of copper (Cu), and 86% of zinc (Zn), but 165% of Mn. Correlation coefficients for the relationship between Coca Cola®-extractable Fe, Zn, and Cu in soils and element concentrations in plants were the same as by means of the DTPA method. For Mn 49% of the variability in Mn concentrations observed in field grown winter wheat plants could be explained by Coca Cola®-extractable soil Mn, but only 39% when employing DTPA. The critical value for available Mn and Zn on the investigated inceptisols was 17.8 mg/kg Mn and 1.3 mg/kg Zn for Coca Cola® and 9.4 mg/kg Mn and 1.8 mg/kg Zn for DTPA. Tentative critical values for Fe and Cu are 19.3 mg/kg Fe and 0.38 mg/kg Cu for Coca Cola® and 73 mg/kg Fe and 0.96 mg/kg Cu for the DTPA method. Besides the better results in extracting available micronutrient fractions from soils, further advantages of Coca Cola® as an extractant are its ubiquitous availability and

¹This paper is dedicated to Prof. Dr. Arnold Finck.

readiness for use but also its easy and safe handling and the fact that the procedure has no harmful impacts on environment.

INTRODUCTION

Extraction procedures and element determination are the two main aspects of soil analysis. Due to high standards of atomization in analytical equipment, particularly in atomic absorption and optical emission spectroscopy, reliable element determination can easily be obtained even by unskilled staff and under unsuitable conditions. The extraction of soils, however, provides several problems, which are of great importance especially when it comes to implementation of soil analysis for micronutrients in laboratories in developing countries: This list of problems involves the availability of highly purified water and "pro analysi" grade chemicals and last but not least the capability of laboratory staff to prepare complex chemical prescriptions accurately. In searching for a solution to all these problems Coca Cola® has been found to provide a number of striking features which could help: The main ingredients of Coca Cola®, phosphoric acid, reducing sugar and carbon dioxide, are well proven in common extraction recipes (Hammes and Berger, 1960; Hoff and Medersky, 1958; Korbobi, 1977) and the water used for manufacturing is highly purified. In addition to these more scientific features Coca Cola® has the great advantage of being manufactured to a quality standard, of being ready to use and of being available nearly all over the world even in the most remote places.

The main objective of the research work reported in this contribution was to investigate the suitability of Coca Cola® for micronutrient extraction and to compare the results obtained with those of already adopted methods for available micronutrients in soils.

MATERIALS AND METHODS

Soil and Plant Materials

Topsoil (0-30 cm) samples were collected in spring from 60 winter wheat sites on the island of Ruegen (54°25 N 13°24 E) in 1993 and 1994 (Haneklaus et al.,

1995). The winter wheat plants had already developed to the GS 31 stage (first node). Each sample comprised 10 subsamples from an area of approximately 100m². Soil samples were air dried and passed through a sieve of 2-mm mesh width. From each of this plots plant material was collected by cutting whole winter wheat tops 3 cm above ground. Each individual sample consisted of approximately 500g fresh material. Plant samples were dried at 85°C and ground by means of an ultracentrifugal mill to a particle size < 0.1 mm.

Chemical Methods

Soil Materials: DTPA extraction: according to Lindsay and Norvell (1978); pH: potentiometric in 1:2.5 suspension with 0.01m CaCl₂. Coca Cola® extraction: 5g air dry soil material were transferred into 100-mL polyethylene bottles, shaken for 1 h with 50 mL genuine Coca Cola®, or Coca Cola Light® on a reciprocal shaker, filtered through a paper filter (Macherey and Nagel MN 614 1/4) and stored refrigerated in polyethylene bottles till further processing. A specific technical advantage of the Coca Cola® extracts is the far quicker passage through the filters than the DTPA extracts. Coca Cola® extracts are also much less prone to fungal growth than DTPA extracts. If there is a need for further simplification of the method, the use of a balance and a measure for the extractant can be avoided by using 150-mL Coca Cola® cans and spoons capable of holding 15 g soil material and shaking manually in clean glass bottles.

Plant Materials: One g dried and ground plant material were transferred to a porcelain crucible and combusted in a muffle furnace at 470°C for 12 h. After cooling down to room temperature, 10 mL of 4m HNO₃ were added to dissolve the remaining ash. Two hours later 40 mL of deionisate were added and the samples were filtered through a MN 614 into polyethylene bottles.

Element Determination

Iron, Mn, Zn and Cu were analyzed by means of atomic absorption spectroscopy (AAS) employing atomization in an air/acetylene flame. The blank values for Fe, Mn, Zn and Cu in Coca Cola®, and Coca Cola Light® delivered in glass

and plastic containers as well as from cans were found to be below the detection limit of AAS.

Statistical Methods

Analysis of variance and correlations were performed by means of the CoHort statistical package (Simons, 1975).

RESULTS AND DISCUSSION

Extraction Force of Different Coca Cola® Ingredients

Table 1 shows the results of an experiment which aimed to evaluate the contribution of individual Coca Cola® ingredients to its extraction force. The difference between Coca Cola® is attributed to the reducing effect of sugar, the difference between the fresh and the degassed solution to carbon dioxide and the remaining to the acidic component of Coca Cola®. The sugar content was estimated to be 106 g/L in genuine Coca Cola® and 0.44 g/L in Coca Cola® light. The content of H₃PO₄ was found to be 6.4 mmol/L in and 5.6 mmol/L respectively.

The treatments showed no significant influence on the amounts of Fe extracted but clearly did on solution pH, Mn, Zn, and Cu (Table 1). Degassing had no effect of the solution pH nor on the extracted amounts of Zn and Cu. In case of Mn, however, 15-29% higher amounts were observed if the extractant was employed without prior degassing. The effect of degassing was higher when using genuine Coca Cola® rather than when using Coca Cola Light®.

In the case of Mn and Zn the higher amounts extracted by genuine Coca Cola® are obviously due to reducing sugar, whereas the higher amounts of Cu found in Coca Cola Light® might be the result of some chelating effects of the substitution of sugar by artificial sweeteners. Table 2 summarizes the relative contribution of the individual constituents to the extraction force for Mn and Zn by both extraction solutions.

Comparison of Coca Cola® with DTPA Extraction

DTPA is a well acknowledged agent for extracting available micronutrients from soils (Lindsay and Norvell, 1979) and is thus used as a standard for comparison with the Coca Cola® method.

Table 1. Influence of degassing of *CocaCola* and *CocaCola light* on the extraction of selected micronutrients and solution pH (means of five replicates)

		pH	Mn	Zn	Cu
<i>Coca Cola</i>	with CO ₂	3.67 a	29.4 a	1.62 a	0.33 a
	without CO ₂	3.63 a	25.4 b	1.56 a	0.33 a
<i>Coca Cola light</i>	with CO ₂	4.21 b	21.6 c	1.19 b	0.38 b
	without CO ₂	4.16 b	16.8 d	1.20 b	0.36 b

note: values with different characters are significantly different by means of the DUNCAN test ($p < 0.05$).

Table 2. Relative contribution (%) of constituents to the extraction force of *CocaCola* and *CocaCola light* for manganese and zinc from inceptisols

Constituent	<i>Coca Cola</i>		<i>Coca Cola light</i>	
	Mn	Zn	Mn	Zn
Sugar	27	24	-	-
CO ₂	14	4	22	1
H ₃ PO ₄	59	73	78	99

Table 3 shows descriptive statistics of the results of the DTPA method and the proposed Coca Cola® method applied to a set of 60 inceptisols sampled on the island of Ruegen. The concentrations of Fe, Zn and Cu were always lower in the Coca Cola® extracts than in the DTPA treatments. Compared to DTPA, Coca Cola® extracted only 27% of Fe, 38 % of Cu and 86% of Zn, but 165% of Mn.

The average amounts extracted by the DTPA method fit well to the averages of 10.9-13.2 mg/kg Mn found by Flueh (1988) and Schnug and Pissarek (1981), the 2.1-2.5 mg/kg Zn found by Franck (1978) and Schnug and Pissarek (1981) who carried out extensive field surveys on the same type of soils in Northern Germany. The average Fe and Cu concentrations extracted by DTPA reported by Schnug and Pissarek (1981) for a set of 169 inceptisols were 96.8 mg/kg Fe and 1.2 mg/kg Cu.

The amounts extracted by the Coca Cola® method were quite similar to what is reported for 0.033M H_3PO_4 in earlier publications (Flueh, 1988; Hammes and Berger, 1960; Hoff and Mederski, 1958). The correlation between micronutrients extracted by both methods was always significant but highest with Mn (Table 3).

In order to estimate the validity of the results for both methods, the available micronutrient concentrations extracted from soils were correlated with the concentrations in young winter wheat plants. The results gathered in Table 4 show a clear advantage of the Coca Cola® method for manganese and zinc. In the case of Fe and Cu the results were not very encouraging but fairly similar for both methods.

For true field samples a correlation of $r = 0.7$ for the relationship between soil and plant Mn is remarkably high (Figure 1). In extensive investigations on the suitability of different extractants for available Mn and for exactly the same type of soils, Flueh (1988) found that on an average over two years only 17% of the variability of plant Mn could be explained by DTPA extractable Mn in soils. Employing an extraction for "active" Mn (Beyme, 1971), which is the officially adopted German standard method for available Mn, to 162 samples of the same soil type Flueh (1988) failed to verify any correlation between soil and plant manganese at all.

Calibration DTPA and Coca Cola® Method

Critical values for both soil extraction methods were calculated by employing the critical values valid for plant analysis in the regression equations obtained from the actual data set (Table 5).

According to Schnug and Haneklaus (1992) the critical values for shooting winter wheat plants (GS31) are 60 mg/kg Fe, 28 mg/kg Mn, 25 mg/kg Zn and 4 mg/kg Cu. It should be mentioned here that these critical values refer to a yield level of 100%.

The critical values for available Mn and Zn for the investigated inceptisols were 17.8 mg/kg Mn and 1.3 mg/kg Zn for Coca Cola® and 9.4 mg/kg Mn and 1.8 mg/kg Zn for DTPA. The critical values for Fe and Cu are only tentative: 19.3 mg/kg

Table 3. Descriptive statistics for DTPA and *Coca Cola* extractable micronutrients in soils (60 inceptisols sampled on the island of Ruegen in 1993 and 1994)

	F e		M n		Z n		C u	
	DTPA	<i>CocaCola</i>	DTPA	<i>CocaCola</i>	DTPA	<i>CocaCola</i>	DTPA	<i>CocaCola</i>
X	73.5	19.5	13.8	23.3	1.61	1.21	1.01	0.37
min.	17.1	8.6	0.56	3.98	0.42	0.17	0.21	0.11
max.	183	29.5	46.8	68.1	6.98	4.20	2.11	0.59
var.(%)	46.1	26.2	64.5	53.3	72.0	67.8	41.0	27.0
r	0.	476***	0.	879***	0.	346**	0.	438***

note: "r" refers to the correlation between the concentration of individual micronutrients in both extractants; *** = $p < 0.001$, ** = $p < 0.01$, all others $p > 0.05$

Table 4. Correlation coefficients for the relations between micronutrient contents in soils extracted by DTPA and *Coca Cola* and micronutrient concentrations in tops of winter wheat plants (EC 32) sampled on the island of Ruegen (n=60)

	DTPA	<i>Coca Cola</i>
Iron	0.076	0.109
Manganese	0.630***	0.700***
Zinc	0.374*	0.400**
Copper	0.076	0.126

note: *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, all others $p > 0.05$

Fe and 0.38 mg/kg Cu for the *Coca Cola*® method and 73 mg/kg Fe and 0.96 mg/kg Cu for the DTPA method.

The critical value for Mn by the *Coca Cola*® method is close to the 20 mg/kg Mn value proposed by Hammes and Berger (1960) and Hoff and Mederski (1958) for an extraction of soils with 0.033 H₃PO₄. For Zn by the DTPA method the critical value reported here agrees well with the Franck's (1978) value of 1.5 mg/kg Zn.

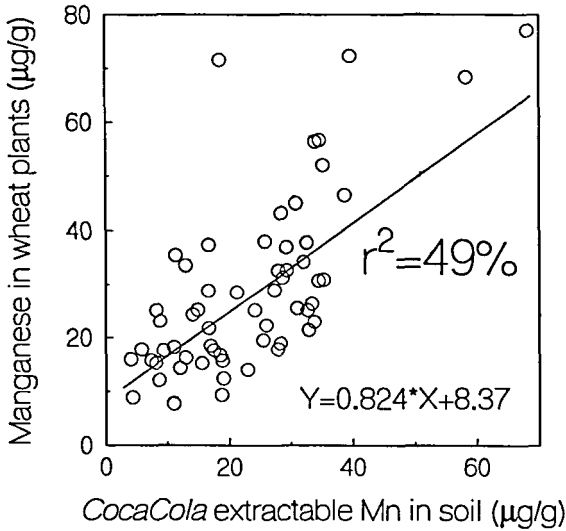


FIGURE 1. Relations between Coca Cola® extractable Mn from inceptisols and Mn concentrations in shooting winter wheat plants.

Table 5. Regression equations for the relation between the DTPA and *Coca Cola* extractable manganese content in soils (X in mg/kg Mn or Zn) and the manganese concentrations in tops of wheat plants (EC 32; Y in µg/g Mn or Zn) sampled from inceptisols on the island of Ruegen (n=60)

Element	Extractant	Regression equation	R ² (%)
Mn	DTPA	$Y = 1.06 * X + 12.91$	39 (p < 0.001)
Mn	<i>Coca Cola</i>	$Y = 0.824 * X + 8.37$	49 (p < 0.001)
Zn	DTPA	$Y = 0.044 * X + 0.54$	14 (p < 0.05)
Zn	<i>Coca Cola</i>	$Y = 0.029 * X + 0.59$	17 (p < 0.01)

CONCLUSIONS

Coca Cola® has been found to be the ideal extractant for available micronutrients from soils and to have highly acknowledgeable scientific and technical features. Correlations with plant concentrations have been shown to be superior to already adopted methods. Technically Coca Cola® offers unbeatable advantages, especially when it comes to micronutrient investigations in remote sites of developing countries. Other advantages include successful analysis independent of explosive and difficult to get chemicals, purified water and proficient staff. With 70% lower costs compared to the DTPA method the Coca Cola® method is also very cheap. Another interesting feature is that laboratory wastes are easy to dispose. Passing through the soil adds a very distinctive flavor which makes the refrigerated extractant freshly after use an interesting beverage.

ACKNOWLEDGMENTS

The authors appreciate to thank Mrs. Christiane Bock and Mr. Reiner Schulze for their careful and reliable work in this exciting project and appreciate very much the efforts of Dr. K. C. Walker, Aberdeen in improving the English of this text.

REFERENCES:

- Beyme, B. 1971. Beziehungen zwischen Mangan-Gehalten in in Haferpflanzen und Boeden. Z. Pflanzenern. u. Bodenkde. 130:271-281.
- Flueh, M. 1988. Untersuchungen zur Verbesserung der Mangan-Versorgung von Getreidepflanzen und Ackerboeden in Schleswig-Holstein. Schriftenreihe Institut für Pflanzenernaehrung und Bodenkunde Universität Kiel, 4.
- Franck, E. v. 1979. Vergleich von Methoden zur Bestimmung des verfuegbaren Zinks im Boden. Mitteilgn. Dtsch. Bodenkundl. Gesellsch. 29:595-602.
- Hammes, J. K. and K. C. Berger. 1960. Manganese deficiency in oats and correlation of plant manganese with various soil tests. Soil Sci. 90:239-244.

- Haneklaus, S., J. Fleckenstein, and E. Schnug. 1995. Comparative studies of plant and soil analysis for the evaluation of the sulphur status of oilseed rape and wheat. *J. Plant Nutr. Soil Sci.* 158:109-112.
- Hoff, D. J. and H. J. Mederski. 1958. Chemical methods of estimating available soil manganese. *Soil Sci. Soc. Amer. Proc.* 22:129-132.
- Korbobiy, E. N. 1977. Comparative estimation of extracts in the determination of the amounts of manganese available to plants in the soils of Middle Amur lowland. *Soil Sci.* 9:324-327.
- Lindsay, W. L. and W. A. Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Sci. Amer. J.* 42:421-428.
- Schnug, E. and H.-P. Pissarek. 1981. Der Ernährungszustand von Raps in Schleswig-Holstein. *Schriftenreihe Agrarwiss. Fak. Kiel (Ed. Parey)* 62:91-100.
- Schnug, E. and S. Haneklaus. 1992. PIPPA : un programme d'interprétation des analyses de plantes pour le colza et les céréales. *Supplément de Perspectives Agricoles* 171:30-33.
- Simons, B. 1995. CoStat / CoPlot / CoDraw. CoHort Software, Minneapolis, MN.