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Content of Different Forms of Potassium in Lebanese Soils

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Abstract

The content of different forms of potassium: water soluble, exchangeable, non-exchangeable, mineral and total potassium were determined at different depths in eight soil profiles representing most soil types in Lebanon. The mineralogy of the soil samples was identified by x-ray diffraction. The results showed that the average values for water soluble-K, exchangeable-K, non-exchangeable-K, mineral-K and total K were: 0.0122, 0.2324, 1.1791, 12.478 and 13.9471 Cmol kg^{-1} soil, respectively. The values for potassium saturation percentage (KSP) ranged between 0.21-2.79, and exchangeable potassium between 0.12-1.35 Cmol kg^{-1} clay. There are wide variations in the values of various forms of potassium and among potassium indices that are associated with mineral composition in different soils. The results show that the values of K forms in most of the studied soils are quite low. Consequently the supplying power of potassium in these soils is low and a need for potassium fertilization is recommended. For further research on potassium, it is suggested that more investigations on the rate of potassium release in Lebanese soils be conducted.

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Introduction

Potassium is a major element for plant nutrition. Available soil potassium (K) in sufficient quantities is a limiting factor in many agricultural and environmental systems. Soil potassium exists in different forms: solution, exchangeable, non-exchangeable, mineral and total K. There are equilibrium and kinetic reactions between these forms that affect the level of soluble potassium at any particular time and thus, the amount of readily available potassium for plants (Sparks, 2001).

The amount of soil soluble potassium is too low to meet the requirement of K by crops, while exchangeable K is often large enough to satisfy the requirement of one crop, but too small to meet the needs of several crops (Sparks and Huang, 1985). Non-exchangeable potassium occupies internal positions of clay sites as well as hexagonal cavities of certain minerals such as illite. Non-exchangeable potassium is moderately to sparingly available to the plant (Mengel and Kirkby, 1987; Al-Zubaidi and El-Semak, 1995). The type of K-bearing minerals greatly affects the release rate of non-exchangeable potassium (Martin and Sparks, 1983). Soil type and pedoclimatic conditions affect the K supplying power of Lebanese soils (Darwish *et al.*, 2003).

Mineral or structural potassium is also known as native matrix. 90-95% of total potassium is bonded within the crystal structure of various K-bearing minerals like feldspar and mica. This form is slowly available to plants. Total potassium represents the sum of all soil potassium forms. There are several factors that affect the quantity of total potassium in soil such as parent material, climate, leaching and vegetative cover.

Improving the knowledge about K-reserve in soil is necessary to better understand potassium nutrition and potassium management. Only a few papers have been published on potassium chemistry in Lebanese soils (Sayegh *et al.*, 1990; Al-Zubaidi *et al.*, 2008). This study was therefore initiated to estimate K-contents and fractions in eight soil profiles which represent most of the agricultural soils in Lebanon.

Materials and methods

Twenty-six (26) soil samples were collected from different depths of eight profiles representing the various great soil groups of Lebanon (see map). The locations, classification and physico-chemical characteristics of the soil samples are shown in Table 1.

The contents of different potassium forms in soil samples were determined using methods described by Pratt (1965): Water soluble potassium (H_2O-K) was extracted by distilled water 1:2 soil:water extract. Exchangeable potassium was extracted by 0.5 M $CaCl_2$ solution; $CaCl_2$ solution was used instead of ammonium acetate to avoid the extraction of fixed potassium (Martin and Sparks, 1983). Non-exchangeable potassium was extracted by 1N HNO_3, total potassium was extracted by digestion with a mixture of HF 48%, H_2SO_4 97% and concentrated $HClO_4$. Mineral potassium was calculated by the formula that was suggested by Martin and Sparks in 1983:

Mineral K = Total K – (K-$CaCl_2$ + K-HNO_3)

Potassium saturation percentage (KSP) was calculated by the following formula:

KSP = (exchangeable K/total exchange-able cations)x100

Exchangeable K/100 g clay was calculated taking into account that the total exchangeable K was present in the clay fraction in the samples.

Identification of clay minerals was done by the x-ray diffraction technique as illustrated by Jackson (1958). The analyses were carried out by pre-

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treatment as deferration, saturation with K, saturation with Mg and glycolation, and heating at 500℃ using the methods described by Tan (1996). Potassium saturation and glycolation of Mg-saturated samples were used to distinguish between expanding and non-expanding minerals (Tan, 1996).

Results and discussion

Soils description

The physio-chemical characteristics of the soil samples are shown in Table 1. The results indicate that the studied soils are non-saline (EC = 0.15 to 0.54 dS m^{-1}), with no considerable change in EC values throughout the soil profile. The pH values ranged between 6.8 and 8.2, indicating that the soils are neutral to slightly alkaline, with very little change in pH values throughout the soil profile. The organic matter ranged between 0.1-4.9%. The highest value of organic matter is in the surface layer (0-30 cm) of profile No. 179. In general, the values of organic matter content decreased with increasing depth.

The $CaCO_3$ content ranged between 0-72%. Several profiles (No. 165, 206, 259 and 272) may be classified as highly calcareous soils, while the top soils (cultivated layers in profiles No. 190, 179, and 49) are considered as non-calcareous.

The clay content of the soil samples ranged between 16-70%. The textural class of six profiles (No. 165, 206, 190, 234, 49, and 272) is clayey, and that of profile No. 179 is sandy, whilst profile No. 259 is a silt clay loam.

The sum of exchangeable cations which approximately represents the CEC value, ranged between 9.1 and 34.2 Cmol kg^{-1}. The contents of clay and organic matter highly affected the values of sum of the exchangeable cations.

Map of locations of the eight soil profiles analysed.

Mineralogy of soils

The interpretation of the x-ray diffraction of the clay minerals is summarized in Table 2.

Content of different potassium forms

The content of different potassium forms in the studied soil samples are displayed in Table 1.

1) Soluble potassium

Table 1 shows that the values of soluble potassium (H_2O-K) in the studied soil samples ranged between 0.0026-0.0479 Cmol kg^{-1} corresponding to 4.05-74.6 kg ha^{-1}, which is very low and not sufficient to support plant growth, and is much lower than the requirement of most crops.

2) Exchangeable potassium

The content of exchangeable potassium as shown in Table 1 ranged between 0.0632-0.651 Cmol kg^{-1}. The average value for exchangeable potassium is

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Table 1. Profiles locations, classification, physico-chemical characteristics and contents of different potassium forms in Lebanese soils of the studied soils

Profile No.	Location, soil type and texture	Depth	EC	pH	O.M	$CaCO_3$	Sand	Silt	Clay	∑ Exch. cations	H_2O - Soluble K	Exch. K	Non-exch. K	Mineral K	Total K	Mineral K /total K
		cm	*dS m⁻¹*		--------------------	%	--------------------			------------------------------		*Cmol kg⁻¹*		------------------------------		*%*
165	Jbab el Homer;	0-20	0.54	7.60	1.80	15	15	36	46	33.90	0.0239	0.6225	3.97	21.20	25.82	82.14
	Calcaric Regosols;	20-60	0.54	7.50	1.00	37	18	30	50	27.85	0.0128	0.2891	0.96	15.69	16.95	92.55
	clay	60-110	0.51	7.70	0.80	34	22	24	50	30.87	0.0043	0.1431	0.86	17.32	18.33	94.48
		110-130	0.50	7.60	0.50	31	32	18	46	28.69	0.004	0.1108	1.05	16.21	17.37	93.30
206	Rachaya; Gleyic	0-25	0.47	7.70	3.10	35	13	48	38	34.20	0.0086	0.2531	0.72	14.60	15.58	93.69
	Cambisols; silty	25-70	0.33	8.10	2.20	39	12	36	50	31.56	0.0039	0.0811	0.36	12.10	12.55	96.44
	clay loam	70-100	0.40	8.10	1.60	30	19	26	54	33.23	0.0102	0.1016	0.49	13.36	13.97	95.69
		100-130	0.53	8.10	0.70	11	27	16	56	28.60	-	-	-	-	-	
259	Hasbaya Plain;	0-20	0.15	7.60	0.60	61	33	38	26	20.43	0.0101	0.0841	0.16	5.95	6.20	95.98
	Calcaric Fluvisols;	20-55	0.26	7.50	3.10	58	31	30	36	22.88	-	-	-	-	-	
	clay loam	55-80	0.25	7.30	3.30	55	33	36	28	16.45	0.0384	0.262	0.53	3.76	4.59	81.93
		80-150	0.35	7.10	1.90	60	33	38	26	17.26	0.0075	0.0817	0.17	4.70	4.95	94.81
190	Batroun; Gleyic	0-10	0.51	6.80	1.60	3	7	40	52	18.79	0.0479	0.5246	1.96	13.02	15.55	83.71
	Luvisols; clay	10-70	0.28	7.10	1.50	2	6	28	64	16.39	0.0079	0.1192	1.01	14.87	16.01	92.90
		70-130	0.29	7.20	0.10	2	5	22	70	18.04	0.0041	0.084	0.92	15.08	16.08	93.75
179	Marjheen; Eutric	0-30	0.29	7.40	4.90	1	58	18	22	15.96	0.0171	0.2191	1.06	11.14	12.44	89.57
	Arenosols; sandy	30-80	0.16	7.70	0.60	1	70	14	16	9.19	0.0079	0.0759	0.60	11.24	11.92	94.30
	clay loam	80-135	0.21	7.40	0.70	1	60	22	18	12.57	0.0059	0.0837	0.87	10.21	11.17	91.37
		135-180	0.21	7.70	0.80	1	50	18	30	24.64	0.0071	0.1524	1.12	12.68	13.95	90.84
234	El Zayniyeh;	0-10	0.28	7.30	2.10	0	7	32	60	26.01	0.0173	0.6511	3.44	20.97	25.08	83.63
	Endostagnic-vertic	10-40	0.27	7.60	1.40	0	7	26	66	26.14	0.0212	0.6445	5.01	28.21	33.88	83.26
	Cambisols; clay	40-110	0.33	7.50	0.80	0	8	26	66	28.03	0.0102	0.5634	3.48	27.26	31.32	87.05
49	Tell-Kalakh	0-20	0.49	7.80	1.60	0	18	28	54	32.95	0.0056	0.1544	0.65	6.91	7.71	89.56
	Tawile;	20-53	0.45	8.10	1.30	2	18	21	58	30.38	0.0036	0.068	0.41	5.51	6.00	91.89
	Hypocalcic	53-90	0.41	8.10	1.10	10	20	27	51	29.97	0.0026	0.0632	0.42	5.21	5.69	91.52
	Vertisols; clay	90-120	0.41	8.20	0.60	38	20	34	44	24.86	0.0032	0.0762	0.27	4.28	4.62	92.47
272	Ed Douair; Vertic	0-30	0.40	7.10	1.81	55	6	28	64	29.41	0.0237	0.4093	0.67	6.69	7.80	85.85
	Clacisols; clay	30-60	0.46	7.20	2.30	57	11	30	56	24.23	0.0102	0.2655	0.55	6.26	7.09	88.37
		60-150	0.48	7.10	2.30	72	10	34	56	15.54	0.0108	0.0913	0.14	N/A	N/A	N/A
Average											0.0122	0.2324	1.18	12.48	13.95	90.42
Maximum											0.0479	0.6511	5.01	28.21	33.88	96.44
Minimum											0.0026	0.0632	0.14	3.76	4.59	81.93

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less than the value reported by Al-Zubaidi *et al.* (2008) for some Lebanese soils. The highest values of exchangeable potassium were observed in soil profile No. 234, while the lowest values of exchangeable potassium were observed in soil profile No. 49.

If the value of 0.4 Cmol kg^{-1} for exchangeable K, which was recommended by Al-Zubaidi and Pagel in 1979, were to be considered as the critical level, then all the soil samples in the seven profiles - except profile No. 234 and topsoil layers in profiles No. 165, 190, and 272 - would be classified as poor in exchangeable potassium and expected to respond positively to potassium fertilization.

Datta and Sastry (1988) proposed the higher value of 0.626 Cmol kg^{-1} for exchangeable potassium as the threshold level for release of non-exchangeable potassium. If we compare this value with the values of exchangeable potassium obtained in this study, then all the profiles except soil profile No. 234 and surface soil sample of profile No. 190 would be lower than the critical value. This indicates that the non-exchangeable (fixed-K) contributes to potassium supply to plant growth in the studied soils.

The high values of exchangeable potassium in soil profile No. 234 may be due to high content of clay fraction with the presence of vermiculite and mica- vermiculite minerals (Table 2). The x-ray diffraction curves of this profile showed a broad peak of 10.40 Å, indicating that micas are undergoing a weathering process in this soil. The relatively low value of percentage of mineral-K to total-K in this profile (Table 1, last column) confirms this conclusion.

Table 2. Mineralogy and texture of the studied soil profiles as identified by x-ray diffraction.

Profile No.	Dominant minerals
165	Group of 14 Å, kaolinite, quartz
206	Regular interstratified chlorite-smectite, kaolinite, quartz
259	Group of 14 Å, mica, kaolinite, quartz
190	Kaolinite and quartz
179	Chloritized montmorillonite, kaolinite, quartz
234	Group of 14 Å (smectite, vermiculite, chlorite), irregular interstratified mica-vermiculite, kaolinite
49	Group of 14 Å, kaolinite
272	Chlorite, regularly interstratified chlorite-mica, mica, kaolinite, quartz

3) Non-exchangeable potassium

Acid (HNO_3) extractable potassium, which is used as an index of non-exchangeable potassium and represents the supplying power of potassium for long-term cropping (Jackson 1958) are shown in Table 1. The values of this form showed a wide variation, ranging from 0.14-5.00 Cmol kg^{-1}. If we consider the critical value for non-exchangeable potassium to be 1.00 Cmol kg^{-1} (400 mg kg^{-1}), as suggested by Pagel (1972), then the values of non-exchangeable potassium in nine soil samples are above this level (high in supplying power), and the remainder of the soil samples can be described as poor in supplying potassium. Soil samples from profile No. 234 contain a very high content of non-exchangeable potassium; which could be due to extensive weathering occurring in this profile.

4) Mineral potassium

The values of mineral potassium showed a wide variation in the studied soil samples, ranging from 3.76 to 28.21 Cmol kg^{-1} (Table 1). The content of this K-form depends on soil type, type of primary and secondary minerals and the degree of weathering (Sharpley, 1987). The lowest values of mineral-K were observed in profile No. 259, 49, and 272 and the highest values were observed in profile No. 234. The values of percentage of mineral-K of total-K ranged from 81.93% to 96.44% (Table 1). The lower values of percentage of mineral-K of total-K indicate a relatively high degree of weathering of K-bearing minerals and vice versa.

5) Total potassium

The values for total potassium in the studied soil samples showed a very wide variation. They ranged from 4.59-33.89 Cmol kg^{-1} (Table 1). The content of total potassium depends on the type of parent material, type of primary and secondary minerals and type of soil fractions. The values for total potassium in Lebanese soils are lower than those reported for Iraqi soils (Al-Zubaidi and Al-Rabai, 2002).

More than 81.9% of the total potassium in the studied soils is in the mineral phase. The high portion of total potassium in primary minerals suggests that the parent material is the origin of most K in the profiles (Martin and Sparks, 1983).

Distribution of different K-forms throughout soil depth

Table 3 shows the distribution of K-forms: exchangeable, non-exchangeable and mineral (expressed as percentage of total potassium) throughout the soil profiles. The patterns of exchangeable and non-exchangeable forms are fairly similar. In general there is a decreasing trend for potassium forms as soil depth increases, except profile No. 259, due probably to the irregular origin of fluvial sediments forming the soil layers.

The distribution of mineral-K

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Table 3. Distribution of mineral, non-exchangeable and exchangeable K-forms in seven of the soil profiles.

Profile No.	Location	Soil type	Depth	Mineral K	HNO_3-K	$CaCl_2$-K
			cm		*% of total K*	
165	Sir Ed Danieh – Jbab el Homr	Calacric Regosols	0-20	82.14	15.36	2.41
			20-60	92.55	5.67	1.71
			60-110	94.48	4.72	0.78
			110-130	93.30	6.04	0.64
206	Rachaya, Ammiq road	Gleyic Cambisols	0-25	93.69	4.63	1.62
			25-70	96.44	2.88	0.65
			70-100	95.69	3.51	0.73
259	Marjayoun, Hasbaya plain	Calcaric Fluvisols	0-20	95.98	2.50	1.36
			55-80	81.93	11.52	5.71
			80-150	94.81	3.39	1.65
190	Batroun	Gleyic Luvisols	0-10	83.71	12.61	3.37
			10-70	92.90	6.31	0.74
			70-130	93.75	5.70	0.52
179	Sir Ed Danieh, Marjheen	Eutric Arenosols	0-30	89.57	8.53	1.76
			30-80	94.30	5.00	0.64
			80-135	91.37	7.82	0.75
			135-180	90.84	8.02	1.09
234	El Zayniye, Baalbeck	Vertic Cambisols	0-10	83.63	13.71	2.60
			10-40	83.26	14.78	1.90
			40-110	87.05	11.12	1.80
49	Tell Kalakh, Tawile	Hypocalcic Vertisols	0-20	89.56	8.36	2.00
			20-53	91.89	6.92	1.13
			53-90	91.52	7.32	1.11
			90-120	92.47	5.81	1.65

throughout soil profiles No. 165, 206, 179, 234, 49, and 190 can be described as follows: increase in mineral potassium with soil depth, whereas its distribution throughout soil profile No. 259 decreases with soil depth. The distribution patterns of mineral-K throughout the soil profile are associated with the type of K-bearing minerals occurring at different soil depths and with their degree of weathering.

Potassium saturation percentage (KSP) and exchangeable-K as Cmol kg^{-1} clay

Two other chemical indices used for evaluating potassium supplying power in soil are potassium saturation percentage (KSP) which equals (exchangeable-K/CEC)x100 and the value of exchangeable potassium in mmol K per 100 g of clay (or Cmol K per kg of clay).

Table 4 shows the values of KSP in the studied profiles which range from 0.21 to 2.79. It seems that most of the studied soil samples, except surface samples (0-10) of soil profile No. 234 and 190 have low values and lower than the critical value (2.3) which was proposed by Pagel and Insa (1974). This indicates that the potassium ion represents a small portion of the CEC in the studied soils.

The average value of exchangeable-K in mmol per 100 g clay is 0.52 (Table 4) is very low and much lower than the values obtained in Iraqi soils (3.6) as reported by Al-Zubaidi (2003). This means that potassium fixation capacity is high in Lebanese soils and most potassium is present in the fixed phase. This data confirms the finding of Al-Zubaidi *et al.* (2008) that Lebanese soils have a high potential for potassium fixation (27.0-47.5%). These results should be taken into consideration when fertilization recommendations are made for various crops, especially K loving crops such as potato, banana and citrus trees.

Conclusion

From the obtained results, it can be concluded that most Lebanese soils are poor in potassium supplying power and may respond to potassium fertilizer application. Our previous field observations on application of potassium fertilizer to wheat and barley in some Lebanese soils (Al-Zubaidi *et al.*, 2009) confirm this conclusion. For further research on potassium status in Lebanese soils, it is suggested to measure the rate of release of potassium in these soils.

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References

Al-Zubaidi, A. 2003. Potassium Status in Iraqi Soils. Proceedings of the Regional Workshop: "Potassium and Water Management in West Asia and North Africa." Edited by A.E. Johnston. International Potash Institute, Horgen, Switzerland. p. 129-142.

Al-Zubaidi, A., A. Alameddine, and I. Bashour. 2009. Preliminary Field Observations on the Response of Wheat and Barley to High Rates of K-Fertilization in Rainfed and Irrigated Regions in Lebanon. *e-ifc* No. 20, June 2009, International Potash Institute, Horgen, Switzerland.

Al-Zubaidi, A., S. Yanni, and I. Bashour. 2008. Potassium Status in Lebanese Soils. National Center for Scientific Research Journal, 9:81-97.

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Table 4. Potassium saturation percentage (KSP) and exchangeable K values of the soil samples.

Profile No.	Depth	KSP	Exch. K
	cm	*%*	*mmol/100 g clay*
165	0-20	1.84	1.35
	20-60	1.04	0.58
	60-110	0.46	0.28
	110-130	0.39	0.24
206	0-25	0.74	0.66
	25-70	0.26	0.22
	70-100	0.31	0.38
259	0-20	0.41	0.31
	20-55	1.15	0.72
	55-80	0.50	0.28
190	0-10	2.79	1.00
	10-70	0.73	0.18
	70-130	0.47	0.36
179	0-30	1.37	1.00
	30-80	0.83	0.50
	80-135	0.67	0.44
	135-180	0.62	0.50
234	0-10	2.5	1.08
	10-40	2.47	0.97
	40-110	2.01	0.80
49	0-20	0.47	0.28
	20-53	0.22	0.12
	53-90	0.21	0.25
	90-120	0.31	0.18
272	0-30	1.39	0.64
	30-60	1.10	0.48
	60-150	0.59	0.16
Average		0.96	0.52
Range		0.21-2.79	0.12-1.35

Al-Zubaidi, A., and B.M. Al-Rubai. 2002. Potassium Status in Rice Soils. Iraqi Journal of Agricultural Sciences, 33:1-8.

Al-Zubaidi, A., and K. El-Semak. 1995. Effect of Soil Salinity on Potassium Equilibrium as Related to Cropping. Mesopotamia Journal of Agriculture, 3:99-105.

Al-Zubaidi, A., and H. Pagel. 1997. Content of Different Forms of Potassium in some Iraqi Soils. Iraqi Journal of Agricultural Sciences, 14:214-240.

Darwish T., T. Masri, M. El Moujabber, and T. Atallah. 2003. Impact of Soil Nature and Mineral Composition on the Management and Availability of Potassium in Lebanese Soils. Proceedings of the Regional Workshop of the International Potash Institute. "Potassium and Water Management in West Asia and North Africa". Amman, Jordan, November 2001. p. 152-160.

Datta, A.C., and T.G. Sastry. 1988. Determination of Threshold Levels for Potassium in Three Soils. J. Indian Soil Science, 35:676-681.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice Hall Inc. Englewood Cliffs, N.J.

Jackson, M.L. 1979. Soil Chemical Analysis. Advanced Course, 2nd Edition. Published by the author, Madison, Wisc.

Martin, H.W., and D.L. Sparks. 1983. Kinetics of Non-Exchangeable Potassium in Soils. Comm. Soil Sci. Plant Anal., 16:133-162.

Mengel, K., and E.A. Kirkby. 1987. Principles of Plant Nutrition. International Potash Institute, Horgen, Switzerland.

Pagel, H. 1972. Vergleichende Untersuchungen über Gehalt an austauschbarem und nachlieferbaren Kalium in wichtigen Böden der ariden und humiden Tropen. Beit. Tropische und sub-tropische Landwirtschaft und Tropenveterinär-medizin, KMU, Leipzig, 10:35-51.

Pagel, H. and I. Insa. 1974. Veränderung wichtiger Grössen des K-Haushaltes in Mongrovenböden Guineas unter dem Einfluss der Nutzung. Transact. 10th Inter. Congress Soil Science, Moscow, 4:349-357.

Pratt, P.F. 1965. Potassium. *In:* C.A. Black *et al.* (ed). Methods of Soil Analysis. Part. 2. Agronomy 9:1023-1031. Amer. Soc. of Agron. Maddison, Wisc.

Sayegh, A., K.H. Khazzakah, A. El-Khatib, S. Sfeir, and M. Khawlie. 1990. Soil Mineralogy of Lebanon. Soil Resources, Land and Water Development Division, FAO.

Sparks, D.L. 1989. Kinetics of Soil Chemical Processes. Academic Press. Inc., England.

Sparks, D.L., and P.M. Huang. 1985. Physical Chemistry of Soil Potassium. p. 201-276.

Sharpley, A.N. 1987. The Kinetics of Soil Potassium Desorption. Soil Sci. Soc. Amer. J., 51:912-917.

Tan, K.H. 1996. Soil Sampling, Preparation and Analysis. New York, Marcel Dekker, Inc. ■

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