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ARTICLE

不同种植年限苹果园土壤磷、钙、硅、镁常量元素垂直分布特征

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摘 要：利用 X 射线荧光光谱测定了黄土高原洛川县 5、20、60 龄苹果园 0—300 cm 剖面土壤中 P_2O_5、CaO 、SiO_2、Al_2O_3、MgO 含量，分析和比较了不同深度、不同种植年限土壤常量元素的变化特征。结果表明：P 元素变化率在不同年限土壤间的差别较大，0—25 cm 表层土壤变化率正值，说明明显的富集现象，可以判断洛川县苹果园土壤磷含量的增加是由于人为原因造成的。不同种植年限土壤中钙、镁元素变化率差异明显，说明随着种植年限的增加果树对钙、镁元素的吸收发生了明显的变化。100 cm 以下剖面，各个年限的磷元素达到迁移平衡，说明磷元素的吸收主要在表层至 100 cm 范围的土层，而镁元素的吸收可以增大到表层至 175 cm 范围的土层。
关键词：苹果园；常量元素；分布特征

The vertical distribution of phosphorus, calcium, silicon, magnesium in apple orchard of different ages

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Abstract: ***Background, aim, and scope*** Soil is an important natural resource for human. It was showed that the nutritional status of apple orchard had an obvious effect on the quality and yield of the apple. Research of soil geochemical composition is helpful not only to recognize the vertical distribution characteristics and their origin, but also helpful to reveal the pollution intensity of human activity and the impact depth. These are great significances to guide farmer to improve the soil quality and make policies for agricultural sustainable development. Apples are usually grown in the Loess Plateau, especially in Luochuan, which is located in the center of Shaanxi province. The average annual rainfall is 622 mm. The average temperature is 9.2℃. Annual average frost-free period is around 167 days. Those conditions are very useful for the growth of apple trees. But as the growing ages increasing, the environmental problem about declining orchard soil quality has been a serious threat to apple quality and production. This study aimed to analyze the elements'

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vertical distribution in the apple orchard and provide some scientific basis on the fertilization and reduce soil pollution. ***Materials and methods*** The apple orchard of 5, 20 and 60 years in A-Si village of the Yong Xiang town, Luochuan, were selected as sample points. We took the samples in August, 2014. All samples were finely ground in agate mortar. These abundances of P_2O_5, CaO, SiO_2, Al_2O_3 and MgO in 0—300 cm depth soil samples were determined by X-ray fluorescence spectrometry (XRF), PW2403, which was purchased from Philips. Analytical uncertainties are ±2% for the major elements except for P_2O_5 (up to ±10%). The concentrations of individual elements are directly influenced by changes of concentration in other constituents. Ratios of elements are not subject to such changes unless one of the constituents of the ratio is altered. Consequently, changes in ratios are particularly useful when applied to genetically related suites of materials such as weathering profiles. Here, in all ratios, Al_2O_3 has been used as the denominator. Because, compared to some alkalis and alkaline earths, it is very stable. The percentage changes to ratios, relative to the fresh parent rock can be calculated according to. Δ (%)=$[(X_s/I_s)/(X_p/I_p)-1]\times100$. Where X_s/I_s is the ratio in a sample and X_p/I_p is the ratio of the same elements in the parent material. All the data were analyzed using Microsoft Excel 2007. And all the figures were depicted using Origin 8.5. ***Results*** The soil parent materials, soil physical chemical properties, soil types and human activities have some effects on the vertical distribution of elements in soil. The studies on vertical distribution of elements in soil not only provide some important knowledge about soil parent materials, but also can tell us whether the soils were polluted. In this paper, there was no obvious concentration difference in apple orchards of different ages for phosphorus, calcium, silicon, magnesium and aluminum. The absolute concentration changes for elements can not reflect the real geochemistry characteristics. But, the vertical rates of changes for phosphorus, calcium, magnesium in different apple orchards were obvious. These phenomena were very useful for this study. ***Discussion*** In this paper, the vertical distributions of major elements were studied, and the migration and enrichment characteristics were also discussed. It was revealed that the rate of change for phosphorus was obvious. >100 cm depth, $\Delta<0$ indicated that phosphorus was migrated relative to stable aluminum. The apple orchards of different ages have the same rate of change for phosphorus. 50—100 cm depth, as the ages increasing, the soil gets more and more compacter, so the ability of migration decreased. 0—25 cm depth, $\Delta>0$ showed that the phosphorus was enriched, which was correlated with human activities. The fertilization is the most important reason. Some research showed that the usefulness for phosphorus in apple orchard is only 2.5%. The rates of changes for calcium, magnesium in different apple orchards were also obvious. It was showed that the migration and enrichment of those elements in different apple orchard occurred. The phosphorus can be adsorbed during 0—100 cm depth soil, while magnesium can be adsorbed during 0—150 cm depth soil. ***Conclusions*** The rate of change for phosphorus showed that phosphorus was enriched in the surface of soil. We can fertilize according to the rate of change for phosphorus. As the ages increasing, the rates of changes for calcium, magnesium and phosphorus were obviously, that showed that the absorption for those elements also changed. ***Recommendations and perspectives*** This paper provided a significant scientific basis for the fertilization and how to make useful of the apple orchard.

Key words: apple orchard; major element; distribution characteristics

许多研究（魏钦平，1993；夏国海等，1998；江泽普等，2003；刘成先，2005）表明，果园产量和果实品质在很大程度上取决于果园土壤的养分状况。肥力高、结构好的土壤，有利于果树根系生长及其对养分的摄取，对提高果树产量和果实品质有重要作用（郗荣庭，2000）。黄土高原有良好的适宜苹果生长的生态条件，是全球范围内苹果适生区之一（杨世琦等，2009）。苹果产业已成为黄土高

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原地区农民增收的主要途径（赵佐平，2009）。有研究者认为我国苹果品质差的原因之一是过量施用化肥（王留好，2008）。因此，研究果园土壤养分状况显得尤为重要，能为提高果园产量和生产优质果实提供理论依据。研究表明，果树所需三分之一的氮素含量，二分之一的磷和钾素含量来自土壤，说明土壤是果树正常生长汲取养分的最主要来源和生存的必要保证（张乃民，1997）。

洛川县地处陕西省中部，位于延安市南部，属渭北黄土高原丘陵沟壑区。境内气候温和，太阳辐射能量丰富，年均气温 9.2℃，年均降水量 622 mm，无霜期 167 d。该区日照充足，昼夜温差大，给苹果的光合物质积累和运转提供了十分有利的条件。本研究选取洛川县不同种植年限苹果园作为采样点，测定了 0—300 cm 土层土壤磷、钙、硅、镁等常量元素的含量，分析了不同种植年限土壤常量元素的垂直分布特征，旨在揭示不同种植年限土壤常量元素剖面的分布规律，以期为洛川果园土壤培肥和合理施肥提供理论依据，同时减少环境污染。

1 材料与方法

1.1 试验材料

选择了洛川县永乡乡阿寺村种植年限分别为 5、20、60 年的苹果园作为采样点，其中 60 年苹果园按照党史记载以及村委会确认。采样时间为 2014 年 8 月。

1.2 取样方法

三个采样点选择果树生长均匀一致的区域，以 4 棵果树树冠空隙对应地面中心为采样点，利用土钻分层采集 0—300 cm 土层土壤样品，每 5 cm 土层取一个样。每个采样点采集 60 个样品，共计 180 个样品。采用四分法从混合土样中选取约 1 kg 土壤作为混合土样。去除样品中植物残体、砾石等外源物质，采用上海齐欣科学仪器有限公司生产的 DHG-9203A 型电热恒温鼓风干燥箱进行烘干处理，温度设置为 70℃。烘干后用玛瑙研钵磨碎，过 1 mm 土筛，再次研磨过 100 目筛，充分混匀后保存于样品袋中。

1.3 检测方法

1.3.1 仪器设备

Phlips PW2403 型 X 射线荧光光谱仪：3.0 kW 高功率、薄铍窗，超尖锐端窗铑靶 X 射线管，PW2540VRC 样品交换器。

1.3.2 样品制备

采用粉末压片法进行制样（李小平和黄春长，2007）。准确称取 4.0 g，过 100 目（0.150 mm）筛，经 105℃烘干的土壤样品放入模具中压平，用硼酸镶边垫底，30 吨压力下压片制样，延时 20 秒，压制成直径为 32 mm 的样片，编号，放入干燥器内，待测。

1.4 数据处理

采用 Microsoft Excel 2007 统计分析数据，Origin 8.5 绘图。

1.5 元素变化率分析

元素含量绝对变化并不能真实反映元素的地球化学行为，因为在化学风化过程中，活动性元素的淋失或剖面体积缩小直接造成样品中稳定元素浓度增加（或残留富集），从而掩盖这一过程中元素富集或迁移的真实面目。为了消除这种影响，目前往往采用某一稳定性元素作参照系，如 K（Nesbitt et al，1980），Ti（Nesbitt，1979），Al（McFarlane et al，1994）等，计算样品中其他元素的变化率。

$$\Delta(\%)=[(X_s/I_s)/(X_p/I_p)-1]\times 100 \quad (1)$$

式中，X_s，I_s 代表样品中元素 X 和参比元素 I 的含量；X_p 和 I_p 为上述元素在全新世黄土中的含量。若 $\Delta<0$，反映元素 X 相对参比元素迁出；若 $\Delta>0$，反映元素 X 相对富集。本研究选择含量适中，稳定性的元素 Al 做参比元素，以全新世黄土代表母质，计算各层土壤中元素的含量变化率百分数。

2 结果与分析

2.1 不同种植年限果园土壤常量元素含量分析

常量元素都是土壤中含量较高的元素，而且许多都是粘土矿物的主要组成元素，如果土壤不在特殊的矿区及其附近，认为施肥对其含量的影响不会太大。表 1 是洛川苹果园土壤剖面中常量元素的含量（每个年限 60 个样本）。从表 1 可以看出，P、Si、Ca、Mg、Al 元素的含量在不同生长年限的土壤没有发生明显的变化。

2.2 不同种植年限果园土壤元素含量变化率分析

2.2.1 磷元素变化率分析

从图 1 可知，随着剖面深度增加，100 cm 以下剖面，$\Delta<0$，说明磷元素相对稳定性元素铝迁出，不同种植年限，活动性元素磷的迁移速率一致。50—100 cm 剖面，随着树龄的增加，土壤的紧密

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度越来越大，活动性磷元素相对 Al 元素的迁移性减弱，显示了随着种植年限增加磷元素逐渐富集的特征。0—25 cm 剖面，$\varDelta$>0，所有磷元素相对富集，与人工施加磷肥和人类活动关系密切。化肥的导入是土壤磷元素积累的重要因素。杨雨林等（2008）研究指出磷的利用率仅有 2.5%，长期大量的化肥施入造成土壤中磷含量不断升高从而导致表层土壤磷的大量累积。

表 1　苹果园土壤常量元素含量

Tab.1　Major elements concentration in apple orchard/%

元素 Element	生长年限 The years of growing											
	5 年　5 a				20 年　20 a				60 年　60 a			
	最小值 Min.	最大值 Max.	平均值 Average	标准偏差 SD.	最小值 Min.	最大值 Max.	平均值 Average	标准偏差 SD.	最小值 Min.	最大值 Max.	平均值 Average	标准偏差 SD.
P[1]	443	961	682	90	534	1363	677	138	619	1019	689	93
Si	63.3	77.3	67.4	3.9	62.9	75.8	67.1	3.9	63.9	73.8	66.4	2.7
Ca	1.74	10.1	7.09	2.67	2.37	10.5	7.37	2.77	3.52	9.90	7.91	1.74
Mg	1.59	2.37	2.08	0.2	1.75	2.35	2.15	0.15	1.88	2.35	2.15	0.16
Al	12.5	15.2	13.4	0.6	12.4	15.1	13.4	0.8	12.5	14.0	13.2	0.4

注：[1] 标注的 P 元素含量单位为 $mg \cdot kg^{-1}$。

Note : [1] Means the concentration unit for P is $mg \cdot kg^{-1}$.

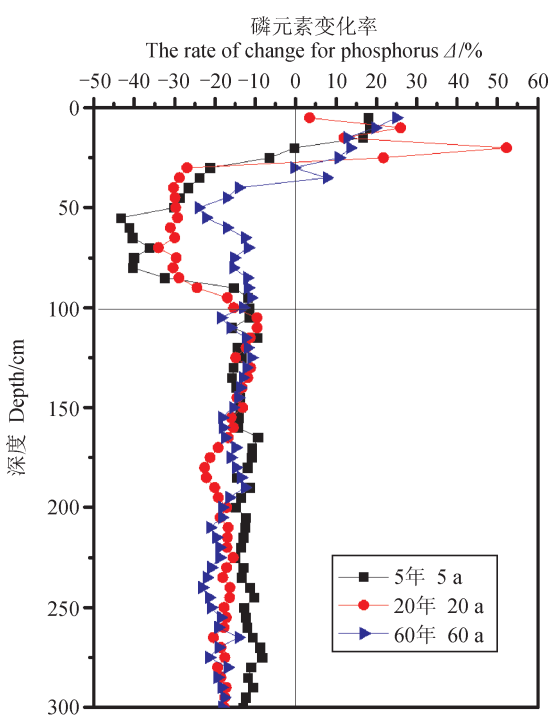

图 1　磷元素变化率分析

Fig. 1 The rate of change analysis for phosphorus

2.2.2　钙元素变化率分析

图 2 显示，随着树龄的增长，土壤的紧实度增加，活动性元素钙相对零迁移剖面上移，说明随着种植年限的增加，钙的有效利用率越来越少，这可能是影响苹果品质的关键因素。0—75 cm 以内，随着剖面深度增加，5 龄苹果园土壤 $\varDelta$ 降低明显，说明迁移增强，钙的活性增大。100 cm 以下剖面，各种树龄土壤的钙质平衡。

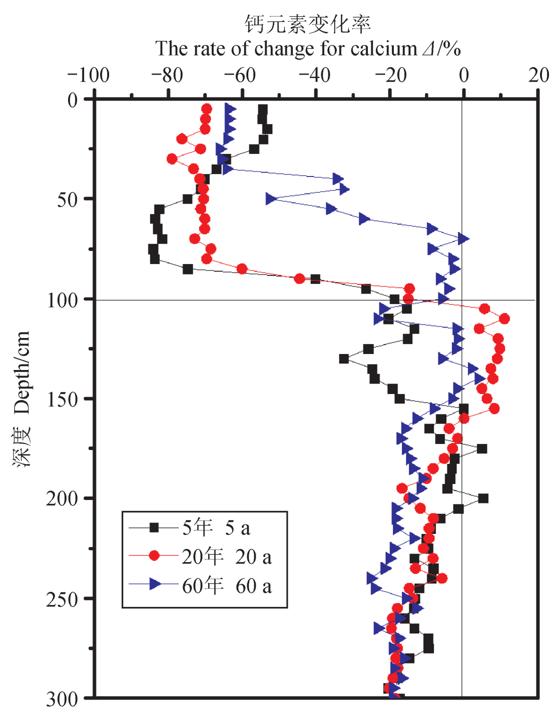

图 2　钙元素变化率分析

Fig.2　The rate of change analysis for calcium

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2.2.3 硅元素变化率分析

图 3 表明：稳定性元素硅的变化与活泼型元素钙相反，因此硅的变化来源于活动性元素钙的亏损或者富集现象。

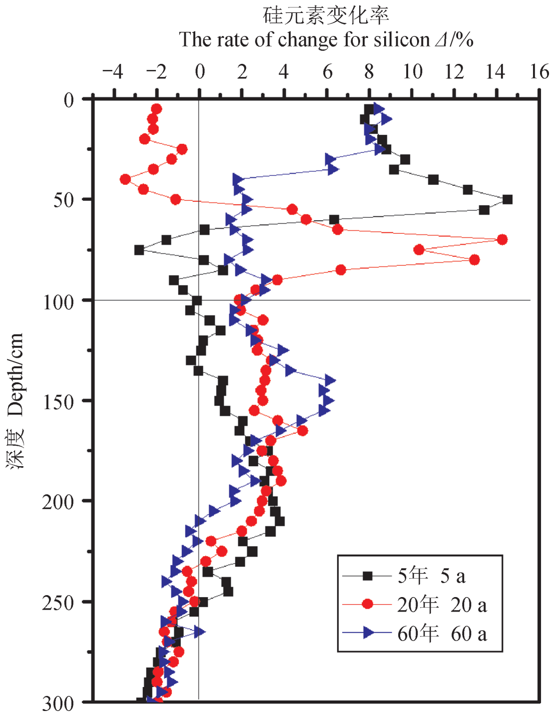

图 3 硅元素变化率分析
Fig.3 The rate of change analysis for silicon

2.2.4 镁元素变化率分析

从图 4 可知，0—50 cm 剖面，随着深度增加，镁元素分布系数 Δ 逐渐降低，各个树龄土壤 Mg 元素有明显的迁移，说明果树对土壤中镁元素吸收明显。50 cm 以下剖面，镁元素有富集趋势，随着树龄增加富集明显。175 cm 剖面以下，各个树龄的镁元素相对稳定性元素铝发生零迁移。说明镁元素的有效利用深度可以达到 175 cm。

3 结论

（1）通过对洛川县不同年龄苹果园土壤中 P、Ca、Si、Mg 等元素的分析，发现不同种植年限土壤间常量元素含量平均值变化都不大。而 P 元素变化率在不同土壤间的差别较大，0—25 cm 表层土壤正值，说明明显的富集现象，可以判断洛川县苹果园土壤磷含量的增加是由于人为原因造成的，应该根据磷元素含量的变化进行有效合理施肥。

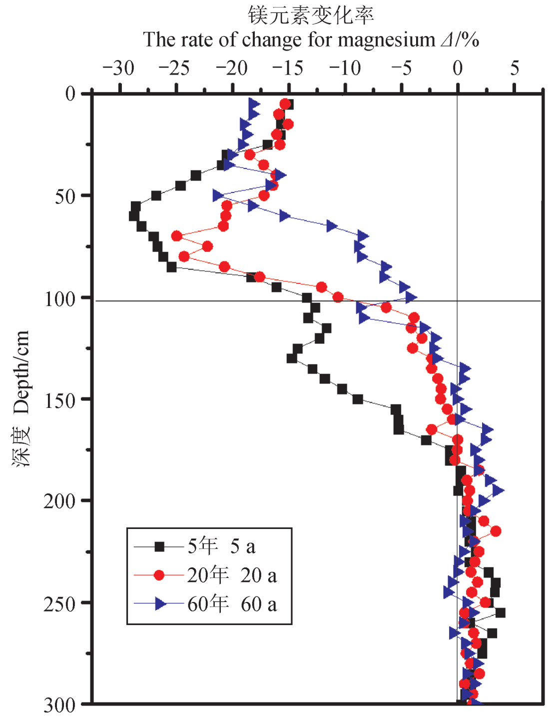

图 4 镁元素变化率分析
Fig.4 The rate of change analysis for magnesium

（2）不同种植年限土壤中 Ca、Mg 和 P 元素变化率差异明显，说明随着种植年限的增加果树对 Ca、Mg、P 等元素的吸收发生了明显的变化。

（3）100 cm 以上剖面，各个种植年限的磷迁移变化大，100 cm 以下剖面达到迁移平衡，说明磷元素的有效吸收深度在 100 cm 以内。镁元素的吸收深度可以增大到 175 cm 以内。

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