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Nutrient and essential elements in spinach during its growth: observation and assessment on translocation of the elements from soil to plant.

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Time-series distributions of several macronutrient elements (Ca, Mg, K, Na, and P), micronutrient elements (Fe, Mn, Cu, Zn, Co, Mo, Cr, and Ni), and non-essential elements (Ti, Al, Sr, Ba, Rb, Zr, Pb, U, Th, and rare-earth elements) in spinach grown in a laboratory condition on a soil composed of 85% illite, 14% quartz and 1% hematite were determined. Leaves and stems of the plant analyzed were sampled at four different periods: 13 days after the seeding, 30 days after the seeding, 60 days after the seeding, and 90 days after the seeding. The elements can be broadly divided into three groups according to their distribution trends in spinach. One of these elemental trends could be described as one with a distinct minimum content at the 30-day period. This trend was found for a very large number of the elements investigated and the elements with this minimum content at the 30-day period included Fe, P, Ti, Al, Cu, Zn, Co, Mo, Cr, Ni, Rb, Zr, Pb, U, Th, and rare-earth elements). A second elemental distribution trend for the plant had a distinct maximum content at the 30-day period and the elements with the maximum content at the 30-day period included Na, K, and Mn. A A third group was marked in general by a continued increase in the contents during the entire 90-day growth period and the elements in this group included Mg, Ca, Sr, and Ba.

The elemental content minima at the 30-day period for all the ones with the exception of Rb are considered to be a reflection of immobilization of these elements with the precipitation of some hydroxy phosphate phase (strengite Fe-hydroxy phosphate, or variscite Al-hydroxy phosphate) by simple reaction of phosphate ions with dissolved Fe, Al, and Mn:

$$Fe^{3+} + HPO_4^{2-} + 2\ H_2O \text{————-}\diamondsuit\ Fe(PO_4)\cdot 2(H_2O) + H^+$$

The antipathy between Fe and Mn could be a reflection of the redox condition during the precipitation. The K and Na maxima at the time of Fe minimum in plants suggest that plant enzyme systems increase in their efficiencies to store these two macronutrient elements in organs of spinach plant when the availability of Fe is reduced to certain level.

Time-series changes in K and Rb contents in spinach observed in this study provides additional insight into the fractionation of the two elements in plants. While the changes in K had a maximum, that in Rb had a minimum at the 30-day period. The K/Rb ratios successively during the growth period were: 1370, 4207, 997, and 901. Each of these ratios for the spinach was much higher than the ratio of the associated soil with a value of about 300. An enzymatic influence may be a significant factor in the storage of the two elements in plants. Unlike K/Rb ratio, the Sr/Ca ratio remained invariant at about 6-8 x 10^{-3} during the entire growth period, suggesting that plant enzyme system involved in the storage of these two geochemically closely related elements are not affected at all by changes in the activities of other elements.

Spinach rare-earth element contents were normalized to that contents of the same in the soil. With the exception of Eu, the contents of other rare-earth elements in plants relative to that in the soil are the same. The pattern of distribution of rare-earth elements in plants relative to the soil is such that Eu is positively anomalous relative to other rare-earth elements at all times during the growth of spinach. The ratio of the soil normalized measured Eu value to the soil normalized projected value calculated from the distribution pattern at each growth period was as follows: 2.8 (13-day), 6.3 (30-day), 3.9 (60-day), and 3.3 (90-day). The highest positive Eu anomaly at the 30-day period corresponded to Mn-maximum and Fe-minimum. As Eu is known to occur in both divalent and trivalent states in natural condition, we suggest that Eu anomaly in the spinach reflected the redox condition in the soil.