# Redistribution of potassium, boron, iron, magnesium and calcium in apple trees determined by an indirect method

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## Abstract

The intensity of the process of redistribution of the elements potassium, boron, iron, magnesium and calcium was determined by following the rate of accumulation of these elements into the fruits of apple (*Malus domestica* Borkh.) trees. The determination is based on the assumption that the process of primary distribution via the xylem becomes relatively unimportant with respect to supply along the phloem during the period of fruit growth. Thus a decreasing rate of accumulation for a phloem-immobile and xylem-mobile element will be seen during this period of growth, while an element which is mobile in both pathways will give a linear rate of accumulation when the supply by the root does not alter too much.

In addition, the ratios of the contents in fruits and leaves were used as an indicator of the relative mobility in redistribution.

In these experiments with apple, potassium and boron showed a high mobility. Magnesium and especially calcium showed a much lower mobility in redistribution than in the primary rate of supply. Iron was intermediary. The results, especially for boron and magnesium, are in contradiction to some of the data in the literature. Further studies are needed before these contrasting results can be explained.

*Key-words:* redistribution, K – B – Fe – Mg – Ca, apple trees, phloem, mobility.

## Introduction

Redistribution is the process of secondary translocation of minerals away from the sites of deposition, to which they were carried by the movement of water along the xylem. Primary distribution mainly occurs through the xylem, while the secondary process of redistribution is linked to the transport of assimilation products in the phloem.

As the phloem sap has a different rate of flow and a very different composition than the xylem sap, its capacity for translocation of a certain element may be quite different from that of the xylem. The mobility of a certain element in the phloem (transported quantity per unit time) in redistribution can thus be very different from that in primary transport. The mobility of an element in redistribution is often related to that in primary transport, and classified as high or low accordingly.

Composition of the whole plant and its green, transpiring parts is mainly governed by the primary transport, while that of those parts receiving large amounts of assimilates – *e.g.* young growing tissues, fruits, seeds and storage organs – mainly reflects the mobility in the phloem.

Differences in mobility in the phloem may occur in the different stages of transport: the loading of the sieve tubes, the rate of the translocation itself, loss during transport and absorption in the sink-organ. In fact, differences in "mobility" are assumed especially in the "loading"-step and considerably less in the transport in the sieve tubes. The loading-step can be determined among other factors by the amount of fixation of an element by the cell components and also by its solubility in the phloem sap. Only in the case of boron, however, has the low mobility of this element in many plants been explained by a large lateral transport from phloem to xylem and subsequent retranslocation back to the depots by the wood vessels (Oertli and Richardson 1970). Reasons for differences in the entry rate into the phloem have been given in an earlier publication (Van Goor and Wiersma 1974).

The mobility of minerals in redistribution can be determined in a number of ways:

1. Comparison of measured contents in different plant parts – such as fruits, tubers, young plant parts and leaves – can give an indication of relative mobility, if they are linked to a different supply system as indicated above.

2. Similarly, the determination of concentration gradients in plants from older to younger leaves can be used. A relatively phloem-mobile element increases in con-

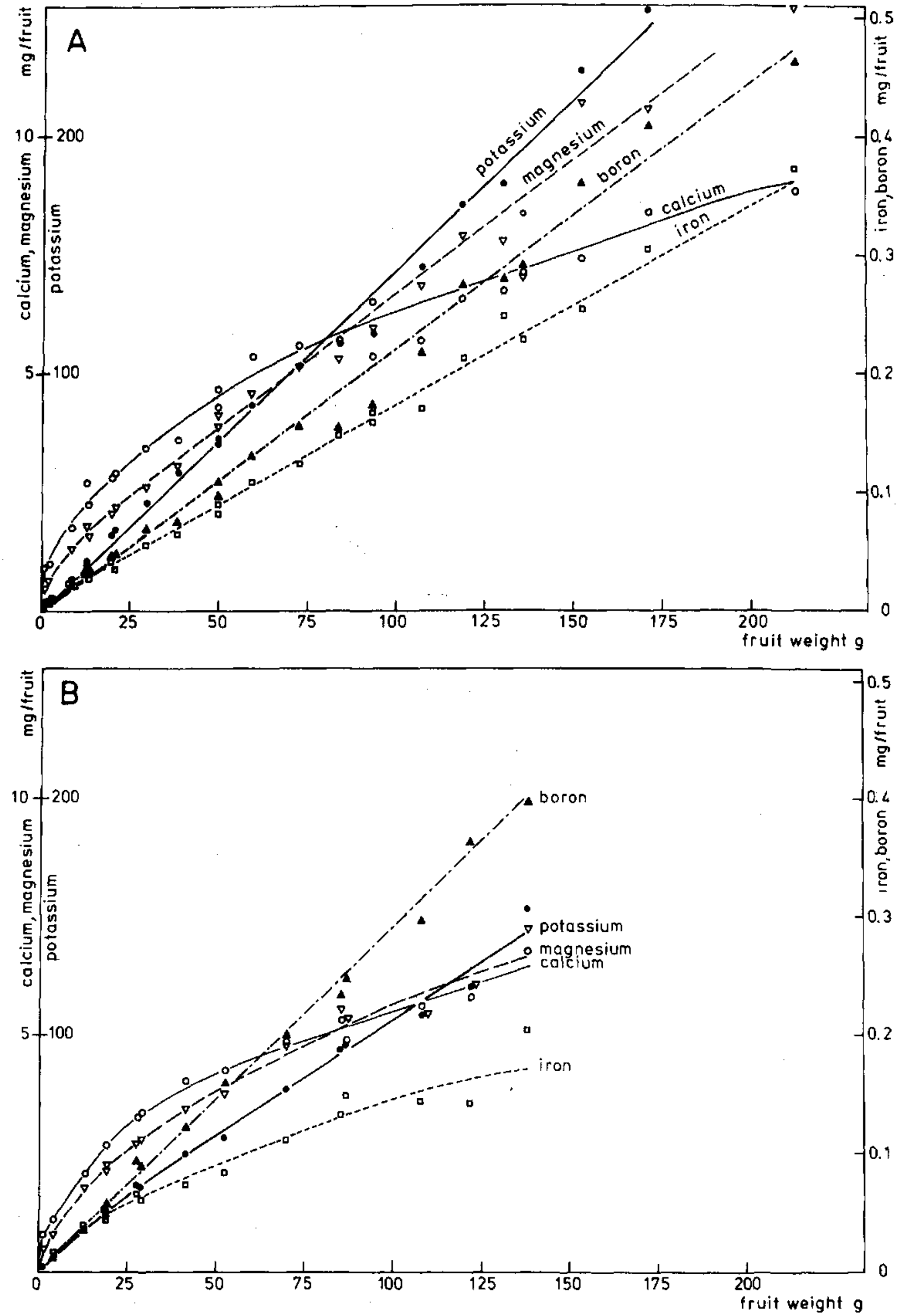

Figure 1. *Relationship between quantity of potassium, boron, iron, magnesium and calcium transported to the fruit of apple and fruit weight.* A. Cox's Orange Pippin. B. James Grieve.

Table 1. *The regression of fruit growth on transport of different elements to the apple.*
Equation $Y = B \cdot X$ and $Y = B \cdot \sqrt{X}$
$Y$ = mg of the element/apple
$X$ = weight of the apples in g
$TB = \frac{B}{\text{standard deviation of } B}$
$r$ = correlation coefficient
Underlined is the equation which fits the results best.

| Element | Equation | Significance TB | Significance r | Mean square deviation from regression |
|---|---|---|---|---|
| *Cox:* | | | | |
| Boron | $\underline{Y = 2.37 \times 10^{-3}X}$ | ** | *** | $6.149\times10^{-4}$ |
| ” | $Y = 1.68 \times 10^{-3}\sqrt{X}$ | * | *** | $6.327\times10^{-3}$ |
| Iron | $\underline{Y = 2.05 \times 10^{-3}X}$ | ** | *** | $9.464\times10^{-4}$ |
| ” | $Y = 1.48 \times 10^{-2}\sqrt{X}$ | * | *** | $2.817\times10^{-3}$ |
| Magnesium | $Y = 0.110\ X$ | | *** | 20.76 |
| ” | $\underline{Y = 0.589\sqrt{X}}$ | *** | *** | 1.429 |
| Calcium | $Y = 0.157\ X$ | | *** | 98.96 |
| ” | $\underline{Y = 0.646\sqrt{X}}$ | *** | *** | 0.200 |
| Potassium | $\underline{Y = 1.541\ X}$ | *** | *** | 229.3 |
| ” | $Y = 11.08\sqrt{X}$ | * | *** | 2699 |
| *James Grieve:* | | | | |
| Boron | $\underline{Y = 3.03 \times 10^{-3}X}$ | *** | *** | $2.102\times10^{-4}$ |
| ” | $Y = 1.95 \times 10^{-2}\sqrt{X}$ | * | *** | $5.037\times10^{-3}$ |
| Iron | $Y = 2.08 \times 10^{-3}X$ | * | *** | $2.395\times10^{-3}$ |
| ” | $\underline{Y = 1.26 \times 10^{-2}\sqrt{X}}$ | *** | *** | $3.849\times10^{-4}$ |
| Magnesium | $Y = 0.107\ X$ | | *** | 13.73 |
| ” | $\underline{Y = 0.517\sqrt{X}}$ | *** | *** | 0.144 |
| Calcium | $Y = 0.137\ X$ | | *** | 34.27 |
| ” | $\underline{Y = 0.589\sqrt{X}}$ | *** | *** | $8.970\times10^{-2}$ |
| Potassium | $\underline{Y = 1.27\ X}$ | *** | *** | 227.0 |
| ” | $Y = 7.67\sqrt{X}$ | * | *** | 557.0 |

* $\leq 5$ % level of significance
** $\leq 1$ % level of significance
*** $\leq 0.1$% level of significance

centration from older to younger leaves; for an element of low relative mobility the converse is true.

3. Direct measurements of the concentrations in the phloem exudates and xylem exudates of plants.

4. Translocation of radioactive isotopes of the relevant element, after application to the older leaf. This method may have the disadvantage of measuring transport of the element in a form in which it may normally not exist.

5. Measuring the rates of influx of an element during the development of fruits. This method is based on the assumption that during development of the fruit there is a change-over in the supply of nutrients and water from a xylem source to a predominantly phloem source supply (Wiersum 1966). The initial xylem supply enables the plant to cope with the transpiration of flowers and very young small fruits, whereas the phloem supply helps to feed the rapidly expanding fruits. This switch will alter the influx-rate for phloem-immobile elements, while elements mobile in the phloem will hardly be affected. A transition from a high early rate to a low rate of supply in later stages of growth is thus an indication of low relative mobility in redistribution, on the condition that the alterations in xylem transport are relatively low.

In the experiments to be described, the last method of determination (5) has been used. In addition, we also used the first method by comparing the ratio content in fruit/content in leaf at different stages of fruit growth. In this way we can correct for any possible alterations in the composition of the primary transport along the xylem-vessels during the growing season, since we account for the fluctuations in the supply to the leaves.

## Materials and methods

The experimental crop was apple (*Malus domestica* Borkh.). The samples used for analysis were obtained from an older experiment with two apple varieties in a

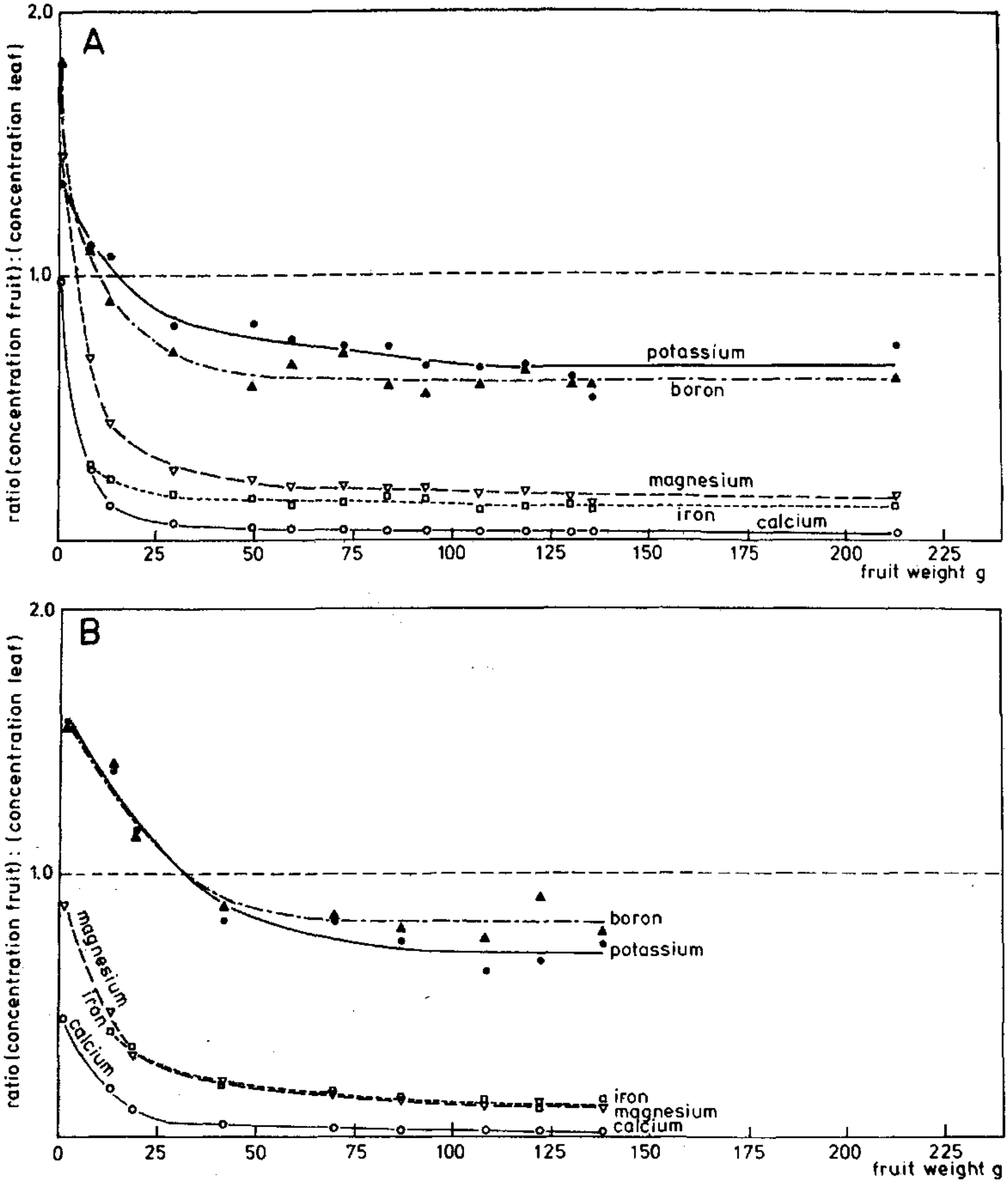

Figure 2. *Relationship between the ratio* (concentration in fruit: concentration in leaf) *for potassium, boron, iron, magnesium and calcium and fruit weight.* A. Cox's Orange Pippin. B. James Grieve.

commercial orchard in the northern part of the Netherlands in 1969. Apple fruits and leaves were used from two series of 40 Cox's Orange Pippin trees and 30 James Grieve trees, on rootstock M IX and M II, respectively. The soil was a marine clay. The trees were about 9 years old. They were not sprayed with calcium salts in 1969. Samples of 20–40 apples per variety were taken at approximately weekly intervals. The samples were selected in such a manner that their diameter and weight were near the average for the stage of development. Samples of leaves were taken at intervals of 1–2 weeks. Details of sampling and sample treatment have been given elsewhere (Van Goor 1971).

The procedures of the determinations of calcium and potassium were described in that publication. Boron was determined spectrophotometrically with carmin reagent, iron and magnesium were determined by atomic absorption spectrophotometry.

## Results and discussion

The experimental results are given in the Figures 1 and 2, and the statistical evaluation in Table 1. Two criteria are used for describing an element as immobile or mobile. The first one is the presence of a sudden decrease in the slope of the transport curves for a low mobile element. Such a curve is mathematically characterized in a better way by $Y = B \cdot \sqrt{X}$ than by the equation $Y = B \cdot X$. The other criterium is the presence of a strong decrease in the ratio elemental content in the fruit/content in the leaves, during growth. In this way the five elements can be divided into three groups. The first group of boron and potassium is classified as mobile in our experiments. The elements have an almost linear transport curve and a ratio for the contents in fruit and leaf which does not decrease below 0.6. From Table 1 it is obvious that the curves for boron and potassium satisfy $Y = B \cdot X$ better than $Y = B \cdot \sqrt{X}$. This can be concluded from a higher value of the factor TB and a lower "mean square deviation from regression" for the first equation. The elements magnesium and calcium have the distinct features of "immobile" elements. Their transport to the fruit usually declines during the growth of the fruit, and the ratio between the content in fruit and leaf becomes as low as 0.1 for magnesium and 0.02 for calcium. The mobility behaviour of iron is intermediary. This can be concluded from Table 1, where for the variety Cox, the equation $Y = B \cdot X$ fits better than $Y = B \cdot \sqrt{X}$, while the reverse is true for the James Grieve apples. However, the ratio between fruit and leaf (Figure 2), as low as 0.1 at the end of the growth period, indicates a low mobility. For the other elements there is good agreement between the two varieties of apples.

In Table 2 our results are compared with the rather scarce literature data from several authors who used different methods. Good agreement exists between the different results for potassium and calcium; they are always classified as mobile and immobile elements, respectively. For the other elements the results mentioned in the literature are much less in agreement, especially for magnesium and boron, which are both characterized as mobile and immobile elements in different experiments. For boron, most results indicate that it is a relatively immobile element (Eaton 1944, MacIlrath 1965). A possible explanation for the poor agreement is that different levels of the relevant element were present in the plant tissue in the experiments of the different authors. Concentrations of the element in the plant may have a large influence on the amount transported in the phloem. This might be explained by the fact that at low levels of an element in the plant, the concentration in the phloem sap is below saturation (Van Goor and Wiersma 1974). At higher total content of an element in the plant, the concentration in the phloem may increase (Wiersum, to be published) until saturation is reached. The relative mobility in comparison to that in xylem or total amount in the plant may decrease in this way. Besides this influence of total plant content on mobility, the method of measuring the mobility can also lead to a different outcome. Further research, in which the nutritional status of the plant is taken into account, will be needed to clarify the contradictory results in Table 2 for different elements.

Table 2. *Compilation of data from the literature including our own data on the secondary mobility of elements.* Results of different authors indicated by x: 1) Bukovac and Wittwer 1957, method 4. 2) Epstein 1971, literature summary, different methods. 3) Humphries and Devonald 1977, method 2. 4) MacIlrath 1965, determination of the soluble boron fraction in old leaves from plants deprived of boron. 5) Eaton 1944, method 1 and 2. 6) This publication, method 1 and 5. 7) Tromp 1975, concluded from curves given there according to method 5.

| Mobility | Potassium | Boron | Magnesium | Iron | Calcium |
|---|---|---|---|---|---|
| Immobile | | x 2)<br>x 4)<br>tomato, tobacco<br>x 5) | x 1)<br>x 3)<br>x 6) | | x 1)<br>x 2)<br>x 3)<br>x 6)<br>x 7) |
| Intermediary | | | | x 1)<br>x 2)<br>x 6) | |
| Mobile | x 1)<br>x 2)<br>x 3)<br>x 6)<br>x 7) | x 4)<br>cotton, turnip<br>x 6) | x 2)<br>x 7) | | |

The knowledge concerning relative mobility of an element in redistribution can be utilized in predicting the possibility of suboptimal development of organs such as fruits and tubers, or even as yet unnoticed disorders caused by local deficiencies. In this sense it is also important to determine how the elements are distributed in organs like fruits and tubers. A more homogeneous distribution can give a lower incidence of deficiency symptoms in these organs (Van Goor 1966). A general low nutrient status of a highly immobile element in the plant should be suspect.

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