Studies on the Import and Re-export of Minerals by Foliage Leaves of Soybean Plant

I. A demonstration of the simultaneous import and re-export of phosphorus, potassium, calcium and nitrogen and the effect of topping on the withdrawal of these minerals from the leaves*

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Quantitative studies thus far made on the diurnal variations in mineral contents of leaves, and therefore on the import and re-export of minerals to or from the leaves, have been mostly limited to the cases where definite net changes in the minerals were observable in the leaves\(^7,^{19}\).

However, recent studies using various isotopes have clearly revealed a dynamic interchange of minerals to occur within the leaves\(^5\). It is, therefore, in all probability possible for a mature leaf to presume that at least during the day, when transpiration is high, any particular mobile element could enter and leave the same leaf simultaneously. If such is the case, the amount of either imported or re-exported minerals as indicated by the difference in the mineral content of the leaves at two discrete intervals would represent merely a portion of that actually involved in the movement.

Although the development of isotope technique has made it possible to visualize the dynamic aspects of minerals in leaves, this technique does not provide a means by which the normal flux components, i. e. influx and efflux, could be quantitatively distinguished.

One possible approach to this problem may be, however, to apply phloem-blocking method to petioles, thereby preventing minerals from withdrawal which otherwise tend to move out of the leaves via the phloem, while allowing those which are carried upwards via the xylem in the transpiration stream to enter the leaves. Since that the mobile minerals move into the mature leaf mainly via the xylem and move out of it mainly via the phloem has been generally established, it is expected that, if petiole phloem is properly blocked by steaming or some other methods, the more minerals should tend to accumulate in the leaf with treated petiole than in the leaf with normal one. By comparison of the total changes in the mineral content between the normal and the treated leaf, the amounts of the imported and re-exported minerals could be approximately estimated.

In this study, using the method outlined above, the patterns of daily import and re-export of phosphorus, potassium, calcium and nitrogen were examined for the selected leaves of the field-grown soybean plants.

The effect of the removal of growing regions on the withdrawal from the leaves of these minerals was examined as well.

**MATERIALS AND METHODS**

Soybean of the variety Shinano-mejiro was planted on May 22, 1961, in rows 90 centimeters apart with a 25-centimeter spacing in a moderately fertilized soil. Immediately prior to the experiment, 240 plants were selected from large population for uniformity, special care being taken for the trifoliate leaves to be tested to have lateral leaflets of approximately equal size. This was done because "twin-leaf" method, described by Denny\(^7\) for measuring changes in leaves, was employed in this experiment.

In studies of this type, the uniformity of the initial materials, among which direct comparisons are finally made after treatments, is of primary importance. In this respect "twin-leaf" method,
in which one of the matched lateral leaflets of
the test trifoliate leaf is removed at the start of
the experiment as a control leaf and the other at
the end as an experimental leaf, appears to be
superior to others.

The 3rd, 5th and 7th trifoliate leaves (num-
bered respectively from the base) on the main
stem were used as the test leaves.

The whole experiment consists of 3 day-experi-
ments and 3 night-experiments. The day experi-
ments were started at 6 a.m. and ended at 6 p.
m. of the same day, while the night experiments
were started at 6 p.m. and ended at 6 a.m. of
the following day. In each experiment 2 groups
of plants were involved, one being the normal
group and the other topped group in which the
plants were decapitated in the internode above
the 7th leaf node and besides all the branches
present were removed as well. The both groups
in turn included the control plants and the ringed
plants in which the petioles of the test leaves were
“ringed” as described below.

Application of superheated steam to a portion
of stem or petiole has frequently been employed
as a substitute for conventional ringing. But this
method is not suitable for carrying out a large
number of treatments in the field experiments.
In this study, therefore, a small electric heater
was devised for this purpose. The heater is made
of electrode carbon shaped in a clothes-pin like
so as to facilitate a firm setting around a petiole.
These heaters were prepared sufficiently in num-
ber so that 60 petioles could be treated at one
time. Temperature of the heaters was controlled
by a transformer at about 100 to 120°C and the
time required for treatment was less than 2 min-
utes. In plants to be ringed the heaters were
placed in position on the petioles of the respective
test leaves before, sometimes many hours before,
each experiment.

Both ringing and topping treatments were con-
ducted immediately before or after the beginning
of each experiment. The experiment began at 6
a.m. on July 14 and alternate day and night ex-
periments were repeated for the successive 3 days.

Plants at that time were in early bloom and had
10 to 11 leaves on their main stems, the 7th leaves
being the youngest matured. Each sample was
made up of 10 leaflets from 10 plants.

Chemical analyses were made for phosphorus,
kalium, calcium and nitrogen. Oven dried and
powdered leaf materials were ashed at 450°C.
The ash was taken up with dilute nitric acid, the
volume made up to 100 cc and phosphorus, potas-
sium and calcium were determined on aliquots of
the solution. Phosphorus was determined by the
ammonium vanadomolybdate method, potassium
by flame photometry and calcium by titration
with EDTA. Total nitrogen was analyzed by the
Kjeldahl method using salicylic acid to include
nitrate.

RESULTS

1. PHOSPHORUS AND POTASSIUM

Because of the close similarity of the results
obtained with phosphorus and with potassium,
these results will be described here together. The
experimental data are summarized in tables 1 and
2. All data presented are averages of 3 experi-
ments.

a) Normal Group. In the untreated control pla-
nts, both phosphorus and potassium contents of
the leaves of all ages examined increased more
or less during the day, but all the increments
except one were statistically not significant due
to the lack of degree of freedom (tables 1(a) and
2(a)).

In the ringed plants, on the other hand, the
increase in each of these minerals in the leaves
during the day was exceedingly high as compared
with the increase in the corresponding leaves of
control plants. The amounts of excess accumu-
lation in the ringed leaves are in most cases sta-
tistically significant.

The difference between the two treatments may
most easily be interpreted by assuming the simul-
taneous occurrence of incoming and outgoing flows
of these minerals in the leaves.

Taking the phosphorus data for instance, it
will be seen in table 1(a) that the average in-
Table 1. Effect of ringing and topping on the phosphorus content of the leaves with different ages.

<table>
<thead>
<tr>
<th>Group</th>
<th>Treatment</th>
<th>Time</th>
<th>7th leaf</th>
<th>5th leaf</th>
<th>3rd leaf</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>P-content</td>
<td>Difference</td>
<td>% Increase</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(mg/10 leaflets)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>Untreated control</td>
<td>6 A. M.</td>
<td>11.62</td>
<td>1.15</td>
<td>9.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 P. M.</td>
<td>12.77**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ringed</td>
<td>6 A. M.</td>
<td>11.48</td>
<td>2.81</td>
<td>24.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 P. M.</td>
<td>14.20**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topped</td>
<td>Control</td>
<td>6 A. M.</td>
<td>11.07</td>
<td>3.30</td>
<td>29.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 P. M.</td>
<td>14.37**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ringed</td>
<td>6 A. M.</td>
<td>11.29</td>
<td>3.95</td>
<td>35.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 P. M.</td>
<td>15.24**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L. S. D.</td>
<td>5%</td>
<td>1.02</td>
<td>1.25</td>
<td>0.65</td>
<td>1.88</td>
</tr>
<tr>
<td></td>
<td>1%</td>
<td>1.55</td>
<td>1.88</td>
<td>0.99</td>
<td></td>
</tr>
</tbody>
</table>

(a) Day Experiment

(b) Night Experiment

* Increase or decrease is significant at 5% level.
** Increase or decrease is significant at 1% level.
N. S. Not significant.
creases in phosphorus per 10 leaflets for 7th leaf are 1.15 mg for the control plants and 2.81 mg for the ringed plants. Since the latter value is a measure of the total phosphorus imported to the 7th leaf during the period of the day experiment, there would have to be a simultaneous export of 1.66 (2.81 - 1.15) mg phosphorus from the same leaf of the control plants to make both ends meet. Thus it may follow that, during the day, 7th leaf not only imported a large quantity of phosphorus but also exported it in significant amount simultaneously. The same general statement is applicable to the older leaves studied and also to the results of potassium.

Import-export relations for phosphorus and potassium are listed in table 4. The younger leaves, owing to their greater size, either imported or exported more of these minerals than did the older leaves, but the relative ability of export (Export/Import x 100) was always highest in the oldest leaf (3rd leaf).

Tables 1(b) and 2(b) show that there was at night a consistent decrease in phosphorus and potassium from each leaf of the untreated control plants. The decrease during the night was such that the net increase during the previous day was approximately offset. On the contrary, both phosphorus and potassium contents of the leaves of ringed plants remained practically constant at night, indicating that the preventing effect of ringing was almost complete.

b) TOPPED GROUP. In order to examine the role of metabolically active parts of the plant on the re-export of minerals from the leaves, plants were topped at right above the 7th leaf node and, in addition, all the branches present were removed. Two characteristic features are seen in the results obtained with the day experiment of the topped group.

In the first place, topping treatment had the

Table 2. Effect of ringing and topping on the potassium content of the leaves with different ages.

<table>
<thead>
<tr>
<th>Group</th>
<th>Treatment</th>
<th>7th leaf</th>
<th>5th leaf</th>
<th>3rd leaf</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Difference* (mg/10 leaflets)</td>
<td>% Increase</td>
<td>Difference* (mg/10 leaflets)</td>
</tr>
<tr>
<td>Normal</td>
<td>Untreated control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ringed</td>
<td>12.54**</td>
<td>16.3</td>
<td>8.24N.S</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.62**</td>
<td>31.5</td>
<td>14.63**</td>
</tr>
<tr>
<td>Topped</td>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ringed</td>
<td>28.72**</td>
<td>39.1</td>
<td>18.99**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32.03**</td>
<td>43.8</td>
<td>17.28**</td>
</tr>
<tr>
<td>L. S. D.</td>
<td>5%</td>
<td>4.34</td>
<td>5.46</td>
<td>3.86</td>
</tr>
<tr>
<td></td>
<td>1%</td>
<td>6.57</td>
<td>8.27</td>
<td>5.84</td>
</tr>
</tbody>
</table>

(a) Day Experiment

(b) Night Experiment

<table>
<thead>
<tr>
<th>Group</th>
<th>Treatment</th>
<th>7th leaf</th>
<th>5th leaf</th>
<th>3rd leaf</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Difference* (mg/10 leaflets)</td>
<td>% Increase</td>
<td>Difference* (mg/10 leaflets)</td>
</tr>
<tr>
<td>Normal</td>
<td>Untreated control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ringed</td>
<td>-10.68**</td>
<td>-11.8</td>
<td>-3.70N.S</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.61N.S</td>
<td>1.7</td>
<td>-0.96N.S</td>
</tr>
<tr>
<td>Topped</td>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.64N.S</td>
<td>0.7</td>
<td>1.91N.S</td>
</tr>
<tr>
<td>L. S. D.</td>
<td>5%</td>
<td>5.22</td>
<td>4.97</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>1%</td>
<td>7.59</td>
<td>7.23</td>
<td>1.94</td>
</tr>
</tbody>
</table>

* Final K content minus initial K content.
** Increase or decrease is significant at 5% level.
* Increase or decrease is significant at 1% level.
N.S. Not significant.
striking effect in increasing both phosphorus and potassium contents of the leaves of all ages regardless of whether the plants were ringed or not. Tables 1(a) and 2(a) show that the percentage increases for the leaves of the topped control plants are around 30% for phosphorus and nearly 40% for potassium, irrespective of their ages. Such high values were never reached in the normal group even by the ringed plants.

In the second place, of more interest is the fact that no differences was found between the results of the topped control plants and the topped-ringed plants. This observation clearly indicates that the re-export of both phosphorus and potassium from the leaves by day is largely dependent upon the presence of aerial growing regions of the plant. When these regions are removed as in the plants of topped group, re-export of minerals from the remaining leaves, at least during the day, is greatly reduced.

One important finding is that the topping treatment, while causing a marked reduction in the rate of export during the day, did not affect it at all during the night. As are shown in tables 1(b) and 2(b), the results obtained with the control plants of both normal and topped groups are essentially the same. It seems, then, that the transport of phosphorus and potassium out of the leaves can occur at night independently of the presence of the aerial growing parts of the plant.

2. CALCIUM

Calcium has long been regarded as a typically immobile element which, once delivered to a leaf, was not transported from the leaf due to its immobility in the phloem. This led the author to expect that calcium would behave in the leaves of ringed plants in much the same manner as did in the leaves of normal plants. The experimental data obtained, however, disagreed this assump-

Table 3. Effect of ringing and topping on the calcium content of the leaves with different ages.

<table>
<thead>
<tr>
<th>Group</th>
<th>Treatment</th>
<th>7th leaf</th>
<th>5th leaf</th>
<th>3rd leaf</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Difference* (mg/10 leaflets)</td>
<td>% Increase</td>
<td>Difference* (mg/10 leaflets)</td>
</tr>
<tr>
<td>Normal</td>
<td>Untreated control</td>
<td>2.35N.S</td>
<td>5.8</td>
<td>1.07N.S</td>
</tr>
<tr>
<td></td>
<td>Ringed</td>
<td>5.32*</td>
<td>13.2</td>
<td>3.82*</td>
</tr>
<tr>
<td>Topped</td>
<td>Control</td>
<td>10.53**</td>
<td>26.2</td>
<td>7.61*</td>
</tr>
<tr>
<td></td>
<td>Ringed</td>
<td>10.02**</td>
<td>24.2</td>
<td>5.37*</td>
</tr>
<tr>
<td>L.S.D. 5%</td>
<td></td>
<td>1.65</td>
<td></td>
<td>3.26</td>
</tr>
<tr>
<td>L.S.D. 1%</td>
<td></td>
<td>2.39</td>
<td></td>
<td>4.93</td>
</tr>
<tr>
<td>Normal</td>
<td>Untreated control</td>
<td>-0.37N.S</td>
<td>-0.8</td>
<td>1.91N.S</td>
</tr>
<tr>
<td></td>
<td>Ringed</td>
<td>2.03N.S</td>
<td>4.6</td>
<td>-0.82N.S</td>
</tr>
<tr>
<td>Topped</td>
<td>Control</td>
<td>-0.44N.S</td>
<td>-1.0</td>
<td>0.33N.S</td>
</tr>
<tr>
<td></td>
<td>Ringed</td>
<td>1.32N.S</td>
<td>3.1</td>
<td>0.23N.S</td>
</tr>
<tr>
<td>L.S.D. 5%</td>
<td></td>
<td>2.05</td>
<td></td>
<td>2.88</td>
</tr>
<tr>
<td>L.S.D. 1%</td>
<td></td>
<td>3.00</td>
<td></td>
<td>4.36</td>
</tr>
</tbody>
</table>

* Final Ca content minus initial Ca content.
** Increase or decrease is significant at 5% level.
N.S. Not significant.
tion, though not in its entirety, yet offering a rather conflicting evidence to the translocation problem of calcium.

The data are presented in tables 3 and 4. Contrary to the author's expectation, the results of the day experiment show marked difference between the two treatments (table 3). It is worthy of note that calcium accumulated in the ringed leaves invariably higher than in the corresponding control leaves. Although the difference between the two treatments was not so marked as was in the case of phosphorus and of potassium, it is nevertheless statistically significant for 7th leaf while those for 5th and 3rd leaves are partially so.

Thus calcium data closely resemble those for phosphorus and potassium. It is, therefore, presumed by analogy that at least during the day, import-export relations similar to those found for mobile elements such as phosphorus and potassium may exist also for calcium. On the basis of this assumption, proportions of export to import for leaves of various ages were calculated in like manner (table 4). It will be noted that the proportion of re-export increases as the age of the leaf advances. For the 7th leaf it was 37%, while for the 3rd leaf it was as much as 83%.

Although there seemed no substantial differences in the results of day experiment among phosphorus, potassium and calcium, behavior of calcium during the night was quite different. It will be seen from the table 3 (b) that there was no evidence of calcium being withdrawn from the leaves during the night. This is exactly what has been repeatedly recognized by a number of investigators.

Now combining the results for day- and night-experiments, it may be concluded that, during the day, excessive amount of calcium is supplied to the mature leaf and part of it is deposited and become immediately immobilized within the leaf, but any excess which has been free from the deposition could be transported, by whatever mechanism, from the leaf. Exportation of excess calcium appears to complete during the day.

3. NITROGEN

The results were less conclusive for nitrogen, so the data are not included here. The diurnal variation in nitrogen in the untreated control leaves was quite obscure. Upon ringing, however, only 7th leaf showed a significant accumulation of nitrogen above that of the untreated control, thus indicating a presence of simultaneous outgoing flow of nitrogen.

Topping treatment increased nitrogen content of all the tested leaves in the daytime significantly in the control plant but to a lesser extent in the ringed plant. Here again, re-exportation during the day was not detected when plants

<table>
<thead>
<tr>
<th>Mineral element</th>
<th>Leaf</th>
<th>DAY</th>
<th>Exported</th>
<th>Exported</th>
<th>Exported</th>
<th>Exported</th>
<th>Exported</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>mg</td>
<td>mg</td>
<td>%</td>
<td>mg</td>
<td>mg</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>7 th</td>
<td>2.81</td>
<td>1.86</td>
<td>0.89</td>
<td>1.66</td>
<td>0.73</td>
<td>59</td>
</tr>
<tr>
<td>Potassium</td>
<td>7 th</td>
<td>23.62</td>
<td>14.63</td>
<td>6.32</td>
<td>11.08</td>
<td>3.15</td>
<td>47</td>
</tr>
<tr>
<td>Calcium</td>
<td>7 th</td>
<td>5.32</td>
<td>3.82</td>
<td>3.27</td>
<td>2.97</td>
<td>2.75</td>
<td>83</td>
</tr>
</tbody>
</table>

Table 4. Amount of daily import and export of minerals by leaves with different ages, (mg per 10 leaflets)
were topped.

**DISCUSSION**

One of the essential findings of the present work is the demonstration in more quantitative terms of the possible occurrence of the simultaneous incoming and outgoing flows of minerals such as phosphorus, potassium and even calcium in the mature leaves of soybean plant. However, since this finding was based on the fact that these minerals accumulated within a single daytime in far greater amounts in the ringed leaves than in the normal leaves, if any factor or factors having a promoting effect on the entry of minerals into the ringed leaves were established within the ringed plants, the above interpretation would be a misleading one. One such possible factor may be a starvation in roots and in stems due to a reduced carbohydrate supply to these tissues following the ringing treatment of the petioles. Starved organs may give rise to a remobilization and the subsequent translocation of minerals they stored.

But the starvation, if occurred, must have been slight in this experiment because only 3 petioles were ringed per plant. Furthermore, the starvation effect is likely to be more on the side of a reduction in mineral absorption by roots. Thus starvation has dual effects on the import of minerals into the leaf, one being the promoting effect due to stimulated redistribution of stored minerals and the other being the inhibitory effect due to reduction in mineral absorption by roots. As a result the former (promoting) effect could be usually lessened or masked by the latter. Excess accumulation of minerals in the ringed leaves, therefore, must not be explained solely by the anomalous migration of minerals due to starvation.

"Twin-leaf" method employed in this study may offer an additional factor which favors the import of minerals into the leaf. However, since this effect should equally be exerted both on the ringed and the control leaves, no serious question may arise in so far as the differences between them are concerned.

From the preceding discussions, it may be inferred that the data obtained in this experiment represent not far from the real. Mason and Maskell (1931) have already suggested that the nutrients, such as nitrogen, phosphorus and potassium, absorbed by the root and carried along in the transpiration stream were mostly translocated to the leaves and that any excess not used currently in the leaves was re-exported to other parts of the plant. That this might be operative was clearly demonstrated by the present investigation. Within the range of leafages herein investigated, phosphorus, potassium and in lesser extent nitrogen all showed evidence of the suggested movement.

The data further indicated that while import of minerals into mature leaves could be detected only in the daytime, re-export occurred by day and by night, and that the amount of re-export was always greater in the daytime than at night. Biddulph, studying the effects of light and darkness on the translocation of radiophosphorus injected into the phloem of a bean leaf, showed that the translocation of \(^{32}\)P took place more rapidly during the hours of daylight than at night. The greater exporting ability of leaves during the day has been also shown by Goodall. In this experiment, proportions of re-export to import for phosphorus and potassium during the 12-hour daytime were 56 to 82% and 44 to 50%, varying with the age of the leaf, respectively. On the other hand, Koontz and Biddulph determined that the percentage of the foliar absorbed \(^{32}\)P which was translocated from the leaflet was about 25% for the first 24 hours and about 60% at the end of the 96-hour experimental period. The observed difference between the two experiments may be due to discrepancies in materials and in method employed.

It is interesting to note that calcium behaved in the daytime as if it followed the same general pattern of transport as in phosphorus and potassium. The immobility of calcium in the phloem has been reported by many investigators.
The fact that the foliar applied tracer calcium almost always failed to move from the leaf renders this concept tenable.

On the contrary, it was claimed that the export of calcium from the leaf was induced by applying either diethyl ether or triiodobenzonic acid to the leaves. However Biddulph later showed that this movement of calcium occurred via the xylem.

In this experiment, calcium accumulated in the ringed leaves in greater amounts than in the untreated leaves, and yet there is no justification for assuming that the increased accumulation is due to abnormal redistribution of calcium within the ringed plant for the very reason of its relative immobility within the plant as a whole. Consequently the possible explanation may be that the excess calcium could be exported from the leaf presumably via the phloem. In this connection it should be of value to refer to the observation by Biddulph et al. that a small but a definitely measurable amount of foliar applied ⁴⁰Ca was translocated from the leaf and that the movement was via the phloem since the translocation was completely prevented by steaming the petiole. They further showed that as concentration of the foliar apply was increased the amount of ⁴⁰Ca translocated away from the leaf also increased.

Without further evidence, it seems to the author that the rate at which foliar applied calcium is absorbed by the leaf may be normally so slow that the larger part of the absorbed calcium could become immobilized within the leaf before it could reach the normal translocation site. On the other hand, the normal internal supply of calcium through the transpiration stream to a mature leaf may be proceeding at higher rate than that at which calcium is immobilized within the leaf, the excess calcium which is remained mobile being directly translocated away from the leaf through the phloem. It may also be said that the initial delivery of calcium to a leaf is not necessarily the final delivery, but the original deposition is the final deposition.

It has frequently been noted that patterns of translocation of substances from the leaves were considerably affected by the occurrence of metabolically active parts (such as meristems and developing fruits) of the plants. Although the topping treatment definitely reduced a transport of minerals out of the leaves, it should be emphasized that this effect was strictly confined to the daylight hours. In this respect, the fact that the movement of ¹⁴C-photosynthe or ¹⁴C-labeled compounds from the leaves during the day is predominantly toward the growing shoot tip, but at night it is predominantly toward the roots may well explain why the above results followed after the topping treatment.

**SUMMARY**

Tissue block, as a substitute for conventional ringing, was applied to petioles of the selected mature leaves of field-grown soybean plants by using specifically devised electric heaters. Minerals generally accumulated in the leaves by day in greater amounts when the petioles were treated than when they were remained intact. This was interpreted as simultaneous import and export of minerals to be occurring within the same leaf. On the basis of this assumption, phosphorus, potassium and even calcium were supposed to be re-exported from the mature leaf during the day when the net increase in each of these minerals tended to result in the leaf. For phosphorus and potassium, the amounts re-exported were invariably greater in the daytime than at night. Calcium, on the contrary, did not move out of the leaf during the night.

Removal of the aerial growing parts of the plant resulted in a marked reduction in the translocation of phosphorus, potassium and calcium from the leaf during the day, but had no influence at night. The data for nitrogen somewhat resembled those for phosphorus and potassium, but the results were less conclusive.

**LITERATURE CITED**

1. BIDDULPH, O. 1941. Diurnal migration of injected radiophosphorus from bean leaves.


[和文摘要]

大豆の葉における無機養分の流入と流出に関する研究

I. リン・カリ・カルシウムおよびチッソの同時流入・流出とそれによる水分の影響について

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通常の剤皮に代る手段として、熱によって葉柄の筒管を閉塞するため特殊な電熱ヒーターを考案した。種々の葉齢の葉について調査した結果、処理を施した葉は処理の葉に比べて、早春12時間に平均2倍以上の無機養分をとり入れることがわかった。この事実は早春同一の葉に対して、無機養分の流入と流出が同時に行われていることを示している。リンとカリの流入と流出は日中きわめて活発で、成熟葉の場合葉が若いほど流入・流出
出とともに絶対量は多いのが、流入に対する流出の割合は古い葉において高い傾向がある。夜間は流入にくく流出のみ行なわれるが、葉からの流出量は各葉において、昼間の方が夜間よりもむしろ多量であった。
意外なことは、従来考えられ難いと考えられているカルシウムさえも、昼間はリンやカリと全く同様に自由に葉から出入口するように思われることである。実験の結果によるとカルシウムも日中盛んに葉に流入し、その一部（若葉37％、古葉83％）は恐らく筋管を経て再び葉から流出しているものと考えられる。しかしカルシウムはリンやカリと異なり、夜間は全く葉から流出しなかった。
これらの無機養分の葉からの移動は、昼間は地上部の生長部分と密接な関係があり、若し生長部分を除去すると葉からの移動はほとんど停止するに至るが、夜間の場合はこのような関係は全く見られず、葉からの移動（カルシウムを除く）は地上生長部の有無にかかわらず、何れの場合も正常に行なわれた。
チッソについての結果はほぼリンやカリに準ずるが、若い葉を除く結果は不明瞭であった。