Transport of the Auxin, Picloram, Through Petioles of Bean and Coleus and Stem Sections of Pea

R. F. Horton and R. A. Fletcher

Department of Botany, University of Guelph, Guelph, Ontario, Canada

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Abstract. The transport of the synthetic auxin, picloram (4-amino-3,5,6-trichloropicolinic acid) was investigated in sections of petioles of Phaseolus vulgaris L. and Coleus blumei Benth. and stems of Pisum sativum L. Transport of $^{14}$C-picloram was basipolar in all tissues, although the degree of polarity was dependant on age. The velocity of picloram movement was calculated at between 0.75 and 1.11 mm/hr. The amount moved in a given time, the flux, was dependant on the concentration applied and the length of the sections used. Picloram did not appear to be metabolized by the tissues during the transport experiments. When compared to the movement of other growth regulators, picloram transport bears marked similarities to that of 2,4-dichlorophenoxyacetic acid.

Picloram (4-amino-3,5,6-trichloropicolinic acid), a synthetic growth regulator with a unique chemical structure (3) acts as a potent auxin in a variety of test systems when used at low concentrations (7). Picloram, which has been used extensively as a herbicide in recent years, appears to be absorbed and translocated readily after foliar application (3, 4). In the present study the transport of picloram was investigated for 2 specific reasons. Extensive investigations of the phytotoxic effects of high concentrations of picloram have established that this compound is not metabolized rapidly, if at all, by plant tissue. One of the problems encountered in physiological studies of growth regulator transport is the occurrence of varying degrees of degradation of the transported molecule during uptake and within the transport system itself (2, 10, 11). Picloram, because of its apparent chemical stability within the tissue, affords the possibility of studying auxin transport in a more simplified system. It is also important to determine whether the capacity of a substance to be transported in plants in a polar manner is a fundamental property of any molecule which exhibits auxin activity. Kefford and Caso (7) have pointed out that picloram possesses a chemical structure which is markedly different from that of any other natural or synthetic auxin.

It is desirable that synthetic growth regulators with a phytotoxic action which in part is dependant upon their chemical stability within plants, are also investigated in terms of their usefulness as tools in a further understanding of a basic physiological phenomena. The technique of applying an isotopically labeled growth regulator in agar blocks to either end of a tissue section and measuring the subsequent transport into plain agar receiver blocks placed at the opposite end allows an accurate determination of the course of transport over short time periods, together with an estimation of the amount of uptake from donor blocks (1, 2, 8, 10, 11, 12). McCready and Jacobs (11) have pointed out that most of the information concerning the movement of the native auxin, IAA, comes from such experiments, whilst ideas on the movement of phytotoxic growth regulators are derived largely from experiments using more nearly intact plants.

In the present study, several initial experiments, which established the polarity of picloram movement in plant tissues, were carried out with sections excised from Coleus and pea plants. The basipolar movement of isotopically labeled picloram was then investigated more fully in sections cut from the petioles of primary leaves of beans.

Materials and Methods

Tissue sections were excised from the expanding petioles of 6 to 8 day old plants of Phaseolus vulgaris L. Contender. In experiments to investigate the transport of picloram in petioles of different ages, 4 to 26 day old plants were used. In some experiments, sections were prepared from petioles of Coleus blumei Benth and from just below the apex of 8 day old plants of Pisum sativum L. Little Marvel. All the plants used were grown in a greenhouse.

Gels of 1.5% agar containing the potassium salt of $^{14}$C-carboxyl-labeled picloram (specific activity 4.25 μc/mg) were sectioned into cylindrical blocks of 20 μl volume. A donor block containing $^{14}$C-picloram was applied to one end of a tissue section.

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A plain agar receiver block was placed at the other end. The sections were laid across the 2 mm gap between 2 glass slides resting on a layer of 3% agar in a 9 cm petri dish and kept in the dark at 25°C. After the transport period the donor and receiver blocks from 10 sections were pooled and assayed for radioactivity by the methods described by McCready (9). Two groups of 10 blocks of each sample of active agar were assayed to determine the amount of radioactivity applied initially to the sections. The self-absorbance of the radioactive samples of dried agar was assumed to be uniform.

In investigations of the transport of isotopically-labeled growth regulators it is essential to determine whether the radioactivity remains in the form of the applied chemical throughout the experiment. After 48 hr of transport from agar blocks containing 5 mg/l 14C-picolram, 20 tissue sections and the 4 corresponding groups of agar blocks were repeatedly eluted with ether and the eluate cochromatographed with picloram on silica gel thin layer plates in phenol-water (5:1 v/v). The developed plates were subdivided into 10 equal bands between the origin and the solvent front. The gel from these bands was removed and suspended in 15 ml of scintillation fluid (5 g 2,5-diphenyloxazole in 1 liter toluene). Radioactivity was determined in a Unilux II liquid scintillation counter.

Results and Discussion

The transport of picloram was shown to be basipolar in sections from bean and Coleus petioles and stems of peas (table I). In all 3 tissues the amount of radioactivity in the basipetal receiver blocks was at least 3 times greater than that in acropetal receiver blocks. Furthermore, polarity was also exhibited in the uptake of 14C-picolram from blocks placed at the physiologically apical or basal ends of the sections.

The time course of transport of picloram applied to bean petiole sections at 3 different initial concentrations is shown in figure 1. For comparative purposes the amounts of radioactivity in the receiver blocks have been plotted on scales proportional to the applied picloram concentrations. After an initial lag period, the basipetal transport of picloram continued at a fairly steady rate which was maintained for the 12 hr duration of the experiment. Although polarity of movement occurred at each concentration at each time of determination, there are significant differences in the uptake and subsequent transport of picloram after application at different initial concentrations. While 12.7% of the picloram applied at 1 mg/l moved through the tissue in 12 hr, only 8.7% appeared in the receiver blocks after application at 5 mg/l. This difference may be due in part to the limited ability of the tissue to absorb picloram at the cut surface, or to the limited capacity of the transport system itself. As uptake has obviously occurred at a changing rate from blocks containing changing concentrations of picloram (fig 2), a detailed analysis of the data is difficult. However, it was clear that more than half the applied picloram had left the basipetal donor blocks during the 12 hr period. Uptake was again polar; more picloram had left the basipetal donors than the acropetal donors.

The degree of polarity of picloram transport decreased with increasing tissue age in both bean and Coleus petioles (table II). Sections which showed marked polarity of transport also exhibited stimulated elongation during the 24 hr treatment.

![Image: Graph showing time course of radioactivity uptake in receiver blocks](https://example.com/graph.png)

**Table I. Basipetal and Acropetal Movement of 14C-picolram in Petiole Sections of Bean and Coleus and Stem Sections of Pea**

The total radioactivity supplied was 2896 cpm. The sections were 3.2 mm in length. The transport period was 24 hr.

<table>
<thead>
<tr>
<th>Transport</th>
<th>Radioactivity in block</th>
<th>cpm</th>
<th>cpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phasoeus vulgaris (petioles)</td>
<td>Basipetal</td>
<td>1164</td>
<td>763</td>
</tr>
<tr>
<td></td>
<td>Acropetal</td>
<td>1935</td>
<td>55</td>
</tr>
<tr>
<td>Coleus blumei (petioles)</td>
<td>Basipetal</td>
<td>2052</td>
<td>435</td>
</tr>
<tr>
<td></td>
<td>Acropetal</td>
<td>2362</td>
<td>16</td>
</tr>
<tr>
<td>Pisum satiunum (stem)</td>
<td>Basipetal</td>
<td>1680</td>
<td>523</td>
</tr>
<tr>
<td></td>
<td>Acropetal</td>
<td>2195</td>
<td>151</td>
</tr>
</tbody>
</table>
with picloram. Because of the progressive increase
with age in the diameter of the tissue sections
particular care must be taken in interpreting the
data. It appears that the decreased polarity of
picloram in older bean petioles is due to an increase
in acropetal transport. In contrast, the decreasing
polarity in Coleus is associated with a decline in
basipetal transport. Therefore, the pattern of trans-
port of picloram in these tissues is similar to that of
IAA and 2,4-D in that the overall degree of polarity
is dependent on the age of the tissue and its corre-
lated ability to elongate under the influence of ap-
plied auxin (5). Furthermore, the physiological
reasons for the decline in the degree of polarity in
older bean petioles is due to a different set of
factors from those regulating the decline in Coleus
petioles (12).

Values for the mean velocity and flux of picloram
movement can be derived from the data for the
course of transport. To ensure the validity of the
derivations it was first necessary to examine the
nature of the lag period occurring between applica-
tion of the donor blocks and the establishment of a
steady rate of accumulation of radioactivity in the
receiver blocks. There are at least 2 possible rea-
sons for this lag period (10). Firstly, processes
occurring at the ends of the sections, such as re-
covery from injury or saturation time of immobiliza-
tion sites, and, secondly, the time taken for picloram
to be transported through the length of the sections.
In order to distinguish between these 2 possibilities
the course of transport through sections of different

lengths was investigated (fig 3). The line of best
fit of the experimental data can be calculated by
the method of least squares. The intersect of the
derived line and the time axis will indicate the
average time taken for molecules of picloram to be
transported through the sections. The calculated
times for transport through the 3 sections are 2.67,
5.70, and 7.69 hr; these times are roughly in the same
proportion as the initial section lengths. On this
evidence it was concluded that the time taken for
transport through the sections, rather than immo-
bilization at the cut surface, was the major reason
for the delay in detectable radioactivity appearing in
the receiver blocks. The data shows that the subse-
quently rate of picloram transport into basipetal re-
ceiver blocks decreased with increasing lengths of
the tissue sections.

![Graph showing the time course of the loss of 14C-picloram from basipetal and acropetal donor blocks placed on 3.2 mm bean petiole sections. Data from same experiment as figure 1. A) Acropetal donors, B) basipetal donors.](image)

- **Table II. Basipetal and Acropetal Movement of 14C-picloram Through Petiole Sections of Different Ages**

The total radioactivity supplied was 2896 cpm. The sections were 3.2 mm in length. The transport period was 24 hr.

<table>
<thead>
<tr>
<th>Age of petioles (days)</th>
<th>Phaseolus vulgaris</th>
<th>Coleus blumei</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Mean length of petioles (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Counts/min in receivers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basipetal</td>
<td>687</td>
<td>708</td>
</tr>
<tr>
<td>Acropetal</td>
<td>13</td>
<td>56</td>
</tr>
<tr>
<td>Polarity (A/B X 100)</td>
<td>1.9</td>
<td>7.9</td>
</tr>
<tr>
<td>% Elongation after picloram application at apex</td>
<td>18.8</td>
<td>12.5</td>
</tr>
<tr>
<td>% Elongation after picloram application at base</td>
<td>18.8</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Fig. 3. Time course of basipetal movement of 14C-
picloram into receiver blocks. Picloram supplied at
initial concentrations of 5 mg/l to Phaseolus petiole
sections of different lengths.
The velocity of basipetal transport in bean petioles derived from the line of best fit of the data, remained relatively constant at between 0.75 and 1.11 mm/hr in bean petioles for a range of section lengths and initial concentrations of applied picloram (table III). 2,4-D is transported at a velocity of 0.6 to 1.0 mm/hr in bean petioles, while IAA moves at a velocity of up to 6 mm/hr (10, 11).

Table III. Velocity and Flux of Basipetal Movement of 
14C-picloram in Petiole Sections of Bean

<table>
<thead>
<tr>
<th>Sampling times (hrs)</th>
<th>4,8,12</th>
<th>5,12,17,24</th>
</tr>
</thead>
<tbody>
<tr>
<td>14C-picloram (mg/l)</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Section length (mm)</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>Velocity (mm/hr)</td>
<td>0.75</td>
<td>1.11</td>
</tr>
<tr>
<td>Flux (cpm/mm/hr)</td>
<td>7.4</td>
<td>13.3</td>
</tr>
</tbody>
</table>

The slope of the line of best fit calculated from the data gave an estimation of the flux of picloram movement. The flux was dependant on both the concentration of picloram applied and the length of the tissue sections. The relationship between flux and section length has been noted for 2,4-D transport (1, 8, 10). The course of picloram transport in bean petioles bears a marked similarity to that of 2,4-D with a correspondingly low velocity when compared to that of IAA. The acropetal velocity of picloram movement appears to be very similar to the basipetal velocity although the flux is considerably lower. Picloram, like 2,4-D (10), continues to move into basipetal receiver blocks after 24 hr of transport, whilst IAA transport (11) reaches a maximum after only 8 to 12 hr.

Chromatographic analysis of extracts of tissue sections and agar blocks after an extended transport period showed detectable radioactivity only at RF 0.5 which corresponded to the RF of synthetic picloram in the system employed. Recent experiments by Hamill (personal communication) using 14C-picloram at phytotoxic concentrations on bean plants show that radioactivity is not lost from the tissue as CO2. It was concluded that the radioactivity remains in the form of 14C-picloram throughout the experiment. The apparent difference in the transport of synthetic and natural auxin may, in part, be due to the more rapid breakdown of IAA in the tissues, and subsequent immobilization of radioactive products. Some radioactivity from applied 14C-2,4-D may also become immobilized in the tissue (10). The inability of the tissue to metabolize picloram may explain the fact that a very high proportion—up to 80%—of the applied picloram can be transported into basipetal receiver blocks within 24 hr.

Jacobs (5, 6) has pointed out that the crucial factor in the difference between IAA and 2,4-D transport in Coleus petioles may lie in the preferred path of movement. More 2,4-D moves basipetally through cambial and vascular tissues, whilst IAA is transported through pith parenchyma. The prerequisite of active cambial proliferation for 2,4-D transport may explain the ineffectiveness of the compound as a herbicide for control of monocotyledonous plants. The high flux of the polar transport of picloram may be the result of such vascular transport accompanied by a low degree of breakdown and immobilization.

Acknowledgment

The isotopically-labeled picloram was a gift from the Dow Chemical Company.

Literature Cited