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soil-to-Plant transfer
MAICCh, Chania, Crete, Greece, September 8-12, 2001

Working Group 3, Soil-Plant-Relationships

Proceedings

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D-88241 Germany
Preface

For several years, Professor Martin Gerzabek did a remarkable job as chairman of ESNA Working Group 3 and as editor of the proceedings of this working group. Due to his efforts and through the support of his institute, year after year, members of the working group and a larger audience of about 100 recipients had the privilege of being able to read the papers after the conference and so to learn about current work going on within “soil plant relationships”. Here, I want to thank Martin again for his excellent work over all these years.

After our conference in Chania, Crete in 2001, several members of the working group asked if, and how, the publication of these Proceedings could continue. It takes time and is a considerable financial burden to produce the proceedings. Several attempts to find a sponsor proved fruitless but these negative responses helped to convince colleagues in Weingarten, Germany, to support this publication financially in order to keep it alive. Finally, with great perseverance from Gregor Zibold, and a delay of 2 years we continue publishing.

Nearly all of the contributions in Chania were given as oral presentations and only a few as posters. In the Radioecology sessions, Skarlou et al. / Athens, report on their progress in classifying soils according to the uptake behaviour of radioactive Cs and Sr. In a second presentation Skarlou et al. describe their detailed study of $^{134}$Cs uptake for crops grown on Greek soils. Oncsik / Hungary reports on studies with tomato fruit and finds that contamination with $^{134}$Cs at harvest time is most severe if applied to the leaves. Brambilla / Italy presented results of his Ph. D. thesis, a dynamic model for leaf to fruit transfer of radionuclides applied to tomato plants. Zibold et al. / Germany addressed measurements and modelling of $^{137}$Cs in a spruce forest ecosystem, and found that observed time-dependencies agree with those found in other European forests.

In the Soil Science and Plant Nutrition sessions 13 papers were submitted for these proceedings. Gasparatos et al. / Athens studied the bio-availability of Pb, Cu and Zn in soils from urban – industrial areas in Greece and found them to be low especially if organic matter is present in the soil. In a second presentation they reported on increased heavy metal concentrations observed in urban and crop soils, while soils covered with natural vegetation and bare soils showed lower levels of contamination. In 9 papers Budoi and coworkers / Romania, reported on global agrochemical indexes of soil fertility, on equations for fertilization in floriculture, on the absorption of nutrients in plants in general, and especially on foliar fertilisation of sunflower, fruit trees, shrubs, grape-vine, hybrid maize, and its consequences on soil fertility in orchards. Finally, Gavrilita et al. / Romania discussed aspects of persistence and penetration of nutrients from foliar fertilizers into plants and in a second presentation the connection between seed treatment and sowing epoch.

The working sessions in the pleasant MAICH Institute were interconnected by tasty meals, original Crete music and a fascinating excursion highlighting olive oil and fruit production, and the manufacture of oils on a cooperative and micro scale. The high waves and stormy weather on the west coast of Crete were refreshing and provided some stunning scenes.

Our thanks go to the chairperson of the meeting, Dr. Vas. Skarlou, and her team for their hospitality and near perfect organisation. On behalf of the ESNA committee and members of working group 3 I would like to thank Gregor Zibold for his work on these proceedings.

Nick Mitchell and Gregor Zibold,
Co-Chairman of Working Group 3
Acknowledgements

Printing and mailing of these proceedings have been supported by the Institute of Applied Research (IAF) and by the Rector of the Fachhochschule Ravensburg-Weingarten. We thank for their important contributions.

Gregor Zibold
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Introduction

There is worldwide need to classify soils according to their uptake behavior of radioactive Cs and Sr. In a recent publication, Frissel et al. 2002, described a method to correlate the uptake as a function of the type of soils. It is based on the observation that most individual species of a crop group show almost the same soil-to-plant uptake factors on the same soil, and on the observation that between crop groups uptake factors seem to be more or less constant; these relations are called *reference values* and *conversion ratios*, respectively. A reference transfer factor (reference TF), depending solely on soil properties, is derived for a reference crop. Crops are divided into groups, depending on the characteristics of the crop; cereals serve as a reference group. The transfer of other groups can be calculated by multiplying values for cereals with a conversion ratio. For the moment, the method is still speculative because the existing database is limited; and will without doubt remain limited for the next few decades. Moreover, existing experiments were not at all planned to derive reference values or concentration ratios. This publication focuses on the preliminary results of a FAO/IAEA/IUR project deriving such values and ratios. It is, besides on reporting progress, intended to provoke scientific discussion and to gain feedback before finalizing the project, FAO/IAEA/IUR 1999. The main aim of the project is to classify soils according to reference values and conversion ratios of radiocesium and radiostrontium. Its official name is ‘The Classification of Soil Systems on the Basis of Transfer Factors of Radionuclides from Soil to Reference Plants’. It started in 1999 with a preparatory meeting, in March 2001 a second meeting was hold. The CRP is scheduled for 5 years and is thus halfway. All experiments follow the FAO/IAEA/IUR protocol, FAO/IAEA/IUR 1998, for uptake measurements. The next paragraphs report on the most relevant news.

What was expected: reference values and conversion ratios

One of the greatest complications in deriving expected soil-to-plant transfer values is the time dependency of the transfer factors. This is especially true for Cs and to lesser degree for Sr. This is best illustrated by fig. 1 that gives the influence of the time on the uptake of Cs by rice. The authors supply therefore separate expectations for acute or accident situations and for routine release or equilibrium situations. Both are based on existing data. They are given in the tables 1 and 2; tables are derived from data of an earlier FAO/IAEA/IUR program, the IUR data bank and a NRPB report, TECDOC in Prep., IUR 1992, Nisbet et al.1999. The authors realize, the time dependency is severely simplified.
The predictions for Cs take into account the nutrient status as main divider, a difficult criterion, certainly if one realizes that it has to cover 5 continents. For the prediction of Sr uptake, the exchangeable Ca is the main criterion. The IAEA project is focussed on the crop groups cereals and green vegetables, some participants included other crops as e.g. beans and potatoes. The for this comparison relevant conversion ratios, again based on existing data, are: Cs vegetables/cereals 8 (ranging from 3 to 13), Sr vegetables/cereals 12.

**Table 1.** Reference transfer factors of Cs for cereals. Reference values are expressed as (Bq/kg dry crop)/(Bq/kg soil in the upper 20 cm of soil).

<table>
<thead>
<tr>
<th>Nutrient status</th>
<th>Soil type</th>
<th>Reference TF's of Cs for steady state releases</th>
<th>Reference TF's of Cs for accidental releases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Expected value</td>
<td>Range</td>
</tr>
<tr>
<td><strong>High nutrient status, pH &gt; 4.8</strong></td>
<td>All soils</td>
<td>0.006</td>
<td>0.002 - 0.01</td>
</tr>
<tr>
<td><strong>Medium nutrient status, pH &gt; 4.8</strong></td>
<td>Clay and loam soils</td>
<td>0.03</td>
<td>0.01 - 0.1</td>
</tr>
<tr>
<td></td>
<td>Sand, peat and other soils</td>
<td>0.05</td>
<td>0.02 - 0.1</td>
</tr>
<tr>
<td></td>
<td>Clay soils</td>
<td>0.2</td>
<td>0.1 - 0.5</td>
</tr>
<tr>
<td></td>
<td>Sand and other soils</td>
<td>0.3</td>
<td>0.1 - 1</td>
</tr>
<tr>
<td><strong>Low nutrient status OR pH &lt; 4.8</strong></td>
<td>pH &gt; 4.8</td>
<td>0.3</td>
<td>0.1 - 1</td>
</tr>
<tr>
<td></td>
<td>pH &lt; 4.8</td>
<td>0.6</td>
<td>0.2 - 2</td>
</tr>
<tr>
<td></td>
<td>Wet, gleicy</td>
<td>3</td>
<td>1 - 10</td>
</tr>
<tr>
<td></td>
<td>Soils with exchangeable K &lt; 0.05 cmol(+)kg</td>
<td>2</td>
<td>1 - 5</td>
</tr>
</tbody>
</table>
Table 2. Expected reference transfer factors of Sr for cereals. Reference values are expressed as (Bq/kg dry crop)/(Bq/kg soil in the upper 20 cm of soil), Ca-exchageable as cmole(+)/kg, and OM as percentages. The pH and OM values may be used if no Ca-exchangeable data are available.

<table>
<thead>
<tr>
<th>SOIL TYPE</th>
<th>REFERENCE TF's OF Sr FOR STEADY STATE RELEASES</th>
<th>REFERENCE TF's OF Sr FOR ACCIDENTAL RELEASES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expected value</td>
<td>Range</td>
</tr>
<tr>
<td>Clay and loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca &gt; 16</td>
<td>0.03</td>
<td>0.01-0.1</td>
</tr>
<tr>
<td>Ca 9-16 (pH &lt; 6)</td>
<td>0.15</td>
<td>0.05-0.5</td>
</tr>
<tr>
<td>Ca &lt; 9 (pH &lt; 5 and OM &lt; 1)</td>
<td>0.3</td>
<td>0.1-1.2</td>
</tr>
<tr>
<td>Sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca &gt; 10</td>
<td>0.06</td>
<td>0.02-0.2</td>
</tr>
<tr>
<td>Ca 2-10</td>
<td>0.25</td>
<td>0.02-1</td>
</tr>
<tr>
<td>Ca &lt; 2 (pH&lt; 5 And/or OM&lt; 1)</td>
<td>0.4</td>
<td>0.1-2</td>
</tr>
<tr>
<td>Organic (peat, OM &gt; 18)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not further specified</td>
<td>0.025</td>
<td>0.01-0.06</td>
</tr>
</tbody>
</table>

Preliminary results

Sixteen countries participate to the project. Participants provided data on the pre-distributed data sheets. So far, some 500 TF values were reported for edible products. As far as possible values are averaged. Some averages are based on more than 10 replicates, others on only 2 or 3 values. The majority of the data were for radiocesium and radiostrontium. Some participants reported data on sites which were contaminated at least 5 year ago. The other data were developed from artificially contaminated soils. This difference is, as said, important as radionuclides from areas, which were contaminated long ago, behave differently than those in recently contaminated soils.

All participants were urged to check the constant ratio, which was supposed to exist between the contamination of cereals and green vegetables, both for Cs and Sr. Of course such calculation can only be made if results are available of TF values of cereals and of green vegetables, and obtained on the same soil. For a project which runs hardly for one year only, a hard task. Yet, eight participants succeeded in deriving ratios for Cs and five for Sr.

The figures 2-4 compare the expected TF values with the observed values. It is distinguished between Cs and Sr, between cereals and vegetables and between long term contamination and short term contamination. For the time being, the limit between long and short term contamination, is set to 4 years. It is remarkable that the agreement between predicted and observed values for the long term contamination is good, for the short term contamination this is not the case. Values which are higher than expected are almost absent, moreover the oversteps are relative small. Many observed values are, however, much lower than expected. This phenomenon is not yet explained.
Fig. 2. Comparison between expected and observed TF’s. Cs, cereals.
Upper part: Observations made with soils with a contact time longer than 4 year (equilibrium cond.)
Lower part: Observations made with soils with a contact time less than 4 year (non-equilibrium cond.)
Expected values are taken from table 1 and are printed in bold.

<table>
<thead>
<tr>
<th>Cs, cereals</th>
<th>Transfer factors, equilibrium conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lower than expected</td>
</tr>
<tr>
<td></td>
<td>expected range (in bold)</td>
</tr>
<tr>
<td></td>
<td>higher than exp.</td>
</tr>
<tr>
<td>nutr st</td>
<td>soil type</td>
</tr>
<tr>
<td>high</td>
<td>All soils</td>
</tr>
<tr>
<td>pH&gt;4.8</td>
<td></td>
</tr>
<tr>
<td>medium</td>
<td>clay, loam</td>
</tr>
<tr>
<td>pH&gt;4.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sand, peat, other</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>low</td>
<td>clay</td>
</tr>
<tr>
<td>pH&lt;4.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sand, other</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>peat pH&gt;4.8</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>peat pH&lt;4.8</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>exK &lt; 0.05</td>
</tr>
</tbody>
</table>

non-equilibrium conditions

| nutr st     | soil type                                | lower than expected |
|-------------|------------------------------------------|
|             | expected range (in bold)                 |
|             | higher than expected                     |
| high        | All soils                                | 0.02 - 0.1          |
| pH>4.8      |                                          | .008 .002 .006 .007 |
|            |                                          | .008 .008 .009 .009 |
|            |                                          | .009 .011 .012      |
|            |                                          | .013              |
| medium      | clay, loam                               | 0.05 - 0.5         |
| pH>4.8      |                                          | .0011 .0032 .005  |
|            |                                          | .007 .007 .009     |
|            |                                          | .012 .019          |
|            | sand, peat, other                        | 0.1 - 0.5          |
|            |                                          | .0013              |
| low         | clay                                     | 0.2 - 1            |
| pH<4.8      |                                          | .0013              |
|            | sand, other                              | 0.2 - 2            |
|            |                                          | .036 .13           |
|            | peat pH>4.8                              | 0.2 - 2            |
|            |                                          | .036 .13           |
|            | peat pH<4.8                              | 0.4 - 4            |

4
**Fig. 3.** Comparison between expected and observed TF’s. Cs, vegetables.
Upper part: Observations made with soils with a contact time longer than 4 year (equilibrium cond.)
Lower part: Observations made with soils with a contact time less than 4 year (non-equilibrium cond.)
Expected values taken from table 1 with a conversion ratio of 10, printed in bold.

<table>
<thead>
<tr>
<th>Cs, vegetables</th>
<th>Transfer factors, equilibrium conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>nutrient status</td>
<td>soil type</td>
</tr>
<tr>
<td>high pH&gt;4.8</td>
<td>All soils</td>
</tr>
<tr>
<td>medium pH&gt;4.8</td>
<td>clay, loam</td>
</tr>
<tr>
<td></td>
<td>sand, peat, other</td>
</tr>
<tr>
<td>low or pH&lt;4.8</td>
<td>clay</td>
</tr>
<tr>
<td></td>
<td>sand, other</td>
</tr>
<tr>
<td></td>
<td>peat pH&gt;4.8</td>
</tr>
<tr>
<td></td>
<td>peat pH&lt;4.8</td>
</tr>
<tr>
<td></td>
<td>exK &lt; 0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cs, vegetables</th>
<th>non-equilibrium conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>nutrient status</td>
<td>soil type</td>
</tr>
<tr>
<td>high pH&gt;4.8</td>
<td>All soils</td>
</tr>
<tr>
<td>medium pH&gt;4.8</td>
<td>clay, loam</td>
</tr>
<tr>
<td></td>
<td>sand, peat, other</td>
</tr>
<tr>
<td></td>
<td>.005</td>
</tr>
<tr>
<td>low or pH&lt;4.8</td>
<td>clay</td>
</tr>
<tr>
<td></td>
<td>sand, other</td>
</tr>
<tr>
<td></td>
<td>peat pH&gt;4.8</td>
</tr>
<tr>
<td></td>
<td>peat pH&lt;4.8</td>
</tr>
</tbody>
</table>
Fig. 4. Comparison between expected and observed TF’s. Sr, cereals
Upper part: Observations made with soils with a contact time longer than 4 year (equilibrium cond.)
Lower part: Observations made with soils with a contact time less than 4 year ((non-equilibrium cond.)
Expected values taken from table 2, expected values are printed in bold.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Sr in cereals</th>
<th>Equilibrium conditions</th>
<th>Non-equilibrium conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lower than expected</td>
<td>expected range (bold)</td>
<td>higher than expected</td>
</tr>
<tr>
<td>Clay, loam</td>
<td>Ca&gt;16</td>
<td>0.01-0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ca 9-16 (pH&lt;6)</td>
<td>0.05-0.5</td>
<td>.06</td>
</tr>
<tr>
<td></td>
<td>Ca&lt;9 (pH&lt;5 and OM&lt;1)</td>
<td>0.1-1.2</td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>Ca&gt;10</td>
<td>0.02-0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ca 2-10</td>
<td>0.02-1</td>
<td>.12</td>
</tr>
<tr>
<td></td>
<td>Ca&lt;2 (pH&lt;5 and/or OM&lt;1)</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Peat</td>
<td>OM&gt;18</td>
<td>0.01-0.06</td>
<td>.23</td>
</tr>
</tbody>
</table>

Tables 3 and 4 give some details of the Cs experiments. There are important differences between the long term contamination experiments and the short term ones. The types of contamination differ, the short term experiments include many irrigated or flooded areas, as well as pot experiments. It is also clear that the high values are more often based on single or duplicate experiments, the core of the values is based on triplicate or more experiments. Means are geometric means.
Table 3. Observed mean TF`s, Cs, cereals. On top long term, below short term observations.**

<table>
<thead>
<tr>
<th>Crop</th>
<th>TF</th>
<th>n.st. soil</th>
<th>Ex-K</th>
<th>t-Co</th>
<th>t-Ex</th>
<th>t-Fa</th>
<th>pHw</th>
<th>fertility, prod.</th>
<th>time</th>
<th>name</th>
<th>FAO/Unesco auth</th>
</tr>
</thead>
<tbody>
<tr>
<td>mix. cereals</td>
<td>0.004</td>
<td>h</td>
<td>S 0.33</td>
<td>A</td>
<td>F</td>
<td>I</td>
<td>7.8</td>
<td>high prod.</td>
<td>54 m</td>
<td>alluvial soil</td>
<td>Sach</td>
</tr>
<tr>
<td>mix. cereals</td>
<td>0.009</td>
<td>h</td>
<td>C 1</td>
<td>C</td>
<td>F</td>
<td>D</td>
<td>6.6</td>
<td>heavy fert.</td>
<td>15 y</td>
<td>chernozem</td>
<td>San</td>
</tr>
<tr>
<td>mix. cereals</td>
<td>0.009</td>
<td>h</td>
<td>C 1</td>
<td>C</td>
<td>F</td>
<td>D</td>
<td>5.7</td>
<td>heavy fert.</td>
<td>15 y</td>
<td>chernozem</td>
<td>San</td>
</tr>
<tr>
<td>mix. cereals</td>
<td>0.010</td>
<td>h</td>
<td>L 0.8</td>
<td>C</td>
<td>F</td>
<td>D</td>
<td>5.5</td>
<td>heavy fert.</td>
<td>15 y</td>
<td>grey-luvic phoe.</td>
<td>San</td>
</tr>
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* value estimated via Cs conc. in straw
**A value in italics refers to a single value
**A value in normal print refers to a duplicate value
**A value in bold refers to a mean of at least 3 observations
Table 4. Observed mean TF’s, Cs, vegetables. On top short term, below long term observations.**

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<td>0.7</td>
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<td>F</td>
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<td>5.5m</td>
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</tr>
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<td>0.44</td>
<td>h</td>
<td>A</td>
<td>1.1</td>
<td>A</td>
<td>P</td>
<td>I</td>
<td>6.9</td>
<td>medium-high pr.</td>
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<td>P</td>
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<td>orthi-thionic fluvisolos Qua</td>
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<tr>
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<td>0.4</td>
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<td>P</td>
<td>I</td>
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<tr>
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<td>m</td>
<td>S</td>
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<td>A</td>
<td>P</td>
<td>5.8</td>
<td>medium fert.</td>
<td>3 m</td>
<td>ferralic acrisols Qua</td>
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Table 5 shows the details of the Sr experiments. The same pattern is shown, the differences are, however, less pronounced than with Cs.
Table 5. Observed mean TF’s, Sr, cereals and vegetables.**

<table>
<thead>
<tr>
<th>N</th>
<th>C</th>
<th>Crop</th>
<th>TF</th>
<th>soil</th>
<th>Ex-</th>
<th>t-</th>
<th>t-</th>
<th>pH</th>
<th>O</th>
<th>fertility, prod.</th>
<th>time</th>
<th>name</th>
<th>FAO/Unesco auth</th>
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</thead>
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<td>l</td>
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<td></td>
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<td></td>
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<tr>
<td>o</td>
<td>x</td>
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### Cereals, long term observations

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<th>C</th>
<th>20</th>
<th>F</th>
<th>F</th>
<th>D</th>
<th>6.0</th>
<th>2.5</th>
<th>heavy fert.</th>
<th>15 y</th>
<th>chernozem</th>
<th>San</th>
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<td>L</td>
<td>15</td>
<td>C</td>
<td>F</td>
<td>D</td>
<td>5.7</td>
<td>1.3</td>
<td>medium fert.</td>
<td>15 y</td>
<td>luvisol, fluvisols, podsoils</td>
<td>San</td>
</tr>
<tr>
<td>Sr C</td>
<td>oats, grain</td>
<td>0.17</td>
<td>C</td>
<td>22</td>
<td>F</td>
<td>I</td>
<td>D</td>
<td>5.5</td>
<td>1.4</td>
<td>low fert.</td>
<td>15 y</td>
<td>sandy podzols</td>
<td>Pri</td>
</tr>
<tr>
<td>Sr C</td>
<td>mixed cereals</td>
<td>0.20</td>
<td>S</td>
<td>6.4</td>
<td>A</td>
<td>F</td>
<td>I</td>
<td>7.8</td>
<td>0.9</td>
<td>high prod.</td>
<td>54 m</td>
<td>alluvial soil fert</td>
<td>Sach</td>
</tr>
<tr>
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<td>oats, grain</td>
<td>0.23</td>
<td>P</td>
<td>4.9</td>
<td>C</td>
<td>F</td>
<td>F</td>
<td>5.5</td>
<td>0.8</td>
<td>fertilised</td>
<td>15 y</td>
<td>histosol peat-bog</td>
<td>Pri</td>
</tr>
<tr>
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<td>oats, grain</td>
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<td>C</td>
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<td>I</td>
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<td>fertilised</td>
<td>15 y</td>
<td>podzoluvisol</td>
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### Cereals, short term observations

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<tr>
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<th>58</th>
<th>A</th>
<th>F</th>
<th>I</th>
<th>6.9</th>
<th>5.7</th>
<th>fertilized</th>
<th>14m</th>
<th>LI</th>
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<tbody>
<tr>
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<td>F</td>
<td>F</td>
<td>F</td>
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<td>4.6</td>
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<td>4 m</td>
<td>Uch</td>
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<tr>
<td>Sr C</td>
<td>cereals</td>
<td>0.014</td>
<td>L</td>
<td>12</td>
<td>A</td>
<td>F</td>
<td>I</td>
<td>7.9</td>
<td>1.3</td>
<td>non-fertile</td>
<td>15 m</td>
<td>aridisol</td>
</tr>
<tr>
<td>Sr C</td>
<td>rice, unhulled</td>
<td>0.03</td>
<td>S</td>
<td>6.5</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>5.4</td>
<td>1.4</td>
<td>non-fertile</td>
<td>8 m</td>
<td>eutric fluvisols</td>
</tr>
</tbody>
</table>

### Vegetables, long term observations

<table>
<thead>
<tr>
<th>Sr V</th>
<th>cabbage</th>
<th>0.20</th>
<th>C</th>
<th>20</th>
<th>F</th>
<th>F</th>
<th>D</th>
<th>6.0</th>
<th>2.5</th>
<th>heavy fert.</th>
<th>15 y</th>
<th>chernozem</th>
<th>San</th>
</tr>
</thead>
<tbody>
<tr>
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<td>cabbage</td>
<td>0.35</td>
<td>S</td>
<td>7</td>
<td>C</td>
<td>F</td>
<td>D</td>
<td>5.8</td>
<td>2.0</td>
<td>low fert.</td>
<td>15 y</td>
<td>sandy podzols</td>
<td>San</td>
</tr>
<tr>
<td>Sr V</td>
<td>cabbage</td>
<td>0.76</td>
<td>S</td>
<td>6.3</td>
<td>A</td>
<td>F</td>
<td>D</td>
<td>4.7</td>
<td>4.6</td>
<td>fertilised</td>
<td>5 m</td>
<td>Al+Fe oxides of Si</td>
<td>Twi</td>
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</table>

### Vegetables, short term observations

<table>
<thead>
<tr>
<th>Sr V</th>
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<th>0.41</th>
<th>S</th>
<th>6.3</th>
<th>A</th>
<th>P</th>
<th>I</th>
<th>7.8</th>
<th>0.9</th>
<th>high prod.</th>
<th>13 m</th>
<th>alluvial soil Kmix</th>
<th>Sach</th>
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</thead>
<tbody>
<tr>
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<td>0.44</td>
<td>S</td>
<td>6.4</td>
<td>A</td>
<td>F</td>
<td>D</td>
<td>5.2</td>
<td>4.6</td>
<td>medium prod.</td>
<td>8 m</td>
<td>eutric fluvisols</td>
<td>Qua</td>
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<tr>
<td>Sr V</td>
<td>cabbage</td>
<td>0.50</td>
<td>S</td>
<td>5.2</td>
<td>A</td>
<td>P</td>
<td>I</td>
<td>6.1</td>
<td>0.7</td>
<td>medium prod.</td>
<td>7 m</td>
<td>aridisol</td>
<td>AIO</td>
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<td>6.3</td>
<td>A</td>
<td>F</td>
<td>I</td>
<td>7.8</td>
<td>0.9</td>
<td>high prod.</td>
<td>7 m</td>
<td>alluvial soil Kmix</td>
<td>Sach</td>
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<td>D</td>
<td>6.9</td>
<td>4.6</td>
<td>fertilised</td>
<td>5 m</td>
<td>Al+Fe oxides of Si</td>
<td>Twi</td>
</tr>
</tbody>
</table>

The tables 6 and 7 finally give the observation ratios which could be derived. For Cs the ratios range from 0.4 to 27, the TF-values ranges from 0.0008 to 19, which means that the conversion ratios vary much less than the TF-values. Remarkable is that, both the high values and the low values of the ratio are based on single or duplicate values only.
Table 6. Observed Conversion ratios for Cs, vegetables/cereals

<table>
<thead>
<tr>
<th>TF details</th>
<th>TF details</th>
<th>Conver cereals of crop ExK of crop s. ratio</th>
<th>t-Co</th>
<th>t-Ex</th>
<th>t-FA pH</th>
<th>productivity</th>
<th>time</th>
<th>name FAO/Unesco Auth</th>
</tr>
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<tbody>
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<td>0.031</td>
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<td>1</td>
<td>C</td>
<td>F</td>
<td>D</td>
<td>6.5</td>
</tr>
<tr>
<td>0.056</td>
<td>wheat 0.03</td>
<td>cabbage 0.5</td>
<td>L</td>
<td>0.6</td>
<td>A</td>
<td>P</td>
<td>I</td>
<td>6.5</td>
</tr>
<tr>
<td>0.009</td>
<td>mixed cereals 0.005</td>
<td>cabbage 0.6</td>
<td>0.385</td>
<td>A</td>
<td>P</td>
<td>I</td>
<td>7.8</td>
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<tr>
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<td>0.366</td>
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<td>P</td>
<td>I</td>
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<tr>
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<td>A</td>
<td>P</td>
<td>I</td>
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</tr>
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<td>mixed cereals 0.011</td>
<td>cabbage 0.9</td>
<td>0.31</td>
<td>A</td>
<td>P</td>
<td>I</td>
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</tr>
<tr>
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<td>P</td>
<td>I</td>
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<tr>
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<td>cabbage 0.9</td>
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<td>A</td>
<td>P</td>
<td>I</td>
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<td>F</td>
<td>D</td>
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<tr>
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<td>kai choi 1.4</td>
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<td>F</td>
<td>D</td>
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<td>33 y</td>
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<td>A</td>
<td>F</td>
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<td>C</td>
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<tr>
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<td>0.04</td>
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<td>F</td>
<td>D</td>
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<td>33 y</td>
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<td>A</td>
<td>P</td>
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<td>C</td>
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<td>P</td>
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<td>P</td>
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<td>A</td>
<td>P</td>
<td>I</td>
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<td>win bok 7.6</td>
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<td>F</td>
<td>D</td>
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<td>A</td>
<td>F</td>
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<td>15 y</td>
<td>chernozem San</td>
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<td>6.9</td>
<td>14m</td>
<td>viocanic soil KS6</td>
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</tr>
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</table>

* value estimated via Cs concentration in straw

Table 7. Observed conversion ratios for Sr, vegetables/cereals

<table>
<thead>
<tr>
<th>TF details</th>
<th>TF details</th>
<th>Conver cereals of crop ExK of crop s. ratio</th>
<th>t-Co</th>
<th>t-Ex</th>
<th>t-FA pH</th>
<th>productivity</th>
<th>time</th>
<th>name FAO/Unesco Auth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.69</td>
<td>mixed cereals 0.53</td>
<td>cabbage 0.8</td>
<td>C</td>
<td>0.5</td>
<td>A</td>
<td>P</td>
<td>I</td>
<td>7</td>
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<td>A</td>
<td>P</td>
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</tr>
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<td>mixed cereals 0.86</td>
<td>cabbage 1.3</td>
<td>S</td>
<td>0.4</td>
<td>A</td>
<td>F</td>
<td>I</td>
<td>7.8</td>
</tr>
<tr>
<td>0.20</td>
<td>mixed cereals 0.35</td>
<td>cabbage 1.7</td>
<td>S</td>
<td>0.3</td>
<td>A</td>
<td>F</td>
<td>I</td>
<td>7.8</td>
</tr>
<tr>
<td>0.12</td>
<td>mixed cereals 0.76</td>
<td>cabbage 6.1</td>
<td>S</td>
<td>0.6</td>
<td>C</td>
<td>F</td>
<td>D</td>
<td>5.8</td>
</tr>
<tr>
<td>0.061</td>
<td>mixed cereals 0.49</td>
<td>cabbage 8.0</td>
<td>C</td>
<td>1.0</td>
<td>F</td>
<td>D</td>
<td>D</td>
<td>6</td>
</tr>
<tr>
<td>0.099</td>
<td>mixed cereals 0.1</td>
<td>cabbage 11</td>
<td>L</td>
<td>0.6</td>
<td>C</td>
<td>F</td>
<td>D</td>
<td>5.7</td>
</tr>
<tr>
<td>0.14</td>
<td>rice 12</td>
<td>cabbage 84</td>
<td>L</td>
<td>0.1</td>
<td>A</td>
<td>P</td>
<td></td>
<td>7.9</td>
</tr>
<tr>
<td>0.22</td>
<td>rice 29</td>
<td>cabbage 133</td>
<td>S</td>
<td>0.1</td>
<td>A</td>
<td>P</td>
<td></td>
<td>5.8</td>
</tr>
<tr>
<td>0.014</td>
<td>mixed cereals 2.4</td>
<td>mean cabbage 172 L</td>
<td>0.8</td>
<td>A</td>
<td>F</td>
<td>I</td>
<td>7.9</td>
<td>7 m</td>
</tr>
<tr>
<td>0.010</td>
<td>mixed cereals 2.0</td>
<td>mean cabbage 191</td>
<td>L</td>
<td>1.2</td>
<td>A</td>
<td>F</td>
<td>I</td>
<td>8.1</td>
</tr>
<tr>
<td>0.006</td>
<td>wheat gr 1.4</td>
<td>chin. cabb. 230</td>
<td>L</td>
<td>0.5</td>
<td>A</td>
<td>F</td>
<td>I</td>
<td>6.9</td>
</tr>
</tbody>
</table>

For Sr, the observed ratios vary in same way as the TF values for cereals, the range of TF-value for vegetables is even smaller. The data are, however, to limited to draw any conclusions as yet.
Conclusion

The project is well underway. A conclusion is not yet possible. It is clear that single values or duplicate values do not contribute in deriving generic TF-values or are very helpful in classifying soils. At the mentioned CRP meeting it was therefore unanimously concluded that the experiments should be continued during the next years, without too many modifications. In this way single value or duplicate ones can be avoided.

References


Transfer of radionuclides from air, soil and freshwater to the foodchain of man in tropical and subtropical environments. TECDOC in preparation, IAEA Vienna.

IUR (1992) IUR databank. Collection of about 3000 Cs and Sr transfer values. TF values were determined by a working group of the IUR between 1982 and 1992..


**134Cs UPTAKE FOR CROPS GROWN ON REPRESENTATIVE AND VOLCANIC GREEK SOILS**

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**ABSTRACT**

134Cs uptake by leafy crops and corn and sunflower plants was studied in a greenhouse pot experiment. Four soil types, including two volcanic, were carefully selected in order to have (and) soil systems in which transfer factors might differ substantially from what would be regarded as normal. The volcanic soils were collected from Santorini island, were both sandy textured, differing in the other properties, and were characterized by the presence of pumice. The other two soils, with contrasting properties, were representative for big agricultural areas of Greece. Spring species (corn and sunflower) were sown on the same pots after the harvesting of the leafy crops (cabbage and spinach). All plant species showed big differentiation in growth in the different studied soils. Despite the big differences in growth of the different plants, transfer factors were higher in the two volcanic soils than in the other two soils for all plant species. The calcareous and clay soil showed always the lowest TF value. The highest to lowest TF ratio for the studied soils ranged from 10 (spinach and sunflower vegetative) to 25 (corn grain). The total contamination expressed as Bq/pot generally confirmed that plants grown on the volcanic soils absorbed higher quantities of 134Cs than plants grown on the other two soils. An effort was made to calculate conversion factors using corn as reference plant. Based on corn's TFs (edible part) in the different studied soils reference TFs for corn are presented.

**INTRODUCTION**

This study is part of the FAO/IAEA/IUR Research Co-ordinated Project "The classification of soil systems on the basis of transfer factors of radionuclides to reference plants". A classification of soil ecosystems might be a way to reduce uncertainties due to the enormous range of uptake parameters. The main objective of this study is to produce data on transfer factors of 134Cs from soil to reference plants in a range of Greek soil systems in which TFs might deviate substantially from average; it will also help to replace generic data of TFs with those more relevant to local conditions. The purpose of the present work was to study 134Cs uptake by leafy crops, corn and sunflower plants grown on representative and volcanic Greek soils. An effort was also made to calculate conversion factors for the studied plants using corn as reference plant. Based on corn's TFs in the different studied soils reference TFs for corn are presented.
MATERIALS AND METHODS

Experimental set up

Four soils with contrasting properties were carefully selected in order to have (and) soil systems in which transfer factors might differ substantially from what would be regarded as normal; two volcanic from Santorini island and two from South Eastern Greece (Peloponese) representative of big agricultural areas.

Large soil samples from the surface layer (0-25 cm) of the selected areas were collected, transported to the laboratory and air dried.

The main characteristics of the selected soils are presented in Table 1.

Table 1: Main soil characteristics

<table>
<thead>
<tr>
<th>Soil</th>
<th>Clay (%)</th>
<th>Silt (%)</th>
<th>Sand (%)</th>
<th>Texture</th>
<th>PH (1:1)</th>
<th>O.M. (%)</th>
<th>C.E.C cmolc/kg</th>
<th>Exch. K⁺ cmolc/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.6</td>
<td>18.0</td>
<td>73.4</td>
<td>SL</td>
<td>5.6</td>
<td>0.46</td>
<td>7.39</td>
<td>0.23</td>
</tr>
<tr>
<td>2</td>
<td>29.3</td>
<td>47.0</td>
<td>23.7</td>
<td>CL</td>
<td>7.4</td>
<td>2.11</td>
<td>17.39</td>
<td>0.42</td>
</tr>
<tr>
<td>3</td>
<td>8.6</td>
<td>27.2</td>
<td>64.2</td>
<td>SL</td>
<td>5.8</td>
<td>0.56</td>
<td>3.48</td>
<td>0.39</td>
</tr>
<tr>
<td>4</td>
<td>7.0</td>
<td>18.0</td>
<td>75.0</td>
<td>LS-SL</td>
<td>6.9</td>
<td>2.71</td>
<td>9.44</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Soil 1 is classified as Alfisol, suborder xeralf, it is an acid soil of coarse – medium texture at a high level of development.

Soil 2 is a medium to heavy textured, calcareous Entisol, suborder fluvent, at its early stages of development, representing a high percentage of the Greek agricultural soils.

Soils 3 & 4 are volcanic ash soils, from Santorini island, developed on pumice and volcanic ash and are classified as Andisols, suborder xerand, according to the recent establishment of this soil order in Soil Taxonomy; The soil genesis process of these soils is determined mainly from the age (approximately 1500 years, when a very strong volcanic eruption took place), the climate of the island, the mineral composition and the texture of the volcanic ash.

According to Misopolinos et al. (1995), the soils in Santorini are characterized by their low clay content and most of them are neutral to alkaline. In the surface soil layers heavier particles are present e.g. gravels of aluminum-iron composition or pumice. The presence of gravels can be explained by the intense wind erosion, where the strong winds take away the fine particles of the soil surface. Gravels also prevent the loss of soil moisture by evaporation, which is crucial for plant growth considering the land on the island is not irrigated. It is noticed that the average rainfall in the island is low (ave 350 mm/year)

The two selected soils from Santorini are of low clay content, but differ in other soil properties, as the pH, the organic matter content, the cation exchange capacity and the concentration of exchangeable potassium (Table 1).

The plants were grown in pots which contain 14 kg air-dried soil, in four replications. The size of pots is considered sufficient for providing reliable data and preventing water shortage and nutrient deficiency problems.

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1 The soils were classified according to US Soil Taxonomy
The crops selected for the experiment were spinach and cabbage as broad leafy crops and corn as a cereal crop. Sunflower was also selected as another spring crop since previous experimentation has shown that this plant species absorbs high quantities of $^{134}$Cs (Massas et al., 1999).

Soil was contaminated with $^{134}$Cs (1.9 MBq pot$^{-1}$) as CsCl on July 28$^{th}$ 1999. The soil was transferred to each pot in seven layers of approximately 2 kg of soil each. On the top of each layer 100 ml of the radioactive solution was added in the form of very small drops. The above technique of soil contamination has been used successfully in previous experimentation with annual and tree crops (Skarlou et al., 1996 and 1999). The distribution of the radioactive material throughout the pot is well controlled by this method and loss via cracks or edges is absent.

The soil in pots was moistened to field capacity and left to stand for two months for the $^{134}$Cs to reach equilibrium.

**Experimental conditions**

**Winter species – leafy crops**

The selected broad leafy crops, cabbage and spinach, were sown on 18$^{th}$ October 1999.

For cabbage two plants were left in each pot; the one was sampled in the middle of the growing period and the other at the harvesting time (six months).

Spinach plants were grown in two successive periods. Spinach plants at the 1$^{st}$ harvesting (two months growth) had a short biological life maybe due to the high for the season temperature prevailing and very soon started flowering; their growth especially in soils 1 and 3 (acid soils) was very poor. In the second effort (two and a half months growth period) plants were grown better only on soil 4. For spinach plants the mean values of the two growing periods are presented.

**Spring species – corn and sunflower**

Spring species were sown on the same pots after the harvesting of the leafy crops; corn after cabbage and sunflower after spinach cultivation.

Corn was sown on May 10$^{th}$ and sunflower on May 18$^{th}$ 2000. They both harvested at the end of September 2000.

It is noticed that in most corn plants grown on soils 1 and 3 (acid soils) no female flowers appeared, which resulted in lack of grain production from these plants. Furthermore, plants grown on soil 4 failed to produce any mature grain yield.

**Analytical methods**

Cation exchange capacity of the soils was determined by the Na-acetate method (Bower et al., 1952). Organic matter content was determined by the Walkley-Black procedure (Nelson and Sommers, 1982). Mechanical composition was determined by the Bouyoukos hydrometer method (Bouyoukos, 1951) and the pH by glass and calomel electrodes in 1:1 soil-water ratio. Exchangeable bases were extracted by 1M NH$_4$-acetate.

After harvesting plants were separated into edible and vegetative parts, where necessary (corn and sunflower); representative plant samples were cut into small species, dried at 70$^\circ$C and counted for $^{134}$Cs with the following system: HpGe detector (efficiency 22% and FW 1.8 keV for the 1332 keV $^{60}$Co $\gamma$-ray) connected to a CANBERRA 35$^{+}$ 4K multichannel analyzer plus a computer with suitable software for gamma-ray spectroscopy analysis. Quantitative determination of $^{134}$Cs was made at the photopeaks of 604.7 and 795.8 keV by measuring the activity of the samples and taking into consideration the efficiency calibration of Ge crystal
for known $^{134}\text{Cs}$ concentration in quite similar geometry ($d = 7$ cm, $h = 2$ cm). The concentration of $^{134}\text{Cs}$ in plant samples was expressed in Bq kg$^{-1}$ dry material.

**RESULTS AND DISCUSSION**

*Transfer factors (TF)*

Transfer factors for the studied plant species are presented in Table 2 and 3. It is noticed that missing TF values for corn grain were calculated from the known ratio $^{134}\text{Cs}$ content in vegetative part : $^{134}\text{Cs}$ content in grain of the plants producing grain. Mean ratio is estimated to be 6.3.

**Table 2:** Transfer factors of $^{134}\text{Cs}$ (Bq Kg$^{-1}$ D.W. plant / Bq Kg$^{-1}$ D.W. soil) of cabbage and spinach grown on four soil types

<table>
<thead>
<tr>
<th></th>
<th>Soil 1</th>
<th>Soil 2</th>
<th>Soil 3</th>
<th>Soil 4</th>
<th>Mean TF plant</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cabbage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.183</td>
<td>0.071</td>
<td>1.036</td>
<td>0.370</td>
<td>0.407</td>
</tr>
<tr>
<td></td>
<td>(0.020)</td>
<td>(0.022)</td>
<td>(0.175)</td>
<td>(0.09)</td>
<td>(0.403)</td>
</tr>
<tr>
<td><strong>Spinach</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.211</td>
<td>0.033</td>
<td>0.339</td>
<td>0.267</td>
<td>0.196</td>
</tr>
<tr>
<td></td>
<td>(0.176)</td>
<td>(0.019)</td>
<td>(0.233)</td>
<td>(0.010)</td>
<td>(0.159)</td>
</tr>
<tr>
<td><strong>Mean TF</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>soil</strong></td>
<td>0.197</td>
<td>0.052</td>
<td>0.689</td>
<td>0.319</td>
<td>0.302</td>
</tr>
<tr>
<td></td>
<td>(0.021)</td>
<td>(0.066)</td>
<td></td>
<td></td>
<td>(0.281)</td>
</tr>
</tbody>
</table>

**Table 3:** Transfer factors of $^{134}\text{Cs}$ (Bq Kg$^{-1}$ D.W. plant / Bq Kg$^{-1}$ D.W. soil) of corn and sunflower grown on four soil types

<table>
<thead>
<tr>
<th></th>
<th>Soil 1</th>
<th>Soil 2</th>
<th>Soil 3</th>
<th>Soil 4</th>
<th>Mean TF plant</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Corn</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetative</td>
<td>0.230</td>
<td>0.037</td>
<td>0.677</td>
<td>0.440</td>
<td>0.346</td>
</tr>
<tr>
<td></td>
<td>(0.051)</td>
<td>(0.009)</td>
<td>(0.233)</td>
<td>(0.094)</td>
<td>(0.272)</td>
</tr>
<tr>
<td>Edible</td>
<td>0.036*</td>
<td>0.005</td>
<td>0.127</td>
<td>0.070*</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td></td>
<td></td>
<td></td>
<td>(0.054)</td>
</tr>
<tr>
<td><strong>Sunflower</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetative</td>
<td>0.177</td>
<td>0.083</td>
<td>0.215</td>
<td>0.812</td>
<td>0.322</td>
</tr>
<tr>
<td></td>
<td>(0.011)</td>
<td>(0.005)</td>
<td>(0.065)</td>
<td>(0.185)</td>
<td>(0.309)</td>
</tr>
<tr>
<td>Edible</td>
<td>0.075</td>
<td>0.039</td>
<td>0.091</td>
<td>0.518</td>
<td>0.187</td>
</tr>
<tr>
<td></td>
<td>(0.019)</td>
<td>(0.014)</td>
<td>(0.055)</td>
<td>(0.132)</td>
<td>(0.217)</td>
</tr>
<tr>
<td><strong>Mean TF</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>soil</strong></td>
<td>0.151</td>
<td>0.041</td>
<td>0.330</td>
<td>0.590</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.078)</td>
<td>(0.029)</td>
<td>(0.290)</td>
<td>(0.211)</td>
<td></td>
</tr>
</tbody>
</table>

*: Calculated values
Despite the big differences in growth of the different plants, TFs were higher in the two volcanic soils than in the other two soils for all plant species. This high caesium absorption may be due to the sandy texture of these soils as well as to the presence of pumice, which has a high water capacity. Soil 2 showed always the lowest TF, which was always significant (p<0.05). It is a calcareous soil with a high clay content and high CEC, factors resulting in a more effective fixation of radiocaesium compared to other soils (Frissel et al., 1990; Gerzabek et al., 1998; Nisbet, 1993; Skarlou et al., 1996).

Comparing the two volcanic soils, leafy crops and corn showed always the highest TF value when grown on soil 3. This can be attributed to the lower pH value, CEC and K-status, factors which might explain the high plant availability of radiocaesium in this soil. Sunflower plants did not follow this tendency and the opposite was observed (significantly higher TF value in soil 4; p<0.001).

**Table 4:** Bq/pot of $^{134}$Cs for cabbage and spinach grown on four soil types

<table>
<thead>
<tr>
<th>Soil 1</th>
<th>Soil 2</th>
<th>Soil 3</th>
<th>Soil 4</th>
<th>Mean Bq/pot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabbage</td>
<td>359.6 (64.7)</td>
<td>327.5 (107.8)</td>
<td>3096.2 (834.2)</td>
<td>3283.6 (512.9)</td>
</tr>
<tr>
<td>Spinach</td>
<td>15.0 (15.2)</td>
<td>42.6 (30.0)</td>
<td>40.3 (35.5)</td>
<td>406.4 (222.1)</td>
</tr>
</tbody>
</table>

**Table 5:** Bq/pot of $^{134}$Cs for corn and sunflower grown on four soil types

<table>
<thead>
<tr>
<th>Soil 1</th>
<th>Soil 2</th>
<th>Soil 3</th>
<th>Soil 4</th>
<th>Mean Bq/pot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Vegetative</td>
<td>1318 (274)</td>
<td>330 (56)</td>
<td>4194 (977)</td>
<td>6702 (2609)</td>
</tr>
<tr>
<td>Edible</td>
<td>-</td>
<td>26 (19)</td>
<td>24</td>
<td>26 (17)</td>
</tr>
<tr>
<td>Sunflower Vegetative</td>
<td>1265 (139)</td>
<td>764 (97)</td>
<td>510 (472)</td>
<td>6714 (1641)</td>
</tr>
<tr>
<td>Edible</td>
<td>184 (35)</td>
<td>63 (25)</td>
<td>84 (53)</td>
<td>653 (364)</td>
</tr>
</tbody>
</table>

**Bq/Pot**

The total contamination expressed as Bq/pot generally confirms that plants grown on the volcanic soils absorbed higher quantities of $^{134}$Cs than plants grown on the other two soils having the highest value on soil four (Table 4 and 5). That soil combines a high yield with a high caesium plant uptake.
Conversion factors and reference TFs

An effort was made from our results to calculate conversion factors using corn as a reference plant. Mean TF values for the leafy crops and TF for the edible part of corn and sunflower grown on a particular soil were used to calculate conversion factors.

Calculated ratios

<table>
<thead>
<tr>
<th>Soil</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio (leafy:corn)</td>
<td>6</td>
<td>13</td>
<td>6</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Ratio (sunflower:corn)</td>
<td>2</td>
<td>8</td>
<td>1</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>

Calculated conversion factors

<table>
<thead>
<tr>
<th></th>
<th>Corn</th>
<th>Leafy crops</th>
<th>Sunflower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs conversion factor</td>
<td>1</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Range</td>
<td>5 - 13</td>
<td>1 - 8</td>
<td></td>
</tr>
</tbody>
</table>

These values coincide with the generic values reported by Frissell et al. (2001) for cereals and green vegetables.

Based on corn’s TFs (edible part) in the different studied soils reference TFs for corn are presented

Reference TFs for corn

Satisfactory nutrient status
(calcareous-clay) 0.005

Medium nutrient status
(acid-sandy) 0.040

Volcanic soils
(acid or neutral) 0.100

References


Frissel et al. (2001). Generic values for soil-to-plant transfer factors of radioesium. To be published in a special issue of the *Journal of Environmental Radioactivity.*


UPTAKE OF RADIOCESIUM BY TOMATO

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Introduction

As tomato is an important component of the total diet, there is a need for improved knowledge based on the processes influencing transfer of radionuclides to fruit (Constantinescu et al. 1988, Knatko et al. 2000, Yera et al. 1999). Plant contamination can result from various processes, like direct deposition on to plant surfaces, absorption by the tomato skin and transport to the interior, deposition to the above-ground parts of the plant, and finally deposition to soil, root uptake, and transfer to the edible part (Coughtry et al. 2001, Paasikallio et al. 1994, Papastefanou et al. 1999).

In our study the fate of $^{134}$Cs in the above ground of tomato plants after wet deposition on soil and leaves was examined under pot experiment conditions. The aim of foliar contamination was to determine the $^{134}$Cs uptake by tomato depending on the time and level of radioactive contamination.

Materials And Methods

The pot experiment of tomato was established on alluvial meadow clay soil on 9th May 2000.

Table 1. Treatments of tomato

<table>
<thead>
<tr>
<th>Code</th>
<th>Contamination</th>
<th>vegetation season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>time</td>
<td>level</td>
</tr>
<tr>
<td>P/1</td>
<td>9 May</td>
<td>100 kBq/pot</td>
</tr>
<tr>
<td>P/2</td>
<td>9 May</td>
<td>200 kBq/pot</td>
</tr>
<tr>
<td>P/3</td>
<td>9 May</td>
<td>300 kBq/pot</td>
</tr>
<tr>
<td>P/4</td>
<td>5 June</td>
<td>50 kBq/pot</td>
</tr>
<tr>
<td>P/5</td>
<td>5 June</td>
<td>100 kBq/pot</td>
</tr>
<tr>
<td>P/6</td>
<td>5 June</td>
<td>150 kBq/pot</td>
</tr>
<tr>
<td>P/7</td>
<td>4 July</td>
<td>50 kBq/pot</td>
</tr>
<tr>
<td>P/8</td>
<td>4 July</td>
<td>100 kBq/pot</td>
</tr>
<tr>
<td>P/9</td>
<td>4 July</td>
<td>150 kBq/pot</td>
</tr>
<tr>
<td>P/10</td>
<td>24 July</td>
<td>50 kBq/pot</td>
</tr>
<tr>
<td>P/11</td>
<td>24 July</td>
<td>100 kBq/pot</td>
</tr>
<tr>
<td>P/12</td>
<td>24 July</td>
<td>150 kBq/pot</td>
</tr>
<tr>
<td>P/13</td>
<td>Control</td>
<td>-</td>
</tr>
<tr>
<td>P/14</td>
<td>Control</td>
<td>-</td>
</tr>
<tr>
<td>P/15</td>
<td>Control</td>
<td>-</td>
</tr>
</tbody>
</table>
5.5 kg absolute dry soil was put in each pot, which had been mixed with fertilizer 150 ppm N, 200 ppm P, and 200 ppm K previously. Some soil characteristics of the experimental field:

pH (KCl): 6.55, Viscosity: 47, Organic matter: 2.28%, Available P (AL-method): 120 ppm, Available K (AL method): 180 ppm. At the same time of the planting of tomato we have contaminated the soil by watery solution of $^{134}$Cs isotope in different concentrations: 100 kBq/pot, 200 kBq/pot and 300 kBq/pot. When calculated in Bq/m$^2$ the levels of contamination were 3, 6, 9 MBq/m$^2$. (Table 1.) We have repeated the same treatments 3 times during the vegetation season: 5$^{th}$ June, 4$^{th}$ July, 24$^{th}$ July.

Variety of tomato was: Kecskeméti törpe (Hungarian). The soil contamination was carried out by amount of water appropriate to 10 mm of precipitation and 1 mm „rainfall” was used for contamination of plants. The tomato was harvested at full ripening stage, on 7$^{th}$ July, 26$^{th}$ July, 2$^{nd}$ August, 10$^{th}$ August.

Results and discussion

The radioactivity of tomato plants was measured in the edible part and stem samples after harvest. In the Table 2. are shown the data of yield of tomato. The average yield of tomato was 150 g fresh weight /pot and the yield of stem was 60 g dry weight /pot.

**Table 2.** Average yield of tomato experiment, 2000.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Code</th>
<th>Date</th>
<th>Yield (g/pot)</th>
<th>Total</th>
<th>Stem</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.harvest</td>
<td>P1</td>
<td>9 May</td>
<td>66.06</td>
<td>144.71</td>
<td>42.93</td>
</tr>
<tr>
<td></td>
<td>P2c</td>
<td>9 May</td>
<td>51.02</td>
<td>172.55</td>
<td>57.19</td>
</tr>
<tr>
<td></td>
<td>P3</td>
<td>9 May</td>
<td>45.07</td>
<td>164.91</td>
<td>59.53</td>
</tr>
<tr>
<td></td>
<td>P4</td>
<td>5 June</td>
<td>31.20</td>
<td>172.48</td>
<td>52.27</td>
</tr>
<tr>
<td></td>
<td>P5</td>
<td>5 June</td>
<td>34.15</td>
<td>165.08</td>
<td>53.39</td>
</tr>
<tr>
<td></td>
<td>P6</td>
<td>5 June</td>
<td>37.06</td>
<td>193.09</td>
<td>71.14</td>
</tr>
<tr>
<td></td>
<td>P7</td>
<td>4 July</td>
<td>42.43</td>
<td>171.90</td>
<td>60.18</td>
</tr>
<tr>
<td></td>
<td>P8</td>
<td>4 July</td>
<td>27.72</td>
<td>170.23</td>
<td>59.75</td>
</tr>
<tr>
<td></td>
<td>P9</td>
<td>4 July</td>
<td>64.77</td>
<td>158.37</td>
<td>55.37</td>
</tr>
<tr>
<td></td>
<td>P10</td>
<td>24 July</td>
<td>59.29</td>
<td>143.53</td>
<td>47.28</td>
</tr>
<tr>
<td></td>
<td>P11</td>
<td>24 July</td>
<td>63.16</td>
<td>154.58</td>
<td>57.61</td>
</tr>
<tr>
<td></td>
<td>P12</td>
<td>24 July</td>
<td>54.50</td>
<td>137.49</td>
<td>55.04</td>
</tr>
<tr>
<td></td>
<td>P13</td>
<td>∅</td>
<td>60.36</td>
<td>147.84</td>
<td>58.11</td>
</tr>
<tr>
<td></td>
<td>P14</td>
<td>∅</td>
<td>61.52</td>
<td>164.44</td>
<td>49.47</td>
</tr>
<tr>
<td></td>
<td>P15</td>
<td>∅</td>
<td>61.70</td>
<td>133.83</td>
<td>59.16</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td>50.66</td>
<td>158.34</td>
<td>57.89</td>
</tr>
</tbody>
</table>

The data of radioactivity are summarised in the Table 3. From the data of soil contamination experiment it is evident that the cesium uptake of tomato is low. The specific activity of tomato has changed between 146-463 Bq/kg fresh weight depending on level of contamination. The highest radioactivity was found in the stems and leaves of tomato. The specific activity of stem has changed between 3.47-20.36 kBq/kg dry weight.
Table 3. Distribution and accumulation of $^{134}$Cs by tomato after the soil contamination

<table>
<thead>
<tr>
<th>Treatment</th>
<th>ACTIVITY Bq/kg fresh m.</th>
<th>Bq/kg dry m.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. sampling</td>
<td>2. sampling</td>
</tr>
<tr>
<td></td>
<td>Stem</td>
<td></td>
</tr>
<tr>
<td>time</td>
<td>type</td>
<td>level of cont. (kBq/pot)</td>
</tr>
<tr>
<td>9 May</td>
<td>Soil cont.</td>
<td>100</td>
</tr>
<tr>
<td>9 May</td>
<td>Soil cont.</td>
<td>200</td>
</tr>
<tr>
<td>9 May</td>
<td>Soil cont.</td>
<td>300</td>
</tr>
<tr>
<td>SD 5%</td>
<td></td>
<td>82</td>
</tr>
<tr>
<td>SD 1%</td>
<td></td>
<td>118</td>
</tr>
</tbody>
</table>

The data of Cs activity of plant samples from the 1st foliar contamination are shown in Table 4. Radioactive contamination here was carried out at the time of flowering. The effect of plant contamination becomes evident primarily in an increased activity of plant parts. Here it is also detectable that the Cs uptake of edible part depends on the level of contamination. According to the results obtained, the Cs activity varied between 1893-7951 Bq/kg fresh weight in the first sampling. The Cs accumulation in stem samples was higher; it ranged between 312 - 1242 kBq/kg dry weight.

Table 4. Distribution and accumulation of $^{134}$Cs by tomato after the 1st foliar contamination

<table>
<thead>
<tr>
<th>Treatment</th>
<th>ACTIVITY Bq/kg fresh m.</th>
<th>Bq/kg dry m.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. sampling</td>
<td>2. sampling</td>
</tr>
<tr>
<td></td>
<td>Stem</td>
<td></td>
</tr>
<tr>
<td>time</td>
<td>type</td>
<td>level of cont. (kBq/pot)</td>
</tr>
<tr>
<td>5 June</td>
<td>Plant cont.</td>
<td>50</td>
</tr>
<tr>
<td>5 June</td>
<td>Plant cont.</td>
<td>100</td>
</tr>
<tr>
<td>5 June</td>
<td>Plant cont.</td>
<td>150</td>
</tr>
<tr>
<td>SD 5%</td>
<td></td>
<td>229</td>
</tr>
<tr>
<td>SD 1%</td>
<td></td>
<td>328</td>
</tr>
</tbody>
</table>

The Cs activity data of 2nd foliar contamination of tomato are shown in Table 5. Here contamination took place in the middle of the tomato's ripening. Radioactivity of the yield was decreased by 44% compared to the first foliar treatment. It is clear from the data that the Cs uptake of tomato varied as a function of contamination level. The Cs uptake of stems and leaves continuously increased. The increase is higher than 300% as compared to the first foliar contamination.
Table 5. Distribution and accumulation of $^{134}$Cs by tomato after the 2$^{\text{nd}}$ foliar contamination

<table>
<thead>
<tr>
<th>Treatment</th>
<th>ACTIVITY Bq/kg fresh m.</th>
<th>Bq/kg dry m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>time</td>
<td>1. sampling</td>
<td>2. sampling</td>
</tr>
<tr>
<td>4 July</td>
<td>Plant cont.</td>
<td>50</td>
</tr>
<tr>
<td>4 July</td>
<td>Plant cont.</td>
<td>100</td>
</tr>
<tr>
<td>4 July</td>
<td>Plant cont.</td>
<td>150</td>
</tr>
<tr>
<td>SD 5%</td>
<td></td>
<td>282</td>
</tr>
<tr>
<td>SD 1%</td>
<td></td>
<td>405</td>
</tr>
</tbody>
</table>

In Table 6 you can see the data of Cs activity of tomato in the 3$^{\text{rd}}$ foliar contamination. It is visible that the Cs uptake by plants is increased at the time of 4$^{\text{th}}$ sampling. The radioactivity of fresh tomato increased from 4.91 kBq to 12.55 kBq. The level of contamination was 150 kBq/pot. With increasing level of contamination from 50 to 150 kBq/pot the Cs uptake of stems and leaves also increased.

Table 6. Distribution and accumulation of $^{134}$Cs by tomato after the 3$^{\text{rd}}$ foliar contamination

<table>
<thead>
<tr>
<th>Treatment</th>
<th>ACTIVITY Bq/kg fresh m.</th>
<th>Bq/kg dry m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>time</td>
<td>1. sampling</td>
<td>2. sampling</td>
</tr>
<tr>
<td>24 July</td>
<td>Plant cont.</td>
<td>50</td>
</tr>
<tr>
<td>24 July</td>
<td>Plant cont.</td>
<td>100</td>
</tr>
<tr>
<td>24 July</td>
<td>Plant cont.</td>
<td>150</td>
</tr>
<tr>
<td>SD 5%</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>SD 1%</td>
<td></td>
<td>36</td>
</tr>
</tbody>
</table>

Conclusions

- $^{134}$Cs activity of tomato has changed according to the treatments.
- Radioactivity of tomato after the soil contamination was low in fresh matter.
- The Cs uptake of tomato increased after foliar contaminations. The activity of tomato has reached the maximum level after the 3$^{\text{rd}}$ foliar treatment (ripening stage).
- The activity rate of the tomato and stems have changed in all treatments, the $^{134}$Cs activity of stems was higher in all cases comparing to the tomato fruit.
- The radioactivity of tomato and stem samples increased parallel with increasing level of contamination.
References


A DYNAMIC MODEL FOR LEAF TO FRUIT TRANSFER OF RADIONUCLIDES IN PROCESSING TOMATO PLANTS (*LYCOPERSICON ESCULENTUM MILL.*) FOLLOWING A DIRECT CONTAMINATION EVENT.

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Abstract

This paper presents results on calibration and validation of a model (*VENTOMOD*) for leaf to fruit transfer of $^{134}$Cs, $^{85}$Sr and $^{65}$Zn in processing tomato plants after leaf contamination. Several models already deal specifically with the transfer of radionuclides to fruits but all these are adaptations of models that were built for agricultural crops such as leafy green vegetables. "*VENTOMOD*", which is a dynamic evaluation model for the short-term behaviour of radionuclide depositions, has been set up with the aim of assessing the level of radionuclide contamination in ripe processing tomato fruits following an accidental radionuclide release into the atmosphere.

Being created for practical purposes it has been built considering tomato plants’ growth physiology but at the same time minimising the number of fluxes and pools to be represented. The model presented identifies the important factors involved in the contamination of processing tomato fruits and can help in assessing the risk of radionuclide contamination of human diet to soundly decide upon the crop management techniques or practical countermeasures.

A validation of the developed model by measured data successfully reproduced the radionuclide distribution and dynamics that were observed in tomato plants grown in pot experiments. The level of uncertainty is within the normal range of similar assessment models, being based on the assumption that all the complex factors influencing radionuclides’ absorption within plants can hardly ever be individually represented in mathematical models.

For a more general use of this model further testing with independent data sets from experiments obtained under different environmental conditions and data from other horticulturally important plant species would be desirable.

1. Introduction

Agricultural products can be polluted by radionuclides originating both from spike and long-term releases into the atmosphere. Edible fruits are an important dietary component; nevertheless, models on this large group of plant types have been given little attention until present.

As reviewed by Watkins & Maul (1995) radionuclides, following a release into the atmosphere, can reach fruits via three principal routes:

1. Deposition to soil followed by vertical migration into the soil profile, root uptake from soil solution and transfer to the edible components of plants.
2. Deposition to exposed plant surfaces (direct from atmosphere or as a result of resuspension) followed by retention, absorption and translocation to fruits and other plant parts.
3. Direct deposition to exposed fruits’ surfaces.

The relative significance of each pathway depends both on the stage of plant development, on the crop and on the season during which the contaminating event occurs.

The processes of radionuclides’ deposition on and interception by vegetation and soil are the starting points for their transfer into the food chain (Müller & Pröhl, 1993). To simulate the transport of radionuclides in soils, plants and domestic animals mathematical models have been developed for agricultural and natural environments. Such models need to take into account a wide variety of different agricultural practices and crops. According to Mitchell (2001) these models can be pragmatically grouped into three categories:

(a) Simple mathematical functions describing radionuclides’ concentration in fruits based on observations following deposition (Antonopoulos Domis et al., 1990).
(b) Models like those by Whickner et al. (1987) and Frissel (1994), that attempt to predict the temporal distribution of radionuclides in soil-plant system, through description of the processes involved.
(c) Radiological dose assessment models that use both equilibrium and dynamic modelling approaches to predict concentrations in edible products (e.g.: “FARMLAND” (Brown & Simmonds, 1995), “ECOSYS” (Müller & Pröhl, 1993) and “SPADE” (Thorne & Coughtrey, 1983)).

The purpose of the work was to set up a short-term dynamic evaluation model with the aim of assessing the level of radionuclide contamination in ripe processing tomato fruits owing to an accidental release into the atmosphere. According to Grimm (1994), a mathematical model should be understandable, manageable and capable of being fully explored. “VENTOMOD”, being designed for practical purposes, has been built considering tomato plant physiology, focusing on important plant components but at the same time minimizing the number of fluxes and pools to be represented.

Because of the complexity of both the agricultural ecosystem and the plant-nuclide interactions it was decided that the main goals of this work should be the understanding and the prediction of:

- Weathering / Absorption processes with subsequent distribution within the green biomass.
- Translocation of radioactivity to red fruits to assess the risk for human ingestion

This model does not take into account long-term releases of radionuclides into the atmosphere or the plant uptake from contaminated soils. As a matter of fact, during the growing season, the time-integrated concentration of radionuclides in vegetation in the first few months after deposition is dominated by the direct foliar interception of deposited material (IAEA, 1996).

2. Material and Methods

2.1 Model description
The proposed model is a quantitative one. Making use of the simulation software VENSIM (Ventana Systems Inc.) a set of equations representing the considered system with a chosen time resolution of one day was developed. In the simulation the time-integrated behaviour of the real system, i.e. the development of radionuclide levels in different plant parts and compartments, as it runs forward in real time, is reproduced.

At the end of each simulation time step two things happen:
• “level” variables (state variables), which represent the system’s state, are brought up to date to represent the “consequences” that have ensued during the previous time step;
• “rates”, which are variables that represent the flow of information/matter and the initiation of action, are evaluated and the necessary actions are set in train.

Levels and rates are the mathematical bases of a system dynamics model but a third type of variable, the “auxiliary”, is also used. According to Coyle R.G. (1986) it reflects the detailed steps by which information about the levels is transformed into rates to bring about future change. In other words, an auxiliary variable may be considered an intermediate concept or calculation that can change instantaneously bearing in mind that, in a system dynamics model, every variable is calculated at every time step.

To set "VENTOMOD” up the VENSIM PLE Plus 4.2a software (Ventana System Inc.) was used. With the help of this tool it was possible to progress from a simple approach with few compartments to a more complex one taking into consideration many of the processes, rates and coefficients. The general approach and the compartments required were mapped out using the logic rules implicit in the software.

“VENTOMOD” is divided into three sub-models:
   a) Weathering / Absorption model
   b) Redistribution model: from green biomass to red fruits and root and peat compartments.
   c) Red Fruits growth model.

The structure of the conceptual diagram of the model is represented in figure 1.

**Figure 1** Conceptual diagram of the model: boxes indicate state variables (pools), double line arrows give flows and single line arrows give feedback mechanisms

The 1st and the 2nd sub-models reflect the radionuclides’ behaviour in each step of their global translocation from leaves, which are the starting point of plants’ contamination, to red tomatoes. The 3rd sub-model was introduced to simulate the biomass increase (fresh weight) of red fruits to help calculate those auxiliary variables that, to be defined, need the fresh
weight of the edible part of the plant. It was assumed that the driving force of nutrient translocation was biomass build-up in fruits.

Six state variables (levels) were defined: activity outside the plant, weathering loss, activity inside the green biomass, activity in roots and peat, activity in red fruits (RF) and biomass (kg of fresh weight). Flows between these variables are represented by the weathering flow (weathering processes) and absorption flow (leaf absorption) for the first sub-model while root and peat flow and red fruits flow are those which represent fluxes in the redistribution model together with the corresponding reverse flows (“root counterflow” and “RF counterflow”). Each flow is controlled by the corresponding rate (expressed as day⁻¹) that was calculated on the basis of an experimental set of data (see in chapter 2.3).

To better represent the transfer of radioactivity from green biomass to red fruits a 3rd order exponential delay function (Coyle R.G., 1996) was introduced. This allowed us to simulate as well as possible plant behaviour and the fate of radionuclides in that state variable considering the fact that fruits were completely absent at the beginning of the calibration experiment. Besides, to be able to reproduce the particular behaviour of strontium activity in red fruits (see table 2), only for this radionuclide a reverse flow (ruled by the corresponding rate) from the red fruits compartment to the green biomass was introduced: ripening processes may cause some metabolites to migrate from ripe fruits (e.g. calcium/strontium) back into the vegetative plant parts. Unripe tomato fruits are green because of their high content of chlorophyll and lack of carbohydrates. The main feature of the ripening process is an increase of ethylene production. This hormone stimulates enzymes like pectinases and cellulases which set cell walls free from insoluble calcium-pectate (Baldini, 1988).

Four constants represent parameters that, together with the above-mentioned rates, mostly influence the nuclide transfer within the plant system. These parameters are:

• “Interception”: Bq intercepted by plants during fallout;
• “Delay time”: average number of days taken by fruits to be seen on the plant;
• “Red Fruits delay time”: average number of days necessary for the ripening processes to start;
• “Plants’ density”: number of tomato plants per each square meter of surface.

Three auxiliary variables named “Bq/kg f.w. in red fruits”, (f.w.: fresh weight), “TLF (translocation factor, m²/kg)” and “Interception/square meter” were introduced too. Their value is calculated at every time step based on the value of the respective levels (constants) with which any auxiliary is connected.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Model calibration: activity intercepted by tomato plants (kBq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radionuclide</td>
<td>134Cs</td>
</tr>
<tr>
<td>Contamination data</td>
<td></td>
</tr>
<tr>
<td>Intercepted Activity</td>
<td>80.00</td>
</tr>
<tr>
<td>Standard Error</td>
<td>6.60</td>
</tr>
<tr>
<td>95% Confidence Level</td>
<td>12.90</td>
</tr>
</tbody>
</table>
2.2 Experimental Set of Data

To calibrate the model an experimental set of data was used. It had been obtained from a set of “undetermined” processing tomato plants (Bianco, 1990), belonging to the “PS 1296” cultivar, which were grown in pots under a tunnel covered with PVC. Brambilla, Fortunati & Carini (2001) have already reported the technical details of this experiment. As tomato plants reached the anthesis of the 2nd truss growing stage, a wet deposition event was simulated by sprinkling an aqueous solution containing $^{134}\text{Cs}$, $^{85}\text{Sr}$ and $^{65}\text{Zn}$ chloride. The activities applied to the plants together with data on interception are reported in table 1: all data are decay corrected to 31st August 1999.

### Table 2  
Model calibration: activities of $^{134}\text{Cs}$ measured (kBq/plant ± 95% confidence level) and calculated (between brackets) in each plant part during the growing cycle

<table>
<thead>
<tr>
<th>$^{134}\text{Cs}$</th>
<th>Days from contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>39</td>
</tr>
<tr>
<td><strong>Red Fruits</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.11 ± 4.46</td>
</tr>
<tr>
<td></td>
<td>(6.02)</td>
</tr>
<tr>
<td><strong>Green Biomass</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>37.0 ± 11.80</td>
</tr>
<tr>
<td></td>
<td>(30.2)</td>
</tr>
<tr>
<td><strong>Roots and Peat</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.2 ± 3.96</td>
</tr>
<tr>
<td></td>
<td>(15.0)</td>
</tr>
</tbody>
</table>

### Table 3  
Model calibration: activities of $^{85}\text{Sr}$ measured (kBq/plant ± 95% confidence level) and calculated (between brackets) in each plant part during the growing cycle

<table>
<thead>
<tr>
<th>$^{85}\text{Sr}$</th>
<th>Days from contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>39</td>
</tr>
<tr>
<td><strong>Red Fruits</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0414 ± 0.0095</td>
</tr>
<tr>
<td></td>
<td>(0.022)</td>
</tr>
<tr>
<td><strong>Green Biomass</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.5 ± 7.7</td>
</tr>
<tr>
<td></td>
<td>(23.6)</td>
</tr>
<tr>
<td><strong>Roots and Peat</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.62 ± 1.85</td>
</tr>
<tr>
<td></td>
<td>(1.72)</td>
</tr>
</tbody>
</table>
Table 4  Model calibration: activities of $^{65}$Zn measured (kBq/plant ± 95% confidence level) and calculated (between brackets) in each plant part during the growing cycle

<table>
<thead>
<tr>
<th>$^{65}$Zn</th>
<th>Days from contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>39</td>
</tr>
<tr>
<td>Red Fruits</td>
<td>0.652 ± 0.220</td>
</tr>
<tr>
<td>Green Biomass</td>
<td>38.3 ± 13.3</td>
</tr>
<tr>
<td>Roots and Peat</td>
<td>5.75 ± 3.16</td>
</tr>
</tbody>
</table>

At the growing stage of 10%, 25% and 90% of red fruits (39, 43, 60 days after treatment) one sample of three replicates for each growing stage was harvested. In each sampling green fruits, red fruits, leaves, stems, roots and peat were analysed separately as single replicates. The activities measured in green fruits, trusses, stems and leaves were summed up and this compartment was defined as “Activity inside the Green Biomass” (table 2, 3 and 4).

The activities measured in roots and peat were summed up too and that compartment was defined as “Root and Peat”. All the activities, expressed as kBq/plant are decay corrected to the 31st August 1999, and calculated as arithmetical mean ± 95% confidence level of three replicates.

In summing up the activities in the compartments studied we assessed the global content of radioactivity within each plant. The loss of radioactivity was determined as the difference between the average intercepted activity and the final one measured within the tomato plants. Arithmetical means and standard error of global activity inside the plant and the loss of radioactivity at the end of the growing cycle, expressed as kBq·plant$^{-1}$ ± 95% confidence level, are reported in table 5.

Table 5  Model calibration: global activity inside the plants and loss of radioactivity from tomato plants both measured (kBq/plant ± 95% confidence level) and calculated (between brackets) at the end of the growing cycle

<table>
<thead>
<tr>
<th></th>
<th>$^{134}$Cs</th>
<th>$^{85}$Sr</th>
<th>$^{65}$Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Activity inside the plant</td>
<td>50.0 ± 7.40</td>
<td>25.6 ± 5.30</td>
<td>38.3 ± 8.13</td>
</tr>
<tr>
<td>Activity Loss</td>
<td>29.9 ± 7.40</td>
<td>14.5 ± 5.30</td>
<td>50.6 ± 8.13</td>
</tr>
</tbody>
</table>
2.3 Model calibration

The model was set up assuming that at the time zero (t₀) all the intercepted activity was completely outside the plant while at the endpoint of the simulation (60 days after the sprinkling - t₆₀-) only 1 Bq of each radionuclide was left on the plant surface. Every day a certain amount of radioactivity enters the plant but at the same time weathering factors cause another amount of it to be dispersed. The higher the amount of radioactivity outside the plant, the higher are both the absorption and the weathering flows (Watkins et al. 1995).

An exponential trend between startpoint and endpoint was assumed, thus at any time we observe:

\[ A_{tx} = A_{to} \cdot e^{-K_{w+a} \cdot t} \]

\[ K_{w+a} = \left(-\ln \frac{A_{tx}}{A_{to}}\right) \cdot t^{-1} \]

- \( A_{tx} \): activity [Bq] outside the plant at any time.
- \( A_{to} \): activity [Bq] outside the plant at time zero.
- \( t \): is the time [days].
- \( K_{w+a} \): weathering + absorption rate [day⁻¹].

Given that: I = GB + W

- \( I \): intercepted activity [Bq]
- \( W \): weathering loss [Bq]
- \( GB \): activity inside the green biomass [Bq]

\[ \text{Absorption rate} = \alpha K_{(W+A)} \text{ [day}^{-1}] \]
\[ \text{Weathering rate} = \beta K_{(W+A)} \text{ [day}^{-1} \]

\[ \alpha = \frac{GB}{I} \]
\[ \beta = \frac{W}{I} = 1 - \alpha \]

Similarly, in case of radioactivity transfer from inside the green biomass towards red fruits and root and peat compartments, exponential expressions were chosen. Rates were calculated in the following way:

- \( GB^0 \): Activity inside the green biomass with no Bq in RF or R&P
- \( GB_f \): Final activity in the green biomass [\( GB_f = GB^0 - (RF + R&P) \)]

\[ \text{Red fruits transfer rate} = \left[-ln \frac{(GB^0 - RF)}{GB^0}\right] \cdot t^{-1} \]
\[ \text{Red fruits counterflow rate} = \left[-ln \frac{RF}{2 \cdot (GB^0 - R \& P)}\right] \cdot t^{-1} \]
\[ \text{Root and Peat Transfer Rate} = \left[-\ln \frac{GB_f}{GB^0}\right] \cdot t^{-1} \]
\[ \text{Root and peat counterflow rate} = \left[-\ln \frac{R \& P}{2 \cdot GB^0}\right] \cdot t^{-1} \]

RF: Activity in red fruits
R&P: Activity inside the root and peat compartment.
Collecting samples at different times after the contamination sprinkling permitted us to assess radioactivity distribution in the considered compartments. All rates were calculated as mentioned before and, being obtained for different time intervals, their average value is expressed as geometrical mean ± 95% confidence level of three samples (Tab. 6).

Table 6  Model calibration: transfer rates (geometrical mean ± 95% confidence level) derived from experimental data expressed as day⁻¹

<table>
<thead>
<tr>
<th></th>
<th>¹³⁴Cs</th>
<th>⁸⁵Sr</th>
<th>⁶⁵Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weathering rate</td>
<td>0.071 ± 0.018</td>
<td>0.064 ± 0.023</td>
<td>0.110 ± 0.017</td>
</tr>
<tr>
<td>Absorption Rate</td>
<td>0.120 ± 0.018</td>
<td>0.110 ± 0.023</td>
<td>0.082 ± 0.017</td>
</tr>
<tr>
<td>Red Fruits T.R.</td>
<td>0.015 ± 0.003</td>
<td>(1.1 ± 0.59)·10⁻⁴</td>
<td>0.002 ± 0.0004</td>
</tr>
<tr>
<td>Red Fruits counterflow</td>
<td>-</td>
<td>0.46 ± 0.016</td>
<td>-</td>
</tr>
<tr>
<td>Root and Peat T.R.</td>
<td>0.013 ± 0.002</td>
<td>0.0027 ± 0.0026</td>
<td>0.0039 ± 0.0034</td>
</tr>
<tr>
<td>R. &amp; P. counterflow</td>
<td>0.075 ± 0.012</td>
<td>0.094 ± 0.028</td>
<td>0.093 ± 0.035</td>
</tr>
</tbody>
</table>

T.R: Transfer Rate
R&P: Roots and Peat

After setting up the 1st and the 2nd sub-model, a fruit growth model was also sketched (fig. 1, left) which allows us to calculate at any time the fresh weight of red fruits. This sub-model was obtained starting from the experimental set of data considering the fresh weight of flowers as starting weight and assuming an exponential increase of weight over time.

Based on this result the auxiliary variable “Bq/kg fresh weight in red fruits” could be calculated by simply dividing, at any time, the activity in red fruits with their fresh weight (see the feedback mechanisms in fig. 1).

The knowledge of the plants’ density inside the tunnel (3.33 plants/m²) allowed us to calculate the “interception/square meter” auxiliary variable (Bq/m²), which is constant. This constant, together with “ Bq/kg fresh weight in red fruits”, allowed us to sketch another interesting auxiliary variable: the “TLF – m²/kg” (IAEA, 1994). It was obtained by dividing at any time the activity concentration in edible parts at harvest (Bq/kg) by the activity retained on 1 m² of foliage at time zero (Bq/m²). This assumption is valid because in processing tomato crops, red fruits represent the edible part of the plant at any time of their cycle so, in case of a nuclear accident, an anticipated harvest, according to the possibility of fruit’s consumption, can be decided.

2.4 Sensitivity analysis

The model contains nine constants that were varied to examine their effect on the simulation output. The density of plants, being a decision taken before setting the crop up, is assumed to be perfectly known: as a matter of fact it is determined in narrow ranges in accordance with the agronomic land management of the district.
For $^{134}$Cs and $^{65}$Zn a multivariate sensitivity analysis was carried out simultaneously varying weathering rate, absorption rate, red fruit translocation rate, root and peat translocation rate, root and peat counterflow, delay time and growth rate. For $^{85}$Sr red fruits counterflow and the corresponding delay time were also considered. For each variable considered a normal distribution was assumed and the maximum and minimum values observed defined the allowed variation. To perform the multivariate sensitivity analysis 500 simulation runs for each radionuclide were performed.

2.5 Model Validation

To validate the model another experimental set of data was used. It was obtained by sprinkling 6 plants with a radioactive solution containing $^{134}$Cs, $^{85}$Sr and $^{65}$Zn as they reached 25% red fruits growing stage. The plants, which belonged to the same cultivar, were polluted on 22nd July 2000. Three of them were immediately picked to determine the interception level, while the others were harvested 14 days later when fruits were completely ripe. These plants were grown in the same environmental conditions as those used to calibrate the model. Also for this experiment, all the technical details have already been reported by Brambilla, Fortunati & Carini (2001).

The activities intercepted both by foliage and fruits (“Direct Fruits interception”) are reported in table 7.

Table 7  Model validation: activities (kBq) intercepted by tomato plants during the 2nd sprinkling expressed as arithmetical mean ± 95% confidence level of three replicates (experimental data)

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Intercepted by leaves</th>
<th>Direct fruit interception</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{134}$Cs</td>
<td>42.7 ±5.18</td>
<td>4.23 ± 0.382</td>
</tr>
<tr>
<td>$^{85}$Sr</td>
<td>22.1 ± 18.50</td>
<td>1.92 ± 0.573</td>
</tr>
<tr>
<td>$^{65}$Zn</td>
<td>16.9 ± 5.46</td>
<td>4.18 ± 0.360</td>
</tr>
</tbody>
</table>

These values, together with the other described parameters, were used to set the model up for the validation run. Table 8 shows the comparison between the constants used during the calibration and the validation runs. In particular it must be considered that, in the 2nd set of runs, the delay time parameter was set to 1 day only. In the same way the “red fruits counterflow rate” for strontium was set to zero because the ripening process had already started and it was supposed not to interfere with the translocation of this radionuclide in the edible part of the plant. Finally the model output was compared with the expected (measured) value obtained from the above-mentioned measurements.

3. Results and Discussion

Figures 2,3 and 4 show the model output for all the considered radionuclides: in all of them it is clear that at the end of the growing cycle considerable amounts of radionuclides could be translocated to fruits. $^{134}$Cs is the nuclide that shows the highest mobility within the plant system.
Figure 2  Model output for $^{134}$Cs activity (Bq/plant) in the green biomass, in roots and peat and in red fruits (2nd Y-axis)

Figure 3  Model output for $^{85}$Sr activity (Bq/plant) in the green biomass, in roots and peat and in red fruits (2nd Y-axis)

Figure 4  Model output for $^{65}$Zn activity (Bq/plant) in the green biomass, in roots and peat and in red fruits (2nd Y-axis).

By running the model with the above mentioned settings (see Tab. 6 and the left column of Tab. 8) we obtained the calculated values that are represented between parentheses in tables 2,
In these tables the good agreement between the measured and the calculated values of activity is evident.

**Table 8** Model calibration and validation: comparison between calibration and the validation runs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Calibration</th>
<th>Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$^{134}$Cs</td>
<td>$^{85}$Sr</td>
</tr>
<tr>
<td>Initial Time (days)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Final Time (days)</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Time Step (days)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Leaf Interception (Bq)</td>
<td>79970</td>
<td>40030</td>
</tr>
<tr>
<td>Direct Fruits Interception (Bq)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Red Fruits growth rate (days$^{-1}$)</td>
<td>0.102</td>
<td>0.102</td>
</tr>
<tr>
<td>RF counterflow rate (days$^{-1}$)</td>
<td>0</td>
<td>0.46</td>
</tr>
<tr>
<td>Delay time (days)</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

With reference to $^{134}$Cs, according to the model, 15.6 kBq/plant are translocated to red fruits at the end of the growing cycle (31.1% of the totally absorbed amount) and 7.00 kBq/plant (13.9% of the absorbed amount) are transferred to the roots and peat compartment. It turns out that, in comparison with the other examined radionuclides, at the end of the growing cycle $^{134}$Cs causes the highest contamination in tomato fruits. This is consistent with the fact that, in case of foliar and ground deposition of radioactive isotopes, the potential of foliar uptake processes could be of considerable importance in contributing to the whole plant content of caesium isotopes: foliar absorbed caesium is extremely mobile within the plant, in particular for those plants, which undergo rapid development (Coughtrey & Thorne, 1983a). Considering the analogy between $^{134}$Cs and K, this is consistent with the fact that, in processing tomato plants, during the ripening process, fruits are the strongest sinks for both assimilates and K (Ho, 1996).

A comparison between figure 2 and figures 3 and 4 illustrates the considerable decrease of caesium activity inside the green biomass compartment. Leaves are the greatest component of this compartment, thus the described behaviour is consistent with Widders & Lorenz (1979) who found that, in some tomato plant cultivars, during their rapid growth, fruits’ requirements were well above the potassium uptake capacity of roots causing potassium from leaves to be remobilized.

$^{85}$Sr is the radionuclide that is absorbed maximally by the plants into the green biomass with 25.3 kBq/plant (63.2% of the intercepted activity). On the other hand, it is the radionuclide which is redistributed the least with only 38 Bq/plant inside the red fruits at the end of the growing cycle, which represent 0.15% of the absorbed amount, while 1220 Bq are stored inside roots and peat (4.8% of the absorbed quantity). This is consistent with Coughtrey &
Thorne (1983a) who reported that most of foliar applied strontium remains in the plant part to which it is applied, in the end less than 3%, is translocated to fruit.

$^{65}$Zn has an intermediate behaviour. As a matter of fact it was the least absorbed radionuclide (38.3 kBq/plant, i.e. 43.1% of the intercepted activity). Nevertheless, 1851 Bq/plant (4.8% of the absorbed amount) are concentrated in red fruits at the end of the growing cycle. Also in this case the model output can be compared with the findings of other authors. Wittwer & Teubner (cited by Coughtrey & Thorne, 1983b) reported that 50% of zinc applied to bean leaves could be absorbed in 24 hours and that the foliar adsorption of soluble and complex compounds of $^{65}$Zn readily occurs. The estimated distribution of Zn activity shows that it tends to be transported toward the active growing parts of the plant (roots and fruits) as reported by Coughtrey & Thorne (1983b).

Figure 5  Model output for the activity of ripe fruits (Bq/kg fresh weight) for $^{134}$Cs, $^{65}$Zn and $^{85}$Sr. The 2<sup>nd</sup> Y-axis scale is related to radiostrontium

Figure 5 shows the model output for activity of Cs, Sr and Zn inside red fruits expressed as Bq/kg of fresh weight. Again $^{134}$Cs is the greatest source of pollution because of its concentration, which is one order of magnitude higher than that of $^{65}$Zn and two orders higher than $^{85}$Sr both at day 34, when it reaches the maximum, and at the end of the cycle.

Figure 6  Model output for translocation factor (TLF, m$^2$/kg). The 2<sup>nd</sup> Y-axis scale is related to radiostrontium

The model output for the translocation factor “TLF” (m$^2$/kg f.w., see Fig. 6) shows a very similar trend. It has been obtained dividing at any time the red fruit’s activity per kg of fresh
weight (Bq/kg f.w.) by the activity retained by 1 m² of foliage at the time of deposition, expressed as Bq/m², which is a constant. In particular, the model calculates this variable multiplying the initial interception (Bq/plant) with the plant’s density expressed as plants/m².

3.1 Sensitivity Analysis

Figures 7 to 9 show the multivariate sensitivity analysis output.

**Figure 7** Multivariate sensitivity analysis of red fruits contamination with ¹³⁴Cs. Data are expressed as Bq/plant

**Figure 8** Multivariate sensitivity analysis of red fruits contamination with ⁸⁵Sr. Data are expressed as Bq/plant
The light grey band indicates the range of values within which 50% of the results from simulation runs can be found. For each radionuclide the results of activity in red fruits expressed as Bq/plant. Comparing the graphs it turns out that the most accurate model performance is observed for $^{85}$Sr. $^{65}$Zn has an intermediate accuracy while the least accurate performance is that of $^{134}$Cs.

### 3.2 Model Validation

Table 9 shows the comparison between the predicted and the measured activities inside the red fruits compartment. In particular, good agreement between measurements and model prediction was found for both $^{134}$Cs and $^{85}$Sr because their expected activity in red fruits is included in the 95% confidence level of the measured value. In the case of $^{65}$Zn the predicted value falls outside the 95% confidence level. Nevertheless, the percentage variation belongs to the same order of magnitude of the previous two.

Table 9   Model validation: measured and predicted activities (kBq/plant) in Red Fruits compartment (RF) expressed as arithmetical mean ± 95% confidence level

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Measured Activity</th>
<th>Predicted Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{134}$Cs</td>
<td>5.96 ± 1.98</td>
<td>7.17</td>
</tr>
<tr>
<td>$^{85}$Sr</td>
<td>2.75 ± 0.84</td>
<td>1.93</td>
</tr>
<tr>
<td>$^{65}$Zn</td>
<td>3.34 ± 1.00</td>
<td>4.50</td>
</tr>
</tbody>
</table>

Table 10 shows the difference between the predicted and the measured activities in the green biomass compartment. As internal activity could not be distinguished from the external one by
available analytical methods, the experimental value needed to be compared with the sum of the calculated activities inside and outside the green biomass. In all cases VENTOMOD tends to underestimate the measured value (on average 34.2%) and the total activity in green biomass falls mostly outside the 95% confidence level.

Table 10  Model validation: measured and predicted activities (kBq/plant) in the Green Biomass (GB) expressed as arithmetical mean ± 95% confidence level

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Measured Activity</th>
<th>Activity inside the GB</th>
<th>Activity outside the GB</th>
<th>Total Activity in GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{134}$Cs</td>
<td>$33.4 \pm 4.06$</td>
<td>20.2</td>
<td>2.78</td>
<td>23.0</td>
</tr>
<tr>
<td>$^{85}$Sr</td>
<td>$22.8 \pm 2.36$</td>
<td>12.6</td>
<td>1.85</td>
<td>14.4</td>
</tr>
<tr>
<td>$^{65}$Zn</td>
<td>$31.9 \pm 3.22$</td>
<td>18.0</td>
<td>3.01</td>
<td>21.0</td>
</tr>
</tbody>
</table>

In table 11 comparison between measured and expected activity in the roots and peat compartment is shown. In all cases the model tends to overestimate the activity in this compartment but, while for $^{134}$Cs and $^{65}$Zn the calculated activities are clearly different from measured data, for $^{85}$Sr the calculated value fits the measured data very well.

Table 11  Model validation: measured and predicted activities (kBq/plant) in the Root and Peat compartment (R&P) expressed as arithmetical mean ± 95% confidence level

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Measured Activity</th>
<th>Calculated Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{134}$Cs</td>
<td>$0.572 \pm 0.224$</td>
<td>2.01</td>
</tr>
<tr>
<td>$^{85}$Sr</td>
<td>$0.158 \pm 0.044$</td>
<td>0.219</td>
</tr>
<tr>
<td>$^{65}$Zn</td>
<td>$0.142 \pm 0.101$</td>
<td>0.415</td>
</tr>
</tbody>
</table>

4. Conclusion

This short-term dynamic evaluation model has been set up to provide both nutritionists and agronomists with a useful tool to forecast tomato plant’s functional behaviour, which is based on environmental and physiological factors. In this way they can soundly decide upon crop management techniques or other practical countermeasures in case of radioactive fallout following a spike release into the atmosphere.

The problem modelled is very complex and many of the processes that interfere with the radionuclide transfer from leaves to fruits are to be considered, but on the other hand an applicable model should be relatively simple and should not involve too many parameters. The uncertainty level derived from the sensitivity analysis can be considered acceptable based on the assumption that all the complex factors influencing radionuclides’ absorption by plants can hardly ever be individually represented in mathematical models.

VENTOMOD identifies the most important factors involved in the contamination of processing tomato fruits and it can help in assessing the risk of radionuclide contamination of human diet.
As is evident from the validation experiment, the developed model allows us to successfully reproduce the radionuclide distribution and dynamics observed in tomato plants during pot experiments, in particular in tomato fruits. Nevertheless, a more general use of the model requires further testing with independent sets of data obtained from other experiments carried out under different environmental conditions and with different horticulturally important species.

4. Acknowledgements
I am very grateful to Prof. Sandro Silva and Prof. Franca Carini of the Catholic University of the Sacred Heart (Faculty of Agriculture) for their scientific and financial support and to Dr. Paolo Fortunati and p.a. Fabrizio Speroni who performed the quality control procedures of the gamma spectrometer. Many thanks are due also to Prof. Martin Gerzabek for his great kindness and availability during my stay at ARCS.

5. References


Brambilla M.; Fortunati P.; Carini F. (2002). Foliar and Root Uptake of $^{134}$Cs, $^{85}$Sr and $^{65}$Zn in processing tomato plants (Lycopersicon esculentum Mill.). Journal of Environmental Radioactivity 60, 351-363.


TIME-DEPENDENCY OF THE $^{137}$Cs CONTAMINATION OF A SPRUCE FOREST IN SOUTHERN GERMANY

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Summary

In recent years we have measured different components of the spruce forest ecosystem with respect to $^{137}$Cs: soil, understorey vegetation, fruit bodies of mushrooms, trees, and wild animals. The distribution of $^{137}$Cs inventories of these components measured in the year 2000 is the following: 91% in soil, and 6% in spruce trees if we assume about 3% in the other components. Using a compartment model similar to RIFE1 we calculated the $^{137}$Cs fluxes between components, and we were able to fit the time-dependencies observed in the forest. The results will be discussed and compared with those for other forests in Europe.

1. Introduction

A review of forest models developed after the Chernobyl nuclear power plant accident is given by Riesen, Avila, Moberg & Hubbard (1999). These authors compare 12 models and find that only the model FORM presented by Frissel, Shaw, Robinson, Holm & Crick (1996), has a game and roe deer compartment. The first model intercomparison study undertaken by the Forest Working Group under Theme 3 of the BIOMASS programme, IAEA (1999), compares the output of 9 different models: five modellers provided predictions for time courses of contamination in game, four models specify deer. The spread of prediction is generally within one order of magnitude. Recently seasonality of the $^{137}$Cs contamination of roe deer has been modelled by Zibold et al (2001). In the following our data from the State forestry Bad Waldsee are used together with the RIFE1 model, which we extended by adding compartments for green plants, and roe deer.

2. Materials and methods

Soil, plants and mushrooms: Data of $^{137}$Cs contamination of soil, upper 10 cm soil layer (mostly organic): “soil 10”, and the soil layer between 10 cm and 20 cm depth (mostly mineral): “soil 20”, and of spruce tree were taken at State forestry Bad Waldsee, district I, section 25 (GPS co-ordinates 47° 51’ 46”N and 9° 41’ 95”E) in March 2000. Additional data of the time dependency of “soil 10”, and understorey vegetation were taken at nearby sites of the same spruce forest, and these data were normalised to the soil contamination at site I25. Inventories of $^{137}$Cs in fruit bodies of mushrooms are assumed to be about 1% of the soil inventory at 17.09.87, the starting date of our measurements of $^{137}$Cs in mushrooms. Inventories of $^{137}$Cs in understorey vegetation are assumed to be about 1% of the soil inventory at 1.09.1995, the date after which the aggregated transfer factor soil-plant is measured to be constant in time. Details of sampling have been described in Zibold et al. 2001.

Tree characteristics: The dominant species is spruce (Picea abies), 347 trees per hectare. The average age of the spruce trees is 70 years. The average age of the trees at the time of
contamination is 55 years. The average height of the trees is 33.6 m. The trunk diameter is 38 cm at the height of 1.5 m. The spruce tree investigated had a height of 32.4 m and a trunk diameter of 31 cm at a height of 1.5 m. Other species in the forest were silver fir (*Abies alba*), larch (*Larix decidua*), beech (*Fagus*), and red oak (*Quercus rubra*), all together 56 pieces per hectare.

The mass of the spruce tree was determined according to Ellenberg et al. (1986), the activity concentration was measured, and the activity of the tree was calculated. With the number of trees per hectare the $^{137}$Cs inventory of the spruce forest was determined, with the result of $(1300 \pm 260)$ Bq/m² at 1.05.2000.

**Roe deer**: In the forest of Bad Waldsee roe deer have been measured since 1987 every year and values of aggregated transfer factors soil-roe deer are comparable to those measured in the spruce forest Ochsenhausen, where these measurements have been performed in great detail, Zibold et al. 2001. Therefore, $^{137}$Cs inventories of roe deer and its time-dependency (geometric mean values for first half-years) were taken from our data from Ochsenhausen spruce forest, and normalised to the soil contamination at site I25. As the fraction of roe deer in the total $^{137}$Cs inventory is only about 16 PPM at 1.10.1987, the influence of roe deer in this study is small, and its seasonality has not been taken into account.

**Model calculation**: The compartment model was solved with the software package Model Maker 2 using the 4th order Runge-Kutta algorithm. To assess the goodness of fit of our model we use the weighted sum of squares to describe the deviation of the data from the fit function, and $r^2$ is the fraction of the total variation explained by the model.

3. **Results and Discussion**

The structure of the extended RIFE1 model is shown in Fig.1. The initial inventories of $^{137}$Cs at 1.05.1986 are chosen as $I_1 = 6332$ Bq/m² and $I_2 = 25328$ Bq/m². In addition to the rate coefficients $k_1$ to $k_{10}$ which are calculated in the model, we take into account radioactive decay.

![Fig. 1 Structure of the model](image-url)
In Fig. 2 data and best fits to the data for the compartments “soil 10” \((r^2 = 0.34)\), “soil 20”, and “tree internal” are given. The large error bars of “soil 10” describe the large variability of soil contamination in forests. Model results for the compartments “litter” and “tree external” are also presented.

**Fig. 2** \(^{137}\text{Cs}\) inventory in 5 compartments of a spruce forest. Measured data points are given together with calculated time-dependencies.

**Fig. 3** \(^{137}\text{Cs}\) inventory in green plant compartment of a spruce forest. Measured data points are given together with calculated time-dependency.
In Fig. 3 the time dependency of the geometric mean values per year are shown for green plants. Absolute values of inventories are assumed to be a 1% fraction of the total inventory in the forest. Fig 3 shows that this assumption has to be changed to about 3% of the total $^{137}$Cs inventory to be located in green plants in order to get a better correlation between data points and model fit. This argument is supported by the high correlation ($r^2 = 0.91$) achieved in Fig. 4 for roe deer. In Fig. 4 results for roe deer are shown as half-year geometric mean values of the inventory due to grazing of green plants, as determined by measurement.

**Fig. 4** $^{137}$Cs inventory in the roe deer compartment of a spruce forest. Measured data points are given together with the model fit.

**Table 1** Forest properties: Effective half-lives ($\ln 2/k_i$) of RIFE1 model for 8 European forest sites, Belli 2000, and this work.

<table>
<thead>
<tr>
<th>Flow</th>
<th>Half-life</th>
<th>RIFE1 Min (years)</th>
<th>RIFE1 Max (years)</th>
<th>This work (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree external - internal</td>
<td>$T_1$</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tree internal - Litter</td>
<td>$T_2$</td>
<td>2.27</td>
<td>5.06</td>
<td>2.4</td>
</tr>
<tr>
<td>Org. Soil (Soil 10) - Tree int.</td>
<td>$T_3$</td>
<td>5.78</td>
<td>69.31</td>
<td>38</td>
</tr>
<tr>
<td>Tree external - Litter</td>
<td>$T_4$</td>
<td>0.45</td>
<td>0.45</td>
<td>0.31</td>
</tr>
<tr>
<td>Litter - Soil 10</td>
<td>$T_5$</td>
<td>-</td>
<td>-</td>
<td>6.3</td>
</tr>
<tr>
<td>Soil 10 – Soil 20</td>
<td>$T_6$</td>
<td>-</td>
<td>-</td>
<td>90</td>
</tr>
<tr>
<td>Litter - Green Plant</td>
<td>$T_7$</td>
<td>-</td>
<td>-</td>
<td>0.0001</td>
</tr>
<tr>
<td>Soil 10 – Green Plant</td>
<td>$T_8$</td>
<td>-</td>
<td>-</td>
<td>1592</td>
</tr>
<tr>
<td>Green Plant - Roe Deer</td>
<td>$T_9$</td>
<td>-</td>
<td>-</td>
<td>1.6</td>
</tr>
<tr>
<td>Roe Deer - Litter</td>
<td>$T_{10}$</td>
<td>-</td>
<td>-</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
From the best fit of the model parameters $k_1$ to $k_{10}$ we obtain the effective half-lives $T_1$ to $T_{10}$ as given in Table 1. Our values $T_2$, $T_3$, and $T_4$ compare well to minimum and maximum values obtained in the SEMINAT project as described for other European forests and model RIFE1 by Belli 2000. However, the number of our free variables (10) and assumptions concerning inventories of green plants and mushrooms is large as compared to the number of our data points (30). From this we conclude, that our data set has to be enlarged in order to get more useful information about the key processes involved in the flow of $^{137}$Cs in the spruce forest ecosystem from fitting. Besides these shortcomings, our results demonstrate the usefulness of the model approach for estimating the inventories of different compartments of an ecosystem and for getting an idea about the time scales involved in the different processes.

4. References


Summary

"Eleonas" area in Athens, Greece, is a site of concentrated industrial activities and continuing urban development. To assess the soil environmental quality total concentrations of Pb, Cu and Zn, extracted with boiling HNO₃, determined for surface soils. Concentration data, environmental guidelines (Dutch classification scheme) and pollution index ratios (PIRs) indicated that the soils of Eleonas show a significant degree of anthropogenic pollution. The soils of the studied area were classified according to their use as urban, crop, covered with natural vegetation and bare. Increased heavy metal concentrations observed in urban and crop soils, while soils covered with natural vegetation as well as bare soils showed lower levels of contamination. Both urban and crop soils were heavily contaminated with Pb, Zn and Cu. The higher concentrations of Cu observed in the crop soils, can be attributed to the use of agrochemicals. Natural vegetation seems to control the deposition of trace metals in soil surface, as indicated by lower concentration of heavy metals in "covered" than in bare soils.

1. Introduction

Over the last decades, heavy metal pollution of the urban environments became a major ecological and health problem. Anthropogenic activities during urban development, such as industrialisation, chemical manufacturing, power generators and motor vehicles, emit various amounts of heavy metals that seriously affect the quality of urban environment. Natural soil ecosystems in the vicinity of residential areas and industrial centres have more than ever been subjected to chemical stress caused by the atmospheric metal emissions. The environmental quality of urban soil is closely related to human health not only through its effect on the composition of food and drinking water, but also through its effect on air quality. Elevated levels of heavy metals in soils and dusts of urban and industrial areas have been reported for many parts of the world such as Denmark (Andersen et al., 1978), USA (Brown et al., 1985), UK (Culbard et al., 1988), Spain (Sanchez-Camazano et al., 1994) and Korea (Chon et al., 1995), In Greece, however, the available information on heavy - metal pollution of urban soils is limited. The objectives of this study were: 1) to assess the heavy metal pollution of surface soils in the Eleonas area and 2) to identify the level of contamination for the different soil categories in relation to land use.

2. Materials and Methods

2.1 Study Area

"Eleonas area" is located almost in the centre of the Athens city and covers an area of about 900 ha. Since the 1950s the land use in Eleonas area has been extensively changed mainly due to the establishment of industrial activities. From that time the increased internal migration from rural to urban areas in Greece led to the development of residential areas in the vicinity of Eleonas. The population of Eleonas in 1990, was 5.000 inhabitants but in the 2.400 industrial activities of the area almost 50.000 people were occupied.
The whole area of Eleonas is surrounded and crossed by highways, avenues and smaller roads with heavy traffic burden that increased during the last years due to the urban development of the greater Athens area. The construction of buildings without any proper planning, the combination of industrial activities with the increasing development and urbanisation and the scarcity of sites covered by vegetation were also significantly contributed to the degradation of Eleonas area.

In terms of air pollution the contribution of Eleonas to the "smog" of Athens is 10% for SO\textsubscript{2}, 4% for smoke and 1.6% for NO. During the 1970s lead pollution was observed in the area with concentrations of lead at the atmosphere up to 2 µg/m\textsuperscript{3}. However after the adoption of clean air legislations by the industries, the significant reduction of Pb content in leaded petrol - from around 0.84 g Pb/l to 0.10 g Pb/l - and the progressive introduction of lead-free petrol, the concentration of lead in the air have significantly declined under 0.3 µg/m\textsuperscript{3} (Ministry for the Environment, Physical Planning and Public Works, unpublished data).

2.2 Soil Sampling
A total of 22 sampling sites, distributed in locations away from specific heavy metal sources and at a distance of at least 20 m from the highways, avenues and roads in order to minimise the roadside effects, were chosen in the study area on a free survey basis depending on land use, topography and accessibility. The soils in the sampling sites had been undisturbed for many years. From each site four surface soil samples were selected (0-5 cm) within a 10 m radius, with a stainless steel sampling tube. For data evaluation the mean value of the four soil samples was used. In all cases the coefficient of variation was less than 7% of the arithmetic mean.

2.3 Total metal concentrations
The collected soil samples air-dried and passed through a 2 mm sieve. The soil properties were determined according to worldwide accepted methods (Page, 1982). Total heavy metals content was determined by refluxing the soil in hot HNO\textsubscript{3} (95 °C) for 16 h. After the digestion, the oxidation of the remaining organic matter was completed by 30 % H\textsubscript{2}O\textsubscript{2}. The digestate was filtered through a Whatman No. 2 filter paper and diluted to 100 ml with deionized water (Miller and McFee, 1983). Metal concentrations in the solutions were determined by flame atomic adsorption spectrophotometry (FAAS) in a Varian SpectrAA-300 atomic adsorption spectrometer. All the chemicals used in this study were of analytical reagent grade. Quality control was assured by duplicate samples and procedural blanks.

3. Results and Discussion
The studied soils were moderately basic (pH range 7.10 - 8.10), with high carbonate content (equivalent CaCO\textsubscript{3} ranged from 20 to 70 %) and their texture was clay loam and loam. Organic matter content showed large variation depending on the presence of vegetation and in most cases was higher in the surface layer (0-5 cm) than in the lower layers, suggesting relatively undisturbed conditions (Massas et al. 1997). The concentrations of Cu, Zn and Pb detected in this study were significantly elevated with respect to the reported base line concentrations for uncontaminated Greek soils (Voutsa et al., 1996). They were also higher than concentrations found in soils from other industrial areas of Greece (Thriasian plain, Thessaloniki) (Table 1).
Table 1. Range, mean, median of the heavy metals concentrations in Eleonas top soils (0-5 cm, n=22) and literature data for comparison (µg/g).

<table>
<thead>
<tr>
<th></th>
<th>Pb</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range</strong></td>
<td>54-279</td>
<td>23.90-213.90</td>
<td>170-620</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>112.11</td>
<td>84.87</td>
<td>342.30</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>90.40</td>
<td>82</td>
<td>335</td>
</tr>
<tr>
<td>Thriasian plain (Greece)a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>14-595</td>
<td>-</td>
<td>52-594</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>89</td>
<td>-</td>
<td>138</td>
</tr>
<tr>
<td>Thessaloniki (Greece) b</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>15.5-37.0</td>
<td>17.9-39.5</td>
<td>36.0-124</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>24.2</td>
<td>26.8</td>
<td>68.3</td>
</tr>
<tr>
<td>Uncontaminated soils (Greece) b</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>4.00-19.2</td>
<td>3.23-14.5</td>
<td>5.40-15.8</td>
</tr>
</tbody>
</table>

a Nakos (1982)
b Voutsa et al. (1996)

Kelly et al. (1996) reported similar heavy metal concentrations in surface soils from an industrial city (Wolverhampton) near to London and Lux (1993) also found mean values of 168.0, 81.0 and 381.0 µg/g for Pb, Cu and Zn respectively in topsoils from Hamburg in Germany.

In order to assess the level of contamination, the concentrations of Pb, Cu and Zn were compared to established guidelines for contaminated soils. In the present study the three level Dutch classification scheme was used. According to this scheme, values fall within the first level represent background heavy metal concentrations (reference value A), Values within the second level represent intermediate levels of contamination (reference value B) indicating the need for further investigation, while values within the third level represent contaminating levels (reference value C) suggesting that the use of countermeasures is necessary. The results of this study showed that the mean topsoil concentrations of Pb, Cu and Zn were close to the reference value B, indicating that the contamination of Eleonas soils requiring further examination and possibly site remediation (Fig. 1).

**Figure 1.** Pb, Cu and Zn mean concentrations in comparison to the Dutch classification scheme reference values (Verner et al., 1996).
Pollution Index Ratios (PIR) defined as the mean element concentrations in the top soils divided by the worldwide average element concentrations of soils were also calculated (Table 2).

**Table 2.** Pollution index ratios (PIR) of heavy metals in top soils of Eleonas area.

<table>
<thead>
<tr>
<th></th>
<th>PIR*</th>
<th>Cu*</th>
<th>Zn*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>1.54-7.97</td>
<td>0.80-7.13</td>
<td>1.88-6.88</td>
</tr>
<tr>
<td>Mean</td>
<td>3.20</td>
<td>2.83</td>
<td>3.81</td>
</tr>
<tr>
<td>Median</td>
<td>2.58</td>
<td>2.73</td>
<td>3.72</td>
</tr>
</tbody>
</table>

*Average concentrations in the world soils after Bowen (1979) (Pb=30, Cu=35 and Zn = 90 µg/g respectively).

PIR values for the surface soils of Eleonas were higher than the world average concentrations by 3.2-fold for Pb, 2.8-fold for Cu and 3.8-fold for Zn. These elevated heavy metal content of the topsoils is mainly attributed to anthropogenic activities in the area. In addition, Massas et al (1997) have proposed recently that the predominant sources of heavy metals in the Eleonas area were the industrial and light manufacture activities followed by automobile emissions. For the soils of Tallin (Estonia), Bityukova et al. (2000) also observed the maximum values of pollution indices (2.0-3.0, and locally up to 3.4) in regions with the highest density of industrial sites.

The soils of Eleonas were classified according to their use as follows:
- a. Crop soils (in agricultural areas)
- b. Urban soils (in residential areas)
- c. Soils covered with natural vegetation (in open areas where the soils were covered with natural vegetation)
- d. Bare soils (in open areas where the soils were not covered with vegetation).

Pb, Cu and Zn concentrations in relation to the land use categories are presented in Table 3. The data in Table 3 suggested that the distribution of the studied heavy metal concentrations in the topsoils of Eleonas was influenced by the land use. However, no statistically significant differences between the heavy metal concentrations in the different land use types were observed, due to the big diversity of concentration values.

**Table 3.** Concentrations of heavy metals of topsoils among soils categories (µg/g).

<table>
<thead>
<tr>
<th>Element</th>
<th>Crop Soils</th>
<th>Urban Soils</th>
<th>Soils with natural vegetation</th>
<th>Bare soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb</td>
<td>Range 66-279</td>
<td>72.8-185.2</td>
<td>63.8-119.1</td>
<td>67.9-185.2</td>
</tr>
<tr>
<td></td>
<td>Mean 132.3</td>
<td>135.1</td>
<td>86.4</td>
<td>100.6</td>
</tr>
<tr>
<td></td>
<td>Median 90.8</td>
<td>141.1</td>
<td>81.4</td>
<td>88.9</td>
</tr>
<tr>
<td>Cu</td>
<td>Range 53.2-213.9</td>
<td>38.6-151.7</td>
<td>36.1-113</td>
<td>43-136.5</td>
</tr>
<tr>
<td></td>
<td>Mean 129.2</td>
<td>105.8</td>
<td>62</td>
<td>77.0</td>
</tr>
<tr>
<td></td>
<td>Median 130.3</td>
<td>116.5</td>
<td>43.9</td>
<td>76.5</td>
</tr>
<tr>
<td>Zn</td>
<td>Range 250-490</td>
<td>170-620</td>
<td>170-410</td>
<td>210-620</td>
</tr>
<tr>
<td></td>
<td>Mean 408</td>
<td>410</td>
<td>280</td>
<td>381.6</td>
</tr>
<tr>
<td></td>
<td>Median 450</td>
<td>425</td>
<td>275</td>
<td>365</td>
</tr>
</tbody>
</table>
Soils covered with natural vegetation were characterised by relative lower levels of Pb, Cu and Zn compared with other soil categories. For these soils the average concentrations were 86.4 µg/g for Pb, 62 µg/g for Cu and 280 µg/g for Zn. and vegetation seems to "control" the atmospheric deposition because a considerable amount of the heavy metal particles in the dust is filtered out and deposited on the leaves (Bloemen et al. 1995). The average Pb, Cu and Zn concentrations in the bare were 1.2, 1.3 and 1.4 fold higher than those in the covered with vegetation soils.

Urban and crop soils exhibited relatively similar elevated contents of Pb and Zn, while Cu concentration was substantially higher in crop soils with a mean value of 129 µg/g. The similar distribution pattern of Pb and Zn in crop and urban soils suggested that the two soil categories were probably influenced by the same pollution sources (mainly by the emissions of industries and automobiles).

The application of various agrochemicals in the crop soils might explain the higher Cu concentrations observed, in agreement with Chen et al. (1997) who supported that copper pollution of agricultural soils is a common phenomenon.

4. References


EVALUATION OF Pb, Cu and Zn BIOAVAILABILITY IN CONTAMINATED SOILS FROM AN URBAN - INDUSTRIAL AREA IN GREECE

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Agricultural University of Athens, Iera Odos 75, Athens, Greece

Summary

The purpose of this study was to evaluate the bioavailability of Pb, Cu and Zn in contaminated soils of "Eleonas", an urban area with extensive industrial activities, near the center of Athens city, Greece. In surface soils, total and available forms of the heavy metals were determined after their extraction with boiling HNO₃ and DTPA respectively. Though in most sampling sites, total metal concentrations indicated elevated pollution levels, the available content of heavy metals were generally low. The high retention capacity of these soils, due to their calcareous nature and their basic pH, may explain the low availability of the studied metals suggesting their association with more stable forms. Organic matter content of the studied mineral soils, though low, seems to control the degree of Pb, Cu and Zn availability, which declines in the order Cu>Pb>Zn; in the same order these metals are associated with soil organic matter.

1. Introduction

Accurate measurements of the total heavy metal concentrations in soils might be useful to predict the potential environmental risk posed by these metals, but they do not always provide a good indicator of metals' labile fraction available for plant uptake. Chemical extractants used to assess the availability of heavy metals in soils fall within four categories: chelating agents, inorganic acids, neutral salts and reducing agents (Martens and Lindsay, 1990). The chelating agent DTPA (diethylenetriaminepentaacetic acid), originally developed to identify soils with inadequate levels of micronutrients (Lindsay and Norvell, 1978), it is widely used in soils with regular or even high heavy metal contents (Singh et al., 1998; Maiz et al, 2000).

In this study the bioavailability of Pb, Cu and Zn in the contaminated soils of "Eleonas" was tested by DTPA extraction.

2. Materials and methods

2.1 Study Site - 2.2 Soil Sampling - 2.3 Total metal concentrations
See the paper "Heavy Metals Distribution in Soils from Eleonas area, Athens, Greece in Relation to Land Use", published in this volume.

2.4 Available Metal Contents

Available metal contents were extracted from the soils by shaking 10 g soil samples (< 2 mm) for 2 h with 20 ml 0.005 M DTPA (pH= 7.3), prepared as described by Lindsay and Norvell (1978). After the extraction the suspension was centrifuged (3000 rpm for 10 min) and the supernatant solution filtered for analysis. Metals in the clear solutions were determined by flame atomic adsorption spectrophotometry (FAAS) in a Varian SpectrAA-300 atomic adsorption spectrometer. All the chemicals used in this study were of analytical reagent grade. Quality control was assured by duplicate samples and procedural blanks.
3. Results and Discussion

Although the total concentrations of Pb, Cu and Zn in the soils of "Eleonas" were high, indicating a significant degree of anthropogenic pollution (for details see the paper "Heavy Metals Distribution in Soils from Eleonas area, Athens, Greece in Relation to Land Use", published in this volume), the bioavailable forms of these metals were generally low (Table 1).

**Table 1.** Range, mean, median of the total and available heavy metals concentrations in Eleonas top soils (0 - 5 cm).

<table>
<thead>
<tr>
<th></th>
<th>Pb total µg/g</th>
<th>Cu total µg/g</th>
<th>Zn total µg/g</th>
<th>Pb DTPA µg/g</th>
<th>Cu DTPA µg/g</th>
<th>Zn DTPA µg/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>54 - 279</td>
<td>23.9 - 213.9</td>
<td>170 - 620</td>
<td>0.74 - 23.9</td>
<td>0.38 - 33</td>
<td>0.38 - 42.2</td>
</tr>
<tr>
<td>(n=22)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>112.11</td>
<td>84.87</td>
<td>342.3</td>
<td>8.31</td>
<td>10.67</td>
<td>14.38</td>
</tr>
<tr>
<td>Median</td>
<td>90.40</td>
<td>82</td>
<td>335</td>
<td>6.82</td>
<td>9.76</td>
<td>9.7</td>
</tr>
</tbody>
</table>

When the fractions of Pb, Zn and Cu extracted by DTPA expressed as a percentage of their total concentration indicated that the availability of these metals was low to moderate but highly variable (Table 2). The comparison of the total and DTPA-extractable Zn content of the top soil samples showed that the amount of available Zn was low ranging from 0.13% to 8.30% with a mean of 3.65%. Ullrich et al. (1999) reported similar results for exchangeable Zn (extracted by 0.5 M MgCl2), that represented on an average 4.6% of the total metal content in contaminated soils from Poland. Available Pb fraction was higher compared to that of Zn, but still low, and ranged from 1.37% to 17.43% with a mean of 7.0 %. Among the tested soil samples the maximum available Pb concentrations measured were 23.9, 19.6 and 16.5 µg/gr representing the 17.2, 10.6 and 17.4 % of the total Pb content respectively. However, in the majority of the surface soils the labile Pb fraction was less than 10 % of the total concentration, indicating a low availability of the metal. The Cu DTPA extracted fraction, that would potentially be available for plant uptake, ranged from 1.60% to 25.57% with a mean value of 11.10 % and was higher compared to that of Zn and Pb. The results showed that, despite the high total concentrations of the studied heavy metals only a small fraction seemed to be available for plant uptake. A possible explanation is that the high retention capacity of these soils, due to their strongly calcareous nature, limited the bioavailability of the metals. The presence of carbonate minerals seems to control the availability of heavy metals because they provide the main adsorptive surfaces in highly carbonate soil types (Pickering, 1982). Moreover, the basic soil pH (as a consequence of CaCO3 presence) influences the availability of heavy metals, because increased pH values usually increase the adsorptive capacity of the soils (Papadopoulos and Rowell, 1988).
Table 2. DTPA extractable Pb, Cu and Zn content in top soils (0-5 cm) as a percentage of the total metal content.

<table>
<thead>
<tr>
<th></th>
<th>Pb</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (n=22)</td>
<td>1.37 - 17.43</td>
<td>1.60 - 25.57</td>
<td>0.13 - 8.30</td>
</tr>
<tr>
<td>Mean</td>
<td>7.00</td>
<td>11.10</td>
<td>3.65</td>
</tr>
<tr>
<td>Median</td>
<td>5.52</td>
<td>11.43</td>
<td>3.17</td>
</tr>
</tbody>
</table>

The results of the present study suggest that the potential bioavailability of Pb, Cu and Zn declines in the order Cu>Pb>Zn and are in agreement with findings of Massas et al. (1997) who concluded that Pb, Zn and Cu retained by soil organic matter in the same order. The influences of organic matter content and quality on the behaviour and potential mobility of heavy metals in soils is well documented (Mellor 2001). Organic matter interact with the metals forming complexes and chelates of varying stability. Leita et al (1999) supported that organic forms of metals present in soils, during organic matter mineralisation, can be released and become more available for plant-uptake.

It is well known that, among heavy metals, Cu shows a high relative affinity for humic substances and the abundance of Cu in organic fraction seems to be responsible for the higher availability of cooper in relation to the other metals.

Significant linear relationships between the total and DTPA extracted concentrations of the studied metals were observed (Figure 1), in accordance with Leita et al. (1999). Garcia and Millan (1998) also reported correlation coefficients between total and DTPA concentrations of 0.75, 0.85 and 0.93 for Cu, Zn and Pb respectively.

In the case of "Eleonas" soils, the strong relationships between total and DTPA extracted metal content, suggest that the bioavailable fraction of, Cu and Zn in that soils can be predicted by the total metal concentrations. The linear relationship for Pb is weaker but also significant.
Figure 1. Linear relationships between total and DTPA extractable Cu, Zn and Pb concentrations.
4. References


GLOBAL AGROCHEMICAL INDEXES OF SOIL FERTILITY

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Summary

The paper presents the establishing modalities of some global indexes of soil fertility, on the basis of the simple and synthetic indexes obtained within the framework of periodical agrochemical soil survey studies or of pedological soil survey studies. These global indexes can serve both to the farmer – in order to have a general image of the soil quality that he cultivates, to establish the strategy of the management of the farm or for a higher precision of some technological elements, and to establish the value of an agricultural land in order to commercialize it on the land market. Depending on the purpose and on the available data, the global indexes are established either at the level of agrochemical plots of average soil sampling, or at the level of a wider surface, such as the field or even the farm.

The establishing of the global indexes at the plot level has, as basic principle, the notation of each index on a scale from 0 to 100 points and thus bringing on the same "denominator" all the indexes taken into consideration. There are presented two methods of granting the notes. On the basis of the note/score given to each of the \( n \) indicators, the global agrochemical index of the plot (GAIP), or, if it also takes into account pedological indexes, the global index of plot fertility (GIPF) is calculated.

GAIP and GIPF interpretation is made on a scale from 0 to 100 points, standardized from 20 to 20 points, to which corresponds the following appreciation: very low fertility (0–20), low (21–40), medium (41–60), high (61–80) and very high (81–100). The paper also presents formulas for the calculation of the global agrochemical indexes (GAIF) and global fertility indexes (GFIF) at the level of a wider land surface: field, farm.

1. Introduction

There are different trials so that, on the basis of agrochemical indexes, or agrochemical and pedological, global indexes of the soil fertility should be established, indexes which to allow to evaluate the fertility level. There are also complex methodologies of evaluation not only of the soil, but of the agricultural lands too (Teaci, 1980), which take into consideration soil factors, climatic factors and others. Elaboration of the computing relations of global indexes is not easy because of the following causes: high complexity of the soil and of its basic feature – fertility; different indexes have no equal weight in the fertility definition; the measure units of the agrochemical and pedological indexes are different; some indexes are "related" between them, they are "relatives" (ex. pH and hydrolic acidity – \( A_h \)) – reflecting to some extent the influence of the "related" or very "related" indexes (ex.: exchangeable sodium, \( Na_{esch} \), and percentage of the adsorbed sodium, PSD) – reflecting in some cases the same thing, which implies great care in selecting the indexes taken into consideration; in some cases the increase of the index value means the increase of the fertility, and in other
cases (other indexes) the increase of the value means, on the contrary, the decrease of the fertility; for some indexes (pH, some nutrients), the increase of the values up to a point positively correlates with the increase of the fertility, then the further increase means the decrease of the fertility etc.

The fertility estimation based on such global indexes is more precise when the number of the indexes taken into account is higher, with the condition that the number of the similar indexes is reduced at minimum. Depending on the purpose and on the available data, the global indexes can be established either at the level of agrochemical plots of average soil sampling (samples taken in the framework of the periodical agrochemical soil survey studies), or at the level of a wider surface, such as the field or even the farm. Such indexes can serve both to the farmer – in order to have a general image of the soil quality that he cultivates, to establish the strategy of the management of the farm or for a higher precision of some technological elements, and to establish the value of an agricultural land in order to commercialize it on the land market.

2. Materials and methods

In România, the soil analyses are made and interpreted according to the official methodology elaborated by The Research Institute for Soil Science and Agrochemistry – RISSA, Bucharest (1981, 1987).

The simple agrochemical indexes, directly determined by analyses within the periodical (2–5 years) agrochemical studies, are:

a) Indexes of the acidity, cation exchanging capacity and base saturation: \( \text{pH}_{\text{H}_{2}\text{O}} \); \( A_h \) – hydrolytic acidity, me/100 g soil (Kappen method); \( SB \) – sum of exchangeable bases, me/100 g soil (Kappen method);

b) Alkalinity indexes: \( \text{Na}_{\text{exch}} \) – exchangeable Na content, me/100 g soil; \( T_{\text{Na}} \) – total cationic exchanging capacity for Na to solonetzs and alkalized soils, me/100 g soil (Bower method); \( CO_{3}^- \) and \( HCO_{3}^- \) – content of carbonate and bicarbonate ions, soluble forms, me/100 g soil; active \( \text{CaCO}_3 \), \% (Juste-Pouget method);

c) Salinity indexes: \( \text{TCSS} \) – total content of soluble salts, mg/100 g soil (by conductometry); \( C_F \), \( SO_{4}^{2-} \) – water soluble ions, me/100 g soil;

d) Indexes of the soil supply with humus and nutrients: \( H \) – humus content, \% (Walkley-Black-Gogoșă method); \( N-\text{NO}_3 \) and \( N-\text{NH}_4 \) – content of nitric and ammoniacal N, ppm N; \( P_{\text{AL}} \) and \( K_{\text{AL}} \) – mobile P and K content, ppm P and ppm K (AL – acetate-lactate or ERD – Egner-Riehm-Domingo method); \( P_{\text{MoCu}} \) – mobile P content, ppm P (Borlan method); \( K_{\text{exch}} \) and \( M_{\text{exch}} \) – exchangeable K and Mg, ppm; Cu, Fe, Mn, Mo, Zn – micronutrient content, mobile forms, ppm element; B – hydrosoluble B content, ppm B. For the arable soils, the most frequent analyses are those of \( \text{pH}, P_{\text{AL}}, K_{\text{AL}}, H, SB \) and \( A_h \).

Synthetic agrochemical indexes. Depending on the purpose, utilization of a synthetic indexe, which include two or more simple indexes, is more useful than that of the constitutive simple indexes. The most important agrochemical synthetic indexes are: total cationic exchanging capacity, \( T_{Ah} \) (me/100 g soil) = \( SB + A_h \); degree of the base saturation, \( V_{Ah} \) (%) = \( \{SB/(SB+A_h)\} \times 100 \); nitrogen index, \( \text{IN} \) = \( H-V_{Ah}/100 \); percentage of the adsorbed sodium, \( \text{PSA} \) (%) = \( (\text{Na}_{\text{exch}}/T_{\text{Na}}) \times 100 \); the index of the clorozant power of the soil – \( \text{IPC} \); index of the magnesium deficiency – \( \text{IDMg} \); index of the cooper deficiency – \( \text{IDCu} \); index of the zinc carence – \( \text{IZn} \); molybdenum index – \( \text{IMo} \).

Indexes of the physical soil features. Among these, there are: clay, dust and sand contents – on the basis of which the soil texture is estimated; porosity – total and of aeration; bulk density; degree of compactation; wilting point; water field capacity, total water capacity, useful water capacity; permeability; soil resistance to penetration et al.

Interpretation of the analytical results (simple indexes) or of the synthetic indexes values is made, according to the RISSA’s methodology, by the method of limits. For example, in the
case of some nutrients, the soil supply is interpreted as: low, medium, high, very high (table 1).

The way of the utilization of the simple and synthetic indexes for calculating some global indexes of the soil fertility is presented at point 3 – results and discussions, insisting on exemplifications on the agrochemical indexes because they are most frequently determined and they are most accessible.

2. Results and discussions

3.1. Global agrochemical indexes at the agrochemical plot level – GAIP, and global fertility indexes at the plot level – GFIP. At the agrochemical plot level, we can calculate global agrochemical indexes, GAIP, if we take into calculation only agrochemical indexes, or global fertility indexes, GFIP, if we take into computation pedological indexes too.

The establishing of the global indexes has, as basic principle, the notation of each index on a scale from 0 to 100 points and bringing so on the same "denominator" all the indexes taken into consideration. On the basis of the note-score (Ni) given to each of the n indicators, we calculate the global agrochemical index of the plot (GAIP) and the global index of plot fertility (GFIP) with relations such as:

\[
GAIP = \frac{\sum_{i=1}^{n} N_i}{n} \quad \text{and} \quad GFIP = \frac{\sum_{i=1}^{n} N_i}{n}
\]

GAIP and GFIP interpretation is made on a scale from 0 to 100 points, standardized from 20 to 20 points (table 2).

**Example:** If a plot has: N_{pH} = 71, N_{IN} = 50, N_p = 40, N_K = 85, N_{VAh} = 80, N_{TAh} = 100, than

\[
GAIP = \frac{(71 + 50 + 40 + 85 + 80 + 100)}{6} = 58 \text{ points},
\]

which means that globally this plot has a medium fertility from the agrochemical point of view (table 2).

The note/score granting for each index. Two methods can be used, the application of one or another depending on the available data.

a) Establishment of the notes using computing formulae. It is the most precise method. In principle, for a quantifiable soil index, there is: an optimum area of values, delimited by two limits, one inferior – X_{opti}, and one superior – X_{opts}, between which the fertility is maximum, and the note is also maximum, 100 points; a minimum threshold – X_{min}, below which the fertility does not decrease or is null; a maximum threshold – X_{max}, over which the fertility does not decrease or is null (fig. 1).

a1) For soil indexes to which the fertility increases up to a point with the increase of the value of the soil index up to X_{opti} and decreases with the increase of the index value over X_{opts}, such as pH, hydrosoluble B content et al., the relations for the calculation of the note N depend on the area in which there is the X value of the soil index, and they are:

1) if X_{opti} ≤ X ≤ X_{opts}, than: \[N = 100;\]
2) if \( X \leq X_{\text{min}} \), then: \( N = N' \) or \( N = 0 \);

3) if \( X > X_{\text{max}} \), then: \( N = N'' \) or \( N = 0 \);

4) if \( X_{\text{min}} < X < X_{\text{opti}} \) and the soil fertility increases with the increase of the \( X \) value between \( X_{\text{min}} \) and \( X_{\text{opti}} \), then:

\[
N = N' + (100 - N') \left\{ \frac{X - X_{\text{min}}}{X_{\text{opti}} - X_{\text{min}}} \right\}
\]

and if \( N' = 0 \), then:

\[
N = \frac{X - X_{\text{min}}}{X_{\text{opti}} - X_{\text{min}}} \cdot 100
\]

5) if \( X_{\text{max}} > X > X_{\text{opts}} \) and the fertility decreases with the increase of the \( X \) value over \( X_{\text{opts}} \), then:

\[
N = N'' + (100 - N'') \left\{ \frac{X_{\text{max}} - X}{X_{\text{max}} - X_{\text{opts}}} \right\}
\]

and if \( N'' = 0 \), then:

\[
N = \frac{X_{\text{max}} - X}{X_{\text{max}} - X_{\text{opts}}} \cdot 100
\]

\[X = \text{some value of the considered soil index;}\]

\[X_{\text{min}} = \text{the minimum value of } X \text{ under which the fertility is not anymore negatively influenced;}\]

\[X_{\text{max}} = \text{the maximum value of } X \text{ over which the fertility is not anymore negatively influenced;}\]

\[N' = \text{the value under which } N \text{ does not decrease anymore if } X \text{ decreases under } X_{\text{min}}; \text{ generally, when } X = X_{\text{min}}, N' = 0;\]

\[N'' = \text{the value under which } N \text{ does not decrease anymore if } X \text{ increases over } X_{\text{max}}; \text{ generally, when } X = X_{\text{max}}, N'' = 0.\]

For example, for \( \text{pH}_{\text{H2O}} \), the relations for the calculation of the note are:

\[
N = \begin{cases} 100 & \text{if } 6.5 \leq \text{pH} \leq 7.5; \\ 0 & \text{if } \text{pH} < 3 \text{ or } \text{pH} > 9.5; \\ \left\{ [\text{pH} - 3]/(6.5 - 3) \right\} \cdot 100 & \text{if } 3 \leq \text{pH} < 6.5; \\ \left\{ (9.5 - \text{pH})/(9.5 - 7.5) \right\} \cdot 100 & \text{if } 7.5 < \text{pH} \leq 9.5. 
\end{cases}
\]

**Example of calculation:** If \( \text{pH} = 5.5 \), then \( N_{\text{pH}} = \left\{ (5.5 - 3)/(6.5 - 3) \right\} \cdot 100 = 71 \text{ points.} \)

**a2) For the indexes to which the soil fertility increases with the increase of their values:** \( V_{\text{Ah}}, \text{SB}, T_{\text{Ah}}, H, \text{IN}, P_{\text{AL}}, K_{\text{AL}} \) et al., without considering that the outrunning of a threshold leads to the decrease of the fertility, we use the equations 1-4 presented above.

**a3) For the indexes to which the soil fertility strictly decreases with the increase of their values:** \( A_{\text{h}}, A_{\text{exch}}, \text{CaCO}_3_{\text{active}}, N_{\text{exch}}, \text{PSA} \), alcalinity – evaluated through the content of \( \text{CO}_3^{2-} \) and \( \text{HCO}_3^- \) disociated ions, total content of the soluble salts et al, the relations for calculation are: 1) if \( 0 \leq X \leq X_{\text{opts}} \), then \( N = 100 \); 2) if \( X > X_{\text{opts}} \) then the relations are those from the point 5 of the a1.

**b) Establishing of the notes with bilaterale tables depending on the number of classes of the soil index and to the class to which its concrete value belong.** The note depends on the qualitative evaluation of the index – made on the basis of concrete analytical values according to RISSA’s official instructions and methodology (1981, 1983, 1987) and on its significance for soil fertility.

**b1) For the indexes to which the soil fertility increases with the increase of their values:** \( V_{\text{Ah}}, \text{SB}, T, H, \text{IN}, P_{\text{AL}}, K_{\text{AL}} \) et al., the score is granted depending on the class \( C_1 \ldots C_n \) in which the index value is included and on the number of classes which characterize the area of variation of the considered index (table 3). The number of classes coresponds to RISSA’s instructions and metodhology (1981, 1983, 1987): 4 classes for \( \text{IN}, K_{\text{AL}}, \text{Mg}_{\text{exch}} \); 5 classes for \( P_{\text{AL}} \); 5 for \( V_{\text{Ah}} \); 5 for humus on mineral soils; 7 for SB and for T\text{Ah} etc.

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of classes of the index*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>( C_1 )</td>
<td>33</td>
</tr>
<tr>
<td>( C_2 )</td>
<td>67</td>
</tr>
<tr>
<td>( C_3 )</td>
<td>100</td>
</tr>
<tr>
<td>( C_4 )</td>
<td>100</td>
</tr>
<tr>
<td>( C_5 )</td>
<td>100</td>
</tr>
<tr>
<td>( C_6 )</td>
<td>100</td>
</tr>
<tr>
<td>( C_7 )</td>
<td>100</td>
</tr>
<tr>
<td>( C_8 )</td>
<td>100</td>
</tr>
</tbody>
</table>

b2) For the indexes to which the soil fertility decreases with the increase of their values: \( \text{Ah} \) – 6 classes; \( \text{Al}_{\text{exch}} \) and \( \text{CaCO}_3 \) active – 8 classes; \( \text{Na}_{\text{exch}} \) and \( \text{PSA} \) – 5 classes; the alcalinity evaluated on the basis of the content of \( \text{CO}_3^{2-} \) and \( \text{HCO}_3^- \) dissociated ions – 6 classes; the total content of soluble salts – 5 classes etc., the score is that from table 4.

b3) For the indexes to which the increase of the value up to a point positively correlates with the increase of the soil fertility and then the fertility decreases with the increase of the index value (e.g. \( B \)) et al. For the classes to which the increase of the index value positively correlates with the fertility, the granting of the note/score is done according to table 3, the framing being done depending on the number of classes up to which the fertility is maximum. For the classes to which the fertility decreases with the increase of the index value, for each additional negative class, the scoring is done according to the inferior classes to the optimal one by a step. The optimal class is that which shows a very good, non toxic supply of nutrients. Because in the case of the potentially toxic excess of nutrients in the RISSA’s instructions and \( \& \) méthodologie the distinction by classes of excess is not done, the scoring will be made depending on the intensity of the excess, toxicity respectively.

3.2. Global agrochemical indexes, GAIF, and global fertility indexes, GFIF, at the field or farm level (higher land surface then the agrochemical plot). A field or a farm has many agrochemical soil sampling plots. With the aim to have a general image on the field or farm, it can calculate GAIF or GFIF. There are two ways of calculation.

a) Calculation of GAIF and GFIF as arithmetical averages of the global indexes of the soil sampling plots, GAIP and GFIP respectively, the interpretation being done by the same scale as for the soil sampling plot.

b) Another modality, more laborious but more precise, consists in calculating the score/note at the field or farm level for each agrochemical or pedological index with specific formulae which take into account the number of class quality (see over) of the considered index and the weight of the surfaces from each class, as % from total land surface (field or farm); then it computes GAIF and GFIF as arithmetical averages of the notes granted to the \( n \) indexes taken into consideration:

\[
\text{GAIF} = \frac{\sum_{i=1}^{n} N_i}{n} \quad \text{and} \quad \text{GFIF} = \frac{\sum_{i=1}^{n} N_i}{n}
\]

The interpretation of the GAIF and GFIF values is made in the same way as for the global indexes at the plot level (GAIP and GFIP).

b1) For the indexes to which the soil fertility increases with the increase of their values, the relations for the note (N) calculation of each index are:

- for the indexes with 3 classes:
  \( N = 0.33 \cdot \text{WC}_1 + 0.67 \cdot \text{WC}_2 + 1 \cdot \text{WC}_3 \)
- for the indexes with 4 classes of quality (e.g. \( \text{In} \), \( \text{K}_\text{AL} \), \( \text{Mg}_{\text{exch}} \)):
  \( N = 0.25 \cdot \text{WC}_1 + 0.5 \cdot \text{WC}_2 + 0.75 \cdot \text{WC}_3 + 1 \cdot \text{WC}_4 \)
- for the indexes with 5 classes (e.g. \( P_{\text{AL}} \), \( V_{\text{Ah}} \) \( \text{humus} \) on mineral soils):
  \( N = 0.2 \cdot \text{WC}_1 + 0.4 \cdot \text{WC}_2 + 0.6 \cdot \text{WC}_3 + 0.8 \cdot \text{WC}_4 + 1 \cdot \text{WC}_5 \)
- for the indexes with 6 classes:
  \( N = 0.17 \cdot \text{WC}_1 + 0.33 \cdot \text{WC}_2 + 0.5 \cdot \text{WC}_3 + 0.67 \cdot \text{WC}_4 + 0.83 \cdot \text{WC}_5 + 1 \cdot \text{WC}_6 \)

### Table 4: The note/score granted to the indexes to which the soil fertility decreases with the increase of their values: \( \text{Ah} \), \( \text{Al}_{\text{exch}} \), \( \text{Na}_{\text{exch}} \), \( \text{CO}_3^{2-} + \text{HCO}_3^- \) et al.

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of classes of the index*</th>
<th>Note/score</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₁</td>
<td>100</td>
<td>100 100 100 100 100 100</td>
</tr>
<tr>
<td>C₂</td>
<td>67</td>
<td>75 80 87 86 87 87</td>
</tr>
<tr>
<td>C₃</td>
<td>33</td>
<td>50 60 67 71 75 75</td>
</tr>
<tr>
<td>C₄</td>
<td>25</td>
<td>40 50 57 62 62</td>
</tr>
<tr>
<td>C₅</td>
<td>20</td>
<td>33 43 50 50</td>
</tr>
<tr>
<td>C₆</td>
<td>17</td>
<td>28 37 37</td>
</tr>
<tr>
<td>C₇</td>
<td>14</td>
<td>25 25</td>
</tr>
<tr>
<td>C₈</td>
<td>12</td>
<td>12 12</td>
</tr>
</tbody>
</table>

– for the indexes with 7 classes of quality (e.g. SB, $T_{abh}$):
$$N = 0.14 \cdot WC_1 + 0.29 \cdot WC_2 + 0.43 \cdot WC_3 + 0.57 \cdot WC_4 + 0.71 \cdot WC_5 + 0.86 \cdot WC_6 + 1 \cdot WC_7$$
– for the indexes with 8 classes of quality:
$$N = 0.12 \cdot WC_1 + 0.25 \cdot WC_2 + 0.37 \cdot WC_3 + 0.5 \cdot WC_4 + 0.62 \cdot WC_5 + 0.75 \cdot WC_6 + 0.87 \cdot WC_7 + 1 \cdot WC_8$$

The symbols $WC_1$…$WC_n$ used in these relations represent the percentual weight of the surfaces which are included in each class of quality of the considered index, as % from the total characterized surface (field, farm). For example, for the mobile K, WC$_1$ represents % soils poorly supplied (class C$_1$), and WC$_4$ % soils very well supplied (class C$_4$). The symbol $N$ (note) will take as index the considered agrochemical or pedological index. For example, NI$_{IN}$ is the note for the nitrogen index – which reflect the soil supply with potentially available N, N$_{P-AL}$ is the note for the mobile phosphorus (P$_{AL}$), N$_{K-AL}$ is the note for the mobile potassium (K$_{AL}$), N$_{VAh}$ is the note for the degree of the base saturation etc.

b2) For the indexes to which the soil fertility decreases with the increase of their values: $A_h$, $Al_{exch}$, active CaCO$_3$, $Na_{exch}$ PSA, alkalinity given by the CO$_3^{2-}$ and HCO$_3^-$ dissociated ions, the total content of soluble salts et al., the computing relations are:
– for the indexes with 3 classes:
$$N = 1 \cdot WC_1 + 0.67 \cdot WC_2 + 0.33 \cdot WC_3$$
– for the indexes with 4 classes:
$$N = 1 \cdot WC_1 + 0.75 \cdot WC_2 + 0.5 \cdot WC_3 + 0.25 \cdot WC_4$$
– for the indexes with 5 classes (ex. $Na_{exch}$ PSA, the total content of soluble salts):
$$N = 1 \cdot WC_1 + 0.8 \cdot WC_2 + 0.6 \cdot WC_3 + 0.4 \cdot WC_4 + 0.2 \cdot WC_5$$
– for the indexes with 6 classes (ex. $A_h$, alkalinity: CO$_3^{2-}$ + HCO$_3^-$):
$$N = 1 \cdot WC_1 + 0.83 \cdot WC_2 + 0.67 \cdot WC_3 + 0.5 \cdot WC_4 + 0.33 \cdot WC_5 + 0.17 \cdot WC_6$$
– for the indexes with 7 classes of quality:
$$N = 1 \cdot WC_1 + 0.86 \cdot WC_2 + 0.71 \cdot WC_3 + 0.57 \cdot WC_4 + 0.43 \cdot WC_5 + 0.29 \cdot WC_6 + 0.14 \cdot WC_7$$
– for the indexes with 8 classes of quality (ex. $Al_{exch}$ CaCO$_3$ active):
$$N = 1 \cdot WC_1 + 0.87 \cdot WC_2 + 0.75 \cdot WC_3 + 0.62 \cdot WC_4 + 0.5 \cdot WC_5 + 0.37 \cdot WC_6 + 0.25 \cdot WC_7 + 0.12 \cdot WC_8$$

b3) For $pH_{H2O}$ the note is computed so:
$$N_{pH} = 0 \cdot WC_1 + 0.29 \cdot WC_2 + 0.49 \cdot WC_3 + 0.71 \cdot WC_4 + 1 \cdot WC_5 + 1 \cdot WC_6 + 0.86 \cdot WC_7 + 0.5 \cdot WC_8 + 0.3 \cdot WC_9 + 0.1 \cdot WC_{10} + 0 \cdot WC_{11}$$

WC$_1$…WC$_{11}$ represent the weights from each class (%); the significance of the classes C$_1$…C$_{11}$ for pH is: C$_1$ = extremely acid, C$_2$ = very highly acid, C$_3$ = highly acid, C$_4$ = moderately acid, C$_5$ = slightly acid, C$_6$ = neutral, C$_7$ = slightly alkaline, C$_8$ = moderately alkaline, C$_9$ = highly alkaline, C$_{10}$ = very highly alkaline, C$_{11}$ = extremely alkaline.

**Example.** If in a farm, by agrochemical soil survey it was established that the soil supply with mobile K is: low (C$_1$) on 20 %, medium (C$_2$) on 30 %, high (C$_3$) on 45 % and very high (C$_4$) on 5 % of the total surface, than the note for the mobile K (index with 4 classes of quality in which the fertility directly increase with its value) is: NK = 0.25·20 + 0.5·30 + 0.75·45 + 1·5 = 64 points.

Doing the interpretation only by this index, then, according to the interpretation scale (table 2), the farm has a good fertility (64 is in the interval 61–80). But, if we know: $N_{pH}$ = 100, NI$_{IN}$ = 50, N$_P$ = 30, N$_K$ = 64, N$_{VAh}$ = 75, N$_{CaCO3 active}$ = 100, N$_{salts}$ = 100; N$_{Na}$ = 100, then:
$$GAI_{F} = (100 + 50 + 30 + 64 + 75 + 100 + 100 + 100) / 8 = 77$$
which means that globally the soils from this farm have a good fertility from the agrochemical point of view (77 is in the interval 61–80).

The establishing system of the global agrochemical fertility indexes and of the global soil fertility indexes above presented is, of course, perfectible, this paper being intended as a starting point for further researches and developments. The system is applicable on computer.
3. References


Budoi Gh., 1998 – *Methods and technics for modelling the processes from the soil-plant system*. Univ. of Agronomic Sciences and Veterinary Medicine, Scientific Papers of the Faculty of Horticulture, Bucharest.


STUDIES CONCERNING THE INFLUENCE OF UNCONVENTIONAL AGROCHEMICAL MEANS (COMPLEX FOLIAR FERTILIZERS) ON DRY MATTER YIELD, N, P, K CONTENT AND N, P, K UPTAKE OF SUNFLOWER

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Summary

The experiment was carried out to see the effect of unconventional agrochemical means (foliar fertilizers) on dry matter yield, N, P, K content and N, P, K uptake of sunflower plant. This unconventional means consist in complex compositions of mineral nutrients (N, P, K, B, Cu, Mo, Zn) and organic substances (aminoacids, ureids, potassium naftenates, aneurine hydrochloride, novocaine hydrochloride) and they are produced using residual protein sources.

The foliar application of these fertilizers on sunflower (HS Select) in green house has significantly increased the dry matter yield, N, P, K content and N, P, K uptake of plants (as compared to unfertilised control) and has positively influenced the degree of productive use in yield of the nutrients from foliar applied fertilizers and from soil resources. All the variants with foliar fertilizers presented values exceeding 100 % (100 % is considered the control value).

1. Introduction

The foliar fertilization method appertains to new developments from crop fertilization domain. This method has received in the last time a large extend, generally due to: the real advantages offered; easy and rapid correction of the primary and secondary nutritional disorders in plants; quantitative and qualitative increases of the yields; diminution of the chemical pollution risks in the environment; high degree of productive use of the nutrients from soil and from the foliar fertilizers (Borlan Z. et al., 1984, 1994, 1995, Boynton D., 1960, Budoi, 2000, 2001). This paper presents new unconventional agrochemical means taken in study in order to establish their influence on dry matter yield, N, P, K content and N, P, K uptake of sunflower plants. The novelty and complexity of these means are represented by the possibility of association within the foliar compositions of the macro and micronutrients with organic active substances (aminoacids, ureids, which also maintain the micronutrients in soluble form).

2. Material and Methods

The tested foliar fertilizers have been produced by hydrolysis process of the residual protein sources (wheaten bran, maize flour, bone glue, degreasing extraction residues, Vinasse
product – resulted from compressed yeast production) with nitrophosphoric acid (4.5 n HNO₃+0.33 n H₃PO₄). To these hydrolyzates, it has been added adequate quantities of the mineral salts with macro and micronutrients. Finally, the obtained foliar compositions was neutralized with concentrated solution of ammonia (25 % NH₄) to pH 6. The chemical composition of the foliar fertilizers is presented in table 1.

Table 1: The chemical compositions of the complex foliar fertilizers (CFF)

<table>
<thead>
<tr>
<th>Elements and substances</th>
<th>Vinasse 1&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Vinasse 2&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Vinasse 3&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Vinasse 4&lt;sup&gt;1&lt;/sup&gt;</th>
<th>TG 1&lt;sup&gt;2&lt;/sup&gt;</th>
<th>TG 2&lt;sup&gt;2&lt;/sup&gt;</th>
<th>M 1&lt;sup&gt;3&lt;/sup&gt;</th>
<th>M 2&lt;sup&gt;3&lt;/sup&gt;</th>
<th>M 3&lt;sup&gt;3&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>N organic, g/l</td>
<td>6.65</td>
<td>5.11</td>
<td>8.4</td>
<td>4.79</td>
<td>16.8</td>
<td>14.3</td>
<td>4.78</td>
<td>9.64</td>
<td>5.65</td>
</tr>
<tr>
<td>N-NO₃, g/l</td>
<td>43.20</td>
<td>45.42</td>
<td>40.82</td>
<td>32.62</td>
<td>42.5</td>
<td>41.2</td>
<td>24.0</td>
<td>33</td>
<td>37.5</td>
</tr>
<tr>
<td>N-NH₄, g/l</td>
<td>42.41</td>
<td>43.72</td>
<td>39.42</td>
<td>37.02</td>
<td>44.5</td>
<td>43.5</td>
<td>45.78</td>
<td>36.5</td>
<td>38.5</td>
</tr>
<tr>
<td>N total, g/l</td>
<td>92.26</td>
<td>94.25</td>
<td>88.64</td>
<td>74.43</td>
<td>103.8</td>
<td>98.8</td>
<td>73.78</td>
<td>79.14</td>
<td>81.6</td>
</tr>
<tr>
<td>P, g/l</td>
<td>17.64</td>
<td>17.49</td>
<td>17.46</td>
<td>14.48</td>
<td>17.87</td>
<td>17.28</td>
<td>18.09</td>
<td>17.48</td>
<td>16.90</td>
</tr>
<tr>
<td>K, g/l</td>
<td>31.70</td>
<td>32.28</td>
<td>32.85</td>
<td>31.28</td>
<td>48.79</td>
<td>38.58</td>
<td>38.25</td>
<td>34.10</td>
<td>32.86</td>
</tr>
<tr>
<td>Mn, ppm</td>
<td>910</td>
<td>700</td>
<td>1050</td>
<td>1075</td>
<td>1050</td>
<td>860</td>
<td>12.0</td>
<td>545</td>
<td>1135</td>
</tr>
<tr>
<td>Fe, ppm</td>
<td>600</td>
<td>325</td>
<td>375</td>
<td>500</td>
<td>450</td>
<td>620</td>
<td>650</td>
<td>375</td>
<td>695</td>
</tr>
<tr>
<td>Zn, ppm</td>
<td>435</td>
<td>435</td>
<td>435</td>
<td>435</td>
<td>431</td>
<td>400</td>
<td>435</td>
<td>387</td>
<td>435</td>
</tr>
<tr>
<td>Cu, ppm</td>
<td>330</td>
<td>240</td>
<td>400</td>
<td>400</td>
<td>370</td>
<td>285</td>
<td>321</td>
<td>380</td>
<td></td>
</tr>
<tr>
<td>Novocaine hydrochloride</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Aneurine hydrochloride</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Potassium naphthenates</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

1) Vinasse 1–4: foliar fertilizers produced using Vinasse product (resulted from compressed yeast production) and residual protein hydrolyzates from bone glue and degreasing extraction residues.
2) TG 1, TG 2: foliar fertilizers produced using residual protein hydrolyzates from wheaten bran;
3) M 1, M 2, M 3 - foliar fertilizers produced using residual protein hydrolyzates from maize flour

The experiment was conducted in green house and was treated as monofactorial with 11 variants in 3 replicates. The soil was cambic chernozem from Fundulea with the following properties: humus - 2.5 %; pH (H₂O) - 6.3; mobile P - 36 ppm P; mobile K – 216 ppm K and clay – 29 %. In all variants, excepting control – sprayed with water and unfertilized in soil, it has been applied 100 mg N, P₂O₅, K₂O/kg soil as an 8-8-8 complex fertilizer. The foliar fertilizers have been applied 3 times as diluted solutions: 0.5-1 % concentrations. The first application was done on 18<sup>th</sup> of July 2000, the second application on 28<sup>th</sup> of July 2000, and the third application on 2<sup>nd</sup> of August 2000. The plants have been harvested after a week from the last application of the foliar fertilizers. The experimental data were processed by the analysis variance method, LSD test (Duncan test) and have been compared with the two controls: sprayed with water and unfertilized in soil; sprayed with water and fertilized in soil.
3. Results and discussions

3.1. The effect of foliar on dry matter yield of sunflower plants.

From the data presented in table 2 it can be observed that all the foliar fertilizers have determined a significant increase of the dry matter yield as compared with both controls. As it concerns the differences among foliar fertilizers, only that between TG1 and M3 these is significant. M3 assured the highest dry matter yield increase (148.5 g/pot) as compared with the control unfertilized in soil.

Table 2: The effect of foliar fertilizers on sunflower dry matter yield

<table>
<thead>
<tr>
<th>Variants</th>
<th>Dry matter yield (g/pot)</th>
<th>Yield increase (g/pot)</th>
<th>Yield Increase (g/pot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control sprayed with water, unfertilized in soil</td>
<td>26.8 d</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Control sprayed with water, fertilized in soil</td>
<td>95.06 c</td>
<td>68.1**</td>
<td>-</td>
</tr>
<tr>
<td>Vinasse 1</td>
<td>161.7 ab</td>
<td>134.9**</td>
<td>66.8**</td>
</tr>
<tr>
<td>Vinasse 2</td>
<td>166.6 ab</td>
<td>139.8**</td>
<td>71.7**</td>
</tr>
<tr>
<td>Vinasse 3</td>
<td>162.5 ab</td>
<td>143.9**</td>
<td>75.8**</td>
</tr>
<tr>
<td>Vinasse 4</td>
<td>170.4 ab</td>
<td>143.7**</td>
<td>75.5**</td>
</tr>
<tr>
<td>TG 1</td>
<td>150.9 b</td>
<td>124.1**</td>
<td>60.0**</td>
</tr>
<tr>
<td>TG 2</td>
<td>157.9 ab</td>
<td>131.1**</td>
<td>63.0**</td>
</tr>
<tr>
<td>M 1</td>
<td>161.2 ab</td>
<td>134.4**</td>
<td>66.3**</td>
</tr>
<tr>
<td>M 2</td>
<td>165.1 ab</td>
<td>137.7**</td>
<td>69.6**</td>
</tr>
<tr>
<td>M 3</td>
<td>175.3 a</td>
<td>148.5**</td>
<td>80.4**</td>
</tr>
<tr>
<td>LSD 5%</td>
<td>19.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSD 1%</td>
<td>26.24</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2. The effect of foliar fertilizers on N, P, K content of plants.

The N, P, K contents of sunflower plants are presented in table 3. From this it can be seen that all the foliar fertilizers have no influence on N, P, K content of the plants as compared with the control fertilized in soil, but generally there are significant differences as compared with the control unfertilized in soil. Thus, it can observe that in all variants with foliar fertilizers, the N and K content registered a decrease as compared with the control fertilized in soil. This can be explained by dilution of N and K in a more quantity of dry matter obtained with the foliar fertilizers. Borlan Z. (1994) has found similar results.

Table 3: The effect of foliar fertilizers on N, P and K content of sunflower plants

<table>
<thead>
<tr>
<th>Variants</th>
<th>N, %</th>
<th>P, %</th>
<th>K, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control sprayed with water, unfertilized in soil</td>
<td>0.74 b</td>
<td>0.22 b</td>
<td>1.83 b</td>
</tr>
<tr>
<td>Control sprayed with water, fertilized in soil</td>
<td>1.77 a</td>
<td>0.24 ab</td>
<td>2.00 a</td>
</tr>
<tr>
<td>Vinasse 1</td>
<td>1.46 a</td>
<td>0.23 ab</td>
<td>1.93 ab</td>
</tr>
<tr>
<td>Vinasse 2</td>
<td>1.52 a</td>
<td>0.25 a</td>
<td>2.00 a</td>
</tr>
<tr>
<td>Vinasse 3</td>
<td>1.65 a</td>
<td>0.26 a</td>
<td>2.01 a</td>
</tr>
<tr>
<td>Vinasse 4</td>
<td>1.60 a</td>
<td>0.24 ab</td>
<td>1.96 a</td>
</tr>
<tr>
<td>TG 1</td>
<td>1.73 a</td>
<td>0.25 a</td>
<td>1.96 a</td>
</tr>
<tr>
<td>TG 2</td>
<td>1.67 a</td>
<td>0.26 a</td>
<td>1.97 a</td>
</tr>
<tr>
<td>M 1</td>
<td>1.75 a</td>
<td>0.25 a</td>
<td>1.97 a</td>
</tr>
<tr>
<td>M 2</td>
<td>1.63 a</td>
<td>0.24 ab</td>
<td>1.94 ab</td>
</tr>
<tr>
<td>M 3</td>
<td>1.66 a</td>
<td>0.23 ab</td>
<td>1.93 ab</td>
</tr>
<tr>
<td>LSD 5%</td>
<td>0.20</td>
<td>0.03</td>
<td>0.10</td>
</tr>
<tr>
<td>LSD 1%</td>
<td>0.27</td>
<td>0.05</td>
<td>0.14</td>
</tr>
</tbody>
</table>

3.3 The effect of foliar fertilizers on N, P, K uptake of plants. As it concerns the influence of foliar fertilizers on N, P and K uptake of sunflower plants (table 4), these have had statistically significant effect as compared with both controls. Thus, regarding N uptake, the foliar fertilizers assured increases between 0.648–1.237 g/pot, for P uptake between 0.156–0.203 g/pot, and for K uptake between 1.220–1.507 g/pot as compared with the control fertilized in soil. The differences between foliar fertilizers are significant for Vinasse 1 and M3 for N uptake, and for TG 1 and M3 for K uptake.

Table 4: The effect of foliar fertilizers on sunflower N, P, K uptake

<table>
<thead>
<tr>
<th>Variants</th>
<th>N uptake (g/pot)</th>
<th>P uptake (g/pot)</th>
<th>K uptake (g/pot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control sprayed with water, unfertilized in soil</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Control sprayed with water, fertilized in soil</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Vinasse 1</td>
<td>0.648–1.237</td>
<td>0.156–0.203</td>
<td>1.220–1.507</td>
</tr>
<tr>
<td>Vinasse 2</td>
<td>0.648–1.237</td>
<td>0.156–0.203</td>
<td>1.220–1.507</td>
</tr>
<tr>
<td>Vinasse 3</td>
<td>0.648–1.237</td>
<td>0.156–0.203</td>
<td>1.220–1.507</td>
</tr>
<tr>
<td>Vinasse 4</td>
<td>0.648–1.237</td>
<td>0.156–0.203</td>
<td>1.220–1.507</td>
</tr>
<tr>
<td>TG 1</td>
<td>0.648–1.237</td>
<td>0.156–0.203</td>
<td>1.220–1.507</td>
</tr>
<tr>
<td>TG 2</td>
<td>0.648–1.237</td>
<td>0.156–0.203</td>
<td>1.220–1.507</td>
</tr>
<tr>
<td>M 1</td>
<td>0.648–1.237</td>
<td>0.156–0.203</td>
<td>1.220–1.507</td>
</tr>
<tr>
<td>M 2</td>
<td>0.648–1.237</td>
<td>0.156–0.203</td>
<td>1.220–1.507</td>
</tr>
<tr>
<td>M 3</td>
<td>0.648–1.237</td>
<td>0.156–0.203</td>
<td>1.220–1.507</td>
</tr>
</tbody>
</table>

LSD 5% 0.20 0.03 0.10
LSD 1% 0.27 0.05 0.14
There is a high, very significant correlation between yield dry mater and N, P and K uptaken by plants (fig. 1).

### 3.4. The ecological effect of foliar fertilizers.

In order to estimate the ecological effect of foliar fertilizers, it has been calculated the apparent degree of productive use of nutrients (N, P, K) from foliar fertilizers in dry matter yields (ADPUNYFF, %) and the degree of productive use of nutrients (N, P, K) from soil resources and from fertilizers applied in soil in dry matter yields (DPUNYS, %).

In order to calculate the ADPUNYFF index, the following formula was used:

$$ ADPUNY_{FF}, \% = \frac{QNDMYI}{QNAFF} \times 100 $$

in which: $QNDMYI$ = quantity of nutrient from dry matter yield increase, g/pot; $QNAFF$ = quantity of nutrient from the foliar fertilizer, mg/pot.

The results showing the ADPNUYFF index (table 5) emphasized that all the foliar fertilizers assured, as compared with control, values exceeding 1000 % (100 % are conventionally considered the control value). Additionally, it can be observed that this index was 20–190 times more than the control. The DPUNYs index was calculated with the following formula:

$$ DPUNY_s, \% = \frac{(QNDMY_{FF} - QNDMY_{C}) - QNAFF}{QNDMY_{C}} \times 100 $$

in which: $QNDMY_{FF}$ = quantity of nutrient from dry matter yield obtained in the foliar fertilized variant, g nutrient/pot; $QNDMY_{C}$ = quantity of nutrient from dry matter yield obtained in the control variant, g nutrient/pot.

### Table 4: Effect of foliar fertilizers on N, P and K uptake of sunflower plants

<table>
<thead>
<tr>
<th>Variants</th>
<th>N, g/pot</th>
<th>P, g/pot</th>
<th>K, g/pot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control sprayed with water, unfertilized in soil</td>
<td>0.193 d</td>
<td>0.043 c</td>
<td>0.486 d</td>
</tr>
<tr>
<td>Control sprayed with water, fertilized in soil</td>
<td>1.676 e</td>
<td>0.220 b</td>
<td>1.896 c</td>
</tr>
<tr>
<td>Vinasse 1</td>
<td>2.360 b</td>
<td>0.376 a</td>
<td>3.116 ab</td>
</tr>
<tr>
<td>Vinasse 2</td>
<td>2.536 ab</td>
<td>0.420 a</td>
<td>3.323 ab</td>
</tr>
<tr>
<td>Vinasse 3</td>
<td>2.673 ab</td>
<td>0.423 a</td>
<td>3.263 ab</td>
</tr>
<tr>
<td>Vinasse 4</td>
<td>2.723 ab</td>
<td>0.403 a</td>
<td>3.344 ab</td>
</tr>
<tr>
<td>TG 1</td>
<td>2.560 ab</td>
<td>0.376 a</td>
<td>2.936 b</td>
</tr>
<tr>
<td>TG 2</td>
<td>2.630 ab</td>
<td>0.410 a</td>
<td>3.110 a</td>
</tr>
<tr>
<td>M 1</td>
<td>2.826 ab</td>
<td>0.393 a</td>
<td>3.176 ab</td>
</tr>
<tr>
<td>M 2</td>
<td>2.720 ab</td>
<td>0.393 a</td>
<td>3.183 ab</td>
</tr>
<tr>
<td>M 3</td>
<td>2.913 a</td>
<td>0.403 a</td>
<td>3.403 a</td>
</tr>
</tbody>
</table>

LSD 5% 0.455 0.083 0.405
LSD 1% 0.619 0.110 0.550

### Table 5: The apparent degrees of the productive use of nutrients (N, P, K) from foliar fertilizers in dry matter yields (ADPUNYFF, %)

<table>
<thead>
<tr>
<th>Variants</th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control sprayed with water, fertilized in soil</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Vinasse 1</td>
<td>2373</td>
<td>2068</td>
<td>9298</td>
</tr>
<tr>
<td>Vinasse 2</td>
<td>2530</td>
<td>2330</td>
<td>9641</td>
</tr>
<tr>
<td>Vinasse 3</td>
<td>3005</td>
<td>2494</td>
<td>9974</td>
</tr>
<tr>
<td>Vinasse 4</td>
<td>3484</td>
<td>2653</td>
<td>10059</td>
</tr>
<tr>
<td>TG 1</td>
<td>4667</td>
<td>3878</td>
<td>11583</td>
</tr>
<tr>
<td>TG 2</td>
<td>4976</td>
<td>4869</td>
<td>15192</td>
</tr>
<tr>
<td>M 1</td>
<td>7127</td>
<td>4200</td>
<td>15575</td>
</tr>
<tr>
<td>M 2</td>
<td>6413</td>
<td>4721</td>
<td>17809</td>
</tr>
<tr>
<td>M 3</td>
<td>6847</td>
<td>4879</td>
<td>19107</td>
</tr>
</tbody>
</table>

### Fig. 1 – The relations between the yield dry mater (Dm) and N, P(x10) and K uptakes of the sunflower plants

- $Dm f(Nupt.) = 55.74x + 14.143$
  $R^2 = 0.9633***$
- $Dm f(Kupt.) = 50.424x + 1,885$
  $R^2 = 0.9979***$
- $Dm f(Pupt.x10) = 37,929x + 11,736$
  $R^2 = 0.9796***$
The data regarding the DPUNYS index are presented in the table 6 and these show that in all the foliar fertilizer variants this index have registered values generally exceeding 100 %. These demonstrate that the foliar fertilizers assured a real ecological protection effect of the environment due to the increase of the degrees of productive use of nutrients from the foliar fertilizers and from soil resources trough the stimulation of the consumptions of nutrients in yield increases.

### Table 6: The degrees of the productive use of nutrients (N, P, K) in dry matter yields, nutrients from soil and from the fertilizers applied in soil (DPUNYS, %)

<table>
<thead>
<tr>
<th>Variants</th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control sprayed with water, unfertilized in soil</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Control sprayed with water, fertilized in soil</td>
<td>768</td>
<td>412</td>
<td>290</td>
</tr>
<tr>
<td>Vinasse 1</td>
<td>1080</td>
<td>740</td>
<td>535</td>
</tr>
<tr>
<td>Vinasse 2</td>
<td>1171</td>
<td>842</td>
<td>578</td>
</tr>
<tr>
<td>Vinasse 3</td>
<td>1242</td>
<td>849</td>
<td>565</td>
</tr>
<tr>
<td>Vinasse 4</td>
<td>1268</td>
<td>807</td>
<td>582</td>
</tr>
<tr>
<td>TG 1</td>
<td>1183</td>
<td>756</td>
<td>500</td>
</tr>
<tr>
<td>TG 2</td>
<td>1220</td>
<td>837</td>
<td>536</td>
</tr>
<tr>
<td>M 1</td>
<td>1321</td>
<td>795</td>
<td>550</td>
</tr>
<tr>
<td>M 2</td>
<td>1266</td>
<td>798</td>
<td>552</td>
</tr>
<tr>
<td>M 3</td>
<td>1366</td>
<td>821</td>
<td>597</td>
</tr>
</tbody>
</table>

**Conclusions:**

– the foliar fertilizers have significantly increased the dry matter yield of sunflower as compared with controls;
– the foliar fertilizers have no significant effect on N, P, K content of sunflower plants as compared with control fertilized in soil; the N and K content registered decreases in foliar fertilized variants, due to dilution of these elements in a higher quantity of dry matter;
– the foliar fertilizers have significant positive effect on N, P and K uptake of sunflower plants as compared with both controls;
– there is a high correlation between yield dry matter and N, P and K uptaken by plants;
– all tested foliar fertilizers assured, for ADPUNYF and DPUNYS indexes, the values exceeding 100 % and determined a high ecological protection of the environment.

### 4. References


EQUATIONS FOR FERTILIZATION IN FLORICULTURE

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Summary

The paper presents mathematical equations which can be used either directly for the computations necessary for the fertilization with nutrients of the flowers cultivated in pots or containers on physico-chemical active substrata, either in computer softwares used for computations or destined to automatic systems of flower fertilization. One of the equations allows the computation of the concentration of the nutritive solution in the considered nutrient, $C_{ns}$, that has to be applied during vegetation when one wants to correct gradually the initial under optimal concentration of the substrata solution, $C_i$, within a given number of days. Others serve to calculate the number of percolations, $n_p$, of the substratum and the total volume of water used for percolation, $V_{ap}$, when it is necessary to correct the excessive concentrations of nutrients from substratum, potentially toxic, by repeated percolations with clean water, in order to get an optimal concentration. Some equations allow to calculate the number of days, $n_d$, in which the initial concentration (optimal for example) of the substratum solution, $C_i$, will decrease to a critical level, $C_{cr}$, as result of the plant consumption.

1. Introduction

The direct application of fertilizers as solide salts on the substratum surface to the plants cultivated in pots and containers is excluded, even if followed by immediate wetting, because of the high salinization effect of the substratum solution on the surface, which can cause burnings at the root system level. For this reason, fertilization in vegetation is only done as diluted nutritive solutions. These are not to be applied to the dried substrata, but to those that have been wetted first so that the volume of the nutritive solution which will be applied should raise the moisture level to that corresponding to the retention capacity of the pot/container or close to this one.

Among the authors who had contributed to specifying flower fertilization method one can mentione: André (1978, 1981, 1985), Della Beffa (1999), Ghidia et. al. (1980), ICPA (1981), Lemaire et. al. (1990), Lesaint et al. (1983), Penningsfeld et al. (1975), Rivière et al. (1987), Sonea et al. (1971, 1979), Ţelaru (1995, 1998). Those who can be considered to have introduced the highest rigour regarding the fertilization of the flowers cultivated in pots and containers on active substratum are Lemaire et. al. (1990). It is recommended that the reading of the present paper should be completed with the lecture of Lemaire's et. al. publication (1990), mentioned in references.
2. Materials and methods

At the bases of the present paper, which refers to the fertilization during vegetation of the flowers cultivated in pots and containers, there is Lemaire's et al. paper (1990). Although in a principle, scientific aspect, Lemaire's method is one of the most modern and most precise, the way of application (calculation) presented by authors is laborious and heavy – being almost accesible only at an accademic level, thus discouraging its utilization. For this reason, having as bases both the principle aspects as well and the calculation examples, and bringing completions to the method, there were elaborated specific equations which facilitate computations and give the user confidence in this method. Moreover, these equations can be succesfully used in computer softwares used to effectuate the calculations rapidly, such as FLOWER-FERT (Budoi, 2001), or in softwares destined to some automatic systems of flower fertilization, which contribute more to the spreading and success of Lemaire's method. It is also one of the aims of this paper.

3. Results and discussions

Lemaire's et al. (1990) method is founded on establishing the nutritive solutions concentration based on the dynamics of the nutrient plant consumption and on the chemical equilibria between the solid and liquid phase of the substratum. In this way, it distinguishes clearly and positively from the methods which propose fixed concentrations of the nutritive solutions, as well as from other methods; by its flexibility, the method allows adapting the concentrations to the plant species and to the specific vegetation phase, with its specific features regarding mineral nutrition.

During vegetation, following problems can occur: a) because of the plant consumption, the nutrient concentration of the liquid phase of the substratum is underoptimal and has to be corrected by application of the adequate nutritive solutions; b) because of some mistakes, the concentration of the liquid phase of the substratum is excessive or even toxique and must be urgently corrected; c) the estimation of the number of days in which the initial concentration of the substratum solution (optimal or underoptimal, but not critical) will decrease, because of the plant consumption, to a critical level for nutrition.

3.1. Correction of the underoptimal concentration of the liquide phase of the substratum by nutritive solution application. The content in nutrients of the substratum is periodically and gradually corrected by nutritive solution application depending on: the initial underoptimal content in nutrient in soluble form in the substratum solution, $C_i$, determined by chemical analyses; the optimal content in soluble nutrient, $C_{i0}$, which has to be obtained by fertilization in the liquid phase of the substratum to the saturation moisture, specific to the cultivated species; the daily average nutrient exportation (consumption) of the plant for the considered vegetation phase, $E_{da}$, also specific for the cultivated species; the concentration of the corrective nutritive solution, $C_{ns}$, in the considered nutrient; the equilibrium ratio between the total form (adsorbed + soluble) and soluble form of the nutrient, $RE_{i/s}$, which establishes between solid and liquid phase of the substratum to the saturation moisture. For the substrata based on acide peat of Sphagnum, the equilibrium ratios presented by André (1978, 1981, 1985) and Lemaire et al. (1990) can be used; for other substrata, these ratios have to be established by chemical analyses, depending on the nature of the substratum.
The method supposes to know the dynamics of the optimal nutrient consumptions for each species or group of species with similar consumptions. Such indispensable data are either obtained from literature (presented in tables or graphics, see fig. 1 for example), or from experiments with plants grown in optimal nutritive conditions; the interval between two moments of plant analyses is chosen so that there are enough data in order to built the nutrient exportation curves. On the basis of these curves, one can estimate the average nutrient exportations in the period of time between two fertilizations depending on the phase of the vegetation period.

The method also supposes to know the optimal nutrient concentrations which have to be obtained in the substratum solution. There can be used, for example, the concentrations presented by Dartigues (1980), which vary according to the plant sensibility to salts and according to the nutrient.

Computation of the concentration of the nutritive solution, \( C_{ns} \), that has to be applied when the gradual correction of the initial underoptimal concentration of the substratum solution, \( C_i \), is intended in a given number of days, \( n_d \). This can be done with the equation:

\[
C_{ns}, \text{me/l} = \frac{(C_o - C_i) \cdot \text{VW}_{hc} \cdot \text{RE}_{eq} + E_{da} \cdot n_d}{V_{nscd} \cdot n_d}
\]

\[
C_{ns}, \text{mg/l} = C_{ns}, \text{me/l} \cdot \text{me}_{n}
\]

where: \( C_{ns} \) = concentration of the nutritive solution in the considered nutrient, me/l and mg/l respectively;

\( C_o \) = optimal content of the soluble nutrient which has to be obtained in the substratum solution (liquid phase) to the saturation moisture, me/l;

\( C_i \) = initial underoptimal content of nutrient in soluble form in the substratum solution, me/l;

\( \text{VW}_{hc} \) = volume of water at the pot or container holding capacity, l/pot or container:

\[
\text{VW}_{hc} \cdot \text{l/pot} = V \cdot \text{CT}_{wh}/100
\]

\( V \) = volume of the pot or container, l;

\( \text{CT}_{wh} \) = total water holding capacity, % from volume;

\( \text{RE}_{eq} \) = equilibrium ratio between the total form (adsorbed + soluble) and soluble form of the nutrient: it practically shows how much of the quantity of the nutrient applied with the nutritive solution remains in the substratum solution; for \( \text{NO}_3^- \), \( \text{RE}_{eq} = 1 \); according to André (1981), the ratio between the adsorbed form and the soluble form for an acide Sphagnum peat is: 1.5 for \( \text{K}^+ \), 1.5 for \( \text{NH}_4^+ \), 40 for \( \text{Ca}^{2+} \), 17 for \( \text{Mg}^{2+} \), 2000 for \( \text{Cu}^{2+} \), 100 for \( \text{Zn}^{2+} \) and 25 for \( \text{Mn}^{2+} \), which equalize the \( \text{RE}_{eq} \) values of: 2.5; 2.5; 41; 18; 2001; 101; 26;

\( E_{da} \) = average daily nutrient exportation of the plant for the considered vegetation phase, me/d/pot, specific for the cultivated species;

\( n_d \) = number of days in which the content of the liquid phase of the substratum has to be corrected by daily application of the nutritive solution in \( V_{nscd} \);

\( V_{nscd} \) = average volume of the nutritive solution consumed daily from the substratum, l/day;

\( \text{me}_{n} \) = miliequivalent of the nutrient or ion, mg.

\textbf{Example.} Compute what concentration of N (\( \text{NO}_3^- \)), P\(_2\text{O}_5\), K\(_2\text{O}\) and MgO, mg/l, must have a nutritive solution in order to correct in 10 days the initial concentrations, \( C_i \), of the substratum.
solution of a Hydrangea culture – being in the period 15/7–30/7, from 8.5 me N(NO₃⁻)/l, 2.5 me PO₄³⁻/l, 3.5 me K⁺/l and 1.1 me Mg²⁺/l, to the optimal concentrations, Cₒ, of 11 me N(NO₃⁻)/l, 3.3 me PO₄³⁻/l, 4.25 me K⁺/l and 1.5 me Mg²⁺/l. The wetting is done daily with a volume of nutritive solution equal to the average daily water consumption of plants (150 ml/day/pot).

It is known that: pot volume, V = 2 l, CT₇₈ = 80 % from volume; VW₇₈ = V·CT₇₈/100 = 2·80/100 = 1.6 l/pot; V₇₈ = 150 ml/day = 0.15 l/day, and the equilibrium ratioes, REₖ/s, are 1 for NO₃⁻, 7 for PO₄³⁻, 3 for K⁺ and 1.8 for Mg²⁺ (if the equilibrium ratio between the exchangeable K⁺ and soluble K⁺ is Kₑ⁺/Kₛ⁺ = 2/1 = 2, resulting that REₖ/s = (Kₑ⁺ + Kₛ⁺)/Kₛ⁺ = (2 parts + 1 part) / 1 part = 3).

From fig. 1 results the average daily plant consumption by pot: Eₕ = 120 mg N:15 days:4 = 0.57 me N/day/pot; 80 mg P₂O₅:15 = 5.33 mg P₂O₅/day/pot, 5.33:23.66 = 0.225 me PO₄³⁻/day/pot; 260 mg K₂O:1.2 = 214.9 mg K⁺/pot, 214.9:15:39 = 0.37 me K⁺/day/pot; 12 mg MgO:15:1.66 = 0.48 mg Mg²⁺/day/pot, 0.48:12.15 = 0.04 me Mg²⁺/day/pot. In these calculations, 39 and 12.15 are the K⁺ and Mg²⁺ miliequivalents, and 23.66 is the transforming coefficient from mg P₂O₅ to me PO₄³⁻.

For the above data, the following concentrations result:

\[ C_{₉₄}N = \frac{(11 - 8.5) \cdot 1.6 \cdot 1 + 0.57 \cdot 10}{0.15 \cdot 10} = 6.47 \text{ me N/l}; \quad C_{₉₄}P = \frac{(3.3 - 2.5) \cdot 1.6 \cdot 7 + 0.225 \cdot 10}{0.15 \cdot 10} = 7.47 \text{ me PO₄³⁻/l} \]

\[ C_{₉₄}K = \frac{(4.25 - 3.5) \cdot 1.6 \cdot 3 + 0.37 \cdot 10}{0.15 \cdot 10} = 4.87 \text{ me K⁺/l}; \quad C_{₉₄}Mg = \frac{(1.5 - 1.1) \cdot 1.6 \cdot 18 + 0.04 \cdot 10}{0.15 \cdot 10} = 7.95 \text{ me Mg²⁺/l}. \]

Thus, the concentrations, as me/l nutritive solution, are: 6.47 me N/l; 7.47 me PO₄³⁻; 4.87 me K⁺/l and 7.95 me Mg²⁺/l. The concentrations, as mg/l nutritive solution, are: 6.47·14 = 91 mg N/l or 6.47·62 = 401 mg NO₃⁻/l; 7.47·23.66 = 112 mg P₂O₅/l or 112·2.29 = 49 mg P/l; 4.87·39 = 190 mg K⁺/l or 190·1.21 = 230 mg K₂O/l; 7.95·12.15 = 97 mg Mg²⁺/l or 97·1.66 = 161 mg MgO/l. So, the nutritive solution must have 91 mg N/l, 112 mg P₂O₅/l, 230 mg K₂O/l, 161 mg MgO/l and a ratio N:P₂O₅:K₂O:MgO of 1:1.23:2.53:1.77.

The above mentioned formula allows the adaption of the concentrations of the nutritive solutions to the plant nutrient requirements, specific for each species and vegetation phase, because it considers the average daily nutrient exportation on vegetation phases.

The number of days, nₙ₉₄, in which a corrective nutritive solution, with a given concentration, has to be applied in a given vegetation phase, in order that the substratum solution goes from an initial underoptimal concentration to an optimal one. This can be calculated with the equation:

\[ nₙ₉₄ = \frac{(Cₒ - Cₛ) \cdot VW₇₈ \cdot REₖ/s}{V₇₈ \cdot Cₙs - Eₕ} \]

where the significance of the terms is above mentioned, and: V₇₈Cₙs = Aₙ = the daily contribution of the nutritive solution regarding the considered nutrient, me/pot; VW₇₈REₖ/s/(A₉₄ - Eₕ) is the reverse of the daily average net gain (me/l) of the nutrient in the substratum solution.

**Example.** We want to fertilize Hydrangea hortensis with K in the period from 15/7 to 30/7, we have a nutritive solution which contains 8.69 me K⁺/l and it is necessary to gradually rise the K⁺ concentration of the substratum solution from the initial value of 2.5 me K⁺/l to optimal value of 4.25 me K⁺/l. It is known that: VW₇₈ = 1.6 l/pot; V₇₈ = 0.15 l/day; Cₒ = 4.25 me K⁺/l; Cₛ = 2.5 me K⁺/l; Cₙs = 8.69 me K⁺/l; REₖ/s = 3; Eₕ = 0.37 me K⁺/day/pot (see the previous example).

The number of days in which the nutritive solution with a concentration of 8.1 me K⁺/l has to be applied is:
3.2. Correction of the excessive concentrations of the nutrients from the substratum solution (liquid phase), potentially toxic. If one observes that the plants suffer because of the application of a too higher quantity of fertilizers or because of the transformation of the wetting water into a concentrated nutritive solution, one must immediately intervene with repeated percolations of the substratum with clean water in order to wash off the excess of the nutrients, and the collected water from the pot supports is thrown away. For the next fertilizations the concentrations of the nutritive solutions have to be reduced and calculated on the basis of the plant consumption as above described.

The disadvantage of the percolation is that not only the excess of the desired nutrient is washed, but also a part of other nutrients which were not in excess, and there can appear deficiencies in those nutrients or different nutrient unbalances. In this case, the analysis of the substratum is required and then the application of a nutritive solution with an adequate composition and concentration which will rebalance the substratum.

The number of percolations (leachings), \( n_p \), of the substratum, which is at the pot or container capacity of water retention, in order to get from an initial excessive concentration to an optimal concentration, can be computed with the relation:

\[
\log(C_o / C_i) / \log(RE_a/t)
\]

where:
- \( C_i \) and \( C_o \) = the initial (excessive) nutrient content in soluble form and the optimal content, respectively, me/l;
- \( RE_a/t \) = the equilibrium ratio between adsorbed form of the nutrient and total form (adsorbed + soluble).

One percolation means a volume of water equal with \( V \cdot W \cdot C_h \), that means the volume of water to the holding capacity of the pot, l/pot, 2 percolations means 2·\( V \cdot W \cdot C_h \) etc. The total volume of clean water used for percolation, \( V_{wp} \), is computed depending on \( n_p \) and \( V \cdot W \cdot C_h \):

\[
V_{wp}, \text{ l/pot} = n_p \cdot V \cdot W \cdot C_h
\]

**Example.** For the same substratum properties as in the previous example, but with \( C_i = 12 \text{ me K}^+/l, C_o = 4,25 \text{ me K}^+/l, RE_a/t = 2/(2 + 1) = 2/3 \), we have:

\[
n_p = \log(4.25/12) / \log(2/3) = -0.451/-0.176 = 2.56 \text{ percolations;} \quad V_{wp} = 2.56 \cdot 1.6 = 4.1 \text{ l/pot.}
\]

3.3. Calculation of the number of days, \( n_d \), in which the initial concentration, \( C_i \) (optimal or underoptimal – but not critical), of the substratum solution will decrease to a critical level, \( C_{cr} \).

3.3.1. Calculation of the \( n_d \) depending on \( E_{da} \) and \( RE_{t/s} \). Because of the nutrient plant consumption and of the rebalancing processes (new equilibria) between the solid and liquefied phase, the optimal concentration obtained by fertilization gradually decreases, untill it reaches a critical level, at which point a corrective nutritive solution has to be applied again. The same thing happens when the application of the nutritive solutions is stopped, and the pots are only wetted with clean water – the concentration gradually decreases. The number of days in which it reaches a given concentration, critical for example, is computed with the formula:

\[
n_d, \text{ days} = (C_i - C_{cr}) \cdot V \cdot W \cdot C_h \cdot RE_{t/s} / E_{da}
\]

where: \( C_i \) and \( C_{cr} \) = me/l; the other terms have the same signification as above.

**Example.** If \( C_i = 4.25 \text{ me K}^+/l, C_{cr} = 3 \text{ me K}^+/l, V \cdot W \cdot C_h = 1.6 \text{ l/pot}, RE_{t/s} = 3 \) and \( E_{da} = 0.37 \text{ me K}^+/\text{day/pot} \), then:

\[
n_d = (4.25 - 3.5) \cdot 1.6 \cdot 3 / 0.37 = 9.7 \text{ days.}
\]
3.3.2. Establishment of the $n_d$ depending on the estimated nutrient consumption based on the average daily water consumption of plants, nutritive solution respectively, $V_{nscd}$, l/day/pot. If it is considered that, for simplification, the daily nutrient consumption is proportional with the water consumption (as a mater of fact – nutritive solution) and that the volume of solution consumed is daily compensated with an equal volume of water, then:

$$n_d, \text{ days} = \frac{\log(C_{cr}/C_i)}{\log(1 - V_{nscd}/V_{Whc})}$$

Example. If $C_i = 11$ me N(NO$_3^-$)/l, $C_{cr} = 5$ me N(NO$_3^-$)/l, $V_{Whc} = 1.6$ l/pot, $V_{nscd} = 0.15$ l/day/pot, then:

$$n_d = \frac{\log(5/11)}{\log(1 - 0.15/1.6)} = -0.342/-0.043 = 8 \text{ days.}$$

Lemaire's method is limited by the knowledge of the dynamics of the plant optimal nutrient consumptions and of the optimal content of the nutrients from the substratum solution, as well as by the rapid obtantion of the analytical data regarding the nutrient content of the liquide phase of the substratum. Once solved these problems, on the basis of specialized computer softwares and special dozing equipments, the fertilization of the ornamental plants cultivated in pots and containers can be automatized.

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NOMOGRAMS FOR FERTILIZATION: I – GRAPE-VINE

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Summary

Beside the theoretical and experimental elements that ground the establishment of the optimum economic rates, OER, valid also for fruit trees and shrubs, the paper also presents the experimental parameters which enter into the equations used to calculate the nutrient action coefficients and the nutrient soil contribution to yield (soil nutrient supply) which, at their turn, enter into the equations used to calculate OER. It also presents nomograms for the establishment of OER of N, P₂O₅ and K₂O as related to the expected yield, Yₑ, and to the soil agrochemical indexes, IA, for the main groups of grape-vine varieties (cultivars). Such nomograms facilitate the operative establishment of the OER. This paper is complementary to another – for fruit trees and shrubs, also published in this volume.

1. Introduction

Fertilization of grape-vine and fruit trees and shrubs has to be done by application of the fertilizers in optimal economic rates, OER, both for economic reasons, and for environmental protection, conservation and improvement of the soil fertility. These are calculated for each species as a function of specific nutrient requirements and response to fertilization as reflected by the action coefficients of the nutrients, ca, of the expected yield level, Ye, of the soil nutrient supply, xₛ, and of the ratio between the unitary selling price of the yield and the unitary fertilizer cost, Pᵧ/Pₓ. This paper is the first from a series of two complementary papers, the second referring to fruit trees and shrubs.

2. Materials and methods

The parameters which enter into the equations used to calculate the nutrient action coefficients and the nutrient soil contribution to the yield (soil nutrient supply) and, so, into the equations used to calculate OER, are established on the basis of experiments with fertilizers. With the basic formula of the calculation presented below, there were calculated OER of N, P₂O₅ and K₂O as related to Yₑ, soil agrochemical index, IA, and Pᵧ/Pₓ ratio. For grape-vine, OER are established on variety groups: table and wine respectively, and within the framework of these on precocity groups (early, middle, and late) and of wine quality (for aromatic wines, for high quality wines, for high yield table wines). Thus, using the data obtained, there were elaborated nomograms – specific graphs, which facilitate the operative

3. Results and discussions

The mathematical deduction of the formula for the establishment of the optimum economic rates of fertilizers, OER. This was presented for the first time by Borlan et al. (1984). OER is the rate which ensures the maximum profit/ha and, on the response curve of the yield (Y) as related to the applied rate of fertilizer (xₖ), corresponds to the point in which the value of the yield increase determined by the last kg of fertilizer is equal to the unitary cost of the fertilizer, which means mathematically – as derivative of the first order:

\[ d(Y\cdot P_y) = d(x_f\cdot P_x) \]

The experimental researches show that the yield increases together with the increase of the total nutrient supply – from soil and from fertilizers (xₛ + xₖ). Since the Mitscherley-Bray-Black response function, in the Borlan (1984) form, which describes this, is (for all the relations, see the significance of the terms below):

\[ Y = Y_{\text{max}}(1 - 10^{-c_a(x_s + x_f)}) \]

and in the value form is:

\[ Y\cdot P_y = [Y_{\text{max}}(1 - 10^{-c_a(x_s + x_f)})]P_y \]

then \( d(Y\cdot P_y) = d\{[Y_{\text{max}}(1 - 10^{-c_a(x_s + x_f)})]P_y\} \), from which results that:

\[ d(Y\cdot P_y) = 2.3c_aP_yY_{\text{max}}10^{-c_a(x_s + x_f)} \]

because \( 10^{-c_a(x_s + x_f)} = e^{-2.3(c_a(x_s + x_f))} \).

Because \( d(x_f\cdot P_x) = P_x \), from the condition of economic optimum \( d(Y\cdot P_y) = d(x_f\cdot P_x) \), results that:

\[ 2.3c_aP_yY_{\text{max}}10^{-c_a(x_s + x_f)} = P_x \]

and \( 2.3c_a(P_y/P_x)Y_{\text{max}} = 10^{-c_a(x_s + x_f)} \). By logaritimation, we obtain:

\[ \log[2.3c_a(P_y/P_x)Y_{\text{max}}] = \log[10^{-c_a(x_s + x_f)}]; \quad \log[2.3c_aY_{\text{max}}(P_y/P_x)] = c_a(x_s + x_f); \]

\[ \log[2.3c_aY_{\text{max}}(P_y/P_x)] = c_a x_s + c_a x_f; \quad \log[2.3c_aY_{\text{max}}(P_y/P_x)] - c_a x_s = c_a x_f. \]

Considering that \( Y_e \) represents more than 95 % from \( Y_{\text{max}} \), we can practically substitute \( Y_{\text{max}} \) with \( Y_e \), the relation becomes \( \log[2.3c_aY_e(P_y/P_x)] - c_a x_s = c_a x_f \), and from it results the equation of the establishment of \( x_f = \text{DOE} \) (Borlan et al, 1982, 1984, 1994):

\[ x_f = \text{DOE}, \text{ kg N, P}_2\text{O}_5 \text{ and K}_2\text{O}/\text{ha} = \{\log[2.3c_aY_e(P_y/P_x)] - c_a x_s\}/c_a \]

The significance of the symbols used in the above relations is: \( Y = \text{yield obtained at some level of the rate}; Y_e = \text{expected yield, for which we calculate OER, established on the basis of the field evaluation studies}; Y_{\text{max}} = \text{maximum yield obtained by fertilization}; P_y = \text{unitary selling price of the yield: lei, $, DM etc.}/\text{kg yield}; P_x = \text{unitary fertilizer cost: lei, $, DM etc.}/\text{kg N, P}_2\text{O}_5, \text{K}_2\text{O} ; x_f = \text{rate of fertilizer, kg N, P}_2\text{O}_5, \text{K}_2\text{O}/\text{ha}; x_s = \text{soil nutrient supply (soil contribution to the yield), kg N, P}_2\text{O}_5, \text{K}_2\text{O}/\text{ha}; c_a = \text{action coefficient of the considered nutrient.} \)

The nomograms for the establishment of the OER of N, P₂O₅ and K₂O for grape-vine, on mechanizable fields, as related to the soil agrochemical indexes and to \( Y_e \) are presented in fig. 1, 2 and 3. They are valid for the average \( P_y/P_x \) ratios on the market, mentioned in each figure.
The change of the $P_y/P_x$ ratios evidently determines the OER change. For this reason, for other ratios, OER are computed by the basic formula presented above.

**The establishment of the nutrient action coefficients, $c_a$.** It was experimentally demonstrated (Borlan et al, 1984, Budoi, 1997, Budoi and Coroianu, 1999) that $c_a$ correlates conversely with $Y_e$. They can thus be established with regression equations of the type:

$$c_a = a + b/Y_e$$

where $a$ and $b$ are coefficients determined on the basis of the experiments with fertilizers, specific for each species and for each nutrient.

**The establishment of the soil nutrient supply (soil contribution to the yield), $x_s$.** It was also experimentally demonstrated that $x_s$ positively correlates with the soil agrochemical indexes, $IA$, established on the basis of agrochemical analyses, and with the level of the expected yield, $Y_e$. For grape-vine, fruit trees and shrubs, the soil nutrient contribution is calculated by equations of the type (Borlan et al, 1984, Budoi et al, 1987, 1988):

$$x_s, \text{kg } N, P_2O_5, K_2O/ha = x_{smax}(1-10^{-ca \cdot IA}) + c \cdot Y_e$$

where $x_{smax} = \text{maximum soil contribution to the yield in conditions of very good supply of nutrients (high but not toxic nutrient content in soil), and } c = \text{coefficient}; x_{smax}$ and $c$ are specific to each species and to each nutrient and have been determined on the basis of experiments with fertilizers; for nitrogen, $IA$ is the soil nitrogen index, $IN = H\cdot V_{Ah}/100$, where $H = \text{humus content ()}$ and $V_{Ah} = \text{degree of base saturation ()}$; for P and K, $IA$ is the soil content of available P and K in the layer 0–40 cm, determined by Egner-Riehm-Domingo method ($P_{ALc}$ corrected as related to soil pH; $K_{AL}$ respectively); $Y_e = \text{expected yield, kg/ha.}$

The specific equations for grape-vine for each of the three macronutrients, N, P, K, and for the three main groups of varieties are presented in Table 1.

**Table 1:** Equations for calculating the soil nutrient contribution to the yield (soil nutrient supply) for grape-vine, $x_s$ (kg N, P$_2$O$_5$, K$_2$O/ha) as related to the soil agrochemical indexes ($IN$, $P_{ALc}$ and $K_{AL}$)* in the layer 0–40 cm and to the expected yield, $Y_e$ (kg/ha)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early table varieties and varieties for red and aromatic wines</td>
<td>$x_s = 80(1-10^{-0.4IN}) + 0.0048Y_e$</td>
<td>$x_s = 140(1-10^{-0.015P_{ALc}}) + 0.002Y_e$</td>
<td>$x_s = 170(1-10^{-0.006K_{AL}}) + 0.002Y_e$</td>
</tr>
<tr>
<td>Middle precocity table varieties and varieties for high quality wines</td>
<td>$x_s = 80(1-10^{-0.4IN}) + 0.0045Y_e$</td>
<td>$x_s = 150(1-10^{-0.015P_{ALc}}) + 0.002Y_e$</td>
<td>$x_s = 180(1-10^{-0.006K_{AL}}) + 0.002Y_e$</td>
</tr>
<tr>
<td>Late table varieties and varieties for high yield table wines</td>
<td>$x_s = 80(1-10^{-0.4IN}) + 0.0042Y_e$</td>
<td>$x_s = 160(1-10^{-0.015P_{ALc}}) + 0.002Y_e$</td>
<td>$x_s = 187(1-10^{-0.006K_{AL}}) + 0.002Y_e$</td>
</tr>
</tbody>
</table>

- IN is the soil nitrogen index: $IN = H\cdot V_{Ah}/100$, where $H = \text{humus content ()}$ and $V_{Ah} = \text{degree of base saturation ()}$; $P_{ALc} = \text{soil available P content, ppm P, corrected as related to pH}; K_{AL} = \text{soil available K content, ppm K (P$_{AL}$ and K$_{AL}$ determined by Egner-Riehm-Domingo method.}
**Fig. 1** – Optimal economic rates-OER of N, P$_2$O$_5$ and K$_2$O for grape-vine (in fruit) – early table varieties and varieties for red and aromatic wines, as related to Y$_s$ and IN and available P and K in the soil layer 0–40 cm (P$_y$/P$_x$ = 0.66 for N, 0.75 for P$_2$O$_5$ and 1.22 for K$_2$O).

**Fig. 2** – OER of N, P$_2$O$_5$ and K$_2$O for grape-vine (in fruit) – middle precocity table varieties and varieties for high quality wines, as related to Y$_s$ and IN and available P and K in the soil layer 0–40 cm (P$_y$/P$_x$ = 0.66 for N, 0.75 for P$_2$O$_5$ and 1.22 for K$_2$O).
4. References


NOMOGRAMS FOR FERTILIZATION: II
FRUIT TREES AND SHRUBS

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Summary

This paper is complementary to another – for grape-vine, in which there are presented the theoretical and experimental elements that ground the establishment of the optimum economic rates of fertilizers, OER, valid also for fruit trees and shrubs. It presents the experimental parameters which enter into the equations used to calculate the nutrient action coefficients and the nutrient soil contribution (nutrient supply) which, at their turn, enter into the equations used to calculate the OER. There are also presented nomograms for the establishment of OER of N, P2O5 and K2O as related to the expected yield, Ye, and to the soil agrochemical indexes, IA, for a high number of fruit trees and shrubs species (in fruit): apple tree, apricot tree, gooseberry, peach tree, pear tree, plum tree, raspberry, sour cherry tree, strawberry and sweet cherry tree. Such nomograms facilitate the operative establishment of the OER.

1. Introduction
See the complementary paper: Nomograms for fertilization: I – Grape-vine.

2. Materials and methods
See the complementary paper: Nomograms for fertilization: I – Grape-vine.

3. Results and discussions
For the beginning, see the complementary paper: Nomograms for fertilization: I – Grape-vine. The basic formula used for the establishment of the optimum economic rates of fertilizers, OER, is (Borlan et al., 1982, 1984, 1994):

\[
\text{DOE}, \text{ kg N, P}_2\text{O}_5 \text{ and K}_2\text{O}/\text{ha} = \frac{\log[2.3 \times c_a \times Y_e \times (P_y/P_x)] - c_a \times x_s}{c_a}
\]

where: \( c_a \) = action coefficient of the considered nutrient; \( Y_e \) = expected yield, kg/ha, established on the basis of the site evaluation studies; \( P_y \) = unitary selling price of the yield: lei, $, DM etc./kg yield; \( P_x \) = unitary fertilizer price: lei, $, DM etc./kg N, P2O5, K2O; \( x_s \) = soil nutrient supply (soil contribution to yield), kg N, P2O5, K2O/ha, established on the basis of agrochemical analyses.

The nomograms for the establishment of OER of N, P2O5 and K2O for fruit trees and shrubs, on mechanizable fields, as related to the soil agrochemical indexes and to \( Y_e \) are presented in figures 1–10. They are valid for the average \( P_y/P_x \) ratios on the market, mentioned in each figure. The change of the \( P_y/P_x \) ratios evidently determines the OER change. For this reason, for other ratios, OER are computed by the above-mentioned basic formula.
Calculation of the nutrient action coefficients, $c_n$, and calculation of the soil contribution (nutrient supply), $x_s$. These are done by the equations from table 1.

**Table 1:** Equations for calculating the nutrient action coefficients, $c_n$, in fruit trees and shrubs, and equations for calculating the soil contribution (nutrient supply), $x_s$ (kg N, P$_2$O$_5$, K$_2$O/ha) as related to the agrochemical indexes (IN, PALc and KAL) in the layer 0–40 cm, and to the expected yield, $Y_e$ (kg/ha)

| Species       | Nutrient      | Apple tree $x_s$ | Apricot tree $x_s$ | Gooseberry $x_s$ | Peach tree $x_s$ | Pear tree $x_s$ | Plum tree $x_s$ | Raspberry $x_s$ | Sour cherry $x_s$ | Strawberry $x_s$ | Sweet cherry $x_s$ | Walnut tree $x_s$ |
|---------------|---------------|------------------|-------------------|------------------|------------------|----------------|----------------|-----------------|------------------|-------------------|-------------------|
|               | Nitrogen      | $c_1 = 0.011 + 100/Y_e$ | $c_1 = 0.012 + 40/Y_e$ | $c_1 = 0.007 + 35/Y_e$ | $c_1 = 0.011 + 100/Y_e$ | $c_1 = 0.012 + 40/Y_e$ | $c_1 = 0.007 + 35/Y_e$ | $c_1 = 0.011 + 100/Y_e$ | $c_1 = 0.012 + 40/Y_e$ | $c_1 = 0.007 + 35/Y_e$ | $c_1 = 0.007 + 35/Y_e$ |
|               | Phosphorus    | $x_s = 65(1-10^{-0.35IN})+0.003Y_e$ | $x_s = 126(1-10^{-0.049P_ALC})+0.0015Y_e$ | $x_s = 134(1-10^{-0.032P_ALC})+0.0022Y_e$ | $x_s = 65(1-10^{-0.35IN})+0.003Y_e$ | $x_s = 126(1-10^{-0.049P_ALC})+0.0015Y_e$ | $x_s = 134(1-10^{-0.032P_ALC})+0.0022Y_e$ | $x_s = 65(1-10^{-0.35IN})+0.003Y_e$ | $x_s = 126(1-10^{-0.049P_ALC})+0.0015Y_e$ | $x_s = 134(1-10^{-0.032P_ALC})+0.0022Y_e$ | $x_s = 65(1-10^{-0.35IN})+0.003Y_e$ |
|               | Potassium     | $c_2 = 0.0075 + 60/Y_e$ | $c_2 = 0.01 + 90/Y_e$ | $c_2 = 0.0072 + 35/Y_e$ | $c_2 = 0.0075 + 60/Y_e$ | $c_2 = 0.01 + 90/Y_e$ | $c_2 = 0.0072 + 35/Y_e$ | $c_2 = 0.0075 + 60/Y_e$ | $c_2 = 0.01 + 90/Y_e$ | $c_2 = 0.0072 + 35/Y_e$ | $c_2 = 0.0075 + 60/Y_e$ |

Fig. 1 – Optimum economic rates, OER, of N, P$_2$O$_5$ and K$_2$O in apple tree on mechanizable fields as related to expected yield, $Y_e$, and to nitrogen index, IN, available phosphorus and available potassium content in soil layer 0–40 cm; $P_y/P_x = 0.445$ for N, 0.51 for P$_2$O$_5$ and 0.833 for K$_2$O.
Fig. 2 – OER of N, P$_2$O$_5$ and K$_2$O in *apricot tree* on mechanizable fields as related to expected yield, $Y_e$, and to nitrogen index, IN, available phosphorus and available potassium content in soil layer 0–40 cm; $P_y/P_x = 0.692$ for N, 0.792 for P$_2$O$_5$ and 1.294 for K$_2$O

Fig. 3 – OER of N, P$_2$O$_5$ and K$_2$O in *gooseberry* on mechanizable fields as related to expected yield, $Y_e$, and to nitrogen index, IN, available phosphorus and available potassium content in soil layer 0–40 cm; $P_y/P_x = 1.638$ for N, 1.875 for P$_2$O$_5$ and 3.061 for K$_2$O
Fig. 4 – OER of N, P₂O₅ and K₂O in *peach tree* on mechanizable fields as related to expected yield, Yₑ, and to nitrogen index, IN, available phosphorus and available potassium content in soil layer 0–40 cm; Pₑ/Pₓ = 0.655 for N, 0.75 for P₂O₅ and 1.224 for K₂O

Fig. 5 – OER of N, P₂O₅ and K₂O in *pear tree* on mechanizable fields as related to expected yield, Yₑ, and to nitrogen index, IN, available phosphorus and available potassium content in soil layer 0–40 cm; Pₑ/Pₓ = 0.445 for N, 0.51 for P₂O₅ and 0.833 for K₂O
**Fig. 6** – OER of N, P\(_2\)O\(_5\) and K\(_2\)O in *plum tree* on mechanizable fields as related to expected yield, Y\(_e\), and to nitrogen index, IN, available phosphorus and available potassium content in soil layer 0–40 cm; P\(_y\)/P\(_x\) = 0.332 for N, 0.38 for P\(_2\)O\(_5\) and 0.62 for K\(_2\)O

**Fig. 7** – OER of N, P\(_2\)O\(_5\) and K\(_2\)O in *raspberry* on mechanizable fields as related to expected yield, Y\(_e\), and to nitrogen index, IN, available phosphorus and available potassium content in soil layer 0–40 cm; P\(_y\)/P\(_x\) = 1.354 for N, 1.55 for P\(_2\)O\(_5\) and 2.531 for K\(_2\)O
Fig. 8 – OER of N, P2O5 and K2O in *sour cherry tree* on mechanizable fields as related to expected yield, \( Y_e \), and to nitrogen index, \( \text{IN} \), available phosphorus and available potassium content in soil layer 0–40 cm; \( \frac{P_y}{P_x} = 0.666 \) for N, 0.762 for P2O5 and 1.245 for K2O

Fig. 9 – OER of N, P2O5 and K2O in *strawberry* on mechanizable fields as related to expected yield, \( Y_e \), and to nitrogen index, \( \text{IN} \), available phosphorus and available potassium content in soil layer 0–40 cm; \( \frac{P_y}{P_x} = 1.332 \) for N, 1.525 for P2O5 and 2.49 for K2O
Fig. 10 – OER of N, P₂O₅ and K₂O in sweet cherry tree on mechanizable fields as related to expected yield, Yₑ, and to nitrogen index, IN, available phosphorus and available potassium content in soil layer 0–40 cm; Pᵧ/Pₓ = 0.786 for N, 0.9 for P₂O₅ and 1.469 for K₂O

4. References


EFFECT OF SPECIAL FOLIAR FERTILIZATION ON YIELD, CONCENTRATION AND ACCUMULATION OF MACRO- AND MICRONUTRIENTS IN INBRED LINES IN HYBRID MAIZE AND SUNFLOWER SEED PRODUCTION

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³Biological Research Institute, 20 Carol I Street, Iasi, Romania

Summary

The paper presents some aspects concerning the influence of special complex foliar fertilizers (CFF) on concentration and accumulation of the macro- and micronutrients in inbred lines in hybrid maize and sunflower seed production. The field experiments were carried out in the pedoclimatic conditions at Iasi experimental Station and the plant test used were inbred maize and sunflower lines in hybrid maize (HT 108 Suceava, HD Turda 200) and sunflower (HS Rapid) seed production. The treatments used were: CFF 622, CFF 622a and CFF Folplant 131 for maize and CFF 624, CFF 624a and CFF Folplant 131 for sunflower. All the treatments were applied three times at 3 % concentration. According to the results, the special foliar fertilizers have significantly increased the yield and the N, Zn and Mo concentrations in hybrid maize and sunflower seeds and have generally no significant effect on P, K, Fe, Mn, Cu and B concentrations. As it concerns the accumulation of the macro- and micronutrients in seeds, the special foliar fertilizers assured a positive increase in directly relation to the level of the yield increases.

1. Introduction

Foliar fertilization is a very efficient means to prevent or to correct the plant nutrition disorders. This is especially useful in seed production, in order to obtain seeds enriched in nutrients, an essential condition to obtain high yields in commercial lands.

Zn deficiency in maize is one of the most frequent micronutrient disorders and is especially met on: acid soils, carbonate soils, overlimed acid soils as well as on overphosphatated soils – because of the Zn immobilization in soil; psamosoils and erodisoils – because of their Zn poverty. Mo deficiency in sunflower, the most frequent micronutrient disorders, is met on cloudy and cold weather (in spring), especially on soils overfertilizad with N–NO⁻, as well as on acid soils, sandy soils, luvisoils etc., with low content of Mo (Budoi, 2000, 2001). A seed rich in these micronutrients can prevent Zn deficiencies in maize and Mo deficiencies in sunflower in commercial crops in conditions which predispose the plants to such nutrition disorders, like those described above.
2. Material and Methods

The special complex foliar fertilizers (CFF) tested have been elaborated by Borlan et al. (1995) from the Research Institute for Soil Science and Agrochemistry (RISSA) using residual protein hydrolyzates. Depending on the manufacturing method, it has been produced two types of hydrolyzates which were completed with adequate quantities of macronutrients – N, P, K and S, micronutrients – B, Cu, Fe, Mn, Co and especially Zn (necessary for maize) and Mo (necessary for sunflower) and with small quantities of organic active substances – procaine, thiamin and potassium naphthenates. Finally it was obtained two foliar compositions destined to correct the micronutrients disorders for inbred maize lines in hybrid maize seed production, coded CFF 622 and CFF 622a, and two foliar compositions destined for inbred sunflower lines in sunflower seed production, coded 624 and 624a (table 1). The complex foliar fertilizer CFF Folplant 231 was produced by Chimenerg Craiova Company – ROMANIA. In order to study these CFF, rigorous field experiments were carried out in the pedoclimatic conditions of Iași Experimental Station.

Table 1: Chemical composition of the special complex foliar fertilizers (CFF) tested on inbred maize lines and on inbred sunflower lines (1998-2000)

<table>
<thead>
<tr>
<th>Elements and substances</th>
<th>CFF 622</th>
<th>CFF 622a</th>
<th>CFF 624</th>
<th>CFF 624a</th>
<th>CFF Folplant 231</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>242</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>94</td>
<td>164</td>
<td>141</td>
<td>166</td>
<td>130</td>
</tr>
<tr>
<td>K₂O</td>
<td>125</td>
<td>100</td>
<td>137</td>
<td>116</td>
<td>40</td>
</tr>
<tr>
<td>S</td>
<td>28</td>
<td>20</td>
<td>21</td>
<td>21</td>
<td>0.1</td>
</tr>
<tr>
<td>Fe</td>
<td>1</td>
<td>0.6</td>
<td>0.4</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Zn</td>
<td>0.5</td>
<td>2</td>
<td>0.35</td>
<td>0.35</td>
<td>0.04</td>
</tr>
<tr>
<td>Cu</td>
<td>0.2</td>
<td>0.2</td>
<td>0.25</td>
<td>0.25</td>
<td>0.04</td>
</tr>
<tr>
<td>Mn</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
<td>0.5</td>
<td>0.25</td>
</tr>
<tr>
<td>Co</td>
<td>-</td>
<td>0.001</td>
<td>0.011</td>
<td>0.105</td>
<td>0.08</td>
</tr>
<tr>
<td>Mo</td>
<td>0.1</td>
<td>0.67</td>
<td>0.15</td>
<td>0.66</td>
<td>0.08</td>
</tr>
<tr>
<td>B</td>
<td>0.4</td>
<td>1</td>
<td>1.50</td>
<td>0.55</td>
<td>0.1</td>
</tr>
<tr>
<td>Mg</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.15</td>
</tr>
<tr>
<td>Procaine–HCl³</td>
<td>1.20</td>
<td>1.20</td>
<td>1.6</td>
<td>1.40</td>
<td>-</td>
</tr>
<tr>
<td>Thiamin–HCl²</td>
<td>0.60</td>
<td>0.60</td>
<td>0.8</td>
<td>0.70</td>
<td>-</td>
</tr>
<tr>
<td>Aminoacids</td>
<td>27</td>
<td>34</td>
<td>29</td>
<td>34</td>
<td>-</td>
</tr>
<tr>
<td>K-naftenates³</td>
<td>2.4</td>
<td>2.4</td>
<td>3</td>
<td>3</td>
<td>-</td>
</tr>
</tbody>
</table>

¹ Procaine hydrochloride; ² thiamin hydrochloride; ³ potassium naphthenates

The soil was a cambic chernozem (haplic phaezem). The main agrochemical properties show a high fertility level (table 2), except the ICZn index, which prognoses the appearance of Zn deficiency in maize.

In maize, the experiments have been done for treble hybrid HT 108 Suceava and for double hybrid HD Turda 200, in 1999, and in sunflower for simple hybrid HS Rapid, in 1998. All types of CFF have been applied as diluted solutions in 3 % (g/g) concentration (500 litre solution/ha per one application). At all, it was done 3 treatments/year: the first treatment in the stage of 4-6 leaves, and the others at 10-14 days between them. A control sprayed with water was used as reference in order to estimate the CFF effects.

The yield experimental results have been processed by the analysis of variance. It was used the Tukey's test and Duncan's test for multiple range comparisons between means.
Table 2: The main agrochemical properties of the cambic chernozem soil (haplic phaezem) from Iasi Experimental Station

<table>
<thead>
<tr>
<th>Inbred lines</th>
<th>pH (H₂O)</th>
<th>Humus (%)</th>
<th>P&lt;sub&gt;AL&lt;/sub&gt; * (ppm)</th>
<th>K&lt;sub&gt;AL&lt;/sub&gt; * (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize HT 108 Suceava</td>
<td>6.30</td>
<td>3.36</td>
<td>66.8</td>
<td>292</td>
</tr>
<tr>
<td>Maize HD Turda 200</td>
<td>6.70</td>
<td>3.30</td>
<td>59.2</td>
<td>287</td>
</tr>
<tr>
<td>Sunflower HS Rapid</td>
<td>5.88</td>
<td>3.64</td>
<td>33.6</td>
<td>176</td>
</tr>
</tbody>
</table>

* Mobile P and K, extracted with ammonium acetate lactate solution (AL) – Egner-Riehm-Domingo method

2. Results and discussions

3.1. Maize. Yield increase. All the three complex foliar fertilizers (CFF), and for both hybrid maize seed production, determined significant yield increases as compared with the control sprayed with water (table 3).

Table 3: The agronomic effect of the special complex foliar fertilizers (CFF) on inbred maize lines in hybrid maize seed production for HT 108 Suceava and HD Turda 200 in 1999

<table>
<thead>
<tr>
<th>Treatments</th>
<th>HT 108 Suceava</th>
<th></th>
<th></th>
<th>HD Turda 200</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yields kg/ha</td>
<td>Yield increases kg/ha</td>
<td>%</td>
<td>Significances</td>
<td>Yields kg/ha</td>
<td>Yield increases kg/ha</td>
</tr>
<tr>
<td>Control</td>
<td>3384</td>
<td>-</td>
<td>100</td>
<td>-</td>
<td>3586</td>
<td>-</td>
</tr>
<tr>
<td>CFF 231</td>
<td>3716</td>
<td>332</td>
<td>110</td>
<td>**</td>
<td>3995</td>
<td>409</td>
</tr>
<tr>
<td>CFF 622</td>
<td>4033</td>
<td>649</td>
<td>119</td>
<td>***</td>
<td>4573</td>
<td>987</td>
</tr>
<tr>
<td>CFF 622a</td>
<td>4215</td>
<td>831</td>
<td>125</td>
<td>***</td>
<td>4781</td>
<td>1195</td>
</tr>
</tbody>
</table>

LSD<sup>5 %</sup> 256
LSD<sup>1 %</sup> 304
LSD<sup>0.1 %</sup> 588

# Tukey test

The best results were obtained with CFF 622a: 831 kg/ha for HT 108 Suceava (25 % yield increase), and 1195 kg/ha for HD Turda 200 (33 % yield increase).

Influence of CFF on seed nutrient concentration. In HT 108 Suceava seed production, all CFF increased significantly the Zn concentration of seeds, which was the main purpose of the treatments (table 4). CFF 622a, which gave the maximum yield increase, enriched also significant the seeds in N, P and B. No effect has been registered on the content of K, Mn, Fe, Cu and Mo.

Table 4: The effect of the special complex foliar fertilizers (CFF) on macro- and micronutrient contents of inbred maize lines in hybrid maize seed production of HT 108 Suceava

<table>
<thead>
<tr>
<th>Treatments</th>
<th>N %</th>
<th>P %</th>
<th>K %</th>
<th>Zn ppm</th>
<th>Mn ppm</th>
<th>Fe ppm</th>
<th>Cu ppm</th>
<th>Mo ppm</th>
<th>B ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.45 b</td>
<td>0.24 a</td>
<td>0.35 a</td>
<td>13.50 b</td>
<td>5.50 a</td>
<td>24.75 a</td>
<td>3.00 ab</td>
<td>0.073 a</td>
<td>3.00 b</td>
</tr>
<tr>
<td>CFF 231</td>
<td>1.48 b</td>
<td>0.22 ab</td>
<td>0.34 a</td>
<td>16.33 a</td>
<td>5.66 a</td>
<td>23.33 a</td>
<td>2.54 ab</td>
<td>0.086 a</td>
<td>2.75 b</td>
</tr>
<tr>
<td>CFF 622</td>
<td>1.56 ab</td>
<td>0.20 a</td>
<td>0.33 a</td>
<td>16.08 a</td>
<td>6.21 a</td>
<td>19.36 a</td>
<td>3.17 a</td>
<td>0.080 a</td>
<td>2.75 b</td>
</tr>
<tr>
<td>CFF 622a</td>
<td>1.61 a</td>
<td>0.19 b</td>
<td>0.30 a</td>
<td>15.66 a</td>
<td>5.83 a</td>
<td>25.75 a</td>
<td>2.29 b</td>
<td>0.096 a</td>
<td>4.00 a</td>
</tr>
</tbody>
</table>

LSD<sup>5 %</sup> 0.123
LSD<sup>1 %</sup> 0.186

# Duncan's test for multiple range comparisons
In **HD Turda 200** seed production, the Zn concentration increased significantly only in the case of CFF 622 and CFF 622a, CFF 622 being the best (table 5). These two CFF enriched also the seeds in N, Mn and Cu, and CFF 622a even in B. All the CFF had no effect on the P, K, Fe and Mo concentrations.

Even if not to high, there is a positive correlation between yield increases and Zn (fig. 1) and N (fig. 2) concentrations of seeds of the inbred maize lines of the 2 studied hybrids. That means that CFF influenced in the same way Zn and N concentrations on the one hand and yields on the other hand, increasing them proportionally.

**Table 5**: The effect of the special complex foliar fertilizers (CFF) on macro- and micronutrient contents of inbred maize lines in hybrid maize seed production of HD Turda 200

<table>
<thead>
<tr>
<th>Treatments</th>
<th>N %</th>
<th>P %</th>
<th>K %</th>
<th>Zn ppm</th>
<th>Mn ppm</th>
<th>Fe ppm</th>
<th>Cu ppm</th>
<th>Mo ppm</th>
<th>B ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.62d</td>
<td>0.19a</td>
<td>0.35a</td>
<td>16.41c</td>
<td>6.25b</td>
<td>20.80a</td>
<td>1.92b</td>
<td>0.070a</td>
<td>2.83b</td>
</tr>
<tr>
<td>CFF 231</td>
<td>1.67e</td>
<td>0.23a</td>
<td>0.39a</td>
<td>17.75bc</td>
<td>6.58ab</td>
<td>17.66a</td>
<td>2.38ab</td>
<td>0.083a</td>
<td>3.00b</td>
</tr>
<tr>
<td>CFF 622</td>
<td>1.81a</td>
<td>0.22a</td>
<td>0.39a</td>
<td>20.50a</td>
<td>7.16a</td>
<td>20.00a</td>
<td>2.79a</td>
<td>0.076a</td>
<td>3.25ab</td>
</tr>
<tr>
<td>CFF622a</td>
<td>1.75b</td>
<td>0.20a</td>
<td>0.35a</td>
<td>18.58ab</td>
<td>7.04a</td>
<td>27.03a</td>
<td>2.75a</td>
<td>0.126a</td>
<td>4.16a</td>
</tr>
</tbody>
</table>

LSD 5% 0.036 0.051 0.049 0.19 0.81 0.63 0.69 0.069 1.10
LSD 1% 0.055 0.078 0.079 0.32 1.23 1.63 1.05 0.104 1.67

*Duncan's test for multiple range comparisons*

Influence of CFF on the amount of nutrients accumulated in seeds per ha.

For both hybrids, all the CFF determined a Zn accumulation in seeds/ha in amounts significantly higher than control. The same thing is true for N (tables 6 and 7). The inbred maize lines of HT 108 Suceava exported much more amounts of Mn in the case of CFF 622 and 622a and Mo and B in the case of CFF 622a (table 6).

**Table 6**: The effect of the special complex foliar fertilizers (CFF) on the amount of macro- and micronutrients accumulated in the seeds of inbred maize lines in hybrid maize seed production of HT 108 Suceava

<table>
<thead>
<tr>
<th>Treatments</th>
<th>N kg/ha</th>
<th>P kg/ha</th>
<th>K kg/ha</th>
<th>Zn g/ha</th>
<th>Mn g/ha</th>
<th>Fe g/ha</th>
<th>Cu g/ha</th>
<th>Mo g/ha</th>
<th>B g/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>49.06d</td>
<td>8.11a</td>
<td>12.14a</td>
<td>45.03b</td>
<td>18.58b</td>
<td>83.75a</td>
<td>10.14ab</td>
<td>0.24b</td>
<td>10.13b</td>
</tr>
<tr>
<td>CFF 231</td>
<td>54.99c</td>
<td>8.41a</td>
<td>12.62a</td>
<td>60.69a</td>
<td>21.05ab</td>
<td>86.7a</td>
<td>9.41b</td>
<td>0.26ab</td>
<td>10.21b</td>
</tr>
<tr>
<td>CFF 622</td>
<td>62.91b</td>
<td>8.06a</td>
<td>13.43a</td>
<td>64.85a</td>
<td>25.03a</td>
<td>78.07a</td>
<td>12.78a</td>
<td>0.32ab</td>
<td>11.08b</td>
</tr>
<tr>
<td>CFF 622a</td>
<td>68.00a</td>
<td>8.00a</td>
<td>12.64a</td>
<td>66.03a</td>
<td>24.6a</td>
<td>108.5a</td>
<td>9.65b</td>
<td>0.40a</td>
<td>16.86a</td>
</tr>
</tbody>
</table>

LSD 5% 4.90 1.11 2.66 6.78 4.14 47.41 2.79 0.14 3.34
LSD 1% 7.43 1.69 4.03 10.27 6.27 71.84 4.22 0.21 5.07

*Duncan's test for multiple range comparisons*
The inbred maize lines of HD Turda 200 exported significantly higher amounts of P, K and Mn for all three CFF; in the case of CFF 622a, even Fe and Mo accumulated more (table 7).

**Table 7:** The effect of the special complex foliar fertilizers (CFF) on the amount of macro- and micronutrients accumulated in the seeds of inbred maize lines in hybrid maize seed production of HD Turda 200

<table>
<thead>
<tr>
<th>Treatments</th>
<th>N kg ha</th>
<th>P kg/ha</th>
<th>K kg/ha</th>
<th>Zn g/ha</th>
<th>Mn g/ha</th>
<th>Fe g/ha</th>
<th>Cu g/ha</th>
<th>Mo g/ha</th>
<th>B g/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>58.21c</td>
<td>6.93b</td>
<td>12.78c</td>
<td>58.86c</td>
<td>22.42c</td>
<td>74.59c</td>
<td>6.88c</td>
<td>0.24b</td>
<td>10.70b</td>
</tr>
<tr>
<td>CFF 231</td>
<td>66.84b</td>
<td>9.08a</td>
<td>15.55b</td>
<td>70.90b</td>
<td>26.27b</td>
<td>70.57b</td>
<td>9.50bc</td>
<td>0.32bc</td>
<td>11.90b</td>
</tr>
<tr>
<td>CFF 622</td>
<td>83.07a</td>
<td>10.21a</td>
<td>17.98a</td>
<td>93.63a</td>
<td>32.76a</td>
<td>91.45ab</td>
<td>12.77ab</td>
<td>0.37ab</td>
<td>14.83ab</td>
</tr>
<tr>
<td>CFF 622a</td>
<td>83.82a</td>
<td>9.69a</td>
<td>16.88ab</td>
<td>93.61a</td>
<td>33.66a</td>
<td>129.22a</td>
<td>13.15a</td>
<td>0.60a</td>
<td>19.94ab</td>
</tr>
</tbody>
</table>

LSD 5% 1.19 1.86 1.96 8.53 3.61 50.89 3.35 0.31 5.46
LSD 1% 1.80 2.82 2.97 12.93 5.47 77.10 5.08 0.47 8.28

3.2. Sunflower. Yield increase. Only CFF 624 and CFF 624a determined significant yield increases as compared with check (table 8). The best result, that of CFF 622a, reached 765 kg/ha, which means 60 % yield increase (distinct significant difference versus control).

**Table 8:** The agronomic effect of the special complex foliar fertilizers (CFF) on inbred sunflower lines in hybrid sunflower seed production of HS Rapid in 1998

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Yields kg/ha</th>
<th>Yield increases kg/ha</th>
<th>%</th>
<th>Significances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1272</td>
<td>-</td>
<td>100%</td>
<td>-</td>
</tr>
<tr>
<td>CFF 231</td>
<td>1611</td>
<td>339</td>
<td>127%</td>
<td>-</td>
</tr>
<tr>
<td>CFF 624</td>
<td>1884</td>
<td>612</td>
<td>148%</td>
<td>*</td>
</tr>
<tr>
<td>CFF 624a</td>
<td>2037</td>
<td>765</td>
<td>160%</td>
<td>**</td>
</tr>
</tbody>
</table>

LSD 5% 431
LSD 1% 754
LSD 0.1% 908

*Tukey's test

Influence of CFF on seed nutrient concentration. Higher significant concentrations of Mo in seeds, one of the main purpose of the foliar treatments, determined CFF 624a and CFF 231, the values being more than double by comparison with check. CFF 624a influenced also positively and significantly Fe content. All the CFF did not influenced P, K, Zn, Cu and B concentrations.

**Table 9:** The effect of the special complex foliar fertilizers (CFF) on macro- and micronutrient contents of inbred sunflower lines in hybrid sunflower seed production of HS Rapid

<table>
<thead>
<tr>
<th>Treatments</th>
<th>N %</th>
<th>P %</th>
<th>K %</th>
<th>Zn ppm</th>
<th>Mn ppm</th>
<th>Fe ppm</th>
<th>Cu ppm</th>
<th>Mo ppm</th>
<th>B ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.48c</td>
<td>0.77a</td>
<td>0.81a</td>
<td>60.20a</td>
<td>15.00b</td>
<td>60.76b</td>
<td>22.25a</td>
<td>0.14a</td>
<td>9.08a</td>
</tr>
<tr>
<td>CFF 231</td>
<td>2.48c</td>
<td>0.77a</td>
<td>0.86a</td>
<td>61.53a</td>
<td>15.83a</td>
<td>52.60b</td>
<td>21.32a</td>
<td>0.34a</td>
<td>9.75a</td>
</tr>
<tr>
<td>CFF 624</td>
<td>2.70a</td>
<td>0.78a</td>
<td>0.86a</td>
<td>61.86a</td>
<td>15.58ab</td>
<td>53.53b</td>
<td>17.91a</td>
<td>0.16c</td>
<td>9.16a</td>
</tr>
<tr>
<td>CFF 624a</td>
<td>2.60b</td>
<td>0.76a</td>
<td>0.84a</td>
<td>61.20a</td>
<td>15.25ab</td>
<td>115.33a</td>
<td>18.33a</td>
<td>0.29b</td>
<td>8.50a</td>
</tr>
</tbody>
</table>

LSD 5% 0.044 0.063 0.100 10.10 0.73 27.47 6.12 0.040 2.80
LSD 1% 0.067 0.096 0.152 15.31 1.12 41.63 9.28 0.061 4.25

*Duncan's test for multiple range comparisons
Influence of CFF on the amount of nutrients accumulated in seeds per ha. For all CFF, Mo accumulated in significantly higher quantities than for check (table 10). The same is true for N, P, K, Zn and Mn, first because of the yield increases determined by CFF. CFF 624a determined also higher exports of Fe, Cu and B, which means that in the case of this foliar fertilizer, all the nutrients have been exported in significantly higher amounts than in the control.

Table 10: The effect of the special complex foliar fertilizers (CFF) on the amount of macro- and micronutrients accumulated in the seeds of inbred sunflower lines in hybrid sunflower seed production of HS Rapid

<table>
<thead>
<tr>
<th>Treatments</th>
<th>N kg/ha</th>
<th>P kg/ha</th>
<th>K kg/ha</th>
<th>Zn g/ha</th>
<th>Mn g/ha</th>
<th>Fe g/ha</th>
<th>Cu g/ha</th>
<th>Mo g/ha</th>
<th>B g/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>31.62d</td>
<td>9.79c</td>
<td>10.30c</td>
<td>76.57c</td>
<td>19.07d</td>
<td>77.29b</td>
<td>28.3b</td>
<td>0.182d</td>
<td>11.55b</td>
</tr>
<tr>
<td>CFF 231</td>
<td>40.05c</td>
<td>12.50b</td>
<td>14.00b</td>
<td>99.12b</td>
<td>25.50c</td>
<td>84.72b</td>
<td>34.36ab</td>
<td>0.470b</td>
<td>15.70ab</td>
</tr>
<tr>
<td>CFF 624</td>
<td>50.91b</td>
<td>14.69a</td>
<td>16.20a</td>
<td>116.55b</td>
<td>29.35b</td>
<td>100.7b</td>
<td>23.54ab</td>
<td>0.313c</td>
<td>17.26a</td>
</tr>
<tr>
<td>CFF 624a</td>
<td>53.00a</td>
<td>15.47a</td>
<td>17.17a</td>
<td>124.65a</td>
<td>31.06a</td>
<td>234.93a</td>
<td>37.34a</td>
<td>0.678a</td>
<td>17.31a</td>
</tr>
</tbody>
</table>

LSD 5% 0.74 1.09 1.66 17.56 1.36 44.72 8.51 0.056 4.50
LSD 1% 1.12 1.65 2.52 26.61 2.07 67.77 12.89 0.084 6.83

* Duncan's test for multiple range comparisons

3. References


A NEW HYPOTHESIS CONCERNING THE ABSORPTION OF NUTRIENTS IN PLANTS

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Summary

In this hypothesis the carriers (C) are produced inside the cell with metabolic energy consumption and, regardless their nature, they have the basic characteristic of easily passing through membranes, both in free stage and in complex stage, as ion-carrier (IC). The production of C in high concentrations achieved by the cell in the cytoplasm forces the carriers, by virtue of the concentration gradient, to pass through plasmalemma to its external part, where they bind the specific ions by complexing. By increasing the IC concentration outside the cell, a concentration gradient of IC is created from outside the cell towards the cytoplasm so that the IC passes through the plasmalemma and in the cytoplasm unbinds in its components, I and C.

Thus, there results a continuous circuit of C from inside towards outside the cell, respectively of IC from outside towards inside the cell. The circuit is controlled by the synthesis of the carrier in the cell, by the ion presence outside the cell and eventually by the ATP-aze implied in the unbinding of the IC complex in the cell. The hypothesis can explain the passage of the ions through any other biological membranes, providing that the C be synthetized in free stage in that part of the membrane in which the ion must be passed.

1. Introduction

There are numerous hypothesis and theories regarding the uptake of the nutrients in plant – roots and leaves. Nowadays it is generally accepted that there are two essential mechanisms of absorption: passive absorption, without metabolic energy consumption, and active absorption, with metabolic energy consumption of the plant.

As far as the active uptake is concerned, there are to be mentioned:

– The van den Honert hypothesis (1937), in which we meet the first concept of ion carrier, described for the phosphate ion as a steadily rotating belt conveyor;
– The Epstein theory (1952, 1953, 1972) regarding the active transport of ions by ion carriers, components of the membranes, mediated by ATP-ases which activate the carriers to bind and transport the ions;
– The ion pump theory, described in Mengel and Kirkby's papers (1987) and others, in which an essential role plays the hydrogen ion pumps which, by the extrusion of H⁺ ions from the cytoplasm and their expulsion to the outside of the plasmalemma, creates an electrical potential across the plasmalemma and a kind of passages more and more negatively charged from the outside part to the inside part, by whom the cations are absorbed inside the cell.

The uptake mechanisms and the nature of the carriers are presented in many papers, among them those of Bergman (1992), Budoi (2000), Burzo et. al. (1999), Epstein (1972), Marschner (1993); Mengel and Kirkby (1987), Tisdale et. al. (1993) and others.
The carriers are sometimes considered as being compounds similar to proteins or even being proteins, other times they are called "ionophors" – organic molecules of low molecular weight, as some polipeptides, components of the membranes. Carriers are also considered some "phytosiderophors", which are chelating agents eliminated by the roots in the rizosphere, where they chelate the nutrient and thus transport it through the plasmalemma.

This paper aim at developing a hypothesis which could explain more clearly and easily the active uptake of ions in plant mediated by ion carriers. In the same time, this paper is an invitation addressed to the scientific community for a collaboration on this important subject.

2. Materials and methods

This new hypothesis is a logical-conceptual development, which takes into consideration, in a critical way, the previous hypothesis and theories, with their valences and limits, and which is based on concepts and experimental proofs accumulated until present. It tries to put the nutrient uptake in plant in a new light.

3. Results and discussions

In this hypothesis the carriers (C) are not the subunits of the biological membranes, as in old hypothesis and theories, but they are produced inside the cell. Either "ionophores", "phytosiderophores", or of other nature, they all have the basic characteristic of easily passing through the phospholipidic membranes both in free stage and in complex stage, as ion-carriers (IC).

For this, C must have lipophilic groups which allow it to pass through the biological phospholipidic membranes, specific situs which should bind the carried ion (I), and after the IC complex formation, the lipophilic groups remain oriented so that the IC could pass through membranes. There are numerous experimental evidences which proves that such molecular compounds exist (Mengel și Kirkby, 1987).

The synthesis of these carriers can only be achieved by metabolic activity, which involves energy consumption.

The production of carriers in high concentrations achieved by the cell on the inside part of the membrane forces the carriers, by virtue of the gradient of concentration, to pass through the membrane to the external part of it (e.g. to outside of the cell in the case of the plasmalemma), where the carrier concentration is null or low.

On the external part of the membrane, the carrier – which has a specific affinity for a given ion, binds the specific ion by complexing, thus increasing the concentration of the IC complex. Formation of the IC complex outside the cell encourages the crossing of the C from the cell outside by maintaining the direction course of the equilibrium to the outside.

But, by increasing the IC concentration outside the cell, there results a concentration gradient of IC from outside the cell towards the cytoplasm, where the IC concentration is null (at the zero moment of the absorption) or low. The IC passing through the plasmalemma continues until the equilibrium is achieved.

In the cytoplasm, the IC complex unbinds in its components, I and C, either because it is unstable in the cytoplasm specific conditions, or the separation is made with energy consumption supplied by ATP.

The instability in the cytoplasm could also be due to pH, which is 7–8 in optimal conditions (Marschner, 1993), so neutral - slightly alkaline, and generally does not decrease below 6.5, the rizosphere and the apparent free space having an acid pH.
In both cases, the carrier is remade and maintains the concentration gradient of C from the cytoplasm toward the apparent free space of the root, at the same time maintaining the IC concentration gradient from the apparent free space towards the cytoplasm by the the IC concentration decreasing from the cytoplasm. Thus, there results a continuous circuit of C from inside towards outside the cell, and of IC from outside towards inside the cell. The circuit is controlled by the synthesis of the carrier in the cell, by the ion presence outside the cell and eventually by the ATP-aze implied in the unbinding of the IC complex in the cell. When in the cell the ion reaches in an optimum concentration, its specific carrier is inactivated more and more by a specific mechanism; the same happens with the enzyme involved in the carrier synthesis. At a certain moment when it is necessary for the ion be uptaken, the carrier is activated and the process repeats. The ion concentration itself in the cell can contribute to the inactivation or activation of the carrier by a feed-back process.

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4. References


INFLUENCE OF SUPPLEMENTARY, STIMULATIVE, FOLIAR FERTILIZATION ON SOME BIOMETRIC INDEXES OF FRUIT TREES UNDER THE CONDITIONS OF SCPP CARANSEBEŞ – ROMANIA

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²University of Agronomical Sciences and Veterinary Medicine, Department of Agrochemistry, 59 Măriști Blvd., 71331 Bucharest, Romania, e-mail: budoi@ecoland.ro
³Research and Production Station for Orchards, Caransebeș, Romania

Summary

From the numerous aspects researched in the experiments with complex foliar fertilizers in different fruit trees, a special attention have been paid to the effect of the foliar fertilizers on the main biometric indexes, specific to these crops. As consequence of the fact that the experiments have been maintained in the same place for three or fourth years, the cumulative effect of the foliar treatments on the studied indexes is evident.

One of the main studied indexes was the trunk circumference. In the apple tree - Spur Golden Delicious/MM106 variety, and in sour cherry tree - Ilva/franc variety, the circumference increases have been much higher in foliar fertilization treatments as compared with control (with soil fertilization but without foliar fertilization). This effect is due to the stimulation of the plant metabolism, the increase of the productive use of nutrients from soil and foliar fertilizers and the increase in the uptake of nutrients from soil. Responsible for these effects are the nutrients from foliar fertilizers, but especially the bioactive substances (hormons and vitamins) in the foliar fertilizers. The foliar biomass was also statistically increased by the foliar treatments.

In sour cherry tree, the total number of flowers increased under the influence of the foliar fertilizers with up to 118 %, the number of fruits formed increased with up to 88 %, and the length of the control branch increased with up to 43 %, as compared with control.

1. Introduction

Through the application of foliar fertilizers in fruit trees, it can be achieved substantial increases of yield, with a high quality.

The complex investigations done in fruit trees, especially bometric measurements, showed that the growing processes of trees registred high values, especially biometric indexes such as: the yearly rate of the circumference increase, the foliar bimass, the total number of flowers and the number of fruits formed, and also the yearly increase of the shoots.
2. Materials and methods

The determinations regarding the main biometric indexes of the fruit trees have been accomplished in the experiences with complex foliar fertilizers (CFF) on a *white luvisoil*, highly pseudogleyed, from SCPP Caransebeş (Caraş-Severin district).

*The species* taken in study have been: apple tree – Golden Delicios variety/MM106; sour cherry tree – Ilva variety/franc; plum tree – Stanley variety/wax cherry tree.

The experiences have been conducted *between 1987-1991*, were it was studied many aspects, among them being the effect of some special foliar fertilizers on the principal biometric indexes, specific for fruit trees.

*The complex foliar fertilizers (CFF)* studied have been from the generation coded 295 (2951–2956) and 628 (6282–6288) – formulated and elaborated by the laboratory of agrochemistry from the Research Institute for Soil Science and Agrochemistry, and the CFF Folifag and Polimet. Yearly have been done 6 foliar treatments, generally concomitant with the treatments for ails and pests. The foliar fertilizers have been applied as diluted solutions (1 % concentration), for each treatment using 1000 l/ha. CFF have been compared with a control sprayed only with water. All the variants, including the control, received the same fertilization for soil.

The data regarding the main biometric indexes determined have been *statistically processed* using the analysis of variance and Tukey test for the significance of differences.

3. Results and discussions

3.1. The effect of the complex foliar fertilizers (CFF) on the growth of the trunk circumference in apple tree and sour cherry tree.

In order to put in evidence this effect, it has been accomplished mesurements every year of the experiment.

*The data for apple tree* (table 1) show that the initial values (in 1991) of the circumference was in favour of control.

*Table 1*: The effect of the complex foliar fertilizers (CFF) on the growth of the truck circumference in apple tree – Golden Delicious/MM106

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Circumferences (C) and differences (D) against control each year (cm)</th>
<th>Differences 1991 versus 1989</th>
<th>Real growth differences against control (1991 versus 1989) &amp; significances</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1989</td>
<td>1990</td>
<td>1991</td>
</tr>
<tr>
<td>Control (water)</td>
<td>27.4</td>
<td>0</td>
<td>28.0</td>
</tr>
<tr>
<td>CFF Folifag</td>
<td>25.8</td>
<td>-1.6</td>
<td>26.0</td>
</tr>
<tr>
<td>CFF Polimet</td>
<td>25.7</td>
<td>-1.7</td>
<td>26.7</td>
</tr>
<tr>
<td>CFF 2951</td>
<td>23.9</td>
<td>-3.5</td>
<td>24.8</td>
</tr>
<tr>
<td>CFF 2952</td>
<td>23.2</td>
<td>-4.2</td>
<td>24.1</td>
</tr>
<tr>
<td>CFF 2953</td>
<td>25.2</td>
<td>-2.2</td>
<td>26.0</td>
</tr>
<tr>
<td>CFF 2954</td>
<td>24.9</td>
<td>-2.5</td>
<td>25.8</td>
</tr>
<tr>
<td>CFF 2955</td>
<td>24.7</td>
<td>-2.7</td>
<td>25.2</td>
</tr>
<tr>
<td>CFF 2956</td>
<td>23.8</td>
<td>-3.6</td>
<td>24.8</td>
</tr>
</tbody>
</table>

LSD 5 % 0.24
LSD 1 % 0.32
LSD 0.1 % 0.45
The negative differences between CFF treatments and the control with water to the start of the experiment (1991), due to natural variability of the thickness of trees, became year by year – during the experimentation, smaller and smaller because of the positive effect of the foliar fertilizers on the plant growth, including circumference of the trunk. In only three years, the CFF Folifag, Polimet and 2953 practically cancelled the differences near zero.

If in 3 years the control grown with only 0.9 cm (3.3 % from its initial circumference), in the CFF treatments the circumferences grown with 2.2–2.7 cm, or 8.5–10.9 % from the initial values, that means up to 3 times more than the control. The real growth differences between CFF and control are statistically very significant and varied between 1.3–1.8 cm in favor of CFF, which is equivalent with 144–200 % supplementary growth (table 1).

*The data for sour cherry tree* (table 2) show the same positive effect of CFF on the circumference growth. The fertilizers which determined the highest increases have been CFF 2952, CFF 2953 and CFF 2955.

**Table 2:** The effect of the complex foliar fertilizers (CFF) on the growth of the trunk circumference in sour cherry tree – Ilva variety/franc

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Circumferences (C) and differences (D) against control each year (cm)</th>
<th>Differences 1991 versus 1989</th>
<th>Differences 1991 versus 1990</th>
<th>Real growth differences against control (1991 versus 1989)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>D</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>Control (water)</td>
<td>24.86</td>
<td>0</td>
<td>25.5</td>
<td>0</td>
</tr>
<tr>
<td>CFF Folifag</td>
<td>28.03</td>
<td>3.17</td>
<td>28.3</td>
<td>2.8</td>
</tr>
<tr>
<td>CFF Polimet</td>
<td>28.33</td>
<td>3.47</td>
<td>28.9</td>
<td>3.4</td>
</tr>
<tr>
<td>CFF 2951</td>
<td>26.60</td>
<td>1.74</td>
<td>27.6</td>
<td>2.1</td>
</tr>
<tr>
<td>CFF 2952</td>
<td>26.06</td>
<td>1.2</td>
<td>27.4</td>
<td>1.9</td>
</tr>
<tr>
<td>CFF 2953</td>
<td>24.76</td>
<td>-0.1</td>
<td>26.1</td>
<td>0.6</td>
</tr>
<tr>
<td>CFF 2954</td>
<td>26.80</td>
<td>1.94</td>
<td>27.7</td>
<td>2.2</td>
</tr>
<tr>
<td>CFF 2955</td>
<td>26.83</td>
<td>1.97</td>
<td>28.4</td>
<td>2.9</td>
</tr>
<tr>
<td>CFF 2956</td>
<td>27.26</td>
<td>2.4</td>
<td>28.5</td>
<td>3</td>
</tr>
</tbody>
</table>

LSD 5 % 0.32
LSD 1 % 0.45
LSD 0.1 % 0.62
*against control

**Table 3:** The effect of the complex foliar fertilizers (CFF) on the length growth of the yearly shoots in sour cherry tree – Ilva variety/franc

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Length (L) and differences (D) against control each year (cm)</th>
<th>Averages (A) 1989–1991 and differences* (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1989 L</td>
<td>D</td>
</tr>
<tr>
<td>Control (water)</td>
<td>55.96</td>
<td>0</td>
</tr>
<tr>
<td>CFF Folifag</td>
<td>62.13</td>
<td>6.17</td>
</tr>
<tr>
<td>CFF Polimet</td>
<td>55.86</td>
<td>-0.1</td>
</tr>
<tr>
<td>CFF 2951</td>
<td>61.86</td>
<td>5.9</td>
</tr>
<tr>
<td>CFF 2952</td>
<td>57.20</td>
<td>1.24</td>
</tr>
<tr>
<td>CFF 2953</td>
<td>58.56</td>
<td>2.3</td>
</tr>
<tr>
<td>CFF 2954</td>
<td>54.93</td>
<td>-1.03</td>
</tr>
<tr>
<td>CFF 2955</td>
<td>51.13</td>
<td>-4.83</td>
</tr>
<tr>
<td>CFF 2956</td>
<td>51.75</td>
<td>-4.21</td>
</tr>
</tbody>
</table>

LSD 5 % 5.72 5.00
LSD 1 % 7.88 6.85
*against control

99
3.2. The effect of the complex foliar fertilizers (CFF) on the length growth of the yearly shoots in sour cherry tree.

The experimental data put in evidence the positive influence of the foliars treatment on this index too (table 3), which is very important for fruit trees. The results are also for 3 years (1989, 1990 and 1991), and for the 3 years averages the statistical calculations have been done taking the years as repetitions. The differences against control are generally statistically assured, excepting the last 3 variants. CFF 2951, CFF Folifag, CFF 2952 and CFF 2953 gave the best results.

3.3. The effect of the complex foliar fertilizers (CFF) on the leaf biomass in apple tree and plum tree.

The results with 628 series of CFF show the excellent positive influence of the foliar fertilization on this biometric index in apple tree and plum tree (table 4). All the differences against control are positive and statistically significant to very significant. The best results (very significant differences) in apple tree gave CFF 6282, CFF 6283 and CFF 6288, and in plum tree all CFF except 6284 (distinct significant difference). The dry matter of apple tree leaves doubled or even more, and in plum tree increased with up to 41%. The leaves have been more vigorous than that of control, with a more intensive photosynthesis, which explain the yield increases obtained with CFF and the high quality of the fruits.

Table 4: The effect of the complex foliar fertilizers (CFF) on the leaf biomass (50 leaves) in apple tree – variety Spur Golden Delicious/MM106, and plum tree – Stanley variety/wax cherry tree (1992)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Apple tree</th>
<th></th>
<th></th>
<th>Plum tree</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td></td>
<td>Differences, &amp;</td>
<td>Biomass</td>
<td></td>
<td>Differences, &amp;</td>
<td></td>
</tr>
<tr>
<td>g dm⁻¹</td>
<td>%</td>
<td>significances</td>
<td>g dm⁻¹</td>
<td>%</td>
<td>significances</td>
<td></td>
</tr>
<tr>
<td>Control (water)</td>
<td>10.95</td>
<td>100</td>
<td>-</td>
<td>15.10</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>CFF 6282</td>
<td>27.38</td>
<td>250</td>
<td>16.43 ***</td>
<td>20.47</td>
<td>133</td>
<td>4.97 ***</td>
</tr>
<tr>
<td>CFF 6283</td>
<td>23.57</td>
<td>215</td>
<td>12.62 ***</td>
<td>20.43</td>
<td>135</td>
<td>5.33 ***</td>
</tr>
<tr>
<td>CFF 6284</td>
<td>22.55</td>
<td>206</td>
<td>11.60 **</td>
<td>18.05</td>
<td>120</td>
<td>2.95 **</td>
</tr>
<tr>
<td>CFF 6285</td>
<td>20.42</td>
<td>186</td>
<td>9.47 **</td>
<td>20.30</td>
<td>134</td>
<td>5.20 ***</td>
</tr>
<tr>
<td>CFF 6286</td>
<td>21.75</td>
<td>199</td>
<td>10.80 **</td>
<td>21.33</td>
<td>141</td>
<td>6.23 ***</td>
</tr>
<tr>
<td>CFF 6287</td>
<td>19.35</td>
<td>177</td>
<td>8.40 *</td>
<td>19.72</td>
<td>131</td>
<td>4.62 ***</td>
</tr>
<tr>
<td>CFF 6288</td>
<td>27.50</td>
<td>251</td>
<td>16.55 ***</td>
<td>21.22</td>
<td>141</td>
<td>6.12 ***</td>
</tr>
<tr>
<td>DL 5 %</td>
<td>6.45</td>
<td></td>
<td></td>
<td>1.99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DL 1 %</td>
<td>8.89</td>
<td></td>
<td></td>
<td>2.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DL 0.1 %</td>
<td>12.24</td>
<td></td>
<td></td>
<td>3.85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
* dry matter

3.4. The effect of the complex foliar fertilizers (CFF) on the number of flowers, fruits formed and length of the control branch in sour cherry tree.

The 295 series of CFF had a small positive influence on these indexes, even if statistically not significant (table 5). The best influence had CFF 2954: flowers more than double (118% number increase), as compared with control, and fruits formed almost double (88% more). The length of the control branch increased with up to 43% (CFF 2955).
Table 5: The effect of the complex foliar fertilizers (CFF) on the number of flowers and fruits formed in sour cherry tree – Ilva variety/frac (1988)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Flowers</th>
<th>Fruits formed</th>
<th>Length of control branch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total number</td>
<td>%</td>
<td>Total number</td>
</tr>
<tr>
<td></td>
<td>(average)</td>
<td></td>
<td>(average)</td>
</tr>
<tr>
<td>Control (water)</td>
<td>233</td>
<td>100</td>
<td>114</td>
</tr>
<tr>
<td>CFF Foliag</td>
<td>259</td>
<td>111</td>
<td>133</td>
</tr>
<tr>
<td>CFF Polimet</td>
<td>302</td>
<td>130</td>
<td>147</td>
</tr>
<tr>
<td>CFF 2951</td>
<td>258</td>
<td>111</td>
<td>132</td>
</tr>
<tr>
<td>CFF 2952</td>
<td>314</td>
<td>135</td>
<td>137</td>
</tr>
<tr>
<td>CFF 2953</td>
<td>309</td>
<td>133</td>
<td>140</td>
</tr>
<tr>
<td>CFF 2954</td>
<td>507</td>
<td>218</td>
<td>215</td>
</tr>
<tr>
<td>CFF 2955</td>
<td>328</td>
<td>141</td>
<td>192</td>
</tr>
<tr>
<td>CFF 2956</td>
<td>278</td>
<td>119</td>
<td>124</td>
</tr>
<tr>
<td>DL 5%</td>
<td>441</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DL 1%</td>
<td>775</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DL 0.1%</td>
<td>2088</td>
<td></td>
<td></td>
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</tbody>
</table>

4. References


SOME CONSEQUENCES OF THE SUPPLEMENTARY STIMULATIVE FOLIAR FERTILIZATION ON SOIL FERTILITY IN ORCHARDS

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Summary

The paper presents experimental results on supplementary stimulative foliar fertilization in apple tree and sour cherry tree. The results disclose the effects of foliar fertilization on the soil fertility as consequences of the increase in the export of soil nutrients by yields.

Foliar fertilization in fruit trees determines significant yield increases and an increase of the productive use of nutrients from soil reserve, which in relative values is about the same as the relative yield increase. In the long run, this can lead to decreases of the soil nutrient contents, especially mobile K and P, to increase of the phosphate buffer capacity, and finally to decrease of the soil fertility if the supplementary nutrient consumptions, exported by yield increases and uncompensated by foliar fertilizers, are not compensated by corresponding soil fertilization.

The paper also presents specific equations that can be used to predict the decrease of the mobile P and K when only foliar fertilizers are used, as well as specific formulas to compute the rates of P and K fertilizers to be applied with the aim to compensate the supplementary nutrient exportations from soil.

1. Introduction

There is a high interest in the improvement of the nutrition for fruit trees and maintaining it at an optimal level by stimulative foliar fertilization, without producing negative modifications of the main agrochemical soil indexes.

The high economical efficiency of the foliar fertilization results from the significant yield and quality increases using small amounts of nutrients. Reported to conventional unit of nutrients ("active substances"), the yield increases obtained by foliar fertilization are three times higher than those obtained by classical soil fertilization because of its stimulative effect and of the high coefficient use of the nutrients. It is stimulated the chlorophyll synthesis and activity, whose efficiency in the use of the nutrients increases, but also determines a supplementary productive nutrient consumption from soil reserves and from the fertilizers applied in soil.

The significant increase of the productive use of nutrients from the soil reserve, which in relative values is about the same as the relative yield increase, can determine, in time, a diminution of the available soil nutrients - especially of the mobile P and K. The mobile P and K from the ploughed layer are considered some of the main agrochemical indexes which reflect the level of the soil culturalization and fertility, emphasizing the positive or negative influence that the crop technologies exert on the soil fertility.
2. Materials and methods

The researches regarding the evolution of the mobile P and K content from the ploughed soil layer have been done on stationary long term field experiments with foliar fertilization on apple tree and sour cherry tree at SCPP Caransebeș. Between 1987–1991, on a white luvisoil, high pseudogleyed, it has been tested the complex foliar fertilizers CFF 2951–2956 (formulated and elaborated by the laboratory of agrochemistry from the Research Institute for Soil Science and Agrochemistry) and Folifag. The cultivars used were Spur Golden Delicious/MM 106 for apple tree and Ilva/franc for sour cherry tree. The foliar treatments have been done during vegetation, corresponding to the critical phases for nutrition between the flowering end and the beginning of the ripening. It was applied 6 treatments, each time 1000 l diluted solution/ha (1 % concentration). The researches allowed to elaborate prognosing formulae for the evolution of the mobile P and K content from the ploughed soil layer as related to the initial soil content and supplementary P and K consumption in the yield increases, uncompensated by foliar fertilizations. The soil analysis regarding mobile phosphorus (P_{AL}) and potassium (K_{AL}) have been done by Egner–Riehm–Domingo method: extraction with ammonium acetate-lactate solution (AL method) at pH 3.76 and colorimetric dozing for P and flamfotometric dozing for K.

3. Results and discussions

Estimation of the diminution of the mobile P from soil (P_{ALt}) after t years of foliar fertilizations.

This can be done with the following formula (Borlan et al.):

\[ \text{P}_{\text{ALt}}, \text{ ppm P} = \text{P}_{\text{ALi}} + \frac{45}{45 + 0.047(45 - \text{P}_{\text{ALi}})^2} \times 0.12 \sum_{n=1}^{\text{CPn}} (-0.8 \times \text{CPn}) \]

in which:

- \text{P}_{\text{ALt}} = mobile P content after t years of foliar fertilization, ppm P;
- \text{P}_{\text{ALi}} = initial mobile P content, ppm P;
- \text{CPn} = supplementary P consumption of plants from soil with the yield increases, uncompensated by foliar fertilization (exceeding foliar fertilizers contribution), kg P_{2}O_{5}/ha·year;
- t = time, number of years of experimentation, at the end of which it is doing the evaluation of \text{P}_{\text{AL}};

0.12 and 0.8 = multiplicative factors: 0.12 = maximum specific rate of the influencing of the soil mobile P by the P consumption (export) with the yield, ppm P/kg P_{2}O_{5}; 0.8 = average share from the P plant consumption which comes from the soil layers underneath the ploughed one.

In order to evaluate \text{CPn}, it has been used average data from literature referring to the specific consumption of P, P_{2}O_{5}/t main product plus the corresponding secondary product.
Estimation of the amount of P fertilizers to be applied in soil in order to compensate the supplementary P consumption of plants from soil with the yield increases, uncompensated by foliar fertilization can be done with the following formula (Borlan et al.):

$$\text{Amount (rate), kg P}_2\text{O}_5/\text{ha} = \frac{(PAL_t - PAL_i) \cdot [45 + 0.047 \cdot (45 - PAL_i)^2] + 4.32 \cdot CPn}{5.4}$$

in which $PAL_i$–$PAL_t$ = diminution of the mobile P content from the initial moment (i) till the t moment as consequence of the P export with the yield increase uncompensated by foliar fertilization.

Estimation of the phosphatic intensity ($I_P$) of the soil. This index characterizes the solubility state of the phosphates and the tendency of the mobile P (which represent the soil quantitative, Q) to pass in the soil solution. $I_P$ can be calculated with the relation (Borlan et al.):

$$I_P, \text{ ppm P} = \frac{\lg PAL_{\text{max}} - \lg(PAL_{\text{max}} - PAL)}{C} = \frac{\lg 95 - \lg(95 - PAL)}{5.24}$$

where 95 is the maximum content of the mobile P (PAL) to which the solubility of the phosphates in CaCl$_2$ 0.01N saline solution increases unrestricted (freely).

Estimation of the soil phosphatic buffering capacity (PBC) and potassic buffering capacity (KBC). These indexes emphasize the modification of the mobile P and K (quantity or Q factor), when $I$ (the content of the soil solution) changes with 1 ppm element. The soil buffering capacity (BC), PBC and KBC can be calculated with the relations:

$$BC = Q/I; \quad PBC = PAL/I_P; \quad KBC = KAL/I_K$$

Estimation of the diminution of the mobile K from soil ($KAL_i$) after $t$ years of foliar fertilizations. This can be done with the formula (Borlan et al.):

$$KAL_t, \text{ ppm K} = KAL_i + \sum_{i=1}^{t_{\text{last}}} -0.8 \cdot CKn \frac{3.61}{3.61} \cdot FT$$

where:
- $KAL_t$ = mobile K content after $t$ years of foliar fertilization, ppm K;
- $PAL_i$ = initial mobile K content, ppm K;
- $CKn$ = supplementary K consumption of plants from soil with the yield increases, uncompensated by foliar fertilization (exceeding foliar fertilizers contribution), kg K$_2$O/ha·year;
- $t$ = time, number of years of experimentation, at the end of which it is doing the evaluation of $PAL_i$;
- 0.8 = average share from the P plant consumption which comes from the soil layers underneath the ploughed one.
- 3.61 = kg K$_2$O that corresponds to 1 ppm K in the ploughed layer with a weight of 3000 t/ha;
- $FT$ = buffering factor of the modification of the soil mobile K, reversibly variable with the product between $KAL_i$ and the cationic exchanging capacity of the soil (T, me/100 g):

$$FT = \frac{400}{KAL_i} - 0.05$$
Estimation of the amount of K fertilizers to be applied in soil in order to compensate the supplementary K consumption of plants from soil with the yield increases, uncompensated by foliar fertilization. This can be done with the formula:

\[
\text{Amount (rate), } \text{kg } K_2O/ha = \frac{3.61 \cdot (KAL_i - KAL_t) + 0.8 \cdot CKn \cdot FT}{FT}
\]

in which \(KAL_i - KAL_t\) = diminution of the mobile K content from the initial moment \(i\) till the \(t\) moment as consequence of the K export with the yield increase uncompensated by foliar fertilization.

Examples of prognoses of the mobile P and K modifications in the ploughed layer of the soil in apple tree and sour cherry tree fertilized with foliar fertilizers.

The calculations refer to the white luvisoil from the long time field experiments of SCPP Caransebeş.

Results for apple tree. The average specific P consumption of 0.65 kg \(P_2O_5/t\) (data from literature), shows that the apple tree is not too exigent to the P nutrition as compared with other nutrients. For this reason, to obtain the yield increases in experiment it was enough the contribution of the foliar fertilizations (6 treatments/year), the foliar fertilizers being quite reach in this nutrient.

The yield increases determined by foliar fertilizations (averages of 5 years experiment), varied between 5.4–9.64 t/ha, depending on the foliar fertilizer (table 1). The soil analyses showed that the initial soil K content varied between 47-106 ppm K. The mobile K contents prognosis for the end of the experiment have been between 33–89 ppm K, which correspond to a diminution of K content (\(\Delta KAL\)) with 10–24 ppm K.

During the 5 years of the experiment, the foliar fertilization determined a supplementary K consumption with the yield increases, uncompensated by foliar treatments, \(CKn\), which varied between 10.42 and 23.14 kg \(K_2O/ha\) (the smallest for Folifag). A higher yield increase with foliar fertilizers has a higher supplementary consumption of K from soil. There is a high positive correlation between the negative changes of the mobile K and \(CKn\) (fig. 1). The K contribution of the foliar fertilizer influenced also \(\Delta KAL\); a fertilizer poor in K determines a higher K consumption from soil and an increase of \(\Delta KAL\) (a decrease of KAL), such as with Folifag.

Table 1: The yield increases determined by foliar fertilization, \(Yi\), the uncompensated K consumption with the yield increases, \(CKn\), and the evolution of the mobile K from the white luvisoil from Caransebeş in a stationary field experiment (1987–1991) with complex foliar fertilizers to apple tree (Delicious Golden Spur)

<table>
<thead>
<tr>
<th>Foliar treatments</th>
<th>Yi, kg/ha</th>
<th>CKn kg K2O/ha·year</th>
<th>FT</th>
<th>KALp ppm K</th>
<th>KALt ppm K</th>
<th>(\Delta KAL) ppm K</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFF2951</td>
<td>6,91</td>
<td>14,95</td>
<td>0,373</td>
<td>83</td>
<td>68</td>
<td>-15</td>
</tr>
<tr>
<td>CFF2952</td>
<td>5,66</td>
<td>11,20</td>
<td>0,438</td>
<td>72</td>
<td>62</td>
<td>-10</td>
</tr>
<tr>
<td>CFF2953</td>
<td>7,57</td>
<td>16,93</td>
<td>0,281</td>
<td>106</td>
<td>89</td>
<td>-17</td>
</tr>
<tr>
<td>CFF2954</td>
<td>9,64</td>
<td>23,14</td>
<td>0,336</td>
<td>60</td>
<td>36</td>
<td>-24</td>
</tr>
<tr>
<td>CFF2955</td>
<td>7,66</td>
<td>17,20</td>
<td>0,287</td>
<td>104</td>
<td>86</td>
<td>-18</td>
</tr>
<tr>
<td>CFF2956</td>
<td>7,10</td>
<td>15,52</td>
<td>0,698</td>
<td>47</td>
<td>33</td>
<td>-14</td>
</tr>
<tr>
<td>Folifag</td>
<td>5,40</td>
<td>10,42</td>
<td>0,436</td>
<td>72</td>
<td>58</td>
<td>-14</td>
</tr>
</tbody>
</table>

Fig. 1 – Correlation between the negative changes of the mobile soil K (KAL) and the consumptions of K uncompensated (CKn): apple tree on white luvisoil from Caransebeş
Results for sour cherry tree. The yield increases and the evolution of the indexes of the soil phosphatic regime in the experiment with sour cherry tree is presented in table 2. The yield increases determined by the foliar fertilizations, as averages of 5 years of experiment, varied between 2.21 t/ha to Folifag and 6.26 t/ha to CFF 2954. The uncompensated P consumption with the yield increases, CPn, varied between 1.58–4.49 kg P$_2$O$_5$/ha-year.

Table 2: The yield increases determined by foliar fertilization, Yi, the uncompensated P consumption with the yield increases, CPn, the evolution of the indexes of the soil phosphatic regime as consequence of the foliar fertilization and the rates of P fertilizers needed to compensate the supplementary exports of P with the yield increases in a long time field experiment (1987–1991) with complex foliar fertilizers in sour cherry tree (Iluva/fragr) on the white luvisoil from Caransebes

<table>
<thead>
<tr>
<th>Foliar treatments</th>
<th>Yi, kg/ha</th>
<th>CPn, kg P$_2$O$_5$/ha-year</th>
<th>PAl, ppm P</th>
<th>PAL, ppm P</th>
<th>APAL, ppm P</th>
<th>IP, ppm P</th>
<th>IP, ppm P</th>
<th>Al, ppm P</th>
<th>PBC, ppm P</th>
<th>PBC, ppm P</th>
<th>APBC, ppm P</th>
<th>Rate, kg P$_2$O$_5$/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFF2951</td>
<td>4.32</td>
<td>1.58</td>
<td>58</td>
<td>57</td>
<td>-1</td>
<td>0.098</td>
<td>0.076</td>
<td>-0.022</td>
<td>744</td>
<td>750</td>
<td>+6</td>
<td>11</td>
</tr>
<tr>
<td>CFF2952</td>
<td>5.60</td>
<td>3.30</td>
<td>55</td>
<td>53</td>
<td>0</td>
<td>0.072</td>
<td>0.067</td>
<td>-0.005</td>
<td>764</td>
<td>791</td>
<td>+27</td>
<td>26</td>
</tr>
<tr>
<td>CFF2953</td>
<td>5.76</td>
<td>3.74</td>
<td>53</td>
<td>51</td>
<td>2</td>
<td>0.067</td>
<td>0.064</td>
<td>-0.003</td>
<td>791</td>
<td>797</td>
<td>+6</td>
<td>24</td>
</tr>
<tr>
<td>CFF2954</td>
<td>6.26</td>
<td>4.49</td>
<td>50</td>
<td>49</td>
<td>-1</td>
<td>0.020</td>
<td>0.018</td>
<td>-0.002</td>
<td>1000</td>
<td>1055</td>
<td>+55</td>
<td>34</td>
</tr>
<tr>
<td>CFF2955</td>
<td>5.32</td>
<td>3.06</td>
<td>56</td>
<td>55</td>
<td>-1</td>
<td>0.074</td>
<td>0.072</td>
<td>-0.002</td>
<td>757</td>
<td>764</td>
<td>+7</td>
<td>12</td>
</tr>
<tr>
<td>CFF2956</td>
<td>5.31</td>
<td>3.06</td>
<td>30</td>
<td>29</td>
<td>-1</td>
<td>0.051</td>
<td>0.030</td>
<td>-0.021</td>
<td>796</td>
<td>977</td>
<td>+8</td>
<td>13</td>
</tr>
<tr>
<td>Folifag</td>
<td>4.47</td>
<td>2.21</td>
<td>60</td>
<td>59</td>
<td>-1</td>
<td>0.083</td>
<td>0.080</td>
<td>-0.003</td>
<td>723</td>
<td>757</td>
<td>+24</td>
<td>12</td>
</tr>
</tbody>
</table>

The initial mobile P content, PAl, has been between 20–60 ppm P and diminished only with 1-2 ppm P during the 5 years of experimentation, that means very little. The phosphatic intensity, IP, diminished with 0.002-0.022 ppm P. There is a positive linear high correlation between P content from soil solution or phosphatic intensity, IP, and mobile P, PAL (fig. 2). The phosphatic soil buffering capacity, PBC, increased with 6–55 ppm mobile P/1 ppm P in soil solution. Eaven if not statistically significant, there is a tendency of linear correlation between the changes (increases) of PBC and the consumption of P with the yield increases, uncompensated by foliar fertilization, CPn (fig. 2). The highest change of the PBC (55 ppm P) has been in the treatment CFF 2954 where it has been the highest uncompensated P consumption by foliar fertilization (4,49 kg P$_2$O$_5$/ha). The highest values of PBC, around

Fig. 2 – a) Correlation between P content of the soil solution (IP) and mobile P of soil (PAL = Q); b) correlation between the changes of the soil P buffer capacity (PBC) and the consumptions of the P uncompensated by foliar fertilization (CPn); c) correlation between the rate of P fertilizers needed for compensation and the consumptions of P uncompensated (CPn): sour cherry tree on white luvisoil at Caransebes
1000 or over, have been in the variants where the PALi had the smallest values (20 and 30 ppm P). Such high values show a quite advanced state of the soil fertility degradation as viewed by the PBC regime.

The rates of P fertilizers needed to compensate the supplementary exports of P with the yield increases, in order to maintain the initial values of the soil mobile P, are not to high, varying between 11–34 kg P₂O₅/ha for a 5 years period. There is a high correlation between the rates of P fertilizers and CPn (fig. 2).

The data referring to the potassium uncompensated consumptions, of the mobile K content in the experiment with sour cherry tree, has been between 17,98 and 28,65 kg K₂O/ha. The initial K content varied between 31–124 ppm K, and the final values between 31–124 ppm K.

**Table 3:** The uncompensated K consumption with the yield increases, CKn, and the evolution of the mobile K from the white luvisol from Caransebeș in a long time field experiment (1987–1991) with complex foliar fertilizers in sour cherry tree (Ilva/franc)

<table>
<thead>
<tr>
<th>Foliar treatments</th>
<th>CKn kg K₂O/ha·year</th>
<th>FT</th>
<th>KAL₀ ppm K</th>
<th>KALₐ ppm K</th>
<th>ΔKAL ppm K</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFF2951</td>
<td>17,98</td>
<td>0.275</td>
<td>108</td>
<td>89</td>
<td>-19</td>
</tr>
<tr>
<td>CFF2952</td>
<td>25,02</td>
<td>0.332</td>
<td>92</td>
<td>66</td>
<td>-26</td>
</tr>
<tr>
<td>CFF2953</td>
<td>25,90</td>
<td>0.489</td>
<td>80</td>
<td>54</td>
<td>-26</td>
</tr>
<tr>
<td>CFF2954</td>
<td>28,65</td>
<td>0.636</td>
<td>60</td>
<td>31</td>
<td>-29</td>
</tr>
<tr>
<td>CFF2955</td>
<td>23,48</td>
<td>0.689</td>
<td>55</td>
<td>32</td>
<td>-23</td>
</tr>
<tr>
<td>CFF2956</td>
<td>23,42</td>
<td>0.432</td>
<td>92</td>
<td>64</td>
<td>-28</td>
</tr>
<tr>
<td>Folifag</td>
<td>20.29</td>
<td>0.189</td>
<td>147</td>
<td>124</td>
<td>-23</td>
</tr>
</tbody>
</table>

The negative changes of the mobile K, ΔKAL, are higher then those for mobile P, and varied between -19 and -29 ppm K. Like in apple tree, there is a high positive correlation between the negative changes of the mobile K and CKn for sour cherry tree (fig. 3).

**Conclusions:** the foliar fertilization in fruit trees determines important yield increases; in long run, this can leads to decreases of the soil mobile P, and especially of the mobile K, to the increase of the phosphate buffer capacity, and finally to the decrease of the soil fertility if the supplementary nutrient consumptions, exported by yield increases and uncompensated by foliar fertilizers, are not compassed by corresponding soil fertilization; this paper presents specific equations that can be used to prognose the decrease of the mobile P and K when only foliar fertilizers are used, as well as specific formulas to compute the rates of P and K fertilizers to be applied with the aim to compensate the supplementary nutrient exportsations from soil.

4. References


PRELIMINARY ASPECTS CONCERNING THE PERSISTENCE AND PENETRATING OF NUTRIENTS FROM FOLIAR FERTILIZERS ON/INTO PLANTS TEGUMENTS

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1)Research Institute for Soil Science and Agrochemistry, Marasti street, No. 61, CP 71331, Bucharest, Romania, E-mail: ionutagr@icpa.ro

Summary

Due to increased physical and economical efficiency and to small imputs of nutrients into plant – soil system by foliar application, the utilization of foliar fertilizers in agriculture became more intensively used in the last time. The specification of some aspects concerning the persistence of nutrients from applied foliar fertilizers on plant teguments is considered to be necessary in this paper. In this context, are presented experimental data from greenhouse which give emphasis to the efficient use of nutrient from applied foliar fertilizers on plants by rain intervention (simulation in greenhouse) at 6, 12 and 48 hours after foliar application of fertilizers.

1. Introduction

The foliar fertilization is an efficient method to increase the yields in agriculture and in the same time by small imputs of nutrients into plant-soil system this fertilization method ensures an ecological protection against chemical pollution of environment (Borlan et. al., 1992, 1995). Majority of researches with foliar fertilizers from now shown the physical and ecological efficiency but nothing about what happening when the rain intervenes at different time after foliar fertilization. The experimental data obtained in greenhouse presented in this paper tray to show some preliminary aspects concerning the productive use of nutrients (N, P and K) in yields from foliar fertilizers applied on sunflower plants by rain intervention at different moments after foliar fertilizers application.

2. Material and methods

The experimental data were obtained in experimental pots from greenhouse. Tested plant was sunflower cultivated on chernozem soil (20 kg of soil/pot). Begining with 7 – 8 leaves three treatments (foliar fertilization) with three types of foliar fertilizers were made. The second and third treatments were made after 7 – 8 days each. Three rain simulation (at 6, 12 and 48 hours) per each foliar treatment were made. The water quantity was 250, 500 and 800 ml/pot corresponing to aproximatively 35, 75 and 115 m³/ha for those three rain simulations. After each rain simulation the plants was harvested and the N, P and K contents in dry matter of sunflower plants were determined by official Romanian determination methodology. In order to compute the apparent degree of productive nutrient use (ADPU) from foliar fertilizers (FF) the following formula was used:

\[ ADPU_{FF} = (A \times B) / C \times 100 \]
In this formula: \( A \) = yield increases (t/ha); \( B \) = nutrients uptaken in yields increases (kg of N, P\(_2\)O\(_5\) and K\(_2\)O/t uptaken in yield increase); \( C \) = nutrients from fertilizers (kg/ha). The results obtained were statistically tested and the differences are significant.

3. Results and discussions

The effect of foliar fertilizers applied on plants is diminuated in rain intervention conditions after their application. This diminuation of foliar fertilization effect depends on the moment at which the rain is intervening. The dry material content in comparison with no foliar fertilized (control) are bigger with 0.4 – 11.18 g/pot (1.1 – 60.7 %); 1.84 – 12.73 g/pot (22.1 – 67.3 %) and 2.18 – 14.16 g/pot (22.7 – 91.2 %) at 6, 12 and respectively 48 hours rain intervention after foliar fertilization (figure 1). Dry material content are increasing with foliar treatments for each foliar fertilizer.

![Fig.1. Effect of rain intervention after foliar fertilization on dry matter accumulation (% as compared to control) in sunflower plants (greenhouse simulation, 2000)](image)

The results obtained by rain simulation at different moment intervening in greenhouse show that the macronutrients (N, P and K) content in dry material of sunflower plants (as compared with no foliar fertilized - control) is increasing according to time rising at which the rain is intervening after foliar fertilization.

For foliar fertilizers tested in greenhouse the increased content of N, P and K are included between 0.003 – 0.271 g N/pot; 0.002 – 0.058 g P\(_2\)O\(_5\)/pot and respectively 0.006 – 0.247 g K\(_2\)O/pot at 6 hours of rain intervention after foliar fertilization, 0.016 – 0.298 g N/pot; 0.006 – 0.065 g P\(_2\)O\(_5\)/pot and respectively 0.029 – 0.308 g K\(_2\)O/pot at 12 hours rain intervention after foliar fertilization and between 0.074 – 0.343 g N/pot; 0.012 – 0.073 g P\(_2\)O\(_5\)/pot and respectively 0.059 – 0.344 g K\(_2\)O/pot at 48 hours rain intervention after foliar fertilization.

Expressed as relative values comparing with no foliar fertilized (control), the N, P and K content are bigger with 1.5 – 47.2 % of N; 14.3 – 117.0 % of P\(_2\)O\(_5\) and 4.5 – 53.3 % of K\(_2\)O at 6 hours rain intervention after foliar fertilization, 6.5 – 50.4 % of N; 28.6 – 120.7 % of P\(_2\)O\(_5\) and 15.4 – 59.6 % of K\(_2\)O at 12 hours rain intervention after foliar fertilization and 34.5 – 85.0 % of N; 52.1 – 137.7 % of P\(_2\)O\(_5\) and 32.1 – 74.8 % of K\(_2\)O at 48 hours rain intervention.
after foliar fertilization (figures 1 – 3). The N, P and K contents are increasing with number of foliar application for each foliar fertilizers.

Fig. 2. Effect of rain intervention after foliar fertilization on Nt accumulation in yields (% of Nt as compared to control) from foliar fertilizers applied on sunflower plants (greenhouse simulation, 2000)

Fig. 3. Effect of rain intervention after foliar fertilization on Pt accumulation in yields (% of Pt as compared to control) from foliar fertilizers applied on sunflower plants (greenhouse simulation, 2000)

Fig. 4. Effect of rain intervention after foliar fertilization on Kt accumulation in yields (% of Kt as compared to control) from foliar fertilizers applied on sunflower plants (greenhouse simulation, 2000)
The correlation between dry material and N, P and K content from sunflower plants are very significant for N (figure 5) and significant for P and K (figures 6 – 7).

**Fig. 5.** Correlation between dry matter and **N**<sub>t</sub> content from sunflower plants as effect of rain intervention after foliar fertilization (greenhouse simulation, 2000)

\[
y = 0.0242x + 0.0141 \quad R = 0.95
\]

**Fig. 6.** Correlation between dry matter and **P**<sub>t</sub> content from sunflower plants as effect of rain intervention after foliar fertilization (greenhouse simulation, 2000)

\[
y = 0.015x^{0.4351} \quad R = 0.56
\]

**Fig. 7.** Correlation between dry matter and **K**<sub>t</sub> content from sunflower plants as effect of rain intervention after foliar fertilization (greenhouse simulation, 2000)

\[
y = 0.0498x^{0.5407} \quad R = 0.66
\]
The efficient use of nutrient in these conditions of rain intervention is also reflected by the increased apparent degree of nutrient productive use (ADPU) in increased yield (82.5 – 4273.16% of N, 4.40 – 5224.6% of P\textsubscript{2}O\textsubscript{5} and 112.5 – 18755.8% of K\textsubscript{2}O for the first moment to rain intervention; 491.3 – 56105.6% of N, 33.5 – 6712.6% of P\textsubscript{2}O\textsubscript{5} and 817.5 – 28368.0% of K\textsubscript{2}O for the second moment of rain intervention and 840.0 – 66640.0% of N; 48.8 – 8616.7% of P\textsubscript{2}O\textsubscript{5} and 1411.7 – 29890.0% of K\textsubscript{2}O for the third moment to rain intervention) according to increase of time at which the rain is intervening and to number of foliar fertilization (table 1).

Table 1: Apparent degree of productive nutrient use (%) from foliar fertilizers applied on sunflower plants (greenhouse simulation, 2000)

<table>
<thead>
<tr>
<th>No. of treatment</th>
<th>Rain intervention (simulation) after foliar fertilization:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>at 6 hours</td>
</tr>
<tr>
<td>FOLPLANT 231</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>82.5</td>
</tr>
<tr>
<td>2</td>
<td>406.1</td>
</tr>
<tr>
<td>3</td>
<td>1005.4</td>
</tr>
<tr>
<td>ECOFERT II</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3117.5</td>
</tr>
<tr>
<td>2</td>
<td>18564.0</td>
</tr>
<tr>
<td>3</td>
<td>42731.6</td>
</tr>
<tr>
<td>BIODOR 2311</td>
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</tr>
<tr>
<td>1</td>
<td>1007.6</td>
</tr>
<tr>
<td>2</td>
<td>3664.9</td>
</tr>
</tbody>
</table>

4. Conclusions

The determination of the effect of rain intervention at different moments after foliar fertilization is very important for use of this method fertilization in agriculture. The increases of N, P and K contents from dry material of sunflower plants in comparison with no foliar fertilized (control) was very small when the rain intervened at 6 hours after foliar fertilization. In this case the repetition of foliar fertilization is necessary. The contents of N, P and K are increasing with duration of rain intervenes. By rain intervention at 48 hours, the contents of N, P and K in dry material of sunflower plants are very significant. The contents of determined nutrients are very significantly correlated with sunflower dry material in case of N. Correlations are weaker in case of P and K. Also the efficient use of nutrient in these conditions of rain intervention is reflected by the increased apparent degree of nutrient productive use (ADPU), in increased yield with duration of rain intervenes and number of foliar fertilization.

5. References


INFLUENCE OF SEED TREATMENT WITH AMINOACIDS AND UREIDES COMPOSITIONS ON SOWING EPOCH OF CROPS

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2) University for Agronomical Science and Veterinary Medicine, Marasti street, No. 59, CP 71331, Bucharest, Romania, E-mail: budoi@ecoland.ro
3 Biological Research Institute, Iasi, Romania

Summary

By acid hydrolisation of some animal proteic sources (bone clay etc.) and adding of metallic microelements and also physiologic activ substances (potassium naftenats etc.), 9 composition with aminoacids and ureides (AUC) resulted. These compositions were used to foliar fertilisation of plants and to seed treatments before sowing. The data obtained from field experiments during 3 – 4 years give emphasis to the positive effects of seed treating with these compositions (0,25 % concentration) in early and late saison in comparison with optimal sowing saison. The results demonstrate that when from different technical and climatic reasons the sowing at optimal time is not possible, then by treating of seeds with aminoacids and ureides compositions (AUC) the increases in yield were at least at the same level as obtained by sowing at optimal time and in some cases they were even bigger than that.

Introduction

The application of some products on seeds before sowing may assure an increase of yields plus of nutrients by bringing other physiological substances for plant in comparison with soil resources and applied fertilizers. In this context Borlan and al. (1993) tested the effect of some liquid composition with aminoacids and ureides which was applied on maize seeds before sowing at different sowing dates. These results are presented in this paper.

Material and methods

9 composition with aminoacids and ureides obtained by acid hydrolisation of some animal proteic sources (bone clay) and adding of metallic microelements and also physiologic activ substances was used for treatment the maize seeds before sowing. These compositions was used in concentration of 0,25 % (0,25 cm3/100 g seeds) in 3 research stations during 3 and 4 years. The experiments was carried out at Podul Iloaiei - Iaşi, Băneasa – Giurgiu and Caransebeş – Caraş Severin Stations. The treated seeds with these compositions was sown in 3 epochs: early, optimal and late sowing epoch. The base fertilization was made according to maize crop technology. At the maize maturity the plants were harvested and the yield increase in comparison with optimal sowing epoch was calculated. The results are presented as yield differences in early and late sowing epochs compared with optimal sowing epoch and as yield differences in early and late sowing epochs compared with optimal sowing epoch control.
Results and discussion

Some of the liquid composition with aminoacids and ureides (LC – AAU) determined positive differences of yield by them application on seeds before sowing in early and late epochs in comparison with normal (optimal) sowing epoch of maize for kernels (figures 1– 3).

Fig. 1. Yield differences determined by application of liquid composition with aminoacids and ureides on sown maize seeds in early and late epochs as compared with them application in optimal sowing epoch at Podul Iloaiei - Iași Station

Fig. 2. Yield differences determined by application of liquid composition with aminoacids and ureides on sown maize seeds in early and late epochs as compared with them application in optimal sowing epoch at Caransebeș - Caraș severin Station

Fig. 3. Yield differences determined by application of liquid composition with aminoacids and ureides on sown maize seeds in early and late epochs as compared with them application in optimal sowing epoch at Băneasa - Girgiu Station
The results are significant as annual obtained results and also as averages of experimental years from experimental places (table 1).

**Table 1:** Average yield differences determined by application of liquid composition of aminoacids and ureides (LC – AAU) on sown maize seeds in early and late epochs as compared with application in optimal sowing epoch

<table>
<thead>
<tr>
<th>Fertilization</th>
<th>Podul Iloaiei – Iasi Station (average values of 4 years)</th>
<th>Băneasa – Giurgiu Station (average values of 3 years)</th>
<th>Caransebeș – Caras Severin Station (average values of 4 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eearly epoch</td>
<td>Late epoch</td>
<td>Eearly epoch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC – AAU-a1</td>
<td>-3.00</td>
<td>-2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>LC – AAU-a2</td>
<td>-5.00</td>
<td>-5.00</td>
<td>-1.00</td>
</tr>
<tr>
<td>LC – AAU-a3</td>
<td>9.00</td>
<td>2.00</td>
<td>12.00</td>
</tr>
<tr>
<td>LC – AAU-a4</td>
<td>8.00</td>
<td>-3.00</td>
<td>-6.00</td>
</tr>
<tr>
<td>LC – AAU-a5</td>
<td>9.00</td>
<td>2.00</td>
<td>5.00</td>
</tr>
<tr>
<td>LC – AAU-a6</td>
<td>1.00</td>
<td>1.00</td>
<td>-2.00</td>
</tr>
<tr>
<td>LC – AAU-a7</td>
<td>-5.00</td>
<td>-6.00</td>
<td>-9.00</td>
</tr>
<tr>
<td>LC – AAU-a8</td>
<td>14.00</td>
<td>3.00</td>
<td>-4.00</td>
</tr>
<tr>
<td>LC – AAU-a9</td>
<td>5.00</td>
<td>3.00</td>
<td>-7.00</td>
</tr>
</tbody>
</table>

In comparison with optimal sowing epoch, the application of LC – AAU on seeds and sowing in early epoch at Podul Iloaiei Station determined yield differences from 1.00 to 14.00 %, except a1, a2 and a3 compositions with yield differences smaller with 3 – 5 %.

By application of these compositions on seeds in late sowing epoch the most yield differences was negatively, except a3, a5, a6, a8 and a9 compositions whose yield differences was included between 1.00 – 3.00 % in comparison with optimal sowing epoch.

At Băneasa, in comparison with optimal sowing epoch the LC – AAU application on seeds which was sown at early epoch determined yield differences which are included between 2.00 – 22.00 %, except a1, a4 and a8 compositions house average yields differences was smaller with 2.00 – 7.00 % than optimal sowing epoch. By late sowing epoch the treated seeds with LC – AAU determined yield differences only for a2, a3, a5 and a7 compositions whose values are included between 1.00 – 6.00 %.

At Caransebeș Station, in comparison with optimal sowing epoch the LC – AAU application (only a1 and a3) on seeds determined significantly yield differences in both early and late sowing epochs. Those of compositions determined yield differences in an inconsequent way for each of both sowing epochs (early and late epoch) in comparison with optimal sowing epoch. Comparing the yields of early and late sowing epochs with yields of optimal sowing epoch control it can be seen that in many cases there are positive and significant differences in yield (table 2). So, in 1995 at Lespezi – Iași Station all of the compositions produced positive yield differences in comparison with control of the optimal sowing epoch as well as a3 and a5 – a6 compositions from 1997 and 1998 respectively. In general the yield differences obtained in late sowing epoch are negative except a3 – a9 composition from 1997 and a5 composition from 1998. At Caransebeș Station, all treatments on maize seeds determined positive yield differences almost in both early and late sowing epochs in comparison with late sowing epoch control, except late sowing epochs from 1995 (except a2 and a7 compositions) and 1998 years. The obtained results from field experiment at Băneasa Station showing that the treatment application on seeds determined positive and negative yield differences in those two sowing epochs in comparison with optimal sowing epoch control. Except a1 and a6 (early sowing epoch) and a2, a7 (late sowing epoch) from 1994 and a5 – a7 and a9 from 1995 (late sowing
all compositions applied on maize seeds produced positive significant yield differences.

**Table 2:** Differences of yields (kg/ha) determined by treatments with aminoacids and ureides liquid compositions on maize for kernels in early and late sowing epochs as compared with optimal sowing epoch control

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Differences (kg/ha) as compared with optimal sowing epoch control</th>
<th>Early epoch</th>
<th>Late epoch</th>
<th>Early epoch</th>
<th>Late epoch</th>
<th>Early epoch</th>
<th>Late epoch</th>
<th>Early epoch</th>
<th>Late epoch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td>3390</td>
<td>-</td>
<td>-</td>
<td>-210</td>
<td>3110</td>
<td>-30</td>
<td>3110</td>
<td>-30</td>
</tr>
<tr>
<td>LC–AAU₁</td>
<td></td>
<td>350</td>
<td>-</td>
<td>-</td>
<td>-1210</td>
<td>3110</td>
<td>-240</td>
<td>60</td>
<td>-30</td>
</tr>
<tr>
<td>LC–AAU₂</td>
<td></td>
<td>490</td>
<td>-</td>
<td>-1080</td>
<td>160</td>
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<td>-</td>
<td>-1370</td>
<td>-210</td>
<td>3120</td>
<td>-210</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>LC–AAU₄</td>
<td></td>
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<td>-</td>
<td>-1380</td>
<td>-360</td>
<td>3120</td>
<td>-210</td>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>LC–AAU₅</td>
<td></td>
<td>770</td>
<td>-</td>
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<td>-760</td>
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<td>-70</td>
<td>30</td>
<td>40</td>
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<td>-1100</td>
<td>-420</td>
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<td>-</td>
<td>-1100</td>
<td>-480</td>
<td>3120</td>
<td>-210</td>
<td>210</td>
<td>500</td>
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<tr>
<td>LC–AAU₈</td>
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<td>-</td>
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**Table 2 Continued:**

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<th>Late epoch</th>
<th>Early epoch</th>
<th>Late epoch</th>
<th>Early epoch</th>
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In conclusion, treating of maize for kernel seeds with LC – AAU compositions in early and late sowing epochs can produce positive significant yield differences in comparison even with optimal sowing epoch control.

**Conclusions**

Having in view that the application of liquid composition of aminoacids and ureides brings a plus of nutrients and physiologic activ components for plants in comparison with soil resources and applied fertilizers, treating seeds with these compositions produced some positive differences in yield in early and late sowing epochs in comparison with optimal sowing epoch. That is reflected by increases in yield obtained as compared with increases in yield obtained in optimal sowing epoch as well as compared with optimal sowing epoch control. These differences in yield are statistically significant. Our results demonstrate that in most cases when the sowing at optimal epoch is not possible due to different technical and climatic reasons e.g. in both early and late epochs, then treating of seeds with aminoacids and ureides compositions will result in good yields. The differences in yield obtained may be at least at the same level as differences in yield obtained in optimal sowing epoch and may be even bigger than that in some cases.
References

