and initial weight of the experimental plants, which could lead to great differences in absolute plant weight during the stage of exponential growth. Although the shoot/root ratio is known to change during early growth, the effect of small differences in age on this property of the plant is much smaller. The variation of the mineral contents is much lower than that of the dry weights (Table 8). The Ca\textsuperscript{++} content varies more than the others. This difference is caused by the rather great variation in plant size. Old leaves accumulate Ca-ions and large plants having more old leaves than small plants will have a higher average Ca\textsuperscript{++} content.

Table 8. Variation in mineral composition within a set of 8 plants of Cynoglossum officinale (contents in meq of mK/kg dry leaf matter).

<table>
<thead>
<tr>
<th></th>
<th>K\textsuperscript{+}</th>
<th>Ca\textsuperscript{++}</th>
<th>N-org.</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean ($)</td>
<td>1540</td>
<td>1366</td>
<td>3297</td>
</tr>
<tr>
<td>coefficient of variation ($/s)</td>
<td>0.03</td>
<td>0.12</td>
<td>0.04</td>
</tr>
<tr>
<td>95% confidence interval</td>
<td>1502–1579</td>
<td>1230–1501</td>
<td>3177–3416</td>
</tr>
</tbody>
</table>

References


6.3. THE INFLUENCE OF SOIL MOISTURE AND TRAMPLING ON GERMINATION AND DEVELOPMENT OF THE SEEDLINGS OF FOUR PLANTAGO SPECIES AT VARIOUS DEGREES OF SOIL COMPACTNESS (C. W. P. M. Blom)

6.3.1. Introduction

Within the scope of the research on the influence of recreation and grazing on the dune vegetation of Voorne and Goeree, the experimental study on the influence of soil compactness on germination of some Plantago species has been continued (see 1972 Progress Report, pp. 106–112), with the addition of experiments on the influence of trampling on germination and the growth of seedlings.

Preceding experiments concerned the influence of soil compactness under optimal soil moisture levels on the germination of Plantago lanceolata, P. coronopus, P. major, and P. media. The present report gives results of experiments on the influence of soil compactness on germination under conditions of a limited water supply and also on the influence of trampling on germination and growth of seedlings. In addition a distinction was made between the germination of seeds lying on the soil surface (uncovered) and those covered with 3 mm sand.

In general Plantago species are found on more or less compacted or trodden soils. For purposes of comparison, Potentilla tabernaemontani, which grows mainly on non-compacted or non-trodden soils in the dune area, was included in the present investigations.
6.3.2. Germination of seeds lying on the surface of soils differing in compactness

6.3.2.1. Material and methods

The experiments were carried out with seeds of *Plantago lanceolata*, *P. coronopus*, *P. major*, *Potentilla tabernaemontani*, all collected in the dune area of Voorne and Goeree in 1971 and 1972, and with seeds of *Plantago media*, which were collected in Zuid-Limburg in 1972. The seeds were stored in envelopes at room temperature. Germination and growth took place in a phytotron (18 hours light, 6 hours darkness, temperature 24°C, relative air humidity 70%) in wooden boxes (30 x 30 x 10 cm) filled with sand originating from the older dunes (humus content about 0.5%, pH ± 9). This substrate was chosen because except for *P. media* the *Plantago* species mentioned and *Potentilla tabernaemontani*, are normally present in the older dunes. *Plantago media* was included to permit comparison of the *Plantago* species occurring in the dunes with one of different origin.

The following treatments were applied. Three series were prepared: in series A the soil was not compacted, in series C there was a maximal compaction, and in series B the compaction was intermediate between A and C. Compaction of the soil was achieved by ramming down the substrate. Soil compaction was determined by measurement of the soil resistance with a penetrometer. The soil resistance in the upper 2 cm was 0 kg/cm² in series A, 5 kg/cm² in series B, and 10 kg/cm² in series C. These soil-resistance values correspond with the following values of pore volume: series A: 45%, series B: 42%, and series C: 39%. Each box had the same quantity of water; the percentage of soil water (expressed as percentage of dry soil) were 10% in series A, 16% in series B and 14% in series C. During the experiments soil water was replenished every 24 hours, at which time the water contents were about 4% lower than the initial values. Since this water content was adequate for maximal germination, the sole limiting factor in this experiment was considered to be the soil resistance.

Unlike the experiments described in the 1972 Progress Report, the seeds were not covered with sand. In each box two plant species were sown separately (200 seeds of each species). In the control series the seeds were placed in the phytotron on wet filterpaper in petri dishes. During the tests the germination rate and the maximal germination were determined. At the end of the experiments the soil resistance was determined again.

6.3.2.2. Results

The results of these experiments are shown in figs. 7a–d, and 10 (mean values of three experiments). One month after the beginning of the experiments the soil resistance had not changed.
6.3.2.3. Conclusions

It can be seen that the highest germination percentages occurred on soils without compaction. The difference between the maximum germination on non-compacted and compacted soils was significant ($X^2$-test). In all series *Plantago major* showed the highest percentage of germination. Therefore, it may be concluded that uncovered seeds of *Plantago major*
lying on a compacted soil are more capable of germination than those of the other species investigated.

6.3.3. The influence of soil compactness and trampling on germination

6.3.3.1. Material and methods

To study the influence of trampling on the germination and development

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**Diagram:**

- **Plantago major**
  - Soil resistance 0 kg/cm²
  - Soil resistance 5 kg/cm²

- **Plantago media**
  - Soil resistance 0 kg/cm²
  - Soil resistance 5 kg/cm²

Fig. 7.
of the seedlings of the four *Plantago* species, the following treatments were applied. Three series (strong compaction, moderate compaction, and no compaction) were prepared in the same way and with the same substrate as described in section 2. The tests were carried out in pots (content 5 litres) and were placed in the greenhouse in July of 1973. The day

![Graph of Plantago lanceolata germination](a)

![Graph of Plantago coronopus germination](b)

Fig. 8. The influence of trampling on germination of four *Plantago* species.
temperature in the greenhouse was about 27° C, the night temperature about 20° C, and the relative air humidity 60%. Per pot, 100 seeds of one species were sown; the seeds were covered with a 3 mm layer of sand, and the percentages of soil water were as described in section 2. Immediately upon sowing, the following trampling treatments were started.

Fig. 8.
Series A (no compaction) was trodden once a day with a strength of 0.05 kg/cm²; series B (moderate compaction) was trodden twice daily at 0.15 kg/cm², and series C (strong compaction) was trodden four times a day at 0.25 kg/cm². In each series a untrodden control was included. During the tests the soil resistance was determined.

6.3.3.2. Results

The results of the trampling experiments are shown in fig. 8a–d. The results of the control tests were compared with those of series A.

In series A and C there was no important difference in soil resistance before and after the trampling treatment; in series B the soil resistance increased by 2 kg/cm².

6.3.3.3. Conclusions

The following conclusions may be drawn from this experiment. Moderate trampling on a moderately compacted dune soil with optimal humidity resulted in a recession of 21% for the seedlings of *Plantago lanceolata*, 34% for *P. coronopus*, and 15% for *P. media*. All of the seedlings of *P. major* survived this treatment. Intense trampling of seedlings growing in a strongly compacted dune soil caused a mortality of 90% for *P. coronopus*, 85% for *P. lanceolata*, 68% for *P. media*, and 50% for *P. major*.

It may therefore be concluded that the seedlings of *P. major* are less sensitive to trampling, whereas those of *P. coronopus* and *P. lanceolata* are highly sensitive to trampling.

In the future, experiments will be undertaken on the influence of trampling on full-grown plants of *Plantago* and some other plant species.

6.3.4. Soil compactness and soil humidity as variable factors in germination experiments

6.3.4.1. Material and methods

In this part of the study two factors, i.e. soil compactness and moisture content of the soil, were considered simultaneously, since in natural situations at least two important limiting factors for germination are conceivably operative: i.e., mechanical impedance (penetration resistance) and restricted availability of water.

The experiments were carried out with seeds of the four *Plantago* species and *Potentilla tabernaemontani*. Except for the level of soil humidity, the series were prepared in the same way as described in section 2. The seeds were placed 3 mm below the surface. In the experiments with *Plantago lanceolata* and *P. coronopus* the initial soil water level was 5%. After 20 and 36 days the quantity of soil water was increased by 1%. Because *Plantago major*, *P. media*, and *Potentilla tabernaemontani* did not germinate with less than 7% soil water, these experiments were started
at 7% of soil moisture; the percentages being raised once a week by 1%.

During the tests the germination rate and the maximum germination were determined.

6.3.4.2. Results

The results are shown in fig. 9a–d (mean values of three experiments). At the end of the tests it was found that the water percentages in the upper layer of the soil were 2% lower than given in the graphs, whereas in the lower layer the water percentages had increased by 2%. In the graphs the mean values of the water percentages are given.

6.3.4.3. Conclusions

From these experiments it may be concluded that seeds of *Plantago lanceolata* and *P. coronopus* were able to germinate at a lower level of soil water than the other species studied.

From the experiments on the influence of soil compactness on germination of *Plantago* seeds it can be concluded that at an optimum availability of soil moisture, the soil compactness is the limiting factor for germination (Fig. 7), whereas at a low level of soil water, the soil humidity is the limiting factor. The water availability is better for seeds in a compacted soil, since the capillary rise is better. In the experiments with a low level of soil water this resulted in a higher percentage of germination in compacted soils.

In addition, it may be concluded that under all of the conditions studied the mechanical impedance is the limiting factor for the germination of seeds of *Potentilla tabernaemontani*. When, at the end of the tests with a low level of soil water, the water content was raised to the optimal level the results of these treatments showed that all of the ungerminated seeds of *Plantago lanceolata* and *P. coronopus* were still capable of germination, whereas those of the other species showed no additional germination. It is possible that during the experiment (see section 4) a number of just-germinated seeds of *Plantago major*, *P. media*, and *Potentilla tabernaemontani* died due to water restriction. The low germination of *Plantago major* could also have been the result of a seasonal factor, since these experiments were carried out in the winter. These tests are to be repeated in other seasons.

6.4. THE STUDY OF THE ROOT-NODULE SYMBIOSIS OF *Hippophaë rhamnoides*; A METHOD TO ESTIMATE THE NUMBER OF INFECTIVE PARTICLES PER UNIT WEIGHT OF NODULE MATERIAL (P. A. I. Oremus)

6.4.1. Introduction

To study the population dynamics of the microorganism that lives in symbiosis with *Hippophaë rhamnoides*, resulting in the formation of root-nodules, it is necessary to develop a method to estimate the number of