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# Study of the Interactions between Cereals with Respect to the Soil Nitrate Nitrogen

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**Abstract.** The interactions between cereals — wheat, barley, rye and oats — in combined cultivation in mixtures of always two species in relation 1 : 1 in the initial phase of growth were studied. During thirty days' cultivation in pots the growth of the experimental plants in pure cultures and in mixtures and the changes of the nitrate nitrogen content of the soil in the experimental vessels were followed.

The experiments showed that all tested species of cereals interacted with each other during the growth in mixture. The growth changes began soon after sowing, were of a stimulating and inhibiting character and increased during the growth. An exception was the small reaction of oats to rye.

Decrease of the nitrate nitrogen content was determined in the soil of the experimental vessels during the cultivation of the plants. The changes of the nitrate nitrogen in the soil corresponded on the whole with the exception of the last phases of the experiments to the growth intensity of the experimental plants. No essential differences, either in the content or in the rate of the decrease of nitrate nitrogen, were found in the soil of control plants and in the soil of plant mixtures. Small differences which were manifested cannot be considered the primary cause of the mutual relations of cereals. The cause of the mutual relations may be attributed to allelopathic factors.

The question of competition in the mutual relations of higher plants, particularly under natural conditions, plays a rather complicated and significant part. Even if — as it appears from many authors (CEDIK-TOMAŠEVIČ 1951, SEKUN 1951, PLHÁK and LAŠTŮVKA 1958, LAŠTŮVKA 1958, PLHÁK 1962, PLHÁK and VICHERKOVÁ 1965, PLHÁK et al. 1965, and others) — the mutual relations between the cereals seem to be mainly conditioned by allelopathic factors, still the question of competition cannot be eliminated without a more detailed study.

The purpose of the present work is to trace what part the level of the soil nitrate nitrogen, a considerable source of nitrogen nutrition of plants, plays in the mutual relations of cereals.

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## Material and Methods

Spring wheat (*Triticum vulgare* WILL. cv. Niva), spring rye (*Secale cereale* L. cv. Těšovské), spring barley (*Hordeum distichon* L. cv. Valtický), and oats (*Avena sativa* L. cv. Český žlutý) were used.

### Plant Cultivation

The experimental plants were sown into flower-pots having a diameter of 20 cm filled with garden soil. Before being filled the pots were lined with polyethylene foil to prevent the washing out and the diffusion of nutrients from the pots. Each pot contained 2·4 kg fresh weight of soil. The soil contained 5% of total humus, 0·31% of total nitrogen (C/N ratio 10 : 1), 79·8 mg/100 g of soil $P_2O_5$, 49·5 mg/100 g of soil $K_2O$. The pH value of the soil reached 6·9.

Experimental pots were placed in the garden under a roofing of polyethylene foil and were regularly moistened. The above-mentioned cereals were sown into the pots as pure cultures and in mixtures of two species in the ratio 1 : 1. Into each pot were sown 50 grains. The experimental plants grew in the pots 30 days.

### Experimental Procedure

The growth of the plants was evaluated in intervals of 5 days by determining the dry matter of the above-ground parts and the roots of one plant as the mean of 125 to 250 plants. For every evaluation plants from five pots were taken — each experimental series was repeated five times. Significant differences in the growth between the control plants and plants from mixtures were statistically evaluated by the t-test (HRUBÝ and KONVIČKA 1954).

At the same intervals after removing the plants for evaluation of growth, representative soil samples were taken from all five pots of each experimental series and immediately dried. The drying of the samples was done under constant conditions at 100°. After drying and sieving through a sieve with pores of 1 mm the content of nitrate nitrogen was determined in the soil samples. The content of the nitrate nitrogen was determined colorimetrically using phenol sulfuric acid according to Malichin's method (OKÁČ 1956). The determination was made in triplicate for every experimental series at least.

## Results

### Experiment with Barley and Rye

The experiment was begun on 17 May 1967. The growth of the dry matter of barley in mixture with rye was evidently influenced beginning with the 20th day of cultivation. The above-ground part was in comparison with the control during the time of growth gradually stimulated, the roots, on the contrary, were inhibited in the same manner (Fig. 1A).

The growth of the rye in mixture with barley was influenced only at the roots. The roots were observably inhibited from the 15th day of common growth (Fig. 1B).

The relative content of nitrate nitrogen diminished during the whole time of cultivation most rapidly in the soil in which the mixture of barley and rye grew. It diminished more slowly in the soil which contained the barley and most slowly in the soil which contained the rye (Tab. 1).

TABLES 1—3

CHANGES IN THE NITRATE NITROGEN CONTENT in the soil by cultivation of different species of cereals and their mixtures in experimental vessels for 30 days. The content of the nitrate nitrogen is expressed in mg per kg dry matter of the soil

Table 1

| Time of cultivation in days | mg N—$NO_3$/kg of soil | | | mg N—$NO_3$/kg of soil | | |
|---|---|---|---|---|---|---|
| | Barley | Rye | Mixture | Barley | Oats | Mixture |
| 0 | 132·0 | 132·0 | 132·0 | 105·3 | 105·3 | 105·3 |
| 5 (7) | 124·0 | 124·0 | 107·2 | 80·4 | 94·8 | 82·1 |
| 10 | 101·0 | 115·2 | 98·0 | 50·8 | 78·3 | 55·6 |
| 15 | 50·4 | 70·0 | 46·0 | 27·3 | 37·2 | 29·9 |
| 20 | 24·0 | 37·6 | 17·6 | 15·0 | 16·5 | 15·9 |
| 25 | 21·0 | 22·4 | 14·0 | 3·9 | 5·4 | 4·8 |
| 30 | 7·2 | 7·2 | 3·6 | 3·3 | 3·3 | 3·7 |

**Experiment with Barley and Oats**

The experiment was begun on 25 May 1967. The growth of dry matter of barley growing together with oats was after ten days of cultivation observably influenced. The growth of the above-ground part was more and more stimulated, the growth of the roots, in contrast, inhibited in comparison with the control (Fig. 2A).

The growth of the above-ground part of oats in mixture with barley was from the fifth to the fifteenth day stimulated, thereafter inhibited. The growth of oat roots was inhibited from the 15th day of cultivation (Fig. 2B).

The content of nitrate nitrogen diminished during the cultivation most rapidly in the soil which contained the barley. It diminished somewhat more slowly in the soil with oats. In the soil with the mixture of barley and oats the diminution of nitrate nitrogen reached the average values among both pure cultures (Tab. 1).

**Experiment with Wheat and Oats**

The experiment was begun on 11 July 1967. The growth of above-ground part of the wheat in mixture with oats was from the fifth day observably stimulated. The stimulation increased with the time of growth. The roots reacted differently. The inhibition began somewhat later (Fig. 3A).

The oats reacted to the presence of wheat by an inhibition of the growth of above-ground part, as well as of the roots. A significant inhibition was already evident in the above-ground part on the fifth day, at the roots on the tenth day of growth (Fig. 3B).

The content of the nitrate nitrogen in the soil diminished rapidly in all three variants during the 10 days. Among the single variants no great difference of diminution of the nitrate nitrogen was evident (Tab. 2).

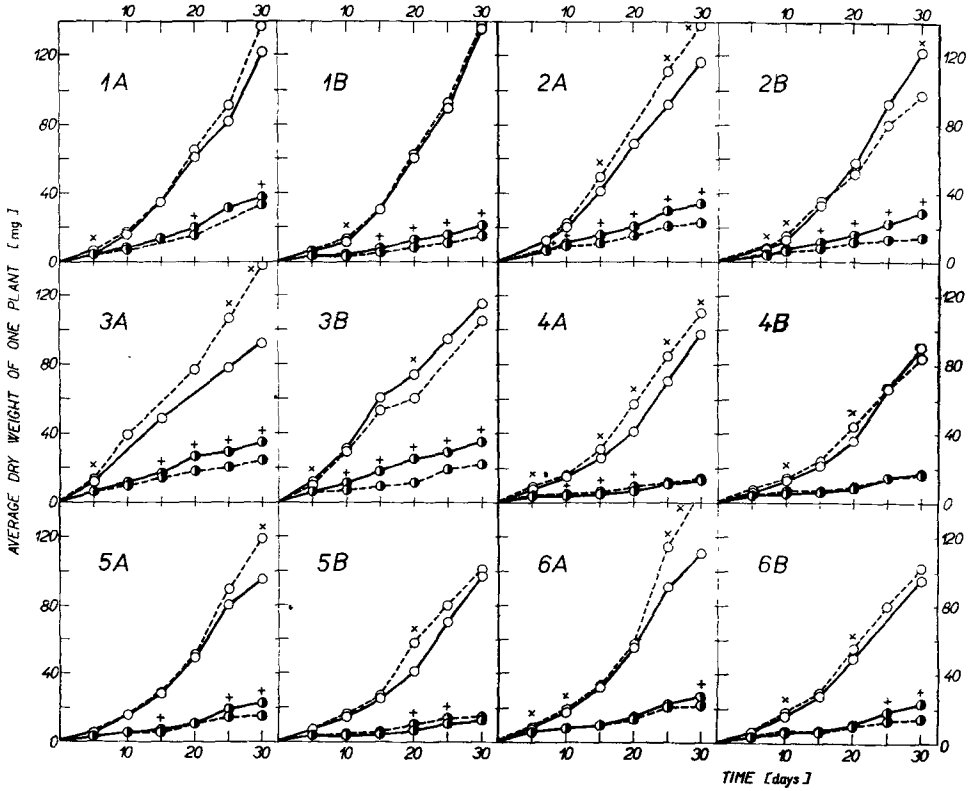


Fig. 1—6.

The intensity of growth of the dry matter of plants in pure cultures and in mixtures during 30 days of cultivation.

○ —— ○ dry matter of the above-ground parts of plants from pure seeds,
○ - - - ○ dry matter of the above-ground parts of plants from mixtures,
◑ —— ◑ dry matter of the roots of plants from pure seeds,
◑ - - ◑ dry matter of the roots of plants from mixtures.

Abscissa: time of growth of plants in days

Ordinate: average weight of the dry matter of one plant in mg

× — significant differences in the weight of above-ground parts (P = 0.05%)
\+ — significant differences in the weight of the roots (P = 0.05%).

Fig. 1A. Barley in pure seed and in mixture with rye.
Fig. 1B. Rye in pure seed and in mixture with barley.
Fig. 2A. Barley in pure seed and in mixture with oats.
Fig. 2B. Oats in pure seed and in mixture with barley.
Fig. 3A. Wheat in pure seed and in mixture with oats.
Fig. 3B. Oats in pure seed and in mixture with wheat.
Fig. 4A. Rye in pure seed and in mixture with oats.
Fig. 4B. Oats in pure seed and in mixture with rye.
Fig. 5A. Wheat in pure seed and in mixture with rye.
Fig. 5B. Rye in pure seed and in mixture with wheat.
Fig. 6A. Barley in pure seed and in mixture with wheat.
Fig. 6B. Wheat in pure seed and in mixture with barley.

TABLE 2

| Time of cultivation in days | mg N—$NO_3$/kg of soil | | | mg N—$NO_3$/kg of soil | | |
|---|---|---|---|---|---|---|
| | Wheat | Oats | Mixture | Rye | Oats | Mixture |
| 0 | 80·4 | 80·4 | 80·4 | 142·0 | 142·0 | 142·0 |
| 5 | 58·5 | 57·0 | 49·5 | 110·4 | 110·4 | 97·1 |
| 10 | 10·5 | 14·1 | 11·1 | 93·0 | 94·8 | 88·5 |
| 15 | 6·0 | 7·2 | 9·3 | 73·5 | 69·0 | 72·0 |
| 20 | 6·0 | 6·6 | 8·0 | 44·1 | 40·5 | 51·0 |
| 25 | 4·2 | 6·0 | 7·2 | 16·8 | 19·8 | 9·9 |
| 30 | 2·7 | 2·7 | 2·7 | 2·7 | 5·4 | 3·9 |

**Experiment with Rye and Oats**

The experiment was begun on 7 September 1967. The growth of the above-ground part of rye in mixture with oats was significantly stimulated from the fifth day of cultivation. The stimulation increased somewhat with the time of growth. The growth of the roots of rye in mixture was also significantly stimulated (Fig. 4A).

The growth of the oat plants in mixture with rye was influenced only slightly compared with the control (Fig. 4B).

The nitrate nitrogen content in the soil of all three variants diminished slowly and regularly with the time of growth. There was no evident difference among the single variants (Tab. 2).

**Experiment with Wheat and Rye**

The experiment was begun on 7 September 1967. The growth of the wheat plants in mixture with rye was at the beginning in accordance with the control. In the later phase of the experiment — from the 25th day the above-ground part was stimulated, the roots on the contrary were inhibited (Fig. 5A).

The rye in mixture with wheat was from the 20th day of the common growth stimulated in the above-ground part and in the roots as well (Fig. 5B).

The nitrate nitrogen content of the soil diminished regularly in all three series during cultivation. In the soil in which the mixture was cultivated, the diminution of nitrate nitrogen in comparison with the two series of pure cultures was somewhat faster nearly throughout the whole time of the experiment (Tab. 3).

TABLE 3

| Time of cultivation in days | mg N—$NO_3$/kg of soil | | | mg N—$NO_3$/kg of soil | | |
|---|---|---|---|---|---|---|
| | Wheat | Rye | Mixture | Barley | Wheat | Mixture |
| 0 | 142·0 | 142·0 | 142·0 | 142·0 | 142·0 | 142·0 |
| 5 | 110·4 | 110·4 | 90·6 | 105·2 | 110·4 | 114·3 |
| 10 | 93·0 | 93·0 | 79·2 | 78·3 | 93·0 | 100·5 |
| 15 | 79·2 | 73·5 | 58·5 | 46·8 | 79·2 | 73·2 |
| 20 | 57·0 | 43·1 | 33·3 | 11·7 | 57·0 | 38·4 |
| 25 | 19·8 | 16·8 | 16·5 | 5·1 | 19·8 | 8·1 |
| 30 | 4·2 | 2·7 | 2·7 | 2·1 | 4·2 | 2·4 |

**Experiment with Barley and Wheat**

The experiment was begun on 7 September 1967. The growth of the barley in the presence of wheat was stimulated in the above-ground part on the fifth day from the beginning of the experiment. The growth of the roots on the contrary was inhibited and that in the second part of the experiment (Fig. 6A). Wheat reacted very similarly to the presence of the barley during the growth (Fig. 6B).

The content of nitrate nitrogen diminished more rapidly in the soil which contained the barley and more slowly in the soil which contained the wheat. In the soil which contained the mixture of both plants a slower diminution of nitrate nitrogen against the two control variants at the beginning of experiment was observed. In the later phases of experiment the diminution was somewhere between the rates of the two control cultures (Tab. 3).

## Discussion

Previously published papers concerning the relations between cereals mainly dealt with mixtures of cereals which had a certain practical importance. Those were combinations of wheat with rye and barley with oats. In these two combinations a mutual influence beginning soon after sowing and manifesting itself during the whole vegetation period was found (CEDIK-TOMAŠEVIČ 1951, SEKUN 1951, LAŠTŮVKA 1958, PLHÁK and LAŠTŮVKA 1958, VICHERKOVÁ 1960, PLHÁK 1962, PLHÁK et al. 1965, PLHÁK and VICHERKOVÁ 1965, and others). Most authors stress according to their results the presence of allelopathic factors.

In the present experiments we ascertained mutual reactions between all four cereals employed. From the results it appears that all cereals tested reacted to the presence of another species of plant in the experimental vessel by a change in growth. Only in one case, namely in the mixture of rye with oats, the oats reacted only slightly to the presence of rye (Fig. 4B).

To explain the mutual reactions of the cereals mentioned allelopathic as well as competetive factors may be taken into consideration. To judge the participation of the competetive factors we traced the changes in the nitrate nitrogen content in the soil with respect to its extraordinary importance for plant nutrition.

The changes in the content of nitrate nitrogen in the soil during the cultivation of experimental plants corresponded substantially to the intensity of plants growth. One may assume they were caused mainly by the absorption of the nitrates by the plants. Certain deviation in the rapidity of the decrease of nitrate content during the experiments made in spring, summer and autumn are probably connected with the different growth intensity of the experimental plant dependent on the climatical conditions of the periods mentioned.

In the experimental series in which barley was cultivated, the content of nitrate nitrogen in the soil decreased faster. The same was observed also in mixtures where barley was present. These results are in agreement with the well-known higher requirements of barley for nutrients in the earlier phases of growth. There was a certain acceleration in the decrease of nitrate nitrogen

against both control series partly also in the mixture of rye with wheat as well as in the mixture of barley with rye. With the other cereals and their mixtures differences in the absorption of nitrate nitrogen were not observed.

TABLE 4

COMPARISION OF THE WEIGHT OF DRY MATTER of the experimental plants grown in mixture and in pure cultures in g per vessel.

| Kind of mixture | Weight of dry matter in g | | Weight of the mixture in per cent of the theoretical weight of the mixture |
|---|---|---|---|
| | Theoretical weight of the plants from mixture | Real weight of the plants from mixture | |
| Barley—rye | 8·05 | 8·20 | 102 |
| Barley—oats | 7·60 | 6·80 | 90 |
| Wheat—oats | 6·95 | 7·30 | 105 |
| Rye—oats | 5·40 | 5·60 | 104 |
| Wheat—rye | 5·70 | 6·25 | 109 |
| Barley—wheat | 6·35 | 7·10 | 111 |

The theoretical weight of the mixture was calculated from the weight of both components growing in pure cultures.

If we compare these results with the changes in the growth of the experimental plants it is evident that only in some cases is there a certain positive dependence. In most mixtures an increase of the total growth in dry matter per vessel could be observed. There was a substantial increase in the mixtures barley-wheat and rye-wheat; the increase was here 11% and 9% against the theoretical yield (Tab. 4). The nitrate nitrogen was absorbed faster only in one of these two mixtures than in the control plants. In cases where an ininhibition in the growth of experimental plants was observed, no substantail difference was determined in the nitrate nitrogen content in the soil of these variants against the control.

These findings do not prove that the competition for the nutrients — judging by one of the principal elements of mineral nutrition — was the primary cause of the growth changes and of the reactions provoked by cultivation of cereals in mixtures. The results, on the contrary, confirm the opinions of a series of authors that the relations between cereals are conditioned by allelopathic factors. In support of this assertion there are numerous indications in literature concerning the release of different organic biologically active substances by the roots of cereals (EBERHARDT 1954, 1955, MARTIN 1956, 1957, PORUCKIJ et al. 1962, VANČURA 1964, SAMCEVIČ 1965, PLHÁK and URBÁNKOVÁ 1969, and others).

If we consider, with regard to the results of our experiments, that allelopathic factors are responsible for the interactions of all four cereals, than we must consider their specificity for every tested species of plant. If two plant species with the same allelopathic factors existed, they could not interact with each other. This specificity may be connected with the specificity of the metabolism of plant species.

In the mutual reaction of some cereals, however, it was possible to observe a certain analogy. Wheat and barley reacted in all cases to every partner plant in the same manner, namely in the stimulation of the over-ground part and in the inhibition of the roots. Rye reacted by a general stimulation to the presence of wheat and oats. Oats reacts, in contrast, to the presence of wheat and barley by an inhibition of growth. Another characteristic growth reaction to the presence of an alien species was the decrease of the weight relation of the roots to the over-ground parts which was manifest in most cases (Tab. 5).

TABLE 5

RELATION OF THE WEIGHT OF ROOTS to the above-ground parts of plants from mixtures expressed in per cent of the values of these relations to the control plants (plants from pure seeds,

| Barley in mixture | % | Wheat in mixture | % | Rye in mixture | % | Oats in mixture | % |
|---|---|---|---|---|---|---|---|
| with rye | 80 | with rye | 52 | with wheat | 108 | with rye | 106 |
| with oats | 57 | with oats | 58 | with oats | 92 | with wheat | 70 |
| with wheat | 58 | with barley | 60 | with barley | 73 | with barley | 61 |

A probable explanation of such similar growth reactions of plants is the small specificity of growth reaction to the different factors of interaction. From this point of view barley and wheat may be characterized as plants having a similar type of reaction. On the contrary rye and oats seem to be different from these two cereals in reaction and different also from each other.

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V práci jsme sledovali vzájemnou reakci obilnin pšenice, ječmene, žita a ovsa při společné kultivaci vždy dvou druhů v počátečních fázích růstu. Pokusy byly prováděny v nádobách naplněných zeminou a uložených na zahradě pod stříškou z polyetylénové fólie. Rostliny byly vysévány jednak v čistých kulturách a jednak ve směsi dvou druhů v poměru 1 : 1. Během třicetidenní kultivace byl sledován růst nadzemních částí a kořenů rostlin a změny v obsahu nitrátového dusíku v zemině pokusných nádob.

V pokusech bylo zjištěno, že všechny testované druhy obilnin se při růstu ve směsích vzájemně ovlivňovaly. Změny v růstu měly stimulační i inhibiční charakter, začínaly záhy po výsevu a s dobou růstu se prohlubovaly. Výjimkou byla malá reakce ovsa na žito.

V zemině pokusných nádob byl stanoven v průběhu kultivace rostlin pokles obsahu nitrátového dusíku. Změny v obsahu nitrátového dusíku v zemině vcelku odpovídaly, s výjimkou posledních fází pokusů intensitě růstu pokusných rostlin.

U směsí ječmene s žitem a žita s pšenicí byl patrný rychlejší pokles obsahu nitrátového dusíku v zemině vůči kontrolám. Tomu odpovídala i zvýšená tvorba celkové váhy sušiny pokusných rostlin. V ostatních zeminách, v nichž byly kultivovány směsi, nebyl nalezen ani v obsahu ani v rychlosti poklesu nitrátového dusíku prakticky žádný rozdíl vůči zeminám, v nichž byly kultivovány kontrolní rostliny.

Z výsledků lze usuzovat, že faktory výživy nejsou primární příčinou vzájemné interakce obilnin kultivovaných ve směsích. Příčiny vzájemné interakce lze přičíst na vrub allelopatickým faktorům.