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Effect of ammonium and nitrate source of nitrogen on productivity of photosynthesis in Scots pine (*Pinus silvestris* L.) seedlings*

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Abstract

Water culture and sand culture seedlings of Scots pine were investigated in respect to their reaction to ammonium or nitrate source of nitrogen nutrition. Photosynthesis, respiration, and dry matter production were studied in three and four months old plants. The results are preliminary but they have indicated that the effect of various form of nitrogen nutrition on gas exchange and growth rates could change during the growing season.

INTRODUCTION

Photosynthesis and respiration of pine seedlings supplied with either ammonium or nitrate form of nitrogen was studied in plants cultivated in the water solutions and in the sand. The purpose of the experiment was to investigate photosynthesis and respiration rates and production of organic substance by plants differentiated in growth activity.

MATERIAL AND METHODS

Seedlings of Scots pine (*Pinus silvestris* L.) cultivated for 3—4 months in nutrient solutions containing different source of nitrogen were used as the research material. The solution recommended for pine by I n g e s t a d (1960, 1962/63) with nitrogen in a form of ammonium nitrate was applied at growing control plants. The other solutions were prepared of either sodium nitrate or ammonium chloride with such an account that quantity of nitrogen was always the same.

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Two experiments were made: one during the winter time, under greenhouse conditions at 16 hours day, plants growing in water culture; the other during the vegetation season, under outside conditions with only nights and rainy periods spent under the glass, plants growing in sand culture were supplied continuously with nutrient solutions. Details of the water culture experiment are described in the work by Zajączkowska (1973). The scheme of the sand culture experiment is shown in Fig. 1. Connection of each pot with the bottle containing the nutrient

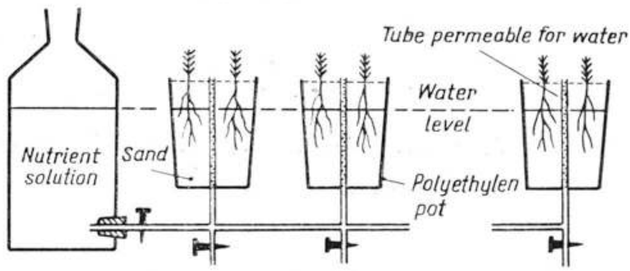

Fig. 1

solution enabled maintenance of the constant level of watering, easy and complete exchange of the solution, application of the same diluted solutions as in experiments with water culture. The last point is particularly important since application of more concentrated solutions in sand deprived of sorption capacity, is usually unsuccessful. Both in the water culture and in the sand culture the nutrient solutions were changed once a week; during that time their pH ranged no more than 4.5—5.5.

When seedlings were three or four months old samples of needles were taken into laboratory for manometric measurements of photosynthesis and respiration. At the end of the vegetation season i.e. when water culture plants were four months, and sand culture plants were five and a half months old samples were taken and dry matter of particular organs (needles, stems, and roots) was determined after drying them at 105°C.

Samples of needles used for manometric determinations of photosynthesis and respiration were brought from the greenhouse into laboratory and after weighing and measuring, they were put into the plexiglass vessels. The vessels were especially designed for experiments with pine needles (Fig. 2). The whole bottom (20 cm^2) served as a reservoir for carbonate buffer while the needles were placed above it on a light construction of a grate form. The total volume of a vessel was about 27 cm^3. Horizontal arrangement of manometric vessels enabled most favourable exposure of needles to light and the most proper conditions of the CO_2 exchange between gaseous and liquid phases.

The carbonate buffer consisted of K_2CO_3 and $KHCO_3$ (1:1) in concentration 2.0 M/l. According to Warburg and Krippahl (1960) such buffer should maintain the concentration of carbon dioxide in gaseous phase at the level of 0.55 V% which is about 18 times more than that of natural air. Stålfelt (1924) has found such concentration of CO_2 to be nearly saturating for Scots pine at 1/3 of natural day illumination.

Round type of Warburg apparatus was used. Four incandescent lamps of reflector type, 500 W each giving at the level of examined

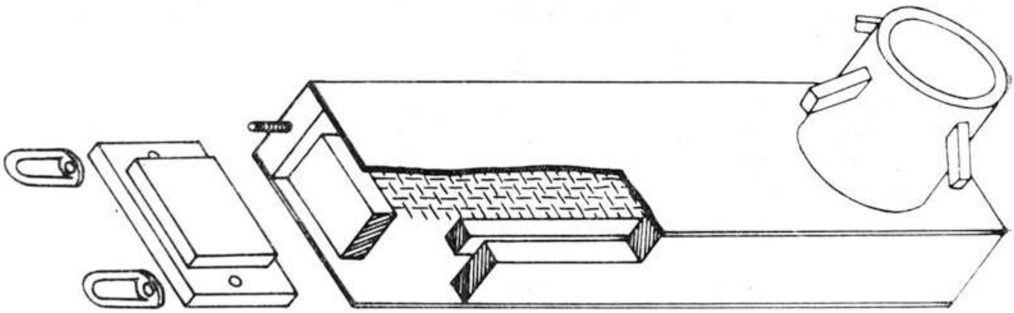

Fig. 2

samples about 20 Klx illumination were placed above an additional water screen, 8 cm thick. The temperature of water bath in which the vessels were inserted was 25°C both in light and in dark determinations. Dark respiration measurement followed the measurement of photosynthesis and the whole experiment usually lasted no longer than 1—2 hours.

For measuring photosynthesis and respiration 20 samples, 5 needles each were taken at two dates of experiment. For determination of the mean dry matter of plants at the end of the growing season 20 seedlings from water culture and 120 seedlings from sand culture of each experimental variant were used.

RESULTS

Rates of photosynthesis were the highest in plants grown with ammonium chloride as a source of nitrogen (Table 1). Both variants with nitrate form of nitrogen exhibited similar rates of photosynthesis. There was a typical tendency to decrease photosynthesis rates towards the end of the growing season but it was more clearly pronounced in plants receiving nitrates than in plants supplied with ammonium. Respiration rates were low and not significantly differentiated among the experimental variants so in the ratio: photosynthesis/respiration the same regularities were observed as in the photosynthesis rates. Both experimental

Table 1

Photosynthesis and respiration rates in ml O_2 per gram of dry weight and hour and the ratio: photosynthesis/respiration (A/R)

Experimental conditions	Form of nitrogen nutrition	Photosynthesis		Respiration		Ratio: A/R	
		age of the investigated plants					
		3 months	4 months	3 months	4 months	3 months	4 months
Water culture, greenhouse during the winter time	$NaNO_3$	16.89	11.18	0.96	1.06	17.6	10.5
	NH_4NO_3	17.27	9.29	0.96	1.14	18.0	8.1
	NH_4Cl	20.28	16.66	0.92	0.92	22.1	18.1
	$t_{0.95\mu}$	1.29	2.31	0.19	0.11		
Sand culture, outside conditions during the vegetation season	$NaNO_3$	15.27	8.82	0.84	0.99	18.2	8.9
	NH_4NO_3	13.05	11.80	0.81	0.87	16.1	13.6
	NH_4Cl	15.98	15.68	0.81	1.02	19.7	15.4
	$t_{0.95\mu}$	2.59	1.37	0.11	0.07		

Table 2

Mean dry weight and length of a single needle and per cent of increase between the 3rd and 4th month of growth

Experimental conditions	Form of nitrogen nutrition	Dry weight in mg			Length in mm		
		Age of plants		Per cent of increase	Age of plants		Per cent of increase
		3 months	4 months		3 months	4 months	
Water culture, greenhouse during the winter time	$NaNO_3$	1.34	2.02	51	32.0	34.2	7
	NH_4NO_3	1.36	1.87	38	32.2	34.2	6
	NH_4Cl	1.82	2.33	28	37.0	37.7	2
	$t_{0.95\mu}$	0.59	0.12		1.3	1.2	
Sand culture, outside conditions during the vegetation season	$NaNO_3$	2.47	2.96	20	33.4	35.5	6
	NH_4NO_3	2.78	3.35	21	35.4	38.2	8
	NH_4Cl	2.96	3.39	15	36.2	38.4	6
	$t_{0.95\mu}$	0.21	0.31		1.9	2.0	

conditions i.e. water culture in greenhouse and sand culture in the open air gave almost the same pattern though generally the rates were higher in the water culture plants than in the sand culture plants.

The size of needles expressed by average dry weight of one needle was the highest in plants supplied with ammonium chloride and usually the lowest in plants which received sodium nitrate (Table 2). Between first and second date of measuring the increase of dry weight of needles was the highest in plants supplied with nitrate and the lowest in plants supplied with ammonium form of nitrogen. Average length of needles was also the highest in plants supplied with ammonium form of nitrogen. The length of needles was similar in both groups of experimental

Table 3

Dry weight of needles, stem, and root at the end of the vegetation season

Experimental conditions	Form of nitrogen nutrition	Dry weight per plant (mg)				Distribution of dry weight (%)			
		Needles	Stem	Root	Whole plant	Needles	Stem	Root	Whole plant
Water culture, greenhouse, during the winter time, plants 4 months old	$NaNO_3$	83	34	69	186	45	18	37	100
	NH_4NO_3	67	30	53	150	45	20	35	100
	NH_4Cl	115	43	76	234	49	18	33	100
Sand culture, outside conditions during the vegetation season, plants $5^1/_2$ months old	$NaNO_3$	167	37	187	391	43	9	48	100
	NH_4NO_3	200	43	207	450	45	10	45	100
	NH_4Cl	226	53	174	453	50	12	38	100

material though their dry weight differed significantly. Between the two dates of harvest the increase in length was much smaller than the increase in weight.

Plants harvested at the end of the vegetation season i.e. when they had formed apical buds exhibited in both experimental series (water culture and sand culture) stronger growth at ammonium than at nitrate form of nitrogen (Table 3). This was especially noticeable in needles and stems and is manifest by opposite trends in percentage distribution of dry matter in needles and roots when the compared variants of nutrition are considered. The suppression of root growth under the conditions of ammonium supply and its stimulation at nitrate form of nitrogen nutrition is clearly pronounced.

DISCUSSION

The two experiments, one carried out in water culture and one in sand culture, are not fully comparable as not only medium but also time of the year and greenhouse or outside conditions differred in both of them. However, some similar tendencies in both groups of experimental material enable common discussion and conclusions.

In both experiments photosynthesis rates, ratio photosynthesis:respiration, sizes of assimilatory organs as well as total production of dry matter were the highest in plants supplied with ammonium chloride. This indicates that in such experimental conditions the ammonium form of nitrogen nutrition is preferred like it was the case in the results obtained by McFee and Stone (1968). However, high rates of photosynthesis at simultaneously outstanding growth of plants from ammonium variant suggest the kind of nitrogen nutrition primarily to affect photosynthesis, growth differentiation being secondary result of the metabolic changes. Although such statement demands further proof the high rate of photosynthesis in plants supplied with ammonium chloride maintaining towards the end of the growing season seems to confirm such a supposition. If the differences in photosynthesis rate were only the result of differences in growth stages then faster growing plants receiving ammonium form of nutrition would have shown a typical seasonal decline of photosynthetic activity as it is the case with plants from other nutritional variants.

During the investigated period of growth an increase of needles size occurred and it was most intensive at nitrate supplied plants and least intensive at ammonium supplied plants both in the water and in the sand culture experiments. Course of growth of needles, changes in photosynthesis rates between the third and the fourth month of growth, as well as final dry weight of the whole plant not differentiated so much as the photosynthetic ability indicate that reaction of pine seedlings to the form of nitrogen nutrition may change during the vegetation season. It seems that at early stages of vegetation ammonium chloride was preferred whereas towards the end of the vegetation season also the sodium nitrate stimulated growth of needles. Similar change in reaction to the form of nitrogen nutrition in various phases of vegetation was found in agricultural crops (see review by Street and Sheat, 1958).

Form of the nitrogen nutrition causes different proportion of organs. At nitrate form of nutrition growth of the root system is stimulated, at ammonium form of nutrition rather the above-the ground parts are privileged. Similar tendencies were found in water and in sand culture plants although percent of dry matter in the root system was higher in the last than in the former ones.

The results of this work generally confirm those obtained by Zajączkowska (1973) working with water culture plants and gasometric (IRGA) technique of CO_2 determination. In fact, the rates of photosynthesis and the ratios photosynthesis:respiration were even more differentiated among the nutrition variants at manometric determinations of oxygen evolution than it was the case at gasometric determinations of carbon dioxide absorption. This is certainly related to the fact that manometric technique reveals photosynthetic capacities at increased CO_2 concentration thereby the possible differences are more clearly pronounced.

CONCLUSIONS

1. The kind of the applied nitrogen nutrition does affect growth rates, gas exchange processes as well as dry matter production and its distribution in particular organs of seedlings.

2. The positive effect of ammonium form of nitrogen nutrition on dry matter production seems to be secondary in relation to the direct effect on photosynthesis.

3. Reaction of seedlings to different form of nitrogen nutrition seems to be changeable in seasonal course, ammonium form being preferred rather at earlier stages of vegetation.

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Wpływ amonowej i azotanowej formy azotu na produktywność fotosyntetyczną siewek sosny zwyczajnej (Pinus silvestris L.)

Streszczenie

Przeprowadzono badania reakcji siewek sosny zwyczajnej, wyhodowanych w kulturze wodnej i piaskowej, na zaopatrzenie w azot w formie azotanowej i amonowej. Wykonano pomiary intensywności fotosyntezy, oddychania i produkcji substancji organicznej u roślin w wieku trzech i czterech miesięcy.

Wyniki badań mają charakter wstępny, jednakże pokazują one, że wpływ formy żywienia azotowego na wymianę gazową i przebieg wzrostu rośliny może być różny w różnych fazach okresu wegetacji.