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Productivity of photosynthesis in Scots pine (*Pinus silvestris* L.) seedlings grown from seed irradiated by X-rays*)

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Abstract:

Dry matter accumulation, growth, photosynthesis and respiration were investigated in seedlings grown in water culture from seed irradiated with various doses of X-rays. The stimulating effect of X-ray treatment appeared in formation of assimilatory organs and in accumulation of dry matter in various parts of a plant. Changes in photosynthesis and respiration activity seem to be rather secondary effects of growth stimulation or inhibition.

Changes in growth, dry matter accumulation, photosynthesis and respiration of plants grown from seed irradiated by X-rays are investigated in the aspects of the influence of ionizing radiation on physiological processes in plants. On the other hand, seedlings grown from seed after X-ray treatment seemed to be an interesting object for studying photosynthetic productivity since stimulatory and inhibitory effects are obtainable here on plant material differentiated by the influence of only one factor i.e. various doses of radiation

MATERIAL AND METHODS

Seeds of Scots pine (*Pinus silvestris* L.) originating from Central Poland (forest district Spała), collected in the winter 1968/69 were irradiated with X-rays in autumn 1969. Between the time of collection and the beginning of experiments (February—October) the seeds were stored in polyethylene bags at about 5°C. Irradiation of seed with 0.5, 1.0, 2.0 and 4.0 Kr doses was achieved at 80 KV, 12 mA by varying the time of exposure at dose intensity 1 Kr/minute.

Immediately after the treatment the seeds were watered and placed in germinators. Seedlings were grown in water culture under greenhouse conditions under 16 hour day of artificial fluorescent light of 3000 lux intensity, enriched by natural illumination

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during the winter days. The nutrient solution recommended by Ingestad (1962/63) was used in 1l glass containers. The nutrient solution was changed every 20 days and sufficient aeration was secured by immersing only a part of the root system in the solution.

At two stages of vegetation, i.e. in full growth and at the period of apical bud formation when the plants were 15 and 20 weeks old, respectively, they were brought into the laboratory for gas exchange determinations. Photosynthesis and respiration were measured in the closed circuit of an infrared CO_2-analyzer. A special double walled plexiglass chamber was used for controlling air temperature (25°C). Plants were illuminated from the combined fluorescent+incandescent light sources which secured a high photosynthesis rate. Photosynthesis was measured within the range of CO_2 concentration 350—300 ppm in the "steady state" after about one hour of adaptation to the experimental conditions. Dark respiration of the shoot was determined after photosynthesis measurement and then the root systems were cut off and their respiration was measured immediately after cutting. Five plants were examined simultaneously and four replications were made of every experimental variant.

Dry weight of needles, stems, and roots was established at 105°. Chlorophyll *a* and *b* content was measured on parallel samples by the spectrophotometric method in 80% acetone extracts (Mackinney 1941; Bruinsma 1963).

Plants taken for gas exchange measurements at 32-day intervals were used for growth analysis with assumption of the linearity of the growth course between the two harvests; (see review by Nečas et al. (1966) and determination of assimilation efficiency (Żelawski et al. 1971).).

RESULTS

The investigated range of X-ray doses had a stimulating effect on the growth of seedlings in both experiments carried out with younger and older plants (Fig. 1). The total dry weight of a seedling reached its maximum in plants grown from seeds

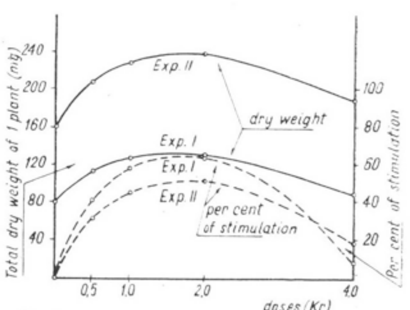

Fig. 1.

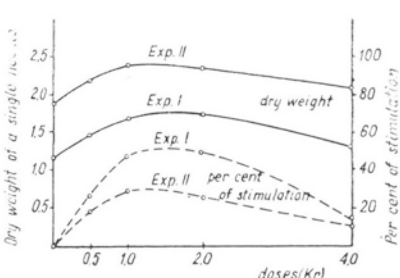

Fig. 2.

Fig. 1. Average dry weight of a seedling in mg, and in per cent of control plants.

Fig. 2. Average dry weight of a single needle in mg and in per cent of control plants.

which received X-ray doses between 1 and 2 Kr. The stimulation amounted to 50—60% as compared with control plants. Inhibition was observed in plants which received 4 Kr before germination, although their dry weight was still somewhat higher than that of control plants.

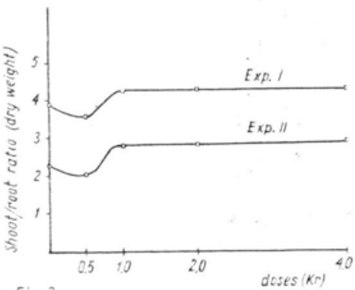

Fig. 3.

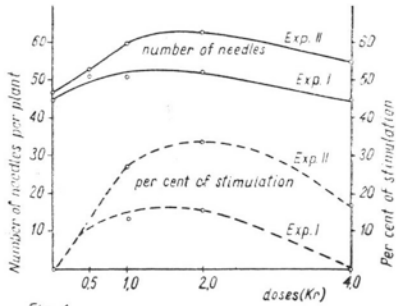

Fig 4

Fig. 3. Ratio: shoot/root (in terms of dry weight).

Fig. 4. Average number of needles per plant and per cent of stimulation in comparison with control plants.

The average size of a needle almost paralelled the size of the whole plant and the heaviest needles were also formed in the plants grown from seeds treated with 1—2 Kr doses. The maximum stimulation effect was of the order of 30—50% (Fig. 2).

The changes in dry matter accumulation were not proportional in the particular parts of the plant. A low dose of X-rays (0.5 Kr) brought about a strong stimulation of root growth which resulted in a decrease of the shoot/root ratio. Higher doses of irradiation (1–4 Kr) affected shoot and root growth similarly, so the ratio remained constant, irrespective of the changes in the total dry weight of the plant; this level was higher at higher doses than in the control or low doses plants. Towards the end of the vegetation period the shoot/root ratio considerably decreased but the differences between the experimental variants preserved the same character (Fig. 3).

The number of assimilatory organs formed on seedlings was also affected by the pretreatment of seeds with X-rays. The strongest stimulation was observed in plants treated with a 2 Kr dose. The difference between control and stimulated plants even increased towards the end of the vegetation season and reached about 15 needles (34%) in the 2 Kr dose plants of experiment II (Fig. 4).

The photosynthesis rate expressed in relation to dry weight of needles exhibited not only a different level but also not quite the same pattern in experiments I and II: in the growth period the rate of photosynthesis showed rather a reversed proportionality in respect to the average dry weight of a needle and was the lowest in growth stimulated plants; at the end of the vegetation the rates of photosynthesis differed less and rather exhibited a trend to increase in plants treated with higher doses of X-radiation (Fig. 5). The same regularity, although less pronounced, was observed when the assimilation number, i.e. photosynthesis rate per mg of chlorophyll $(a+b)$ was considered; this was so, since the concentration of chlorophyll $(a+b)$ showed either decreasing values at higher dose of X-radiation (experiment I: 12.3–9.4 mg per g of dry weight) or almost constant values (experiment II: 11.9–10.7 mg per g of dry weight).

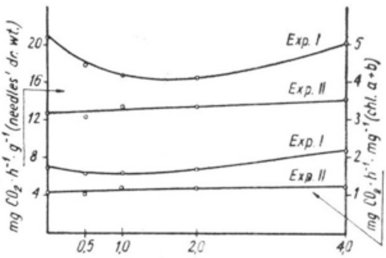

Fig. 5.

Fig. 5. Photosynthetis rate (mg CO_2/g of needles dry weight/hour) and assimilation number (mg CO_2/g of chlorophyll $a + b$/hour).

Photosynthetic activity expressed either per one assimilatory organ (Fig. 6) or per one plant (Fig. 7) exhibited maximum values in seedlings which received a dose of 1 or 2 Kr. Owing to the combined effect of the increased size of needles and greater number of assimilatory organs per plant, the photosynthetic activity of the whole plant was up to 100% higher in seedlings exhibiting growth stimulation than in the control ones.

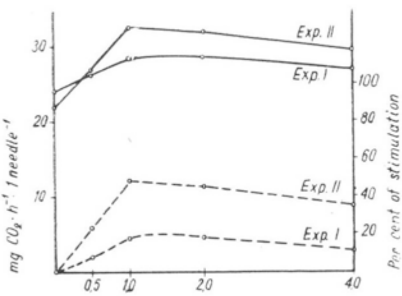

Fig. 6.

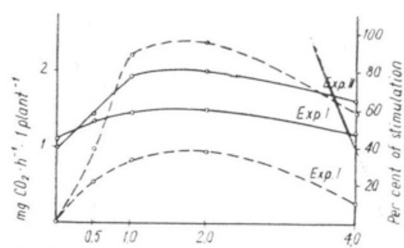

Fig 7.

Fig. 6. Photosynthetic activity of a single needle in mg CO_2/hour and in per cent of control plants.
Fig. 7. Photosynthetic activity of a whole plant in mg CO_2/hour and in per cent of control plants.

Respiration activity of the whole shoot essentially followed its dry weight changes and was the highest in plants which received the dose of 1 or 2 Kr. (Fig. 8). However, the respiration rate expressed per 1 g of needles dry weight exhibited a distinct depression in plants grown from seed treated with low X-radiation dose (0.5 Kr). On the other hand the respiration rate of the root system and also respiration activity of the whole root were just highest in plants which received this X-ray lowest doses

(0.5 Kr or 1.0 Kr) (Fig. 9). Essentially the same regularity was observed in both experiments, although it was more pronounced in shoots of younger plants and in roots of older plants than vice versa. Respiration activity of the whole plant was the highest in plants after treatment with 1 or 2 Kr of X-radiation. The decrease in

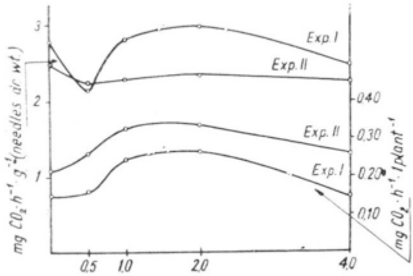

Fig 8.

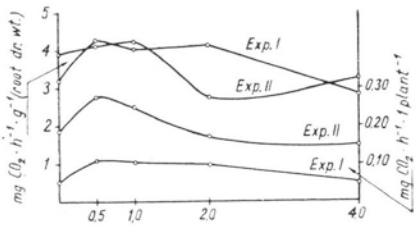

Fig 9.

Fig. 8. Respiration rate in mg/hour/1 g of needles dry weight and respiration activity of the whole shoot (above—the ground parts of a plant).

Fig. 9. Respiration rate in mg/hour/1 g of root dry weight and respiration activity of the whole root system.

respiration of the whole plant at higher doses of X-radiation was more pronounced than the decrease in dry matter accumulation; consequently the respiration activity of plants after treatment with 4 Kr equalled that of the controls (Fig. 10). Owing to the described pattern of respiration in shoot and in root, the ratio between the activities of both also exhibited a typical picture with a clear-cut depression in plants after low X-ray doses (0.5 Kr).

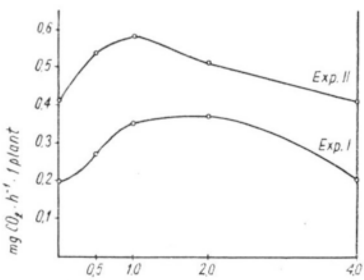

Fig. 10.

Fig. 10. Respiration activity of the whole plant (shoot + root) in mg/hour

The net assimilation rate calculated for the 32 days interval between the two harvests showed the lowest values in plants with the highest dry weight accumulation, i.e. after 1 and 2 Kr of X-radiation and the highest values in control and in inhibited plants. Assimilation capacity, i.e. maximum dry matter accumulation per g of needles dry weight and per day when the plants grow in optimum conditions was also the highest in control and in inhibited plants, but its minimum was shifted towards lower doses of X-radiation (0.5 Kr); as a result the index of "assimilation efficiency" (per cent of the true net assimilation in relation to assimilation capacity — Żelawski et al. 1971) was the highest at low dose (0.5 Kr) and in control plants and markedly lower in plants treated with 1, 2 or 4 Kr (Table 1).

Table 1

Net assimilation rate , assimilation capacity, and assimilation efficiency in seedlings after various doses of X-rays treatment

Index	Treatment with X-rays (doses in Kr)				
	Control	0.5	1.0	2.0	4.0
Net assimilation rate (NAR_{true}) mg dry weight $day^{-1} \cdot 1$ g needles dry $weight^{-1}$	35	31	28	28	36
Assimilation capacity (NAR_{cap}) mg dry weight $day^{-1} \cdot 1$ g needles dry $weight^{-1}$	148	124	132	134	161
Assimilation efficiency (%)	24	25	21	21	22

DISCUSSION

The growth stimulating effects of X-rays are known to occur in various plants after irradiation with relatively low dose (see reviews: Kuzin (editor), 1963; Skok et al. 1965, IAEA Technical reports, 1966; Nalborczyk, 1969). In spruce seedlings Thas (1967) was able to show quite significant stimulation effects after 2.5 Kr dose applied to the seed after 24 hours imbibition. For Scots pine seedlings up to 30% stimulation effects were shown by Nalborczyk et al. (1971) after 0.5–1.5 Kr doses applied to air dry seed. In the experiments described in this work, the stimulation of dry matter accumulation exceeded even 60% in seedlings after treatment with 2 Kr. The reaction of the investigated coniferous seedlings seems to be more distinct than that of herbaceous plants. It is worth mentioning that no stimulation effects, and only inhibition of growth and reduction of needle length, were observed in growing *Pinus rigida* stands under chronic influence of gamma irradiation (Sparrow et al. 1965). However, the phenomena induced by irradiation of seed and those observed on growing plants are not quite comparable for various reasons one of them being different radiosensitivity of growing and dormant meristem. Also investigations of very young seedlings after irradiation of seed do not show a distinct stimulation effect (Suszka et al. 1960).

From various experiments with plants after irradiation of seed it is known that X-rays affect more the root systems than the above ground parts of plants. In these experiments the shoot/root ratio also decreased at low dose of irradiation (0.5 Kr) and increased at higher ones.

Investigation of the needles average dry weight and the number of assimilatory organs per plant indicates that in pine, not only the size of needles but also the rate of their formation considerably increases with X-radiation applied within the stimulating range. Such stimulation effects have also been reported by Khudatov (1963 a, b), Roze and Kiece (1963), Ibragimov (1963) for various organs of crop plants.

In the described experiments with pine some tendency was observed of levelling of the dry weight differences between the experimental variants towards the end of the vegetation period. However, the difference in the number of needles rather increased during the time between experiments I and II, indicating a continued formation of new needles in plants treated with 1–4 Kr of X-rays.

Differences in dry weight still distinct at the end of the vegetation period, and particularly the increasing differences in the number of assimilatory organs, indicate that the stimulation effects of X radiation do not disappear as fast as suggested by Thas (1967) from his determinations of needles fresh weight at various levels of 9-week old spruce seedlings.

The changes in photosynthesis and respiration activities of plants grown from irradiated seed may be an indirect result of growth differentiation. The increment of needles average dry weight was associated with some decrease of the photosynthesis rate, but still the photosynthetic activity of one needle was much higher in the plants stimulated in growth. As neither the photosynthesis rate nor the assimilation number exhibited stimulation effects hardly any changes other than secondary are to be expected in the gas exchange processes of plants grown from X-ray pretreated seeds. However, the stimulation effect on photosynthetic activity of one needle indicates that, in plants stimulated in growth, not only elongation or enlargement of the same structures occured, but also formation of additional active tissues must have taken place. This is a further indirect evidence that irradiation of seed with X-rays affects the stage of differentiation in the growth processes. Similarly as the needle number also the photosynthetic activity of one needle differed more between the experimental variants in older than in younger plants.

Some shift in respiration activity from shoot to root in plants after low-dose (0.5 Kr) treatment could be related with the above mentioned shift in the shoot/root ratio. Stimulation of root growth by the lowest dose of X-radiation (0.5 Kr) could also effect translocation of photosynthetic products, and consequently the increase in respiration activity.

The presented data on assimilation capacity and assimilation efficiency (AE %) indicate that only up to 1/4 of the total capacity is achieved in the process of dry matter accumulation. Most efficient were plants which received low X-ray dose (0.5 Kr), followed by control plants, and last came the plants after higher-doses treatment (1—4 Kr). Although the index of "assimilation efficiency" has only a relative meaning when comparing the relation between dry matter accumulation and direct gas exchange determinations (Żelawski, Kucharska and Kinelska 1971) it indicates the best utilization of the given growth conditions in low-dose plants or in unirradiated plants.

CONCLUSIONS

1. Irradiation of Scots pine seed with X-rays affects the growth rate and dry matter accumulation of plants cultivated in water culture; the maximum stimulation was up to 60% after treatment with doses 1 or 2 Kr.

2. The stimulating effect of X-rays appears mainly in formation and differentiation of assimilatory organs, not only the size of needles but also their number per plant being affected.

3. Changes in photosynthetic activity should rather be considered as secondary effects of growth stimulation or inhibition in assimilatory organs; the almost 100% increase of the total activity per plant is the result of changes both in the size and number of needles.

4. The obtained pattern of shoot/root ratio indicates a different reaction of these organs to seed irradiation.

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Produktywność fotosyntezy siewek sosny zwyczajnej (Pinus silwestris L.) wyhodowanych z nasion poddanych działaniu promieniowania X

Streszczenie

W pracy omówiono charakterystykę morfologiczną, natężenie fotosyntezy i oddychania oraz produktywność fotosyntezy siewek wyhodowanych w kulturze wodnej z nasion poddanych działaniu dawką promieniowania X do 4 Kr. Stwierdzono stymulujące działanie niskich dawek promieniowania wyrażające się wyższym nagromadzeniem suchej masy do 60% w porównaniu z roślinami kon. trolnymi. Stymulujący wpływ promieniowania jonizującego przejawia się głównie w kształtowaniu organów asymilacji, których nie tylko wielkość, ale także i liczba zmienia się w zależności od dawki promieniowania. Stwierdzone różnice aktywności fotosyntetycznej wydają się być raczej wtórnym efektem zmian wywołanych różnym tempem wzrostu roślin. Interesujące jest również stwierdzenie różnic w reakcji korzeni i pędów zarówno w procesach oddychania, jak w przebiegu wzrostu tych organów.

Badania procesów wymiany gazowej i akumulacji suchej masy u roślin poddanych działaniu promieniowania jonizującego mają znaczenie w aspekcie poznawania efektów popromiennych oraz mogą także przyczynić się do wyjaśnienia różnic produktywności fotosyntetycznej roślin wykazujących różne tempo wzrostu.