M.Sc. Horticulture

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# THE EFFECT OF PRE-PLANTING IRRADIATION OF POTATO TUBERS ON GROWTH, YIELD AND QUALITY OF POTATOES.

## ABSTRACT

The effects of pre-planting irradiation with low doses of $Cobalt^{60}$ on potato seed tubers were investigated. Potato tubers at various physiological stages were used e.g. resting, dormant or slightly sprouted.

Doses of 150, 300 and 500 rad applied to slightly sprouted tubers nine days before planting delayed the emergence when whole tubers were used and did not affect the emergence of cut tubers. In both experiments, the yield, the number of tubers and the quality were unaffected.

Doses of 0, 150, 300, 500, 750 and 1,000 rad did not break the rest period of tubers dug 13 days before irradiation. Only the 1,000 rad dose affected sprout growth and apical dominance. Doses of 0, 500, 1,000, 1,500 and 2,000 rad did not affect the onset of sprouting of tubers treated at the end of the rest period but still unsprouted. Doses of 500 and 1,000 rad had no effect on the sprout growth but doses of 1,500 and 2,000 rad decreased sprout growth and affected apical dominance.

Effect of Preplanting Irradiation Potato Tubers

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by

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POTATO PRE-PLANTING IRRADIATION

(suggested short title)

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# INTRODUCTION

The potato, Solanum tuberosum L. is a plant grown in almost every country of the world and is a cheap but nutritive staple food. Because of the necessity of increasing food production to meet the needs of the ever increasing population, any means which might be helpful to achieve this end should be investigated. Furthermore, the potato is an important crop in the Province of Quebec. Statistics indicate that 71,000 acres were planted to this crop in 1967 (Department of Industry and Commerce, 1968).

It has been reported that irradiation hastens sprouting of potatoes in the spring (Vidal, 1959; Serebrennikov and Kiryukhin, 1965), brings about earlier maturity and increases yield and quality (Serebrennikov and Kiryukhin, 1965; Kahan and Susnoscki, 1967). If this is true, it would be beneficial to both growers and the processors. The growers would be able to harvest earlier, thereby minimizing frost damage at that time and to obtain higher returns through increased yields. Because local potatoes show signs of selinity and fry darker at the end of storage, processors must buy potatoes from the United States in early summer. If irradiation permits earlier harvesting, the processors may be able to get their supplies from Quebec earlier and reduce their importations. If it increases the quality of potatoes or the specific gravity, processors would use less oil in frying.

It is widely accepted that ionizing radiations can inhibit potato sprouting and produce genetic mutations on plants. However, the previously mentioned effects are not widely accepted and many questions remain unanswered, such as the optimum dose for a specific variety, the environmental factors which affect the radiosensitivity of the seeds, the effect of irradiation on the metabolism of the seeds or the plants. Some of these questions have been answered but there is no unanimity.

This investigation was carried out to study some of these problems using a variety grown in the Province of Quebec. The definitions of some terms used in this work may be useful at this time. According to the International Commission Recommendations (1954) the absorbed dose of any ionizing radiation is the amount of energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest. This absorbed dose is expressed in rad. The rad is the unit of absorbed dose and is 100 ergs per gram. This unit will be used for this work but since many authors in the review of literature will deal with roentgen (r) it is felt useful to give its definition. The roentgen is a unit which can be used for X- and gamma ray doses and is the quantity of X- or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air produces in air, ions carrying one electrostatic unit of quantity of electron of either sign.

It has been reported that the response of potato seed tubers to ionizing radiations depends upon the physiological state of the tuber (Grechushnikov and Serebrennikov, 1965). Thus it might be expected that the response of the tubers would be different whether they are in the rest period or in the dormant period. The rest period is the period immediately after harvest during which the potato tuber will not sprout even when placed under conditions optimal for sprouting. The dormant period is the one during which the tubers do not sprout when stored at some temperature below the optimum point for sprouting (Emilsson and Lindblom, 1963). From this it is evident that potato tubers in the dormant period would sprout when brought up at a temperature permitting the growth but not potato tubers in the rest period. Investigations on the effect of irradiation on resting and dormant tubers will be performed.

# II

# REVIEW OF LITERATURE

It was deemed necessary to include other plants than potatoes in the review of the literature but, as the potato was the plant under investigation, the literature dealing with potatoes will be reviewed more extensively.

## 1. Effects of low doses of radiation on plant growth.

Since the discovery of X-rays by Roentgen in 1895, many reports have been published on the effects of ionizing radiations on plant growth. The early work on this particular subject has been well reviewed by Breslavets (1946) in his book "Plants and X-rays". Therefore, only the more recent papers will be reported here along with Breslavets' conclusions.

Breslavets explained the divergence of results of the different early workers investigating the same plant species on the inaccurate measurement of dosage, on the small numbers of seeds used in the experiments, on the small variations of dosages, on the limited duration of the investigations for each experiment and in some cases, on the preconceived notion held by the investigators who planned their experiments to show what they wanted to. He also reported the results of his own experiments. He found that X-irradiation of dry seeds prior to sowing accelerated the growth and increased the yield of different plants. For instance, a dose of 750 r increased the yield of rye by 66 per cent and a dose of 350 r significantly increased the number of pods of peas. However, dry or soaked wheat seeds did not respond to any dose. Rye and peas were stimulated in their development. He also reported a positive after-effect in the $F_1$ crops for both rye and peas. He observed that doses from 200 to 250 r increased the percent germination of rye grass, stimulated its growth and increased its yield by 19 per cent. He also reported that Afanas'eva failed to find any growth promotion following low doses of irradiation of seeds of red fescue, red top grass, Kentucky blue grass, fescue, timothy and some other forage plants.

Breslavets (1946) concluded that X-rays stimulated plant growth and increased yield to a degree that could be economically useful. However Sparrow, who edited the translation of his book, wrote in his introduction that Breslavets' conclusions received little or no support from recent work outside of U.S.S.R. and is even questioned in some Russian publications.

Kuzin (1955) reported that X-irradiation of seeds promoted growth. He found that the maximum length of the roots were obtained with a dose of 1,000 r for rye, 500 r for peas and radishes. He did not get any clear-cut results for cucumbers but an optimal dose of 300 r accelerated the growth of the first true leaves. A dose of 750 r produced maximum root diameter due to accelerated cell division following X-irradiation of dry rye seeds. Kuzin also reported an increase in yields of plants following X-irradiation of the seeds: a dose of 1,000 r increased the yield of radishes by 33 per cent in one experiment and by 40 per cent in another; a dose of 1,000 r increased the yield of cabbage by 19 per cent whereas a dose of 5,000 r increased that of peas by 21 per cent; a dose of 750 to 1,000 r increased the yield of spring rye by 21-22 per cent (based on the weight of 1,000 seeds). A dose of 250 r of gamma rays from Cobalt$^{60}$ on soaked pea seeds increased the yield by 22 per cent. Kuzin observed an acceleration of growth of buckwheat grown under exposure to chronic gamma irradiation from Cobalt$^{60}$ in doses of 4.3 to 116.7 r per day. He finally reported that there was no essential difference between the effect produced upon seeds by X-rays and by gamma rays while the use of Cobalt$^{60}$ as a source of irradiation is far more practical.

Sax (1955) reported that he obtained a significant increase of 27 per cent in the yield of lettuce and of 16 per cent increase in the yield of cabbage following X-irradiation of dormant seeds at 3,000 r. He carried out additional controlled experiments which showed no significant effect. He failed to show positive results with X-irradiation of dormant seeds of carrot, turnip and beet. Also, irradiation of Gladiolus bulbs with 4,000 r of X-rays did result in significantly earlier flowering. Spencer (1955) reported that doses of 5,200 r of X-irradiation on bulbs and corms of 16 varieties from 12 genera of cultivated monocotyledonous species resulted in significantly earlier flowering for seven of them the first season after treatment. There were no differences in the second year indicating no after-effect.

Vlasyuk (1955) concluded from his experiments that treatment of seeds with small doses of ionizing radiations before sowing increased yield and plant productivity. He felt that this practice should be recommended for extensive agricultural trials. However in 1956, Norman <u>et al</u>. concluded that there was no evidence that plant growth is stimulated or crop yield increased by exposure to low levels of radiation.

Sarić (1958) clearly showed that the ontogenetically youngest seed is more susceptible to irradiation than the ontogenetically older seed. Thus, the two groups reacted differently to ionizing radiations.

Vidal (1959) reported that gamma irradiation of seeds with doses from 200 to 5,000 rad stimulated the growth of some crop plants and in some cases increased the yield. Thus, he observed that stems from wheat plants grown from seeds irradiated at levels varying from 1,000 to 5,000 rad were larger than those of controls. He observed growth stimulation following irradiation of pea seeds at doses of 250 to 2,000 rad and of spinach seeds at 800 rad. He observed an increase of 300 per cent in the yield of radishes after irradiation of the seeds with 5,000 rad. He also found that doses from 1,000 to 5,000 rad increased the yield of tomatoes, doses of 100 to 500 rad stimulated the growth of lilies of the valley and that irradiation of begonia tubers stimulated their growth. On the other hand, he failed to find any dose which would stimulate the growth of turnips and carrots. He felt that adverse growing conditions might be responsible for this. In some cases, he observed a definite stimulation of growth following irradiation of the seeds during the first stages of development which disappeared later. Thaung (1960) failed to find any stimulation of germination of dry rye seeds exposed to 500, 1,000 or 1,500 r of $Cobalt^{60}$ prior to seeding but he observed an increased yield, the increase varying with the varieties and the doses. Osborne and Bacon (1960) observed growth inhibition of seedlings of 12 species after treating the seeds with 5,000 rad of gamma rays but they observed growth stimulation of wheat seedlings after treating the seeds with 500, 1,000 or 2,500 rad.

In 1962, Bowen _et al_. reported that doses from 0 to 800 rad of $Cobalt^{60}$ gamma rays on dormant flax, radish and cabbage seeds had no significant effect on growth. Also, irradiation of young flax, cabbage and clover seedlings with 50 rad of $Cobalt^{60}$ did not produce any significant result. A significant stimulation was observed with lettuce but they felt that this experiment should be repeated on a larger scale before this result could be confidently accepted. Pinus sylvestris was also significantly stimulated with a dose from 2 to 6 rad.

Sharma (1963) reported that treating buckwheat seeds with 10,000 r of X-rays produced a significant stimulation of earliness (sprouting, expansion of the first true leaf and flowering) and height (seedling and plant height). Lower doses did not affect the emergence of the seedlings or the number of plants that reached maturity while higher doses resulted in significant reduction. Sax (1963), taking into account the fact that the early work on the stimulating effects of ionizing radiations was based upon inadequately controlled experiments still concluded that there was critical evidence that low levels of irradiation do have a stimulating effect on certain stages of plant development. But claims that the irradiation of seeds results in greater yields of crop plants still lacks critical confirmation.

Süss and Haisch (1964) reported that ionizing radiations in the range of 0.5 to 100 r significantly stimulated the growth of cereals while a dose of 200 r inhibited it. They obtained the same results during three years. They also reported a highly significant growth stimulation by small radiation doses in the $F_1$ progeny of the irradiated seeds. Skok et al. (1965) X-irradiated dry sunflower seeds at doses ranging from 50 to 5,000 r. They observed a significant growth stimulation with lower exposures but this stimulation was generally not reproducible. Depression of growth was observed with higher exposures. They also irradiated buckwheat seeds. They observed a great stimulatory effect with 5,000 and 10,000 r in one experiment and a marked depressive effect with the same treatment in another experiment. Irradiation of buckwheat seedlings with a dose of 750 r increased height by about 10 per cent and their irradiation with four successive exposures (from 50 to 500 r) had a depressive effect on growth. This experiment was repeated four times and the results were quite similar. They concluded that stimulatory effects of ionizing radiation on the growth of plants could be obtained. The increases, though significant in some instances, are small. They also pointed out that when stimulation is found, it is not always reproducible. They felt therefore that stimulatory effects are obtained only under specific conditions and that the factors affecting radiation responses must be studied. Preobrazhenskaya (1965) reported that dry barley seeds irradiated with 7,000 rad of Cobalt$^{60}$ emerged one to three days later than the control and gave a lower yield. He showed that the climatic conditions under which the seeds were grown before irradiation affected their sensitivity to irradiation. Thus, the seeds grown at the lowest temperature were more radiosensitive than those grown at higher temperatures, hence a greater yield reduction for the former.

Russian workers (MacQueen, 1968) reported that the optimum doses for pre-sowing irradiation of seeds have been established. They are as follows: carrot - 2,500 r; cabbage - 2,000 r; radish - 1,000 r; cucumber - 300 r; maize - 500 r; rye - 10,000 r; turnip - 500 r; flax - 1,000 r; sugar beets - 1,000 r. These doses produced the following results: carrot - 24 to 30 per cent increase in the yield of roots and 6 to 12 per cent increase in carotene content; cabbage - 5 to 10 per cent yield increase; radish - 5 to 7 days earlier maturation and 20 to 30 per cent yield increase; cucumbers - 15 to 20 per cent yield increase; maize - greater weight of green material and 15 per cent increase in sugar content of the kernels; rye - 20 per cent increase in the grain yield;

turnip - 30 to 37 per cent increase in the yield of roots; flax - 10 cm elongation of the stem and 5 cm elongation of the effective length; sugar beets - 30 per cent or more increase in yield.

Savin and Shutov (1966) reported that Cobalt$^{60}$ irradiation of barley seeds at a dose of 5,000 rad inhibited the growth of the primary leaves but stimulated the growth of the leaves of the upper formations and increased the number of lateral shoots. Kahan and Avidov (1967) irradiated onion bulblets at 300, 600 and 900 rad. Only the 300 rad dose increased the yield (5%) of first quality onions when irradiated eight days before planting. The same dose applied 17 and 25 days before planting reduced the yield. They also irradiated air dried or wetted onion seeds (50% moisture) at 300, 600 and 900 rad. Both produced slightly higher total and first quality yields at 600 rad. The increases were 5 per cent of control for wetted seeds and 7 per cent of control for air dried seeds. At 300 and 900 rad, the yield was reduced. In both experiments, germination and subsequent growth were stimulated during the first four weeks at 300 and 600 rad. Woodstock and Justice (1967) reported that treating corn, wheat, sorghum and radish seeds with a dose of 5,000 rad of Cobalt$^{60}$ produce a slight, but consistent stimulation in the growth of seedlings.

Recently, Nuttall <u>et al</u>. (1968) found that gamma irradiation of seeds of garden crop plants prior to sowing at the 100 rad level produced various but positive responses for all the vegetables used with the exception of cucumber. For instance, doses of 100 and 300 rad brought about a more concentrated maturity of sweet corn and a dose of 100 rad slightly increased the early yield of eggplant and produced the greatest early yield of lettuce. This same dose gave the best emergence and the highest yield of peas, gave the highest early and total yields of marketable fruits of tomatoes. The 100 and 300 rad doses gave considerably higher early yield of pumpkin. Finally, cucumber growth was inhibited by all the doses used. They concluded that these results suggest that low dose gamma irradiation stimulated an earlier maturity and increased yields. However, they recommended further studies before commercial application.

2. Effects of low doses of radiation on plant metabolism.

Breslavets (1946) reviewed the early work on this subject. Therefore, only the more recent papers will be reported here.

Gordon and Weber (1950) reported that 25 or 100 r of X-rays on plant leaves immediately lowered the auxin levels in the plant although recovery occurs in about one to two weeks. Vlasyuk (1955) reported that treating seeds with small doses of ionizing radiations intensified the metabolic rate. Kuzin (1955) demonstrated retardation of the syntheses of nucleic acids and proteins in plant tissues two hours after irradiation with a dose of 1,000 r.

Gordon (1957) found that auxin is not sensitive to X-rays below 10,000 r but that auxin and desoxyribonucleic acid (DNA) biogenesis are inhibited at doses as low as 35 r. Desrosiers and Rosenstock (1960) reported that a dose of 10 r resulted in approximately 10 per cent inhibition of the enzyme which converted tryptophan to indoleacetic acid. The synthesis of DNA occurs in meristematic tissues. Cells which have been irradiated in the mitotic stage did not elaborate DNA and the mitotic activity was delayed. Doses as little as 35 r were sufficient to temporarily inhibit the synthesis. So it appeared that the inhibition of DNA synthesis caused the mitotic inhibition. Since both auxin and DNA are required for cellular multiplication, radiation damage to the growth of a plant may be related to both auxin and DNA biogenesis.

Kaindl and Linser (1961) in their literature review stated that it is certain that the formation of peroxide radicals in the tissue fluids activated by radiations is of fundamental importance since their effect on organic compounds, in conjunction with the direct effects of radiation, produced strong chemical reactions which impair or inhibit the enzymatic activity of protein substances.

Meletti _et al_. (1964) found that the stimulation of growth following X-irradiation of seeds resulted from the destruction or inactivation of an inhibitor present in the endosperm of after-ripened seed. This inhibitor was not present in detectable amounts in the endosperm of seeds during the total period of dormancy (first three months or more after harvest) but appeared after such a period.

Simonis (1966) concluded from his review of literature that enzymes were very resistant to irradiation and that enzymes activity could be enhanced by irradiation in a few cases. Most of the time, the increased activity might be caused by the destruction of an inhibitor, by the release of an activator or by the release of inactive enzymes from their links with intracellular structures. However, he concluded that it was evident that low doses of radiation were sufficient to inactivate the synthesis of enzymes and of DNA.

Flaig and Schmid (1966) concluded from a study of different papers that low doses of radiation would not be directly responsible for the observed effects, but that these effects could be brought about by substances formed by the action of radiation. Thus, it has been found that during irradiation different enzymes could be set free. Metabolic products formed by the action of these enzymes could eventually produce effects on the metabolism. They also concluded that the effects of low doses of radiation are caused by substances which are perhaps comparable in their chemical constitution to some of those compounds that the authors investigated as physiologically active substances. They finally concluded that low doses of radiation do not cause much alteration in DNA; therefore the effects observed on plant yield may not be attributed to them.

Il'ina et al. (1965) observed that after irradiation, the ratio between starch and protein changes in wheat seeds. Woodstock and Justice (1967) observed that a dose of 5,000 rad of $Cobalt^{60}$ on seeds increased the oxygen uptake, decreased the respiratory quotient or both in corn, wheat and sorghum but not in radish seeds.

3. Effects of pre-planting irradiation on the growth, yield and quality of the potatoes.

On the growth and yield

The first experiment involving irradiation of potato seed tubers was performed by Jacobson in 1923. He reported that X-ray treatments increased the yield of one variety by 84 per cent and that of another variety by as much as 200 per cent. Irradiation also increased the size and number of tubers. Johnson (1928) reported that pre-planting treatment of unsprouted tubers of the variety Early Ohio with a very light dose of X-rays resulted in a 27 per cent increase in the number of tubers per hill over the control. However, because the average weight of these tubers was 18 per cent lower than that of controls, the average total weight of tubers per hill was practically the same for the controls and the experimental plants. There was no evidence that irradiation resulted in an increased weight for the total crop. The pre-planting treatment of sprouted tubers also resulted in a greater number of tubers per hill than the controls but with a smaller weight per tuber.

In 1929, Sprague and Lenz reported that certified seed of both Irish Cobbler and Green Mountain varieties treated with X-rays did not behave as in Johnson's experiment. The potatoes were treated when the sprouts were just beginning to develop. One lot of half tubers (the other half being used as a control) was irradiated ten minutes and another lot was irradiated five minutes. The ten-minute irradiation treatment caused the first leaves of the plants to assume a peculiar shape and reduced the total yield and the number of tubers but increased the average weight per tuber of marketable stock. The five-minute irradiation treatment increased the total yield by 3 per cent over the control, the number of tubers by 4.7 per cent and the number of marketable tubers by 5.1 per cent. They concluded that high dosages reduced the number of tubers formed but that even with a lower number of tubers, the yield was not reduced, the tubers formed attaining a greater size.

Johnson (1931) reported on the results of her studies carried out with the Colorado wild potato, <u>Solanum jamesii</u>. The tubers were grown for two successive years and the results for the second year were obtained from over 14,000 tubers grown at three different altitudes. The data showed conclusively that light exposures to X-rays before planting did not stimulate growth. However in 1937, she reported that a 1,500 r X-ray treatment of seed tubers increased tuberization. She also observed in five different trials involving a large number of tubers that irradiation of unsprouted tubers resulted in only a slight increase in the number of progeny and in average weight per hill but that irradiation of sprouted tubers gave a marked increase not only in the average number and weight of tubers per hill but in the average weight per tuber. She suggested that the increased yield might be due to an increased rhizome development which resulted in greater tuber production.

In 1950, Sparrow and Christensen planted potatoes of the Katahdin variety after exposing the tubers to different doses of X-rays at a dose rate of 80 r per minute. Statistical analysis showed no significant effect on yields following doses of 18.75, 75 and 300 r but did show a significant adverse effect following doses of 1,200 and 4,800 r. They also investigated the effects of chronic gamma irradiation on the potato. A gamma source of 16 curies of Cobalt$^{60}$ providing continuous irradiation of 0.26, 1.15, 4.8, 19.5 and 79.9 rad per day to give full-season totals of approximately 28, 123, 516, 2,086 and 8,529 rad respectively was used. These treatments did not produce any adverse effect on growth or yield and there was no significant relationship between dosage and yield.

Hagberg and Nybom (1954) concluded from their experiments with three varieties of potatoes, using eight tubers for each variety and each dose, that the radiosensitivity of potato varieties to X- and $\gamma$-rays varied considerably from one to the other. They also reported that the X-ray treatment of potato seed tubers having very small sprouts with doses of 1,250 to 2,500 rad retarded sprouting and that the vitality of the plant measured by the size of the top was reduced although the number of plants was not reduced.

In 1958, research workers of the National Defense Establishment, Paris, reported that doses of gamma rays below 1,000 rad did not inhibit germination, nor did it affect the subsequent development of the plant grown from the irradiated tubers. On the contrary, it seemed that they had a beneficial effect as shown by better vegetative growth and increased crop yield. However, no data were reported.

Jaarma (1958) reported that a pronounced stimulation of germination was observed after treating potato seed tubers with $Cobalt^{60}$ at doses of 350 to 800 rad. A 15 per cent increase in the yield of Bintje and President varieties which were irradiated with 400 to 800 rad was obtained. He also showed that X-rays were more stimulatory than gamma rays. Thus, an X-ray dose of 800 r given at a dose rate of 800 r per minute increased the average number of sprouts of irradiated tubers while a gamma ray dose of 800 rad given at the same dose rate did not cause any stimulation. Furthermore, he showed that stimulation of sprouting of X-irradiated potatoes was greater at a dose rate of 32 rad per minute than at a dose rate of 800 rad per minute. He also observed that doses as low as 2,000 rad reduced sprouting. Vidal (1959) reported that gamma irradiation in the range of 500 to 1,000 rad did have some stimulatory effect on the growth of the potato but the effect was limited.

Korableva (1960) reported that the structure of a potato shoot forced into growth by irradiation at 500 to 2,000 r differed from that of a control shoot. This alteration of the shoot had disappeared 25 to 30 days after sprouting and the growth rate was similar to the controls afterwards. In 1961, Fischnich _et al_. reported the results of their experiments performed since 1954. They studied the development of sprouts of X- and gamma irradiated potatoes in dose smaller than 100 r in storage and in the field. In storage, the sprout length of irradiated unsprouted tubers of the varieties Bona and Ackersengen was significantly reduced one year but not another. In most years, slightly sprouted tubers of the variety Ackersengen irradiated and stored at $18^{\circ}C$, showed a marked increase in sprout length over the control but sprouted tubers, treated similarly developed shorter sprouts than the untreated ones. Tubers de-sprouted immediately before irradiation and stored at 18°C showed no difference in sprout length when compared with the de-sprouted controls. In the field, unsprouted tubers of the variety Olympia, irradiated at 100 r showed a greater growth potential in two years than similar non irradiated material. They also found that slightly sprouted tubers stored at 12°C before irradiation and at 18°C after treatment showed greater sprout development than the control and than those which had been stored at a lower temperature before irradiation. They also found that irradiation of unsprouted tubers of the variety Ackersengen followed by storage at 18°C had no material effect on the number of sprouts formed but substantially increased the number of sprouts of the variety Bona. They concluded that the effect of irradiation depended on the variety, the physiological condition of the tuber (unsprouted, slightly or well sprouted respectively and de-sprouted before and after irradiation) and the conditions of storage of the tubers because the effect of low doses is obtained only when the metabolism is stimulated before and after irradiation.

Smalik _et al_. (1962) observed sprout stimulation in four varieties during the first two days after having exposed the seed tubers to 250, 1,000 and 1,750 r of X-rays and a stimulation of the overall growth of the plants grown from sprouts exposed to 250 r. They also observed deformation of the leaves and stems and deformation of the tubers with all four varieties from 1,000 r and higher. Even a dose of 250 r affected the shape of the tubers.

Gantzer and Heilinger (1964) treated freshly dug tubers with rindite and with X-rays two weeks later. Low doses increased sprouting whereas a dose of 1,000 r decreased it. Six to eight weeks later, the differences had disappeared. They observed varietal differences. Thus, a 100 r dose did not have any effect on sprout growth of the variety Corona but improved the sprout growth of the variety Feldeslohn. They also observed that doses from 100 to 500 r had more effect on the variety Corona than on the variety Feldeslohn. The effect of different doses on the sugar content of irradiated tubers was investigated. They found that treating seed tubers with doses of 1,000 and 4,000 r increased their sugar content but that doses lower than 500 r had no effect. They felt that irradiation did not have any effect on the starch breakdown itself but did probably act on the intermediate products between starch and sugars.

In another experiment, Gantzer and Heilinger (1964) used ten month-old seed tubers of the variety Corona previously stored at 4°C and then sprouted at 16-17°C. They observed a definite dose rate effect. A dose of 3,200 r given at a dose rate of 45 r per minute caused a greater reduction in sprout weight after 30 days than at a dose rate of 4 r per minute. Also, tubers stored for six weeks at 12°C and then irradiated at a dose of 2,000 r had a reduced sprout weight for the first two months. Two months later the differences had disappeared. They also concluded that doses of 100 r or lower had no influence on sprout growth.

Serebrennikov and Kiryukhin (1965) reported that Lipsits succeeded in 1947 in increasing the yield of potato tubers of the Vol'tman and Kornea varieties by 25 to 38.5 per cent as compared with the controls with pre-planting treatment with doses of 400 to 800 rad. They also reported that Berezina _et al_. published a paper in 1963 stating that the optimum dose for the Berlichingen variety ranged from 500 to 2,000 rad.

Serebrennikov and Kiryukhin (1965) found that gamma irradiation of unsprouted potato tubers with doses of 150 to 500 rad increased the number of eyes which sprouted and accelerated the emergence of sprouts by three to four days. However, an increase to 1,000 rad delayed sprouting. The irradiated tubers produced a greater number of stems and a larger assimilative surface. Doses of 150, 300 and 500 rad increased the yield, 300 rad causing the greatest increase. At this dose, an increase in yield of 20 to 35 per cent for the Lorkh variety and of 24 to 28 per cent for the Early Priekul'skii variety was observed when compared with the controls. But 1,000 rad decreased the yield for both varieties over a three-year period. Also, they reported that the optimum dose for obtaining a stimulating effect in the irradiation of Lorkh variety tubers which had been allowed to sprout for 40 days in the light was 50 rad while that for irradiating tubers which had not been allowed to sprout was 300 rad. They observed a definite link between stimulating doses of irradiation and the biological earliness of a variety of potatoes. Thus, the optimum irradiation dose was 150 rad for an early variety, 300 rad for a mid-early one and 500 rad for another mid-early one. They also showed, using radioactive Carbon$^{14}$ that, in the leaves of plants grown from tubers treated with a dose of 300 rad, the photosynthetic process was more intense and the products of assimilation were translocated more quickly from the leaves to the tubers. As a result of irradiation of the tubers, there was an increase not only in the carbon supply to the plants but in the absorption of tagged phosphorous from the soil.

Grechushnikov and Serebrennikov (1965) reported that Kuzin believed that pre-planting irradiation of the seeds of potato plants and tubers with doses that are optimum for each species and variety can break dormancy, promote the acceleration of germination, and better growth and development which will result in better yield. They also reported that Roze and Kavatse, through irradiating tubers with gamma rays, obtained an increase in yield with the Early Priekul'skii variety while the irradiation of tubers of other varieties gave negative results. They also reported that Rubin and others did not obtain an increase in yield when they irradiated tubers because they carried out this treatment long in advance of planting. The time elapsed between irradiation and planting appears to have some importance. Serebrennikov and Kiryukhin (1965) stated that tubers are best irradiated six to ten days prior to planting. Irradiation of tubers 20 to 30 days prior to planting causes them to sprout prematurely and when they are transplanted to the field the sprouts break easily.

Grechushnikov and Serebrennikov (1965) concluded that the contradictory results published on the effect of irradiating tubers with various doses on plant productivity indicate that the effect of irradiation depends upon the physiological state of the tubers, the dose and dose rate and the agro-climatic conditions under which the plants are grown. They reported that gamma irradiated tubers with doses of 1,000 to 3,000 rad produced plants showing considerable morphological deviations from the controls, such as modified sprouts and leaves, e.g. thickness, number of epidermal cells and stomata. Plants grown from tubers treated with 300 rad were the tallest and had the largest number of stems and the most extensive leaf area. A 300 rad dose resulted in a 19 per cent increase yield over the control for the Lorkh variety and in 22.8 per cent increase yield for the Priekul'skii variety. This dose seemed to be the optimal one. A 1,000 rad dose considerably decreased the yield of the Lorkh variety and slightly decreased that of the Priekul'skii variety which indicated again the different radio-sensitivity of the varieties. Gertsuskii _et al_. (1966) reported that pre-planting irradiation of tubers with small doses (250-500 rad) of gamma rays had a stimulating effect during the early development. This stimulation disappeared with time. They observed a greater effect of protons on growth and yield of potato than of gamma rays. Süss (1966) irradiated slightly sprouted potato seed tubers with low doses at a dose rate of 9.75 r per minute. He observed some reduction in yield and starch content on the crop from a dose of 1 r and some increase from doses of 10 to 50 r. These differences were not significant. The number of sprouts was not affected but the number of tubers per plant was increased. He observed a positive after-effect the following season, the greatest increase in yield being at 100 r. He also reported a greater stimulation of germination from irradiation when the tubers were stored at 10°C, compared to 15°C.

Rohrmann and Brownell (1967) conducted an experiment in 1965 with freshly dug field grown potatoes of the Russet Burbank variety which were irradiated with doses of 250 to 2,000 rad of $Cobalt^{60}$ and then cut. They were divided into two groups. One group was air cured for two days before planting and the other was planted directly. The air cured seed showed massive sprouting 21 days after planting and, subsequent to transplanting outdoors, produced a second crop of potatoes before the first major winter freeze. The second group did not sprout for several weeks. They concluded that growth stimulation in the form of early sprouting can be produced by treating tubers in their rest period with low doses of irradiation (500 to 2,000 rad), if other synergistic factors are present. There were also indications of increases in yield in plants grown from seed receiving 2,000 rad as compared to lower doses. In 1966, they observed that a dose of 1,500 rad of $Cobalt^{60}$ on freshly dug tubers which were taken from chemically defoliated fields caused a 40 per cent emergence as compared to 5 per cent for the controls. In the same experiment, a dose of 1,800 rad on tubers taken from actively growing but mature plants caused a 15 per cent emergence of seedlings as compared to 0 per cent for the controls. They also observed in another experiment that storing tubers on ice for two weeks before irradiation with doses ranging from 0 to 2,100 rad delayed emergence, and reduced growth rate and yield. They felt that the stimulation of sprouting observed was similar in 1965 and 1966 but that the subsequent growth response of the 1966 crop was different from that of 1965 leading them to conclude that more research was needed to explain the radiation effect on growth and yield.

Lure et al. (1967) found that treating potato tubers with 300 r of gamma rays before planting increased the yield of the crop. Kahan and Susnoscki (1967) showed that the elapsed time between irradiation and planting of tubers was important. Thus tubers treated with doses ranging from 20 to 200 rad and planted 14 days after irradiation showed an increase yield of 33 to 41 per cent over the controls while a dose of 200 rad on tubers planted 28 days after irradiation was required to increase the yield but only by 27 per cent. They also observed that irradiation (50-100 rad) increased the rate of germination, the absolute percentage of germination on a definite planting date and the average number of stems per plant.

Farooqi et al. (1967) carried out an experiment in which potatoes were gamma irradiated 15 days after harvest and then stored at 28.3°C and 69 per cent relative humidity. They observed that, 60 days after irradiation, the tubers which had received 2,000 rad had larger sprouts than the control. They concluded that this dose stimulated sprouting.

Some workers also investigated the effects of phosphorus$^{32}$ in the fertilizer on the growth of the potato. Stanton and Sinclair (1951) used two doses, 10 $\mu$c and 100 $\mu$c. They concluded that at least 100 $\mu$c must be applied to produce observable effects on the tubers. At this dose, the growing point received about 3,000 r. Hagberg and Nybom (1954), using 500 $\mu$c of phosphorus$^{32}$, reported a delayed development of the plants. They also observed leaf abnormalities, a larger number of leaflets and rolling of the leaves as reported by Stanton and Sinclair (1951). In 1955, Zhezhel reported that radioactive fertilizers such as radium, uranium and shale which contained radioactive material did increase the yield of potatoes by 10 to 20 per cent. The radioactive content of these fertilizers varied from $1 \times 10^{-12}$ curie per kg to $1 \times 10^{-9}$ curie per kg. In 1955 also, Kuzin reported that radium ($1 \times 10^{-9}$ curie/kg) and uranium ($1 \times 10^{-4}$ curie/kg) increased the yield of potatoes by 24.2 per cent and 37.3 per cent respectively in 1947 and by 32.1 per cent and 21.9 per cent respectively in 1954.

On quality

Low doses of irradiation on potato seed tubers were found to affect the quality of the progeny. Grechushnikov and Serebrennikov (1962) observed an increase in nitrogen content in the tubers grown from seed tubers irradiated with 100 to 300 r. Grechushnikov et al. (1964) observed that a dose of 300 r speeded up the translocation of the products formed in the photosynthetic process to other parts of the plants, among them the tubers. As a result of this, the sugar concentration in the leaves was rapidly depressed. The concentration of dissolved carbohydrates in the leaves was increased at 1,000 r as a result of the slower translocation of the photosynthetic products. Using radioactive Carbon$^{14}$, Serebrennikov and Kiryukhin (1965) also showed that in plants grown from irradiated tubers the products of photosynthesis were translocated more rapidly from the leaves to the tubers.

Serebrennikov and Kiryukhin (1965) and Grechushnikov and Serebrennikov (1965) reported that gamma ray doses of 150, 300 and 500 rad increased the starch content of potatoes grown from irradiated seed tubers with the varieties Lorkh and Early Priekul'skii. This increase in starch content could be explained by the more rapid translocation of the sugars from the leaves mentioned earlier.

4. Effect of radiation on the metabolism of the irradiated tubers.

When a tuber starts sprouting, the starch is hydrolyzed into soluble sugars (Emilsson and Lindblom, 1963; Edelman and Singh, 1966). These sugars are used for sprout growth. The rate at which starch is hydrolyzed to sugars is very important for sprout growth.

According to Roberts and Proctor (1954) starch grains are very resistant to the action of radiation, but Grechushnikov and Serebrennikov (1965) found that tubers irradiated with gamma rays at doses ranging from 100 to 1,000 rad showed an increase in sugar content and in starch decomposition. The accumulation of soluble carbohydrates could be detected one day after irradiation and depended upon the strength of the dose and its physiological effect. Thus the accumulation of soluble carbohydrates took place more slowly at 100 rad than at 300 and 1,000 rad. The largest amount of soluble carbohydrates accumulated in tubers treated with a dose of 1,000 rad. Ten days after treatment with 100 and 300 rad, the soluble carbohydrate content dropped somewhat which, together with the simultaneous disintegration of starch, indicated that the carbohydrates were being used in the growth processes of the sprouts. The same pattern of carbohydrate metabolism was also observed on the control tubers. At a dose of 1,000 rad, however, the soluble carbohydrate content of the tubers kept on increasing after ten days while the rate of starch disintegration approached that at other doses and in the controls. It was therefore natural to assume that the soluble carbohydrates were only slightly utilized in the growth processes of the sprouts.

Serebrennikov and Kiryukhin (1965) stated that investigations have established that irradiation of potato tubers with gamma rays with doses of 150 to 500 rad increases the activity of the physiological and biochemical processes in the tubers. They suggested that during irradiation, the starch, because of increased enzymatic activity, is converted more rapidly into soluble carbohydrates. As a result, a larger number of eyes and buds appear and the emergence of sprouts is accelerated by three to four days. However, an increase in dose to 1,000 rad inhibits the physiological and biochemical processes and the sprouts appear two to three days later than in the controls.

As reported by Grechushnikov and Serebrennikov (1965), Rubin et al. suggested that the increase in soluble sugars is due to the action of gamma rays on all the links of the enzymatic conversion of carbohydrates in the tubers; the activity of phosphoglucomutase and amylase is intensified and that of phosphorylase inhibited.

The nucleic acids are also involved in plant growth. In experiments with potatoes, Serebrennikov (1965) showed that nucleic acid synthesis was increased at a dose of 300 r and was decreased at a dose of 1,000 r. The intensity of cell division followed a similar pattern.

Jaarma (1966) found that there were only traces of proline in freshly harvested tubers while, after storing them for several months, there was a considerable amount of this amino acid. He also found that there was more proline in the apical end of potato which had just begun to sprout than in the other parts of the tubers. As sprout-stimulating agents such as gibberellin and rindite seem to be responsible for an increase in proline content, stimulating doses of irradiation should produce a similar effect. However he failed to observe such an effect at low doses of gamma irradiation but observed it at high doses. He concluded that gamma rays exert an influence on the proline metabolism which seems to be directly or indirectly connected with sprouting.

# III

# EXPERIMENTATION

## A. Experiment I

A study on the effect of irradiation pre-treatment of seed tubers on the growth, yield and quality of potatoes was conducted during the summer 1967. This preliminary experiment was carried out to investigate a possible trend in the responses. It was conducted on Mr. Gérard Riendeau's farm at St-Rémi, Napierville County. The land was uniform but lower than the surrounding area. The soil type was a silt loam.

### 1. Materials and Methods

#### Experimental design

A simple design was used in this experiment (Fig. 1). Every treatment alternated with a control row and every treatment was replicated twice. The rows were 122 meters long and the spacing on the row was 18 cm for the Kennebec variety and 23 cm for the Sebago variety. The rows were 0.91 meter apart.

#### Varieties and treatments

Certified Sebago seed and Kennebec seed one year away from certification were used. The Sebago seed was still dormant while the Kennebec seed showed a little sprouting. The Sebago seed was kept in a refrigerated storage at Macdonald College at 4.4°C until irradiation while the Kennebec was kept at the grower's storage at about 7.2°C. On May 2, they were taken to St-Hilaire for irradiation and kept at 21.1°C until the next day. On May 3, the tubers were divided at random into four groups e.g. control, 150, 300 and 500 rad. These figures correspond to the minimum doses

Figure 1

Design of the preliminary experiment, summer 1967.(1)

| Sebago | Kennebec |
|---|---|
| Replication 1 | |
| 0 | 0 |
| 150 | 150 |
| 0 | 0 |
| 300 | 300 |
| 0 | 0 |
| 500 | 500 |
| 0 | 0 |
| Replication 2 | |
| 0 | 0 |
| 500 | 500 |
| 0 | 0 |
| 300 | 300 |
| 0 | 0 |
| 150 | 150 |
| 0 | 0 |

(1) Figures correspond to the actual doses received.

received. For irradiation, the potatoes were laid one layer thick in cardboard boxes to insure uniform treatment. A special rack holding six boxes was used for the treatment. The rack was at 3.65 meters from the source. Each group of boxes was exposed on one side and then turned over in the middle of the exposure. The controls were left in the adjacent room.

The source was an industrial Cobalt$^{60}$ irradiator. The average dose rate was 2,300-2,700 rad per hour or 38.33-45 rad per minute. The variation in the dose or uniformity was 1.15-1.2 to 1 which means that a dose of 150 rad could be as high as 172.55 or 180 rad but not less than 150 rad. The radiation released by the source during its way up and its way down from the storage well was taken into account.

The potatoes were irradiated on May 3 and 4. After treatment, they were stored at 21°C at St-Hilaire until May 9 when they were taken to St-Rémi and cut mechanically. The seed pieces weighed about 57 g. They were kept at 10°C until planting.

Planting and management

As mentioned in the review of literature, irradiated tubers should be planted from six to ten days after treatment to avoid sprout breakage. Because of rainy weather, planting was delayed for 22 days after irradiation. The potatoes were planted on May 25 with a conventional two-row planter. The fertilizer was applied in bands with the planter on each side and slightly below the seed pieces. Normal cultural practices for commercial potatoes were used. Hilling and spraying for insect and disease control were carried out by the grower along with his commercial potato operation.

Measurements

During the growing season, ten visual observations were made between

June 19, 1967, 24 days after planting, and the final harvest on September 15. Size of plants and date of bloom of the irradiated potatoes were compared with those of the controls. Tubers were harvested at different times during the growing season to study the yield pattern.

In order to eliminate the border effect, three meters were left untouched at each end of the replications. Tubers were harvested by hand on August 9, August 23 and September 6. In an attempt to obtain a more representative sample, each plot was made up of two sub-plots selected at random on the row. Each sub-plot was 1.5 meters in length and contained six plants. On September 15, a final harvest was carried out from a plot 15 meters in length, using a conventional one-row digger.

At each harvest, the tubers were weighed, counted and graded as to size into three lots: under 2.54 cm, 2.54 cm to 5.70 cm and 5.70 cm and up. Specific gravity of the tubers was determined for the last three harvest dates by the brine method (Murphy and Goven, 1959) using ten tubers of comparable size from each plot.

2. Results

Visual observations

Emergence was slow during the first month after planting probably because of the cold rainy weather which prevailed. Growth was also retarded later in the season during a very dry period. Unfortunately, late blight affected the crop which could account for the discrepancies observed between the early harvests and the last one.

The size of the vines grown from the irradiated tubers and the controls and the date of bloom were nearly identical for both varieties, indicating that irradiation had no effect on these characteristics in this experiment.

Yields

As statistical analyses were not performed on the data collected, these are reported as the actual values obtained. The results for the irradiation treatments are also expressed in percent of the controls. In all tables, the data reported represent the average of two plots with the exception of the controls where an average of four plots is given.

- Kennebec variety

The data on the yield and number of tubers (Tables 1 and 2) indicate that, on the first two harvest dates, yields from the irradiated tubers were lower than that of the controls, although the differences were small in some cases. However, on the last two harvest dates, yields from the tubers treated with 300 and 500 rad were higher than that of the controls, the last harvest date showing the greatest differences. Tubers treated with 150 rad produced a lower yield and a smaller number of tubers than the controls throughout the season while the number of tubers from seed treated with 300 rad was larger than that of the controls on the last three harvest dates. With the 500 rad treatment, only the last harvest date showed a larger number of tubers. On the last harvest date, only the tubers treated with 300 and 500 rad produced a higher marketable yield and a larger number of marketable tubers (Table 3). The specific gravity was not affected by radiation (Table 4).

- Sebago variety

The control, which had the smallest number of tubers at the first harvest date yielded less than the tubers irradiated with 300 and 500 rad. However the results were reversed at the other three harvest dates (Tables 5 and 6). At the last harvest, the marketable yield and the number of

Table 1

Average yield per treatment and percent of control, Kennebec variety, at four harvest dates. (Yield expressed in kg per plot three meters in length.)

| Dose in rad | Harvest dates | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | August 9 | | August 23 | | September 6 | | September 15[1] | |
| | Yield | % | Yield | % | Yield | % | Yield | % |
| 0 | 2.2 | 100.0 | 3.3 | 100.0 | 3.8 | 100.0 | 1.7 | 100.0 |
| 150 | 1.8 | 81.8 | 2.7 | 81.8 | 3.6 | 94.7 | 1.5 | 88.2 |
| 300 | 1.5 | 68.2 | 3.0 | 90.9 | 4.2 | 110.5 | 2.0 | 117.6 |
| 500 | 2.1 | 95.4 | 3.0 | 90.9 | 4.1 | 107.9 | 2.1 | 123.5 |

[1] Data taken from plots 15 meters in length and adjusted to three meters.

Table 2

Average number of tubers per treatment and percent of control, Kennebec variety, at four harvest dates. (Plots three meters in length.)

| Dose in rad | Harvest dates | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | August 9 | | August 23 | | September 6 | | September 15[1] | |
| | Number | % | Number | % | Number | % | Number | % |
| 0 | 54.5 | 100.0 | 54.2 | 100.0 | 61.2 | 100.0 | 18.3 | 100.0 |
| 150 | 43.0 | 78.8 | 51.0 | 94.0 | 48.5 | 79.2 | 16.8 | 91.8 |
| 300 | 47.5 | 87.1 | 61.5 | 113.4 | 68.1 | 111.2 | 22.8 | 124.5 |
| 500 | 57.0 | 104.5 | 50.5 | 93.1 | 52.0 | 84.9 | 23.6 | 128.9 |

[1] Data taken from plots 15 meters in length and adjusted to three meters.

Table 3

Average marketable yield and average number of marketable tubers per treatment, Kennebec variety, September 15, 1967. (Plots 15 meters in length.)

| Dose in rad | Yield in kg | Percent of control | Number of tubers | Percent of control |
|---|---|---|---|---|
| 0 | 6.7 | 100.0 | 45.2 | 100.0 |
| 150 | 5.0 | 74.6 | 38.5 | 85.1 |
| 300 | 7.6 | 113.4 | 58.0 | 128.3 |
| 500 | 8.0 | 119.4 | 59.0 | 130.5 |

Table 4

Average specific gravity of ten tubers, Kennebec variety, at three harvest dates.

| Dose in rad | Specific gravity | | |
|---|---|---|---|
| | Harvest dates | | |
| | August 29 | September 9 | September 26 |
| 0 | 1.080 | 1.077 | 1.080 |
| 150 | 1.083 | 1.077 | 1.082 |
| 300 | 1.081 | 1.073 | 1.078 |
| 500 | 1.081 | 1.078 | 1.076 |

Table 5

Average yield per treatment and percent of control, Sebago variety, at four harvest dates. (Yield expressed in kg per plot three meters in length.)

| Dose in rad | August 9 | | August 23 | | September 6 | | September 15[1] | |
|---|---|---|---|---|---|---|---|---|
| | Yield | % | Yield | % | Yield | % | Yield | % |
| 0 | 1.6 | 100.0 | 3.2 | 100.0 | 4.5 | 100.0 | 2.8 | 100.0 |
| 150 | 1.5 | 95.4 | 2.5 | 78.0 | 4.0 | 89.0 | 2.4 | 85.8 |
| 300 | 1.9 | 118.8 | 2.8 | 87.5 | 3.4 | 75.5 | 2.6 | 93.0 |
| 500 | 1.7 | 106.1 | 2.8 | 87.5 | 3.0 | 66.7 | 1.8 | 64.3 |

[1] Data taken from plots 15 meters in length and adjusted to three meters.

Table 6

Average number of tubers per treatment and percent of control, Sebago variety, at four harvest dates. (Plots three meters in length.)

| Dose in rad | August 9 | | August 23 | | September 6 | | September 15[1] | |
|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % |
| 0 | 53.7 | 100.0 | 87.7 | 100.0 | 92.7 | 100.0 | 39.8 | 100.0 |
| 150 | 59.5 | 110.8 | 73.0 | 83.2 | 87.0 | 93.8 | 38.8 | 97.4 |
| 300 | 64.0 | 119.1 | 88.0 | 100.3 | 79.5 | 85.7 | 40.0 | 100.5 |
| 500 | 66.5 | 123.8 | 77.5 | 88.3 | 73.5 | 79.2 | 26.1 | 65.5 |

[1] Data taken from plots 15 meters in length and adjusted to three meters.

marketable tubers from the irradiation treatments were lower than that of the control (Table 7). The specific gravity was not affected by irradiation (Table 8).

3. Discussion

As mentioned earlier, this preliminary experiment was conducted to investigate possible trends in the response of seed tubers treated with irradiation. From the result obtained for the first three harvest dates it would appear that irradiation at the doses used was somewhat detrimental. However, the differences were generally small. No conclusion can be drawn from the last harvest date because of a late blight infection which was first observed early in September. The disease progressed fairly rapidly and a large number of infected tubers were found on September 15 ranging from 3.6 per cent to 35.2 per cent in the different plots. These tubers were not included in the results. In addition, machine harvesting eliminates the under-size tubers which would further account for the smaller numbers obtained at the last harvest.

B. Experiment II

As mentioned in the review of literature, some workers (Grechushnikov and Serebrennikov, 1965; Serebrennikov and Kiryukhin, 1965) reported increases in yield and quality of potatoes following an exposure to low levels of ionizing radiations but they did not state at what time in the growing season the effect of irradiation manifested itself to produce these increases. Others reported an earlier emergence (Jaarma, 1958; Gantzer and Heilinger, 1964; Serebrennikov and Kiryukhin, 1965) and even the breaking of the rest period (Rohrmann and Brownell, 1967) through irradiation. This earlier emergence of the plants could result in the vines attaining a larger size

Table 7

Average marketable yield and average number of marketable tubers per treatment, Sebago variety, September 15, 1967. (Plots 15 meters in length.)

| Dose in rad | Yield in kg | Percent of control | Number of tubers | Percent of control |
|---|---|---|---|---|
| 0 | 8.5 | 100.0 | 66.7 | 100.0 |
| 150 | 5.6 | 66.0 | 48.5 | 72.7 |
| 300 | 6.6 | 77.6 | 53.5 | 80.2 |
| 500 | 3.9 | 45.9 | 29.0 | 43.4 |

Table 8

Average specific gravity of ten tubers, Sebago variety, at three harvest dates.

| Dose in rad | Specific gravity | | |
|---|---|---|---|
| | Harvest dates | | |
| | August 29 | September 9 | September 26 |
| 0 | 1.076 | 1.075 | 1.079 |
| 150 | 1.074 | 1.075 | 1.081 |
| 300 | 1.077 | 1.072 | 1.083 |
| 500 | 1.078 | 1.075 | 1.082 |

earlier, thereby producing more total photosynthetic material, which would have an effect on yield and quality. On the other hand, if irradiation does not produce earlier emergence and yet an increase in yield is obtained, it might be due to a faster growth rate of the plants after emergence as a result of irradiation.

This experiment was performed to detect if irradiation brings about earlier emergence and, presumably, higher yields. If it does not, any difference which may occur in the aerial portions as well as in the underground portions of the potato plants could be due to an acceleration of growth as a result of irradiation rather than earlier sprouting. An attempt was made to determine the period in the growing season when such a difference might occur. This experiment was conducted in the greenhouse at Macdonald College from December 1967 to May 1968.

1. Materials and Methods

Experimental design

A randomized block design was used (Fig. 2). The blocks were arranged to insure uniformity within blocks to take into account the variations in temperature in the greenhouse caused by the location of the heating pipes on both ends.

Four replications were used. Each replication contained five treatments and each treatment contained four plots to permit harvesting at different dates during the growing season. Each plot consisted of two pots and was randomized within each replication.

Seed treatments

Certified Kennebec seed, grade B size, grown in Grand Falls, New Brunswick, was used in this experiment. It was stored at Macdonald College

Figure 2

Greenhouse layout. Experiment II.[1]

| | | | | |
|---|---|---|---|---|
| | 0 | ch | 500 | 0 |
| | 0 | 0 | 150 | ch |
| Rep. I | ch | 500 | 500 | 150 |
| | ch | 150 | 300 | 500 |
| | 300 | 300 | 150 | 300 |
| | 300 | 0 | 500 | ch |
| | 500 | ch | 0 | 0 |
| Rep. II | 150 | 0 | 300 | ch |
| | 300 | ch | 150 | 150 |
| | 150 | 500 | 500 | 300 |
| | ch | 0 | 500 | 0 |
| | 150 | 150 | ch | ch |
| Rep. III | ch | 500 | 300 | 300 |
| | 150 | 300 | 0 | 150 |
| | 500 | 0 | 300 | 500 |
| | ch | 0 | 0 | ch |
| | ch | 300 | 500 | 500 |
| Rep. IV | 300 | 0 | 150 | 300 |
| | 300 | ch | 150 | 500 |
| | 150 | 150 | 500 | 0 |

(1) The figures correspond to the actual doses received.

ch = chemical treatment

in an air cooled storage at about $7^{o}C$ until treated. The tubers had not yet begun to sprout at that time.

On December 18, 160 tubers weighing between 56.7 g and 64 g were selected and were divided into five lots at random. One lot of tubers was treated with rindite, a mixture of compounds known to break the rest period (Varga and Ferenczy, 1956). While it was probable that, on the day of treatment, December 18, the rest period of the tubers was over and that they were in the dormant stage, this chemical treatment was introduced to ascertain if the rest period was indeed completed. Also, since Rohrmann and Brownell (1967) reported that irradiation breaks the rest period, it was felt that a comparison of the two methods might give useful information. Rindite is composed of seven volumes of ethylene chlorohydrin, three volumes of ethylene dichloride and one volume of ethylene tetrachloride. The treatment consisted of exposing the 32 tubers in the lot to 0.6 ml of this mixture for 24 hours in a sealed container. The chemical was deposited on a filter paper placed under the tubers and did not come in contact with them.

The four other lots of tubers were taken to St-Hilaire irradiator on December 19. Three lots were treated at 150, 300 and 500 rad respectively, using the procedure described previously in Experiment I and one lot was left untreated as the control. The dose rate was 2,130-2,500 rad per hour or 35.32-41.67 rad per minute. They were brought back to Macdonald College and held at $21^{o}C$ with the chemically treated tubers until planting on December 21.

<u>Planting and management</u>

The tubers were grown in polystyrene pots measuring 25.6 cm in diameter at the top and 12.8 cm at the bottom, and 25.6 cm in height. Broken clay pot pieces were placed at the bottom to insure good drainage. The soil mixture used to grow the potatoes was composed of 50 per cent vermiculite and 50 per cent peat moss. After analysis, a 6-12-12 chemical fertilizer containing 2 per cent magnesium was incorporated to the mixture to improve fertility and its pH was adjusted to 6.2 with precipitated calcium carbonate.

The pots were first filled to a height of 15 cm with the soil mixture. The tubers were then planted with the apical end up and covered with an additional 7.5 cm of soil after which the potatoes were watered thoroughly. The pots were then laid out on two benches in the greenhouse, each replication running across the two benches. An air circulating fan was employed to minimize temperature variations within the greenhouse. From December 21, 1967 to March 24, 1968, the night-time temperature was maintained at about 18.3°C and the day-time temperature was set at 21°C. From March 24, until the end of the experiment, the night-time temperature was set at 15.6°C and the day-time temperature at 19.4°C. While the night-time temperature was fairly uniform, the day-time temperature varied considerably.

The potatoes were grown under Gro-lux lamps controlled by a time clock from February 18, 1968 until the end of the experiment. The illumination given simulated the normal day-length of which growing potatoes are exposed in the field. They received about 700 foot-candles on cloudy days and about 1,200 foot-candles on sunny days.

Watering was done when needed. During the first 60 days, little water was required. After that period, watering was more frequent because of increased transpiration of the plants. The amount of water given varied with the size of the vines. To maintain the fertility level, approximately 3 g of a 28-14-14 soluble fertilizer was applied on March 1 and on March 8 with the water. On April 29 the plants received a foliar application of

23-19-17 containing traces of boron, sulfur, magnesium oxide and vitamin B.

The crop was fumigated on March 10, March 16 and April 24 to control the greenhouse whiteflies (Aleyrodes vaporariorum Westw.). This treatment caused some leaves or leaflets to turn upside down for a few days. This effect was noticed after each fumigation and the plants always recovered.

Measurements

Data were collected throughout the growing season. In addition to the four harvests, the number of days to emerge was recorded. A plant was considered as emerged when it had reached a height of 3.5 cm above the soil surface and had two opened leaves. The data about emergence are reported in percentages but the analyses of variance and Duncan's multiple range tests (1955) (whenever applicable) were performed on transformed values. As shown in Appendix Tables 1, 2 and 3, the original percentages were converted by using the angular transformation as recommended by Bartlett (1947). Analyses of variance were performed on these values and inferences are based on these transformed values.

Four harvest dates at regular intervals were planned but because of the very slow early growth, it was impossible to follow the original schedule. In every harvest, the fresh and dry weights of the vines were recorded. The stems were cut at the level of the first stolons, weighed and then frozen until drying. The fresh weights of the stolons along with their numbers and lengths were recorded in the first two harvests conducted on March 6 and March 21, 1968 on plots 1 and 2 of every treatment. The number of sprouts on the seed tuber which produced the aerial stems was also recorded for every treatment, except for the chemical one. Since this chemical treatment was introduced to check whether or not the rest period was over it was not harvested like the other treatments. All the plots from this treatment were harvested on March 19. The incidence of premature tuber formation and of decay was recorded.

On April 10, a third harvest was carried out on plots 3 of every treatment. Data on the weight of vines, the number of tubers and their weight were also collected. After each harvest, the pots were given more space on the benches while staying as close as possible to the previously set design.

A final harvest was conducted 132 days after planting. The plots were watered thoroughly the night before harvest in order to get plants of approximately the same water content. On May 2, the fresh weights of the vines were recorded after which they were frozen. On May 3, the tubers were harvested and data on the yield and the number of tubers were collected. The tubers were then stored at 3.3°C for four days.

On May 7, the tubers were allowed to warm up for 24 hours. On May 8, the specific gravity was determined using the sodium chloride method (Murphy and Goven, 1959). The number of marketable tubers being restricted, tubers of comparable size from treatment to treatment within a replication were selected. For instance, two tubers of medium size and two tubers of a larger size for every treatment were used within a replication while in another replication the sizes were different. The results are comparable within a replication. The temperature of the water was identical to that of the tubers. The potatoes were previously washed and dried before the determinations.

On June 6, the vines of the four harvests were taken out of frozen storage and dried at 88°C for 17 hours in a forced air dryer in which the heated air passed through the trays containing the frozen material. After this drying, the vines were taken out of the dryer and weighed immediately.

2. Results

Irradiation failed to stimulate sprouting of dormant tubers, hence the emergence of plants. Thirty days after planting, in no case did the sprouts reach the soil surface and when they emerged and reached a height of 3.5 cm, no difference was observed between the treatments. Thus, the percentages of emerged plants were not significantly different from one treatment to the other 55, 60 and 65 days after planting (Table 9 and Appendix Table 4).

Table 9

Average percentage of emerged plants per treatment at various number of days after planting.(1)

| Dose in rad | Number of days 55(2) | 60(2) | 65(2) |
|---|---|---|---|
| 0 | 18.75 | 40.62 | 75.00 |
| 150 | 18.75 | 78.12 | 87.50 |
| 300 | 31.25 | 71.87 | 84.37 |
| 500 | 34.37 | 50.00 | 68.75 |

(1) Analyses of variance were performed on transformed values.

(2) Differences were not significant at level $P = 0.05$.

The results of the chemical treatment which was included to compare the effect of irradiation and of rindite on the breaking of the rest period are not reported. In this experiment, this treatment caused the decay of

25 per cent of the tubers and induced premature tuber formation from the seed piece.

When plants emerged, necrosis of the apical bud was observed on many plants. It was thought to be a physiological disorder but the cause was not found. Necrosis appeared on both irradiated and control plants.

Harvests were carried out during the growing season. Most of the data collected on the first three harvests was rejected and is not reported because of the great variations between two pots in the same plot and between plots in the same treatment. The differences were so large that reliable conclusions could not be drawn.

On the first two harvests, the number of sprouts which emerged was recorded. It was found that only one sprout grew from the seed tuber. It was not possible to check this characteristic later in the season, the seed tubers having decayed. However, on the fourth harvest, the number of stems originating from a sprout was recorded. It was found that there was only one main stem for all treatments. Thus, it was concluded that irradiation did not induce multiple sprouting. The fresh and dry weights of vines at this harvest were not of any use because too many basal leaves were missing.

Data from the last harvest are reported because the differences between plants were not as great after the long period of growth. To improve the reliability of inferences, analyses of variance were performed on the sub-plots values. Irradiation did not have any significant effect on the total yield and on the number of tubers per treatment (Appendix Table 5). Thus, the average yield and average number of tubers per treatment were similar (Table 10). Irradiation slightly increased the specific gravity although not to a significant level (Table 11 and Appendix Table 6).

Table 10

Average yield and average number of tubers per treatment 130 days after planting.

| Dose in rad | Yield in kg[1] | Number of tubers[1] |
|---|---|---|
| 0 | 1.3 | 33.5 |
| 150 | 1.3 | 44.5 |
| 300 | 1.4 | 39.2 |
| 500 | 1.3 | 36.2 |

[1] Differences were not significant at level P = 0.05.

Table 11

Average specific gravity of tubers per treatment 130 days after planting.

| Dose in rad | Specific gravity[1] |
|---|---|
| 0 | 1.076 |
| 150 | 1.078 |
| 300 | 1.081 |
| 500 | 1.080 |

[1] Differences were not significant at level P = 0.05.

3. Discussion

The tubers took more than ten weeks to produce sprouts long enough to emerge at soil surface. This was most unusual for potatoes held at about $7^{o}C$ for some three months before planting and grown at $18.3^{o}C$ to require such a long time to emerge. This fact confirmed that the tubers were still dormant at time of planting (actually they were not sprouted) and it showed that irradiation and rindite did not stimulate sprouting.

Premature tuber formation and decay occurred mainly in the rindite treatment. Only one tuber which had received a dose of 500 rad produced similar premature tuber formation and just a few tubers decayed in the 0, 150, 300 and 500 rad treatments.

The pots were watered uniformly at planting time and three weeks later when the soil surface was slightly dry. The next watering was delayed until the emergence of a few plants. Thus, the soil medium at the tuber level remained moist and had no chance of drying from water utilization by the plant, nor from evaporation from the sides of the polystyrene pots. According to Van Shreven (1956) such a condition favors premature tuber formation and according to Young (1968) this condition increases decay and delays sprouting. Thus it was felt that this condition was probably responsible for delayed emergence and might have counteracted the irradiation effect. This condition might be responsible for the decay and for the premature tuber formation which occurred. Considering that 25 per cent of the rindite treated tubers decayed and that most of the plants formed premature tubers, rindite probably had synergistic role with the medium and both increased decay and premature tuber formation to such an extent that the treatment had to be discarded.

No definite conclusion can be drawn from this experiment because of the considerable variations observed in the growth of the plants. However, from the data obtained at the last harvest, it seems that irradiation of the seed tubers was neither beneficial nor detrimental.

## C. Experiments III and IV

These two experiments were carried out at Macdonald College during the summer 1968 to repeat under field conditions the greenhouse experiment which did not yield much information. Two separate experiments were conducted in order to have a large enough plant population to make valuable inferences and to permit harvests during the growing season in one experiment, and in the other to harvest at the end of the growing season. The land selected was quite uniform with a very slight slope at one end of the rows. The soil type was a silt loam.

### 1. Material and Methods

#### Experimental design

A randomized block design was used in both experiments (Fig. 3). There were four replications in each experiment, each replication containing three levels of irradiation and a control. One guard row separated the two experiments and three guard rows were planted on each side of the experimental field. There was one row per treatment in each replication. The rows, 15 meters in length, were laid out in the direction of the slope. At harvest time, three meters at each end of the rows were left to eliminate the border effect. Therefore, only the nine meters in the center were harvested.

#### Seed treatments

Foundation Kennebec seed, grade B size, grown in New Denmark, New Brunswick, was used. Upon arrival at Macdonald College on March 5,

Figure 3

Experimental design of Experiments III and IV.[1]

| Experiment III | Experiment IV |
|---|---|
| **Replication 1** | |
| 500 | 0 |
| 0 | 150 |
| 300 | 300 |
| 150 | 500 |
| **Replication 2** | |
| 300 | 0 |
| 150 | 150 |
| 0 | 300 |
| 500 | 500 |
| **Replication 3** | |
| 500 | 500 |
| 0 | 0 |
| 150 | 300 |
| 300 | 150 |
| **Replication 4** | |
| 300 | 150 |
| 150 | 0 |
| 500 | 500 |
| 0 | 300 |

(1) Figures correspond to the actual doses received.

1968, the seed was stored at 4.4°C. As small sprouts were noticed on May 6, the temperature was brought down at 3.3°C to stop growth until May 13.

Whole seed was used in Experiment III. The tubers were weighed individually and divided into lots of the same weight. Each lot was assigned to a single replication in order to minimize the variation due to tuber weight. The average weight of the tubers was 51 g for the whole experiment. Tubers used in Experiment IV were selected from the largest ones of the grade B size lot. After irradiation, the weight of the tubers was adjusted to about 57 g by cutting off some of the stem end. The apical end was left untouched.

The potatoes were taken out of storage on May 13, 1968, and brought to St-Hilaire for irradiation on the same day. The source used was the same as previously described in Experiment I but the dose rate was 1,994-2,341 rad per hour or 33.24-39.02 rad per minute. The uniformity was still 1.15-1.2 to 1. The doses given were 0, 150, 300 and 500 rad. These figures corresponded to the minimum dose received. The potato seed was brought back on the same day and kept at 18°C until planting.

Planting and management

The seed was planted on May 22, 1968, nine days after irradiation. Furrows were opened at every 92 cm on the previously prepared land. An 8-16-16 fertilizer was spread in every furrow at the rate of 276 kg per hectare and covered with 5 cm of soil. The tubers were then planted by hand at the rate of 85 seed pieces per row or one tuber at every 15 cm. They were immediately covered with 8 cm of soil.

The furrows were hilled twice during the growing season. The field was irrigated when necessary and sprayed to control insects and diseases.

On September 7, the vines were killed using sodium arsenite at a concentration of 0.69 l per hectare.

Measurements

Data were collected on the rate of emergence in both experiments from 17 days after planting until emergence of all the plants. A potato plant was considered as having emerged when it appeared at the soil surface. As in Experiment II, data on emergence are reported in percentages and were transformed, using the angular transformation. Analyses of variance and Duncan's multiple range tests (whenever applicable) were performed on these transformed values. Inferences are based on these transformed values.

Harvests were carried out during the growing season in Experiment III, and only at the end of the season in Experiment IV.

- Experiment III

The first harvest was carried out at the end of July, 69 days after planting. The plants from three-meter plots were harvested. Data were collected on the fresh and dry weights of the vines which were cut at the soil level and weighed. They were dried at 88°C in a drier for 15 hours and weighed again. The tubers were dug by hand. All the tubers were gathered. They were counted, weighed and graded as to size as described previously. The number of sprouts on the seed tubers which produced the aerial stem was also recorded.

A second harvest was carried out in the third week of August, 92 days after planting. The plants from the next three-meter plots were harvested as described earlier and the same data on the tubers were recorded. No data were recorded on the vines.

The last harvest was carried out in the third week of September, 123 days after planting and 16 days after the vine killer treatment. Here again, three-meter plots were dug up, but with a conventional one-row digger this time. Data were collected on the number of tubers, their size and weight. Soil particles adhering to the tubers were removed before weighing.

- Experiment IV

As mentioned earlier, this experiment was harvested at the end of the growing season, 124 days after planting. Nine-meter plots were dug up with a conventional one-row digger. The same data as in the last harvest of Experiment III were collected and the same methods were followed.

- Specific gravity

Specific gravity of the harvested tubers was determined in both experiments at the final harvest using a potato hydrometer according to the method described by Murphy and Goven (1959).

## 2. Results

### a. Experiment III

Irradiation delayed the emergence of plants. Thus, 17 and 24 days after planting, there were significant differences in the treatments percentages of emerged plants (Appendix Table 7). Duncan's multiple range tests showed that 17 days after planting the treatment means of the 300 and 500 rad doses were significantly smaller than that of the control; 24 days after planting, only the treatment mean of the 500 rad dose was significantly smaller than that of the control. Twenty-six days after planting, there were no significant differences between the treatments, most of the plants having emerged (Table 12).

Table 12

Average percentage of emerged plants per treatment 17, 24 and 26 days after planting.(1)

| Dose in rad | Number of days 17 | 24 | 26(3) |
|---|---|---|---|
| 0 | 16.70 a(2) | 87.90 a(2) | 90.55 |
| 150 | 13.47 a b | 86.15 a | 90.55 |
| 300 | 9.07 b | 80.55 a b | 86.97 |
| 500 | 3.15 c | 75.85 b | 84.10 |

(1) Analyses of variance and Duncan's multiple range tests were performed on transformed values.

(2) Means followed by same letter were not significantly different at level P = 0.05.

(3) Differences were not significant at level P = 0.05.

Sixty-eight days after planting, the seed piece had not yet decayed. This made it possible to check the number of sprouts emerging from the seed piece. It was found that only one sprout emerged to produce the aerial stem on practically all the tubers of all treatments.

The fresh weight of vines 68 days after planting was not significantly different from one treatment to the other but the dry weight of vines was significantly affected by irradiation (Appendix Table 8). The fresh weight of vines was reduced at the 500 rad dose but not to a significant extent. A Duncan's multiple range test on means of dry weight data showed that the treatment mean of the 500 rad dose was significantly lower than the one of the control. Treatment means of the 0, 150 and 300 rad doses were not significantly different (Table 13).

Table 13

Average fresh and dry weights of the potato vines per treatment 68 days after planting.

| Dose in rad | Fresh weight in kg(1) | Dry weight in kg |
|---|---|---|
| 0 | 12.71 | 1.07 a(2) |
| 150 | 12.74 | 1.04 a b |
| 300 | 13.01 | 1.09 a |
| 500 | 11.61 | 0.96 b |

(1) Differences were not significant at level P = 0.05.

(2) Means followed by same letter were not significantly different at level P = 0.05.

The average yield of the control was slightly superior to those of the irradiated tubers at the three harvest dates (Table 14) but the differences were not significant (Appendix Table 9).

The total number of tubers per treatment was not significantly different 68 and 122 days after planting but it was significantly different 92 days after irradiation (Appendix Table 10). A Duncan's multiple range test showed that the treatment means of the 300 and 500 rad doses were significantly lower than that of the control 92 days after planting (Table 15).

The average marketable yield of the control was slightly superior to those of the irradiated tubers at the three harvest dates (Table 16) but

Table 14

Average yield per treatment 68, 92 and 122 days after planting (yield expressed in kg).(1)

| Dose in rad | Number of days 68 | 92 | 122 |
|---|---|---|---|
| 0 | 4.24 | 9.31 | 12.86 |
| 150 | 4.07 | 8.73 | 12.25 |
| 300 | 3.98 | 8.61 | 12.32 |
| 500 | 3.91 | 7.86 | 11.21 |

(1) Differences were not significant at level P = 0.05.

Table 15

Average number of tubers per treatment 68, 92 and 122 days after planting.

| Dose in rad | Number of days 68(1) | 92 | 122(1) |
|---|---|---|---|
| 0 | 358 | 335 a(2) | 129 |
| 150 | 328 | 321 a b | 141 |
| 300 | 314 | 291 b c | 138 |
| 500 | 357 | 277 c | 134 |

(1) Differences were not significant at level P = 0.05.

(2) Means followed by same letter were not significantly different at level P = 0.05.

Table 16

Average yield of marketable tubers per treatment 68, 92 and 122 days after planting (yield expressed in kg).[1]

| Dose in rad | Number of days 68 | 92 | 122 |
|---|---|---|---|
| 0 | 3.92 | 6.13 | 11.45 |
| 150 | 3.80 | 5.67 | 10.69 |
| 300 | 3.72 | 6.11 | 10.87 |
| 500 | 3.53 | 5.71 | 9.56 |

(1) Differences were not significant at level $P = 0.05$.

the differences were not significant (Appendix Table 11).

The total number of marketable tubers per treatment was not significantly different 68, 92 and 122 days after planting (Appendix Table 12). Thus the treatment means of all doses were very similar at the three harvest dates (Table 17).

Irradiation did not have any significant effect on the specific gravity of the irradiated tubers (Appendix Table 13). Thus, the average specific gravity of tubers was identical from one treatment to the other (Table 18).

b. Experiment IV

Irradiation did not have any significant effect on the emergence of plants (Appendix Table 14). However, although not significant, the percentages of emerged plants were lower at the 300 and 500 rad doses 17 days after planting. The differences were much smaller 23 days after

Table 17

Average number of marketable tubers per treatment 68, 92 and 122 days after planting.[1]

| Dose in rad | Number of days 68 | 92 | 122 |
|---|---|---|---|
| 0 | 111 | 56 | 75 |
| 150 | 107 | 55 | 75 |
| 300 | 104 | 57 | 75 |
| 500 | 107 | 52 | 69 |

(1) Differences were not significant at level P = 0.05.

Table 18

Average specific gravity of tubers per treatment 122 days after planting.[1]

| Dose in rad | Specific gravity |
|---|---|
| 0 | 1.074 |
| 150 | 1.075 |
| 300 | 1.074 |
| 500 | 1.074 |

(1) Differences were not significant at level P = 0.05.

planting (Table 19).

Table 19

Average percentage of emerged plants per treatment 17 and 23 days after planting.[1]

| Dose in rad | Number of days | |
|---|---|---|
| | 17 | 23 |
| 0 | 17.30 | 82.60 |
| 150 | 16.40 | 86.72 |
| 300 | 9.65 | 83.48 |
| 500 | 5.25 | 70.25 |

[1] Differences were not significant at level P = 0.05.

The total yield and total number of tubers were not significantly different from one treatment to the other (Appendix Table 15). The 150 rad dose had the highest yield and the highest number of tubers (Table 20) although these differences were not significant.

Similarly, irradiation did not have any significant effect on the total marketable yield and the total number of marketable tubers (Appendix Table 16). The 150 and 300 rad doses had slightly higher average marketable yields but again, this was not significant. The average numbers of marketable tubers were almost identical from one treatment to the other (Table 21).

Finally, it was found that irradiation did not have any significant effect on the specific gravity of tubers (Appendix Table 17). The average

Table 20

Average yield and average number of tubers per treatment 123 days after planting.[1]

| Dose in rad | Yield in kg | Number of tubers |
|---|---|---|
| 0 | 33.70 | 420 |
| 150 | 34.20 | 442 |
| 300 | 33.54 | 421 |
| 500 | 33.02 | 426 |

[1] Differences were not significant at level $P = 0.05$.

Table 21

Average marketable yield and average number of marketable tubers per treatment 123 days after planting.[1]

| Dose in rad | Yield in kg | Number of tubers |
|---|---|---|
| 0 | 29.14 | 209 |
| 150 | 29.22 | 208 |
| 300 | 29.30 | 207 |
| 500 | 28.83 | 211 |

[1] Differences were not significant at level $P = 0.05$.

specific gravity of the treatments was almost identical in all treatments (Table 22).

Table 22

Average specific gravity of the tubers per treatment 123 days after planting.(1)

| Dose in rad | Specific gravity |
|---|---|
| 0 | 1.072 |
| 150 | 1.075 |
| 300 | 1.072 |
| 500 | 1.072 |

(1) Differences were not significant at level P = 0.05.

### 3. Discussion

Irradiation retarded the emergence of plants in Experiment III but did not in Experiment IV. This different effect might be attributed to the difference in the seed tubers used. Whole seed was used in Experiment III and cut seed was used in Experiment IV. Even if the apical end was not disturbed in Experiment IV, the internal metabolism might have been affected, possibly by increased respiration. This might have been sufficient to cause a different behavior.

On the first harvest of Experiment III, the dry weight of the vines was significantly reduced. Since the fresh weights did not show any significant difference while the dry weight did (Table 13), this might be attributed to uneven drying obtained by the method employed, unless irradiation of the tubers at 500 rad affected the production of dry matter.

There was also a slight reduction in fresh weight at 500 rad. Even though it was not significant, it is not in agreement with the findings of Grechushnikov and Serebrennikov (1965), of Serebrennikov and Kiryukhin (1965) and of Kahan and Susnoscki (1967) who reported an increased number of stalks, an increased height and a larger assimilative surface. Multiple sprouting was not observed at this harvest.

A greater number of marketable tubers was observed on the first harvest than on subsequent harvests in Experiment III. This unusual finding was most likely due to the fact that the tubers were graded by size using a ruler and that on the first harvest, the tubers which were border-line were placed in the higher class and on subsequent harvests they were placed in the lower class. Because of this method of grading, it is preferable to compare the number of marketable tubers for each treatment on a definite harvest date rather than between harvest dates.

It will be noted that fewer tubers are reported for the last harvest than for the previous ones (Table 15). This is due to the fact that on the last harvest, the tubers were dug up with a mechanical harvester. Thus, the smaller tubers were lost, hence a smaller number of tubers.

D. Experiment V

It has been reported recently (Rohrmann and Brownell, 1967) that low doses of gamma irradiation interrupted the rest period of freshly dug mature potatoes. Since no work had been done in this particular field with a Quebec grown variety, an experiment was conducted in the greenhouse at Macdonald College in the fall 1968 to investigate if such treatments would have a similar effect.

1. Materials and Methods

Experimental design

A randomized block design (Fig. 4) with four replications was used. Each replication contained six plots of 20 tubers, each plot representing one treatment.

Seed treatments

Tubers of the Kennebec variety were used. These were the progeny of the Foundation stock planted as guard rows in Experiments III and IV. No virus symptoms were noticed in these guard rows. They were harvested on September 25, 1968, and stored at 21°C until treatment. Tubers of grade B size were selected and mixed together. They were then divided at random into six groups corresponding to the six treatments. On October 8, the tubers were taken to Ottawa for irradiation with the Atomic Energy Commission equipment and brought back on the same day. The source was a pneumatic $Cobalt^{60}$ irradiator having a dose rate of 5,885 rad per hour or 98.1 rad per minute. The variation in the dose was 1.15-1.2 to 1. The minimum doses given were 150, 300, 500, 750 and 1,000 rad. The distance between the center of the source and the center of the cardboard container holding the potatoes was 3.2 meters. The container was turned over in the middle of the exposure to provide equal treatment on each side.

Planting and management

The experiment was set on two benches in such a way as to minimize the temperature variation due to the heating pipes. The night-time temperature was set at 18°C and the day-time temperature at 21°C. The tubers were planted in perlite. This medium was used to simulate soil conditions

Figure 4

Greenhouse layout. Experiment V.[1]

| Replication I | Replication III |
|---|---|
| 750 | 1000 |
| 1000 | 150 |
| 300 | 300 |
| 500 | 0 |
| 0 | 500 |
| 150 | 750 |

| Replication II | Replication IV |
|---|---|
| 300 | 0 |
| 1000 | 500 |
| 500 | 300 |
| 0 | 1000 |
| 150 | 150 |
| 750 | 750 |

(1) Figures correspond to the actual doses received.

in that it provided moisture to the tubers and prevented them from greening. Checking sprout growth was facilitated with this material. The tubers were planted the day after irradiation in individual polystyrene pots measuring 10 cm in diameter at the top, 7.5 cm in diameter at the bottom and 8.5 cm in height. The bottom of the pots was first covered with about two cm of perlite. The tubers were then put in and covered completely with more perlite. A thorough watering followed.

Measurements

Before recording any data, a few tubers selected at random in every treatment were examined twice a week to detect initiation of sprouting. A few tubers showed sprouting 44 days after irradiation. Data were collected from that time until 91 days after treatment. Observations were taken on the end of the rest period, sprout elongation, breakdown in apical dominance and multiple sprouting. The end of the rest period was checked by counting the number of sprouted tubers in every treatment on a definite date. A single sprout was sufficient to indicate that the rest period was over. Sprout growth in each treatment was determined by counting the number of tubers having sprouts longer than 0.5 cm, 1 cm or 1.5 cm, at each date of examination.

Breakdown in apical dominance and multiple sprouting were determined 91 days after irradiation. Before that date, the sprouts were too small to permit valid observations. Apical dominance was considered as broken if the longest sprout or sprouts were located near the stem end. It was not considered as broken if the sprout or sprouts appeared at or near the apical end. Multiple sprouting was determined by counting the number of vigorous sprouts on each tuber. Data were converted into percentages which were transformed according to the angular transformation. Analyses of variance and Duncan's multiple range tests (whenever applicable) were performed on these transformed values. Inferences were based on these transformed values.

2. Results

The results of this experiment indicate that, although irradiation appears to stimulate the initiation of sprouting, no significant differences in the percentages of sprouted tubers were found 44 and 48 days after treatment. The 1,000 rad dose appeared to have a greater effect, and 54 days after treatment, the percentage of sprouted tubers was significantly higher at that dose. The differences between the treatments were no longer significant 61 days after irradiation, most of the tubers having sprouted at that time (Table 23, Appendix Table 18).

As with the initiation of sprouting, the 150, 300 and 500 rad doses appeared to stimulate the rate of sprout growth. The average percentages of tubers with sprouts longer than 0.5 cm in these treatments were higher than the control 54 and 61 days after treatment but the differences were not significant (Table 24). However, the 1,000 rad dose, which resulted in a significant increase in the percentages of sprouted tubers 54 days after irradiation, had an adverse effect on sprout growth. The percentages of tubers with sprouts longer than 0.5 cm were significantly lower at that dose, 54 and 61 days after treatment. This is reflected in the analysis of variance which shows significant differences between treatments (Appendix Table 19).

The rate of sprout growth was determined 68 days after irradiation by determining the percentage of tubers with sprouts longer than 0.5 cm, 1 cm and 1.5 cm. There were no significant differences in the percentages of tubers with sprouts longer than 0.5 cm and 1 cm but a significant difference

Table 23

Average percentages of sprouted tubers 44, 48, 54 and 61 days after irradiation.(1)

| Dose in rad | Number of days 44(2) | 48(2) | 54 | 61(2) |
|---|---|---|---|---|
| 0 | 7.50 | 25.00 | 62.50 a(3) | 96.25 |
| 150 | 13.75 | 43.75 | 76.25 a | 97.50 |
| 300 | 16.25 | 36.25 | 76.25 a | 96.25 |
| 500 | 20.00 | 47.50 | 82.50 a | 96.25 |
| 750 | 23.75 | 46.25 | 81.25 a | 96.25 |
| 1000 | 25.00 | 58.75 | 90.00 b | 97.50 |

(1) Analyses of variance and Duncan's multiple range test were performed on transformed values.

(2) Differences were not significant at level P = 0.05.

(3) Means followed by same letter were not significantly different at level P = 0.05.

was obtained in the percentages of tubers with sprouts longer than 1.5 cm (Appendix Table 20). The treatment mean of the 1,000 rad dose was significantly lower than those of all other doses (Table 25).

Data on the length of the sprouts were not collected after 68 days because of the presence of Rhizoctonia solani (Kühn) on the sprouts which affected the growth pattern.

Irradiation significantly affected apical dominance and multiple sprouting (Appendix Table 21). The 150, 300 and 500 rad doses had no

Table 24

Average percentages of tubers with sprouts longer than 0.5 cm, 54 and 61 days after irradiation.[1]

| Dose in rad | Number of days 54 | 61 |
|---|---|---|
| 0 | 31.25 a b[2] | 80.00 a |
| 150 | 52.50 a | 85.00 a |
| 300 | 50.00 a | 86.25 a |
| 500 | 46.25 a | 88.75 a |
| 750 | 32.50 a b | 77.50 a |
| 1000 | 13.75 b | 50.00 b |

(1) Analyses of variance and Duncan's multiple range tests were performed on transformed values.

(2) Means followed by same letter were not significantly different at level P = 0.05.

effect on apical dominance but the 750 and 1,000 rad doses significantly increased the percentages of tubers showing a breakdown in apical dominance. The 1,000 rad dose significantly increased multiple sprouting. The lower levels had no significant effect (Table 26).

### 3. Discussion

Irradiation did not break the rest period of the potato tubers. Kehr *et al*. (1964) indicated that the Kennebec variety will begin to sprout after a storage period of nine weeks at 21°C. In this experiment, 13 days elapsed between harvest on September 25 and irradiation on October 8. The

Table 25

Average percentages of tubers with sprouts longer than 0.5 cm, 1 cm and 1.5 cm, 68 days after irradiation.(1)

| Dose in rad | Minimum sprout length 0.5 cm(2) | 1 cm(2) | 1.5 cm |
|---|---|---|---|
| 0 | 100.00 | 91.25 | 71.25 a(3) |
| 150 | 97.50 | 91.25 | 80.00 a |
| 300 | 97.50 | 96.25 | 83.75 a |
| 500 | 97.50 | 91.25 | 85.00 a |
| 750 | 93.75 | 85.00 | 73.75 a |
| 1000 | 93.75 | 72.50 | 51.25 b |

(1) Analyses of variance and Duncan's multiple range test were performed on transformed values.

(2) Differences were not significant at level P = 0.05.

(3) Means followed by same letter were not significantly different at level P = 0.05.

results show that, 44 days after irradiation, there were no significant differences in the percentages of sprouted tubers between treatments. Since the time elapsed between harvest and initiation of sprouting was a little over eight weeks, it can be assumed that sprouting occurred because the rest period was terminated and that irradiation had no effect.

The 1,000 rad dose significantly increased the number of sprouted tubers 54 days after irradiation, broke down the apical dominance and

Table 26

Average percentages of tubers showing breakdown in apical dominance and multiple sprouting 91 days after irradiation.[1]

| Dose in rad | Breakdown in apical dominance | Multiple sprouting |
|---|---|---|
| 0 | 3.75 a[2] | 10.00 a[2] |
| 150 | 0.00 a | 13.75 a |
| 300 | 3.75 a | 15.00 a |
| 500 | 5.00 a | 21.25 a |
| 750 | 13.75 b | 25.00 a |
| 1000 | 20.00 b | 55.00 b |

(1) Analyses of variance and Duncan's multiple range tests were performed on transformed values.

(2) Means followed by same letter were not significantly different at level $P = 0.05$.

induced multiple sprouting which would result in an increased number of stems. However, since this dose also caused a reduction in sprout growth, it would appear to be more detrimental than beneficial. It was felt that Rhizoctonia solani (Kühn) did not affect the early sprout growth and that the data collected were reliable. The disease might have had an effect on apical dominance and multiple sprouting by destroying the first emerging sprouts. However, about the same number of tubers were affected in each treatment which indicates that the effect of the disease would have been about the same in all treatments.

E. Experiment VI

This experiment was carried out to investigate the effect of doses of irradiation slightly higher than those previously used, on the growth of sprouts of seed tubers near the end of their rest period. This experiment was conducted in the greenhouse at Macdonald College in the fall 1968.

1. Materials and Methods

Experimental design

A randomized block design (Fig. 5) with three replications was used. Each replication contained five plots of 15 tubers, each plot representing one treatment.

Seed treatments

Grade B size seed from the same source as in Experiment V was used. It was harvested on September 25, 1968, and kept at 21°C until irradiation. The size of the tubers was very uniform from one treatment to the other in this experiment.

The potatoes were taken to Ottawa on November 20 for irradiation with the source described in Experiment V and brought back on the same day. The dose rate was 97.1 rad per minute. The doses given were 0, 500, 1,000, 1,500 and 2,000 rad. Those figures are the minimum doses received. The variation in the dose was 1.15-1.2 to 1.

Planting and management

The day after irradiation, the tubers were planted in individual square polystyrene pots measuring 8 cm across the top, 6.5 cm across the bottom and 8 cm deep and using perlite as the growing medium. The pots were placed on

Figure 5

Greenhouse layout. Experiment VI.[1]

Replication I

2000

1000

0

500

1500

Replication II

0

1500

1000

2000

500

Replication III

500

2000

1500

0

1000

[1] Figures correspond to the actual doses received.

one bench in the greenhouse. A thorough watering followed. The soil medium was kept slightly moist throughout the experiment.

The night-time temperature of the greenhouse was set at 18°C and the day-time temperature at 21°C for the duration of the experiment.

Measurements

Data were collected on sprout growth from eight to 49 days after irradiation. Observations were taken on the initiation of sprouting, the rate of sprout elongation, the breakdown of apical dominance and multiple sprouting. The methods used to collect these data were identical to those used in Experiment V. Data were converted into percentages and transformed for analyses as in Experiment V.

2. Results

Irradiation had no effect on the initiation of sprout growth. Thus no significant differences were observed in the percentages of sprouted tubers per treatment 8, 13 and 19 days after irradiation (Table 27, Appendix Table 22).

The higher doses significantly decreased the rate of sprout growth. Thus, 8, 19, 28 and 40 days after irradiation, significant differences were observed in the percentages of tubers with sprouts longer than 0.5 cm (Appendix Table 23). It was found that 8 days after irradiation, the treatment means of the 1,000 and 2,000 rad doses were significantly lower than those of the control. Nineteen days after irradiation, only the treatment mean of the 2,000 rad dose was significantly lower than those of the control and the other treatments. Twenty-eight and 40 days after irradiation, the treatment means of the 1,500 and 2,000 rad doses were significantly lower than those of the control, and the other treatments (Table 28).

Table 27

Average percentages of sprouted tubers 8, 13 and 19 days after irradiation.[1]

| Dose in rad | Number of days | | |
|---|---|---|---|
| | 8[2] | 13[2] | 19[2] |
| 0 | 68.86 | 86.60 | 98.33 |
| 500 | 62.20 | 82.16 | 96.66 |
| 1000 | 62.20 | 91.06 | 95.00 |
| 1500 | 71.06 | 86.63 | 95.00 |
| 2000 | 55.53 | 82.20 | 96.66 |

(1) Analyses of variance were performed on transformed values.

(2) Differences were not significant at level P = 0.05.

Forty-nine days after irradiation, as the sprouts elongated there were no significant differences, between treatments in the percentages of tubers having sprouts longer than 0.5 cm and 1 cm but a significant difference was observed on a 1.5 cm basis (Appendix Table 24). With this sprout length, there was no significant difference between the means of the control and of the 500 rad doses but the means of the 1,000, 1,500 and 2,000 rad doses were significantly lower than that of the control (Table 29).

Irradiation significantly affected apical dominance and multiple sprouting (Appendix Table 25). While the 500 and 1,000 rad doses had no effect on apical dominance the 1,500 and 2,000 rad doses significantly increased the percentages of tubers showing a breakdown in apical dominance.

Table 28

Average percentages of tubers with sprouts longer than 0.5 cm, 8, 19, 28 and 40 days after irradiation.(1)

| Dose in rad | Number of days 8 | 19 | 28 | 40 |
|---|---|---|---|---|
| 0 | 19.96 a(2) | 77.76 a | 95.53 a | 100.00 a |
| 500 | 15.53 a b | 82.20 a | 95.53 a | 100.00 a |
| 1000 | 4.43 b c | 82.16 a | 95.53 a | 97.76 a |
| 1500 | 6.53 a b c | 62.20 a | 73.26 b | 84.43 b |
| 2000 | 0.00 c | 37.73 b | 68.83 b | 75.50 b |

(1) Analyses of variance and Duncan's multiple range tests were performed on transformed values.

(2) Means followed by same letter were not significantly different at level P = 0.05.

These same doses significantly increased multiple sprouting (Table 30).

Observations on sprout growth were not made at a later date because of the presence of <u>Rhizoctonia solani</u> (Kühn) on the sprouts affecting their growth pattern.

### 3. Discussion

The tubers selected for irradiation, 56 days after harvest, were still unsprouted but some tubers in the lot from which they were taken had begun to sprout. This indicated that the rest period of the selected tubers was almost over and that they would sprout very soon. As expected, the control and the treatments started to sprout at approximately the same time indi-

Table 29

Average percentages of tubers with sprouts longer than 0.5 cm, 1 cm and 1.5 cm, 49 days after irradiation.(1)

| Dose in rad | Minimum sprout length | | |
|---|---|---|---|
| | 0.5 cm(2) | 1 cm(2) | 1.5 cm |
| 0 | 100.00 | 100.00 | 100.00 a(3) |
| 500 | 100.00 | 100.00 | 97.76 a b |
| 1000 | 97.76 | 93.53 | 88.86 b c |
| 1500 | 97.76 | 91.06 | 82.20 c |
| 2000 | 91.06 | 84.43 | 77.73 c |

(1) Analyses of variance and Duncan's multiple range test were performed on transformed values.

(2) Differences were not significant at level P = 0.05.

(3) Means followed by same letter were not significantly different at level P = 0.05.

Table 30

Average percentages of tubers showing a breakdown in apical dominance and multiple sprouting 49 days after irradiation.(1)

| Dose in rad | Breakdown in apical dominance | Multiple sprouting |
|---|---|---|
| 0 | 2.20 a(2) | 11.06 a |
| 500 | 6.63 a | 17.73 a b |
| 1000 | 6.63 a | 17.73 a b |
| 1500 | 17.73 b | 37.73 b c |
| 2000 | 26.63 b | 42.20 c |

(1) Analyses of variance and Duncan's multiple range tests were performed on transformed values.

(2) Means followed by same letter were not significantly different at level P = 0.05.

cating that irradiation had no effect on the initiation of sprouting.

The 1,500 and 2,000 rad doses significantly increased the number of tubers showing a breakdown in apical dominance and multiple sprouting. However since sprout growth was also reduced at these two doses, they would appear to be more detrimental than beneficial. As in Experiment V, it was felt that *Rhizoctonia solani* (Kühn) did not affect the early sprout growth and that its effect on apical dominance and multiple sprouting, if any, was about the same in all treatments.

# IV

## GENERAL DISCUSSION

The results of Experiments I and II will not be discussed because of the conditions which prevailed during these experiments. The results of the other experiments will be discussed under three subdivisions: 1. effect of irradiation on yield and quality of potatoes, 2. effect of irradiation on the rest period and on the sprouting of potatoes, and 3. factors affecting the response of plants to irradiation.

### 1. Effect of irradiation on yield and quality of potatoes.

The results of the present study are not in agreement with most of the recent findings. Low doses of irradiation failed to increase the yield and quality of the crops grown from irradiated tubers. Recent papers by Jaarma (1958), Vidal (1959), Serebrennikov and Kiryukhin (1965), Grechushnikov and Serebrennikov (1965), and Kahan and Susnoscki (1967) reported increased yields as a result of treating seed tubers with low doses of irradiation. Grechushnikov and Serebrennikov (1965), and Serebrennikov and Kiryukhin (1965) also reported an increased starch content in tubers grown from irradiated seed tubers which would increase specific gravity. The results reported here did not confirm this finding.

Hagberg and Nybom (1954), Jaarma (1958), Fischnich *et al*. (1961), and Gantzer and Heilinger (1964) have shown that potato varieties differed in their radiosensitivity and, therefore, had different responses to irradiation. Süss (1966) indicated that plant varieties differed in their growing habit, therefore also in their metabolism, which could explain the different reactions to irradiation. The variety used in this investigation has not been used previously. This might be the reason for the general lack of response.

Johnson (1937) showed that slightly sprouted tubers responded more favorably to irradiation than tubers at any other physiological state. However, Serebrennikov and Kiryukhin (1965), found that irradiating unsprouted tubers with low doses increased yield. Other authors did not indicate the physiological state of the tubers. The tubers used in these field experiments were slightly sprouted. Thus it would appear that the different results obtained are not due to the physiological state of the tubers unless they were so active physiologically that stimulation by irradiation, if any, had no effect.

As shown in the review of literature, the response of the seed tubers to irradiation is dependent upon the dose given. Jaarma (1958), Vidal (1959), Serebrennikov and Kiryukhin (1965), and Kahan and Susnoscki (1967) reported increased yields from doses of 350 to 800 rad, 500 to 1,000 rad, 150 to 500 rad and 20 to 200 rad, respectively. The doses used in Experiments III and IV were in a similar range with the exception of the levels used by Vidal. Doses higher than those used in the present experiments would not have been beneficial since slightly lower yields were obtained at the 500 rad dose. Because results similar to those observed in this study were obtained by Sparrow and Christensen (1950) and Süss (1966) using doses of 18.85 to 300 rad and 1 to 100 r respectively, it would appear that failure to obtain higher yields by irradiation was not due to the doses given.

According to Jaarma (1958), and Gantzer and Heilinger (1964) the dose rate has a considerable influence on the subsequent growth responses of the potato. They indicated that a low dose rate was more stimulating than a high rate, when a small dose was given. Since Serebrennikov and Kiryukhin

(1965), and Grechushnikov and Serebrennikov (1965), using dose rates of 317 and 300 rad per minute, respectively, reported increased yields from irradiated tubers, the lower dose rate of 36 rad per minute used in Experiments III and IV should have had a beneficial effect. However this was not the case. It would therefore appear that failure to obtain higher yields was not due to the dose rate employed.

Serebrennikov and Kiryukhin (1965) stated that the best results were obtained with tubers planted six to ten days after irradiation to avoid breaking of the developing sprouts. Kahan and Susnoscki (1967) observed a greater increase in yield when the tubers were planted 14 days after irradiation as compared to 28 days. Since the tubers were planted nine days after irradiation, in the present study, failure to obtain increased yields cannot be attributed to the delay between irradiation and planting.

Grechushnikov and Serebrennikov (1965) and Süss (1966) reported that the agroclimatic conditions under which the plants were grown had an effect on the response of tubers to irradiation. Also, Preobrazhenskaya (1965), working on grass species, showed that the climatic conditions under which the seeds were grown before irradiation affected the response to irradiation, and that climatic conditions which prevailed after the planting of irradiated seeds also affected the radiation response. However, Johnson (1931) did not observe any difference in yield from irradiated tubers grown at three different altitudes. In this study, the growing conditions were likely different from those of all workers. Since favorable responses were observed under various agroclimatic conditions, it is difficult to visualize any effect arising from this factor.

2. Effect of irradiation on the rest period and on the sprouting of potatoes.

Rohrmann and Brownell (1967) reported that low doses of irradiation broke the rest period of freshly dug potatoes. Jaarma (1958), Fischnich *et al.* (1961), and Gantzer and Heilinger (1964) reported stimulation of sprout growth from low doses of irradiation. The results obtained in the present study are not in agreement with these findings.

As shown previously, irradiation failed to induce sprouting of resting tubers which were irradiated 13 days after harvesting from chemically defoliated fields. Some similarities existed between this study and the work of Rohrmann and Brownell (1967), but the results obtained were quite different. In their first experiment, they used tubers dug and irradiated on the same day with doses of 250 to 2,000 rad after which they were cut and divided into two groups. They reported that the group which was air cured for two days before planting showed massive sprouting 21 days later without elaborating on what was meant by "massive sprouting". In another experiment, they observed a 35 per cent increase in the sprouting of tubers also taken from a chemically defoliated field, and irradiated immediately with a dose of 1,500 rad. The fact that whole seed irradiated 13 days after harvest was used in this study might explain the lack of response to irradiation obtained along with the possible variety effect.

As discussed previously, sprout growth began when the rest period was over in Experiment V. After initiation of sprout growth, the results from Experiment VI were quite similar to those of Experiment V. In both experiments, the lower doses of irradiation had no effect on sprout growth but the higher ones were inhibitory, the 1,000 rad dose in Experiment V and the 1,500 and 2,000 rad doses in Experiment IV giving a significant decrease in sprout growth. These results suggest that the radiosensitivity of the resting tubers was different from that of tubers near the end of their rest period. This finding is in agreement with that of Mathur (1963) who observed that the nearer the potatoes were to the stage when dormancy breaks, the greater was the dose of gamma irradiation required to prevent sprouting. Thus, tubers close to the end of the rest period would be more radioresistant than those at the beginning of the rest period.

As mentioned previously, a dose of 1,000 rad in Experiment V and doses of 1,500 and 2,000 rad in Experiment VI resulted in a reduction in sprout length. These results are in agreement with those of Hagberg and Nybom (1954), Jaarma (1958) and Gantzer and Heilinger (1964) who used X-ray doses of 1,250 to 2,500 rad, a gamma ray dose of 2,000 and an X-ray dose of 2,000 r respectively. They reported a reduction in sprout length or sprout weight. It must be noted that unsprouted tubers were used in the present study while Hagberg and Nybom (1954) used slightly sprouted tubers. Jaarma (1958) did not specify the physiological state of the tubers he used and Gantzer and Heilinger (1964) used tubers which had been stored for six weeks at 12°C. There was some similarity between this last experiment and Experiment VI since the tubers used in this experiment were stored for eight weeks at 21°C before irradiation. On the other hand, Farooqi et al. (1967) reported that, 60 days after irradiation, they observed an increase in sprout length of tubers irradiated with a 2,000 rad dose 15 days after harvest. This different finding might be due to the dose rate employed, which was not indicated, the variety and the storage conditions.

Irradiation with doses smaller than 1,000 rad given at a dose rate of 97 to 98 rad per minute, failed to stimulate sprouting or to increase sprout length. These results are not in agreement with the findings of Jaarma (1958) and Gantzer and Heilinger (1964). Jaarma reported sprout stimulation from gamma ray doses of 350 to 800 rad but did not indicate the dose rate used or the physiological state of the tubers. Gantzer and

Heilinger (1964) observed a stimulation of sprouting as a result of treating tubers with X-ray doses of 100 to 500 r at a dose rate of 50 r per minute. They used freshly dug tubers treated with rindite and irradiated two weeks later. They also reported that a dose of 100 r stimulated sprouting in one variety but did not in another. On the other hand, Fischnich et al. (1961) reported that an X-ray dose of 100 r given at a dose rate of 28 r per minute reduced sprout growth of unsprouted tubers in the two varieties used in one year but had no effect in another year. The dose rate used in this study and those used by these workers are in a similar range. The conflicting results obtained would appear to be due to the different varieties used and the physiological state of the tubers.

Fischnich et al. (1961) stated that the beneficial effect of low doses is obtained only when the metabolism is stimulated before and after irradiation such as when the tubers are stored at warm temperatures. However, low doses of irradiation failed to stimulate sprouting significantly in the Experiments V and VI. Since these tubers were stored at 21°C before irradiation and were grown at a minimum temperature of 18°C after irradiation, the metabolism should have been stimulated by the temperature and a beneficial response to irradiation should have been obtained.

As already mentioned in the beginning of this discussion, Serebrennikov and Kiryukhin (1965) reported that in field experiments, the best response to irradiation was obtained when the tubers were planted six to ten days after treatment. While the tubers were planted on the day after irradiation, in Experiments V and VI, it is felt that this time interval was not responsible for the discrepancy in the results because of the temperature maintained in the greenhouse.

In addition, the acceleration of emergence from low doses of irradiation in field experiments reported by Grechushnikov and Serebrennikov (1965) and Kahan and Susnoscki (1967) could not be confirmed in the present study.

3. Factors affecting the response of plants to irradiation.

There are a number of other factors which have been shown to affect the response of different plant species to irradiation, in addition to those already discussed for potatoes. While it is possible that some of these factors might affect the response of potatoes, several workers (Sparrow and Christensen, 1953; Gunckel, 1957) have shown that the results obtained with one species did not necessarily apply to others.

The reaction of plants to irradiation was affected by the water content of the seeds (Johnson, 1936; Caldecot, 1955; Gunckel and Sparrow, 1961; Micke, 1966; Süss, 1966), the temperature (Nylan, 1956; Gunckel and Sparrow, 1961; Fishnich _et al_., 1961; Süss, 1966), the oxygen tension (Caldecot, 1955; Nylan, 1956; Gunckel and Sparrow, 1961; Micke, 1966; Süss, 1966; Davies, 1967), protective substances, the type of radiation and the soil type (Gunckel and Sparrow, 1961), the carbon dioxide in the atmosphere, the storage of seeds and the pre-treatment of seeds with chemicals (Nylan, 1956), the different radiosensitivity phases of the plant (Sarić, 1958; Biebl, 1959), the relative humidity of the atmosphere (Micke, 1966) and the nutrient content of seeds (Süss, 1966).

Finally, reproducibility of the results is an important consideration. In this study, low doses of irradiation failed to improve the growth and yield of potatoes in the various experiments conducted. Süss and Haisch (1964) were able to obtain reproducible results for three years. However, Fischnich _et al_. (1961), and Sax (1955), showed that the results obtained from irradiation were not always reproducible and Süss (1966) reported that the same cereal variety showed different responses to irradiation from year to year.

It may be pointed out that many of the reports in the literature indicating favorable responses to treatment of potato tubers with low doses of irradiation were based on visual observations and physical measurements which did not appear to have been submitted to statistical analysis. In the present study, there were instances where some levels of irradiation seemed to produce favorable results. However, when analyzed statistically, these results did not prove to be significant. It is therefore possible that some of the favorable results reported in the literature were not significant. Furthermore, some workers based their conclusions on a relatively small number of tubers, which may not have taken into account the variability between the tubers.

## V

## SUMMARY

The effects of pre-planting irradiation of potato seed tubers with low doses of Cobalt$^{60}$ gamma rays were investigated. Tubers at different physiological states, namely resting, dormant and slightly sprouted, were used in different experiments.

A preliminary field experiment was carried out with slightly sprouted tubers of the Kennebec variety and with unsprouted tubers of the Sebago variety. Doses of 150, 300 and 500 rad were given. The results were inconclusive because of the incidence of late blight.

A greenhouse experiment was carried out with unsprouted tubers of the Kennebec variety to investigate the effects of low doses of irradiation on the emergence of sprouts from dormant tubers, and on the yield and quality of the crop. Doses of 150, 300 and 500 rad were given. Irradiation did not hasten emergence and did not affect the yield and quality of the crop. However, there was a great variation among the plants which did not permit a definite conclusion.

Two carefully controlled experiments were carried out under field conditions to investigate the effects of low doses of irradiation on the emergence and growth of the plants and on the yield pattern during and at the end of the growing season. Slightly sprouted tubers of the Kennebec variety were irradiated at doses of 150, 300 and 500 rad. Irradiation did not hasten the emergence of the plants and had no significant effect on the yield and quality of the tubers.

A greenhouse experiment was carried out with tubers harvested from a chemically defoliated field to investigate the effect of irradiation on the rest period and subsequent sprout growth. Tubers of the Kennebec variety were irradiated at doses of 150, 300, 500, 750 and 1,000 rad. Irradiation did not break the rest period and only the 1,000 rad dose had a significant effect on sprout growth. This dose broke the apical dominance and induced multiple sprouting but reduced sprout development.

Another greenhouse experiment was conducted with tubers harvested from a chemically defoliated field to investigate the effect of irradiation on tubers which were at the end of their rest period but had not sprouted yet. Tubers of the Kennebec variety were irradiated at 500, 1,000, 1,500 and 2,000 rad. Irradiation did not hasten sprouting and only the 1,500 and 2,000 rad doses had a significant effect on sprout growth. The doses broke apical dominance and induced multiple sprouting but reduced sprout development.

It is felt that the significant effect of the higher doses of irradiation used in the last two greenhouse experiments was detrimental to the growth of the potato rather than beneficial.

# VI

## SUGGESTIONS FOR FURTHER RESEARCH

Because the results obtained in the present study conflict with those published by different workers, more research is needed to investigate the response of potato seed tubers to low doses of irradiation.

Research could be carried out to study the effect of temperature before, during and after irradiation of the seed tubers, the effect of the relative humidity at which the tubers were stored before irradiation, and the effect of the sites where the tubers are grown after irradiation.

Research could be conducted on the effect of low doses of irradiation at different dose rates on different varieties since there is a possibility of varietal differences in the responses. Results of economic importance might be obtained.

Research could be carried out on the effect of low doses of irradiation on the growth substances and on the carbohydrate metabolism of irradiated tubers. Such research might lead to a better understanding of the mode of action of low doses of irradiation.

# VII

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# APPENDIX

Appendix Table 1

Percentage of emerged plants 55 days after planting. Experiment II.

| Dose in rad | Replication I | II | III | IV |
|---|---|---|---|---|
| 0 | 37.5 | 12.5 | 0.0 | 25.0 |
| 150 | 25.0 | 12.5 | 25.0 | 12.5 |
| 300 | 37.5 | 25.0 | 0.0 | 62.5 |
| 500 | 25.0 | 12.5 | 25.0 | 75.0 |

Appendix Table 2

Transformed values of the percentages of emerged plants 55 days after planting using the angular transformation (Fisher and Yates, 1963; Bartlett, 1947). Experiment II.

| Dose in rad | Replication I | II | III | IV |
|---|---|---|---|---|
| 0 | 37.76 | 20.70 | 2.85 | 30.00 |
| 150 | 30.00 | 20.70 | 30.00 | 20.70 |
| 300 | 37.76 | 30.00 | 2.85 | 52.24 |
| 500 | 30.00 | 20.70 | 30.00 | 60.00 |

Appendix Table 3

Analysis of variance of the percentages of emerged plants 55 days after planting using the angular transformation. Experiment II.

| Source | d.f. | S.S. | M.S. | F |
|---|---|---|---|---|
| Replications | 3 | 1417.68 | 472.56 | 2.80 |
| Treatments | 3 | 366.20 | 122.06 | 0.72 |
| Error | 9 | 1516.16 | 168.46 | |
| Total | 15 | 3300.04 | | |

Appendix Table 4

Mean squares of the percentages of emerged plants 55, 60 and 65 days after planting. Experiment II.(1)

| Source | d.f. | Number of days | | |
|---|---|---|---|---|
| | | 55 | 60 | 65 |
| Replications | 3 | 472.56 | 513.28 | 854.35 |
| Treatments | 3 | 122.06 | 596.08 | 210.35 |
| Error | 9 | 168.46 | 184.32 | 253.65 |

(1) Analyses of variance were performed on transformed values.

Appendix Table 5

Mean squares of the yield and number of tubers after 130 days of growth. Experiment II.

| Source | d.f. | Yield | Number of tubers |
|---|---|---|---|
| Replications | 3 | 0.0363 | 319.12 |
| Treatments | 3 | 0.0030 | 44.37 |
| Error | 9 | 0.0356 | 19.70 |
| Sampling error | 14[1] 15[2] | 0.0232 | 40.20 |

(1) Two d.f. were lost due to two sub-plots missing.

(2) One d.f. was lost due to one sub-plot missing.

Appendix Table 6

Mean squares of the specific gravity of tubers after 130 days of growth. Experiment II.

| Source | d.f. | M.S. |
|---|---|---|
| Replications | 3 | 0.0000256 |
| Treatments | 3 | 0.0000463 |
| Error | 9 | 0.0000183 |
| Sampling error | 14[1] | 0.0000297 |

(1) Two d.f. were lost due to two sub-plots missing.

Appendix Table 7

Mean squares of the percentages of emerged plants 17, 24 and 26 days after planting. Experiment III.

| Source | d.f. | Number of days | | |
|---|---|---|---|---|
| | | 17 | 24 | 26 |
| Replications | 3 | 71.01 | 159.92 | 116.71 |
| Treatments | 3 | 152.78** | 90.09* | 36.73 |
| Error | 9 | 16.30 | 22.19 | 20.42 |

* Differences were significant at level P = 0.05.

** Differences were significant at level P = 0.01.

Appendix Table 8

Mean squares of the fresh and dry weights of the potato vines 68 days after planting. Experiment III.

| Source | d.f. | Fresh weights | Dry weights |
|---|---|---|---|
| Replications | 3 | 1.790 | 0.0070 |
| Treatments | 3 | 1.533 | 0.0133* |
| Error | 9 | 0.657 | 0.0028 |

* Differences were significant at level P = 0.05.

Appendix Table 9

Mean squares of total yield of tubers 68, 92 and 122 days after planting. Experiment III.

| Source | d.f. | Number of days | | |
|---|---|---|---|---|
| | | 68 | 92 | 122 |
| Replications | 3 | 0.0816 | 0.420 | 0.686 |
| Treatments | 3 | 0.0843 | 1.426 | 1.882 |
| Error | 9 | 0.2180 | 0.632 | 1.990 |

Appendix Table 10

Mean squares of the number of tubers 68, 92 and 122 days after planting. Experiment III.

| Source | d.f. | Number of days | | |
|---|---|---|---|---|
| | | 68 | 92 | 122 |
| Replications | 3 | 3049.2 | 478.00 | 483.54 |
| Treatments | 3 | 1895.2 | 2872.16** | 105.21 |
| Error | 9 | 2643.9 | 396.38 | 488.46 |

** Differences were significant at level P = 0.01.

Appendix Table 11

Mean squares of the marketable yield of tubers 68, 92 and 122 days after planting. Experiment III.

| Source | d.f. | Number of days | | |
|---|---|---|---|---|
| | | 68 | 92 | 122 |
| Replications | 3 | 0.0776 | 0.2473 | 0.840 |
| Treatments | 3 | 0.1100 | 0.2470 | 2.494 |
| Error | 9 | 0.2005 | 0.5248 | 1.044 |

Appendix Table 12

Mean squares of the number of marketable tubers 68, 92 and 122 days after planting. Experiment III.

| Source | d.f. | Number of days | | |
|---|---|---|---|---|
| | | 68 | 92 | 122 |
| Replications | 3 | 163.50 | 9.17 | 64.83 |
| Treatments | 3 | 40.16 | 18.67 | 36.16 |
| Error | 9 | 62.44 | 46.17 | 110.11 |

Appendix Table 13

Mean squares of the specific gravity of tubers 122 days after planting. Experiment III.

| Source | d.f. | Mean squares |
|---|---|---|
| Replications | 3 | 0.00002033 |
| Treatments | 3 | 0.00000233 |
| Error | 9 | 0.00000744 |

Appendix Table 14

Mean squares of the percentages of emerged plants 17 and 23 days after planting. Experiment IV.

| Source | d.f. | Number of days | |
|---|---|---|---|
| | | 17 | 23 |
| Replications | 3 | 39.01 | 66.69 |
| Treatments | 3 | 116.05 | 112.35 |
| Error | 9 | 44.23 | 32.93 |

Appendix Table 15

Mean squares of the total yield and of the total number of tubers 123 days after planting. Experiment IV.

| Source | d.f. | Total yield | Total number of tubers |
|---|---|---|---|
| Replications | 3 | 4.733 | 857.26 |
| Treatments | 3 | 0.946 | 384.76 |
| Error | 9 | 6.202 | 1276.18 |

Appendix Table 16

Mean squares of the total marketable yield and of the total number of marketable tubers 123 days after planting. Experiment IV.

| Source | d.f. | Marketable yield | Number of marketable tubers |
|---|---|---|---|
| Replications | 3 | 7.137 | 240.90 |
| Treatments | 3 | 0.164 | 12.23 |
| Error | 9 | 5.711 | 227.23 |

Appendix Table 17

Mean squares of the specific gravity of the tubers 123 days after planting. Experiment IV.

| Source | d.f. | Mean squares |
|---|---|---|
| Replications | 3 | 0.00002633 |
| Treatments | 3 | 0.00000733 |
| Error | 9 | 0.00000422 |

Appendix Table 18

Mean squares of the percentages of sprouted tubers 44, 48, 54 and 61 days after irradiation. Experiment V.

| Source | d.f. | Number of days | | | |
|---|---|---|---|---|---|
| | | 44 | 48 | 54 | 61 |
| Replications | 3 | 30.13 | 189.77 | 476.64 | 85.03 |
| Treatments | 5 | 151.03 | 195.74 | 200.78* | 5.67 |
| Error | 15 | 73.55 | 81.24 | 52.65 | 18.89 |

* Differences were significant at level P = 0.05.

Appendix Table 19

Mean squares of the percentages of tubers with sprouts longer than 0.5 cm, 54 and 61 days after irradiation. Experiment V.

| Source | d.f. | Number of days | |
|---|---|---|---|
| | | 54 | 61 |
| Replications | 3 | 226.66 | 30.20 |
| Treatments | 5 | 359.17* | 362.49** |
| Error | 15 | 96.98 | 45.48 |

* Differences were significant at level P = 0.05.

** Differences were significant at level P = 0.01.

Appendix Table 20

Mean squares of the percentages of tubers with sprouts longer than 0.5 cm, 1 cm, and 1.5 cm, 68 days after irradiation. Experiment V.

| Source | d.f. | Minimum sprout length | | |
|---|---|---|---|---|
| | | 0.5 cm | 1 cm | 1.5 cm |
| Replications | 3 | 85.79 | 44.60 | 66.97 |
| Treatments | 5 | 89.24 | 236.29 | 268.02** |
| Error | 15 | 54.66 | 96.88 | 49.10 |

** Differences were significant at level P = 0.01.

Appendix Table 21

Mean squares of the percentages of tubers showing breakdown in apical dominance and multiple sprouting 91 days after irradiation. Experiment V.

| Source | d.f. | Breakdown in apical dominance | Multiple sprouting |
|---|---|---|---|
| Replications | 3 | 9.63 | 29.50 |
| Treatments | 5 | 306.01** | 471.17** |
| Error | 15 | 52.93 | 31.36 |

** Differences were significant at level P = 0.01.

Appendix Table 22

Mean squares of the percentages of sprouted tubers 8, 13 and 19 days after irradiation. Experiment VI.

| Source | d.f. | Number of days | | |
|---|---|---|---|---|
| | | 8 | 13 | 19 |
| Replications | 2 | 101.45 | 49.09 | 96.64 |
| Treatments | 4 | 45.28 | 27.33 | 23.46 |
| Error | 8 | 69.04 | 24.33 | 91.10 |

Appendix Table 23

Mean squares of the percentages of tubers with sprouts longer than 0.5 cm, 8, 19, 28 and 40 days after irradiation. Experiment VI.

| Source | d.f. | Number of days | | | |
|---|---|---|---|---|---|
| | | 8 | 19 | 28 | 40 |
| Replications | 2 | 17.41 | 133.86 | 146.53 | 37.10 |
| Treatments | 4 | 280.74* | 436.33** | 480.18* | 561.78** |
| Error | 8 | 63.62 | 54.16 | 85.23 | 33.20 |

* Differences were significant at level P = 0.05.

** Differences were significant at level P = 0.01.

Appendix Table 24

Mean squares of the percentages of tubers with sprouts longer than 0.5 cm, 1 cm and 1.5 cm, 49 days after irradiation. Experiment VI.

| Source | d.f. | Sprout lengths | | |
|---|---|---|---|---|
| | | 0.5 cm | 1 cm | 1.5 cm |
| Replications | 2 | 133.67 | 177.78 | 66.40 |
| Treatments | 4 | 102.48 | 249.84 | 429.22** |
| Error | 8 | 42.49 | 88.47 | 59.27 |

** Differences were significant at level P = 0.01.

Appendix Table 23

Mean squares of the percentages of tubers with sprouts longer than 0.5 cm, 8, 19, 28 and 40 days after irradiation. Experiment VI.

| Source | d.f. | Number of days | | | |
|---|---|---|---|---|---|
| | | 8 | 19 | 28 | 40 |
| Replications | 2 | 17.41 | 133.86 | 146.53 | 37.10 |
| Treatments | 4 | 280.74* | 436.33** | 480.18* | 561.78** |
| Error | 8 | 63.62 | 54.16 | 85.23 | 33.20 |

* Differences were significant at level P = 0.05.

** Differences were significant at level P = 0.01.

Appendix Table 24

Mean squares of the percentages of tubers with sprouts longer than 0.5 cm, 1 cm and 1.5 cm, 49 days after irradiation. Experiment VI.

| Source | d.f. | Sprout lengths | | |
|---|---|---|---|---|
| | | 0.5 cm | 1 cm | 1.5 cm |
| Replications | 2 | 133.67 | 177.78 | 66.40 |
| Treatments | 4 | 102.48 | 249.84 | 429.22** |
| Error | 8 | 42.49 | 88.47 | 59.27 |

** Differences were significant at level P = 0.01.

Appendix Table 25

Mean squares of the percentages of tubers showing breakdown in apical dominance and multiple sprouting 49 days after irradiation. Experiment VI.

| Source | d.f. | Breakdown in apical dominance | Multiple sprouting |
|---|---|---|---|
| Replications | 2 | 155.79 | 35.43 |
| Treatments | 4 | 288.15** | 258.95* |
| Error | 8 | 29.85 | 49.33 |

* Differences were significant at level P = 0.05.

** Differences were significant at level P = 0.01.