of living is inversely proportional to life span, as Rubner, Pearl, Brody, and other scientific investigators have realized for some time. But the possibility that action is the determinant may lead to more refined predictions. In this context, constancy of action would mean that a gain in longevity at the expense of power consumption is not real gain, but only a relative one, and that efforts to extend the existence of a living thing should be directed toward increasing its total action.

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TECHNICAL PAPERS

Plant Growth-regulating Properties of Some Nicotinium Compounds

John W. Mitchell, J. W. Wirwille, and Leopold Weil

Bureau of Plant Industry, Soils, and Agricultural Engineering, Beltsville, Maryland, and
Eastern Regional Research Laboratory, Bureau of Agricutural and Industrial Engineering, U.S. Department of Agriculture, Wyndmoor, Pennsylvania

Six related nicotinium compounds have been found to possess growth-regulating properties when tested on bean plants. These include: parachlorobenzylnicotinium chloride, 2,4-dichlorobenzylnicotinium chloride, 3,4-dichlorobenzylnicotinium chloride, orthochlorobenzylnicotinium thiocyanate, benzylnicotinium bromide, and orthochlorobenzylnicotinium bromide. Applied to bean plants, these compounds brought about a reduction in stem elongation without typical gall formation or other form changes commonly observed in the use of other plant growth-regulating chemicals. The compounds were systemic in effect when applied to stems. The effects were expressed by illuminated plants as well as by others grown in darkness.

2,4-Dichlorobenzylnicotinium chloride (2,4-DNCl) was the most effective, ½ mg per plant greatly inhibiting elongation of plants grown in darkness and to a lesser degree the elongation of illuminated ones.

To test the effect of 2,4-DNCl on plants subjected to darkness, potted snap bean seedlings of the Black Valentine variety, germinated in a greenhouse, were selected for uniformity at a stage of development when only the hypocotyls were exposed above the surface of the soil. Half of the plants were treated by applying approximately

50 mg of lanolin paste containing 20% of Tween 20, 79% of lanolin, and 1% of 2,4-DNCl. The mixture was spread as a band about 5 mm wide around each hypocotyl. The remaining plants were left untreated and both groups placed in darkness. Extension of stems of the treated ones was retarded a noticeable amount during the first 48 hr following treatment, but there was no apparent effect on their diameters. There was a marked difference in the length of the hypocotyls and of the first internodes of the treated and the untreated plants (Fig. 1).

At the end of 13 days hypocotyls of treated plants were approximately half as long as comparable parts of untreated ones. First internodes of treated plants were about one-fourth the length of comparable parts of the untreated seedlings. Leaves of treated plants were equal to or slightly larger in size than those of untreated plants. Treated seedlings grown in darkness for 10 days were comparable in appearance to vigorous field-grown plants of a similar age, except that they were not green in color, while untreated ones showed the spindly growth expected in plants grown in darkness.

After 13 days of darkness, the average fresh weights of hypocotyls, first internodes, third internodes, and terminal buds of treated plants were significantly less than

FIG. 1. At left, elongated stems of Black Valentine bean seedlings grown in darkness; compared with short thick stems that developed on comparable plants at right, treated with 2,4-dichlorobenzylnicotinium chloride. Plants grown in complete darkness and photographed 120 hr after treatment.

comparable parts of untreated plants. In contrast, the fresh weight of primary leaves of treated plants was 28.2% greater than that of primary leaves of untreated ones. The total fresh weight of the aboveground portions

TABLE 1

LENGTH AND THICKNESS (IN MM) OF STEMS OF ILLUMINATED BEAN SEEDLINGS TREATED WITH RELATED NICOTINIUM COMPOUNDS COMPARED WITH THAT OF UNTREATED PLANTS

Treatment	Hypocotyl	First internode	Second internode	Total height	Diam of second internode
Untreated	95	62	41	246	2.42
Parachlorobenzyl-nicotinium chloride	94	34*	28*	186*	2.91*
3,4-dichlorobenzyl-nicotinium chloride	86	30*	20*	176*	3.09*
2,4-dichlorobenzyl-nicotinium chloride	81	25*	17*	148*	4.49*
Benzylnicotinium bromide	95	33*	33†	208†	2.74*
Orthochlorobenzyl-nicotinium bromide	81	33*	25*	176*	3.00*
Orthochlorobenzyl-nicotinium thiocyanate	80	39*	22*	168*	3.15*

* Significantly different from control at 1% level.
† Significantly different from control at 5% level.

of treated seedlings was 12.3% less than that of the untreated.

In testing the effect on the growth of illuminated plants, Black Valentine bean seedlings were selected for size and uniformity and divided into groups. One group was left untreated and designated controls. Each of the others was treated by applying approximately 50 mg of the above lanolin paste containing, separately, the six nicotinium salts, as a band around the first internode of each plant.

Length of the hypocotyls was not affected (Table 1), but all treatments resulted in a highly significant reduction in the length of the treated portion of the stems (first internode). The most marked effect (59.7% reduction) resulted from the application of 2,4-DNCl. All treatments brought about a significant reduction in length of second internodes and in the total height of the plants. 2,4-DNCl was most effective in reducing the over-all height (66.1% less than control) and benzylnicotinium bromide was least effective in this respect.

All of the compounds used brought about a significant increase in the diameter of the stems, the greatest increase (85.6%) resulting from the application of 2,4-DNCl.

A group of bean seedlings was selected for uniformity and used to test the effect of 2,4-DNCl when applied to different parts of the plant. Fifty mg of lanolin paste (containing 0.5 mg of 2,4-DNCl as previously described) was applied to each plant. Plants in respective groups were treated by applying the paste either as a band around the hypocotyl, as a band around the first internode, as a thin layer along the midrib of one primary leaf, or as a thin layer on the cotyledons of each plant. Comparable controls were similarly treated with lanolin containing 20% of Tween 20 but no 2,4-DNCl.

Ten days after treatment there were marked differences in the way the plants had responded. Treatment of the first internode reduced stem length by 33.5%. An equal amount of 2,4-DNCl applied to the hypocotyl reduced stem length by 22.8%, while the same amount of chemical applied to the leaf brought about only a 7% reduction in stem elongation. Treatment of the cotyledon had no significant effect on stem elongation, although the cotyledons were fleshy when treated and remained attached for several days following treatment. It is obvious from these results that the effectiveness of 2,4-DNCl in inhibiting internodal elongation varied, depending upon the part of the plant treated.

Bean plants in different stages of development were used to compare the effect of 2,4-DNCl on stem elongation of plants in different stages of maturity. Seedlings selected for the first group were about 3 in. tall and their hypocotyls were still increasing in length. Plants in the second group were 4–5 in. tall, their hypocotyls had nearly completed elongation, and the first internodes were elongating. Plants in the third group were 6–7 in. tall, the hypocotyls had reached maximum length, and the first trifoliate leaf was beginning to unfold. Part of the plants in each group were treated by applying 50 mg of the paste containing 2,4-DNCl as a band around the hypocotyl of each plant. The remaining plants in each age group were left untreated for comparison.

During the following 10 days, stem elongation of the youngest treated plants was reduced by 35.8% and of those in the medium age group by 28.6%, whereas treatment of the oldest plants reduced stem length only 6.2% in comparison with elongation of comparable untreated plants in each age group.

With respect to molecular configuration of the compounds used, there was a statistically significant difference between the activity of the three chlorides. Parachlorobenzylnicotinium chloride was least effective, 3,4-dichlorobenzylnicotinium chloride was somewhat more effective than the para form, and 2,4-dichlorobenzylnicotinium chloride was very effective in reducing internodal elongation. The three compounds assumed the same order of activity when classified on the basis of their effect on stem diameter. Differences between the activity of the compounds evaluated on this basis were highly significant from the statistical standpoint.

With respect to the two bromides used, the substitution of one chlorine atom in the ortho position in the benzene ring significantly increased activity when evaluated either on the basis of the inhibition of stem elongation or increase in stem diameter.

In preliminary experiments the following coal tar derivatives[1] have been found to bring about responses in bean plants similar to those that resulted when the nicotinium compounds were applied: 2,4-dichlorobenzylpyridinium chloride, 2,4-dichlorobenzyl-2-picolinium chloride, 2,4-dichlorobenzyl-3-picolinium chloride, and 2,4-dichlorobenzyl-4-picolinium chloride. The effect of these coal tar derivatives on plant growth is being studied further.

[1] Coal tar derivatives prepared by Dr. C. F. Woodward and Dr. D. H. Saunders, Eastern Regional Research Laboratory, Wyndmoor, Pennsylvania.

Conduction in Photoconductive PbS Films

Hubert M. James

Purdue University, West Lafayette, Indiana

Sosnowski, Starkiewicz, and Simpson (*2*) have produced photoconductive PbS films which contain both Pb and O atoms as impurities, in concentrations ($10^{19}/cm^3$) that are, for semiconductors, relatively high. The Pb and O atoms tend to make the film an n-type or p-type semiconductor, respectively. Photoconductive sensitivity demands a very careful balance of these impurities to make the conductivity a minimum; this occurs, presumably, when Pb and O impurities are present in equal numbers. Variations in the densities of the two impurities will then cause the film to consist of p and n regions interspersed. The very high resistance of the film is attributed to the p-n barriers, and the photoconductive effect to the reduction in height of these barriers by the redistribution of electronic charge produced by illumination (photovoltaic effect).

This note presents some extensions of these ideas, and conclusions as to the film structure desired for maximum photosensitivity.

First, it must be noted that purely random fluctuations in the densities of the two types of impurities can produce important fluctuations of the conductivity and potential within the film. Consider, for instance, the most homogeneous possible film containing 10^{19} O atoms and 10^{19} excess Pb atoms per cm³. A 1-μ cube will then contain about 10^7 atoms of each type. Random fluctuations in these numbers, from cube to cube, will be of the order of $\sqrt{10^7}$. The excess of one impurity over the other (net impurity density), which determines the character of the conduction in a region, will be on the average some $\sqrt{2 \times 10^7} = 4.5 \times 10^3$ atoms, or about the number of impurity atoms in an equal volume of an ordinary semiconductor with 5×10^{15} impurities/cm³. For larger regions the fluctuations in net impurity density will be less; in smaller regions the potential fluctuations discussed in the next pararaph cannot follow closely the fluctuations in impurity density. The "homogeneous" film considered here will thus in effect consist of n and p regions, of the order of 1 μ in diameter, with conductivities ranging from the intrinsic level to values of the order of those produced by 10^{16} impurities of one type per cm³.

Fluctuations in net impurity density may cause important fluctuations of potential in the film, even when they do not involve the appearance of n-p barriers. In an ideal homogeneous semiconductor the Fermi ζ-level is extremely sensitive to changes in the relative numbers of