4-1983

The Effect of Indoleacetic Acid and Related Chemicals on Growth Patterns of Decapitated Bean Plants

Lewis V. Buchanan

THE EFFECT OF INDOLEACETIC ACID AND RELATED CHEMICALS ON GROWTH PATTERNS OF DECAPITATED BEAN PLANTS

by

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A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Arts
Department of Biology

Western Michigan University
Kalamazoo, Michigan
April 1983

THE EFFECT OF INDOLEACETIC ACID AND RELATED CHEMICALS ON GROWTH PATTERNS OF DECAPITATED BEAN PLANTS

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Western Michigan University, 1983

Bean plants were used to study effects of IAA and related chemicals on plant growth patterns. Plant apical growth tips were removed, eliminating apical donimance. Decapitated plants were treated in experimental groups with IAA, tryptophan, 5-hydroxy indoleacetic acid, serotonin, and melatonin. Two other groups served as controls, one cut, and one uncut.

Growth measurements were taken to determine if the treatments could effectively restore apical dominance. Cut control plants showed a loss of apical dominance, with decreased apical growth, and release of inhibition of axillary growth, when compared to the uncut group.

Tryptophan and melatonin treatments restored little or no apical dominance. IAA, 5-HIAA, and serotonin treatments promoted apical dominance, with enhanced apical, and inhibited axillary growth.

This study indicated an ability of bean plants to utilize animal hormones chemically related to IAA to produce a variety of plant growth patterns.

ACKNOWLEDGEMENTS

My sincerest thanks go to Dr. Dona Fowler, and other members of my graduate committee, Dr. Imy Holt, and Dr. Leo VanderBeek. I am also grateful to Michelle Parpart for her assistance in plant care, and Raymond Moeller for his help with computer analysis.

A special thanks to my wife Julie for her moral support and encouragement.

Lewis V. Buchanan II

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WESTERN MICHIGAN UNIVERSITY M.A. 1983

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Much work relating to the area of apical dominance has been done over the past seventy years. Over this time span many talented and dedicated scientists have discovered many clues to the puzzle of apical dominance, and the effects induced by the plant growth hormone indoleacetic acid (IAA).

In more recent years studies have been conducted on IAA analogs in search of such things as plant growth stimulators, and herbicides (Moore 1979). Research has also uncovered the presence in plants of serotonin, a substance related to IAA (Applewhite 1973). There is, however, little evidence of the physiological activity of serotonin in plants.

Past studies have revealed the ability of IAA to promote a return of apical dominance when applied to the fresh cut of decapitated bean plants. This study involved the use of serotonin and other substances related to IAA to stimulate apical dominance in bean plants whose apical centers had been removed. Activity of serotonin, an animal hormone, would provide an interesting example of a substance that was physiologically active as a hormone in both plants and animals.

CHAPTER II

LITERATURE SURVEY

Plant Hormones and Auxin

Plant hormones are extremely important agents in the rigidly controlled process of plant development. A plant hormone may be described as an organic substance other than a nutrient, that is active in minute amounts. It is formed in certain parts of a plant and translocated to other sites, where it causes specific biochemical, physiological, and morphological results (Moore 1979).

The first type of plant hormone to be discovered was auxin. In 1954, a committee of plant physiologists defined auxins as compounds characterized by their ability to induce elongation in apical shoot cells. It was thought at that time that auxins resembled IAA, the only known naturally occurring auxin. Today it is generally agreed that IAA is the major, and perhaps the only native auxin of higher plants (Moore 1979).

Apical Dominance

Apical dominance can be considered to be manifested in three ways: (1) by complete or almost complete inhibition of growth in the axillary, or lateral buds; (2) by inhibition of growth of one shoot by the presence of another dominant shoot; and (3) by the directive effects of the apical shoot on the orientation of lateral organs

such as leaves, roots, and branches.

The most studied aspect of apical dominance is the effect of the apical bud on the growth correlations between the apical and axillary buds. The effect of the apical bud upon the axillary buds is commonly termed correlative inhibition (Wilkins 1969). Thimann and Skoog (1933;1934) demonstrated apical dominance, when application of auxin to the surface of stems of decapitated bean plants caused stimulation of the apical bud, and inhibition of lateral buds.

Substances other than IAA have been found to play a role in apical dominance. Cytokinins, particularly kinetin, when treated to axillary buds, released those areas from correlative inhibition (Sachs and Thimann 1964). In all cases of bud release by kinetin, it was found that apical dominance reappeared a short time later. Sufficient cytokinin and auxin appear to be requirements for bud growth.

Treatment of plants with a gibberellin leads to enhanced apical dominance. Jacobs and Case (1965) showed that treatment of a decapitated plant with gibberellic acid and IAA, resulted in an increased inhibitory effect on the axillary buds when compared to plants treated with only IAA.

Thus, it appears that apical dominance is not the direct result of a single molecule, but rather, is a complex event resulting from a series of substances that interact to induce the final effect of correlative inhibition.

Auxin Content and Growth

According to Leopold (1955), IAA was synthesized in large amounts in a few localized areas, such as shoot tips, young leaves, enlarging leaves, and flowers and fruits. Leopold's findings of relative auxin content, and the corresponding growth for various plant areas, are given in Appendix 1. There were marked differences in the sensitivity of the different plant parts to IAA. Roots showed greatest growth rates at 10^{-10} molar concentrations, but were inhibited at higher levels. Buds showed highest growth at 10^{-8} concentrations, and inhibition at 10^{-7} and higher concentrations. Stems grew at the greatest rate under IAA concentrations of 10^{-5} molar, and also showed inhibition at higher levels.

Plant Regulation of IAA Concentrations

Free and Bound IAA

IAA concentrations, like any other plant or animal hormone, must be rigidly controlled. Control can be achieved: (1) by maintaining the amount of active or free IAA; (2) by regulating the quantity of IAA produced from precursors; and (3) by controlling the rate of use of IAA. These processes are all interrelated, causing maintenance of IAA levels to be a complex system (Moore 1979).

Free IAA was considered to be that which was readily available for plant use. Bound IAA referred to inactive IAA that could be enzymatically activated (Leopold 1955).

There are over sixteen different inactive storage forms of IAA, including isomeric esters of IAA and myo-inositol, IAA esters of myo-inositol glycosides, and IAA esters of high molecular weight glucans. Auxin glysyl esters apparently represent most inactive storage forms of IAA (Moore 1979).

IAA synthesis is a principal means of controlling, and maintaining proper IAA levels in plants. The amino acid tryptophan is commonly considered to be the primary precursor for the synthesis of IAA. By one pathway, (Appendix 2), tryptophan is converted to 3-indole pyruvic acid. The 3-indole pyruvic acid is then decarboxylated to 3-indole acetaldehyde, which is in turn oxidized forming IAA (Moore 1979).

The second major pathway, (Appendix 2), involves the decarboxylation of tryptophan, to form tryptamine. Tryptamine is then transformed to 3-indoleacetaldehyde. The 3-indoleacetaldehyde is then oxidized to IAA (Moore 1979).

IAA metabolism can be considered to be the chief way of lowering IAA levels, and occurs by two basic processes: (1) enzymatic metabolism; and (2) photooxidation.

The enzymatic process requires IAA oxididase, manganese, and hydrogen peroxide (Hinman and Lang 1965). About 0.1 moles of hydrogen peroxide per mole of IAA were required for the process, given in Appendix 2. The dominant products were 3-methylene oxindole and indolealdehyde. Indolealdehyde formation was particularly favored by high IAA concentrations, and the presence of cytochromes.

Photooxidation products were identical to those of the enzymatic process, but the mechanism requires strong light doses. The net result was of little significance in lowering IAA levels.

IAA Formation and Metabolism in Animals

The pathway of IAA formation given by Ludwig and Associates (1968), was the same in plants and animals. Tryptophan was converted to either tryptamine or 3-indolepyruvic acid, which was metabolized to indoleacetaldehyde, from which IAA was formed. From this point the plant and animal pathways differ.

In plants, IAA was converted to indolealdehyde and 3-methylene indole. In animals IAA was transformed to indoxyl-k-sulfate, and indoxyl phosphate. See Appendix 2.

IAA Transport

The movement of endogenous IAA in shoots was primarily polar basipetally, from the apex to the base. Polar transport was possible in both parenchymatous and vascular tissue (Moore 1979). Polar movement of IAA was an energy requiring, active transport process. Its movement ranged from twelve to twenty millimeters per hour, a rate too rapid to be accounted for by simple diffusion (Moore 1979).

Synthetic IAA Analogs

There are five major groups of purely synthetic auxins, which exhibit physiological action similar to IAA. The groups are listed in Appendix 3, and include: indole acids, naphthalene acids,

naphthalene acids, chlorophenoxy acids, benzoic acids, and picolinic acid derivatives (Moore 1979).

Synthetic auxins such as 2,4-D, and naphthaleneacetic acid, have shown polar basipetal movement similar to IAA. Studies using IAA analogs have shown that the structural requirements for activity were: (1) a ring with at least one double bond; (2) a side chain adjacent to the double bond; and (3) a carboxyl group separated from the ring by one or two carbons (Bonner and Varner 1976).

The Occurrence of Serotonin in Nature

Serotonin (5-hydroxy tryptamine) is widely distributed in plants and animals. The presence of serotonin is closely associated with several poisonous plants such as the stinging nettle, and cowhage (Garattini and Valzelli 1965).

Collier and Lewis (1958) suggested that a plant's ability to produce serotonin is either primitive in evolution, or the ability is readily evolved as occasion demands. He also proposed that plant synthesis of serotonin provided the plant with survival mechanisms. For example, the stinging sea nettle released serotonin, producing effects on muscle coordination in vertebrates. The experience might discourage an individual from future encounters with the sea nettle.

Serotonin was also found to be present in various fruits and vegetables such as bananas and tomatoes by Udenfriend, Lovenberg, and Sjoerdsma (1959). Applewhite (1973) reported the existance of serotonin in the species Phaseolus multiflorous, at levels of about two micrograms per gram of petiole tissue.

Nissau and Associates (1959) showed that serotonin increased longitudinal growth in maize, and also counteracted the inhibitory effect of IAA on roots. Serotonin also mimicked the action of IAA on Avena coleoptiles, causing them to bend toward light.

Serotonin, Melatonin, and 5-HIAA Synthesis and Metabolism

The synthesis and metabolic pathways of serotonin, melatonin, and 5-hydroxy indoleacetic acid (5-HIAA) in plants, were not found in the literature. Their formation in animals depends upon certain available enzymatic systems and available substrates. See Appendix 2.

The principal synthesis pathway for serotonin and 5-HIAA given by Garattini and Valzelli (1965) began with tryptophan, which was transformed to 5-hydroxy tryptophan. The 5-hydroxy tryptophan was changed to 5-hydroxy tryptamine, or serotonin. 5-hydroxy tryptamine was metabolized by monoamine oxidase to form 5-HIAA.

The melatonin pathway of synthesis (Appendix 2) shows that it was formed from serotonin, which was converted to N-acetyl serotonin. N-acetyl serotonin was then converted to melatonin (Altschule 1975). Melatonin was inactivated by converting to 6-hydroxy melatonin, which became conjugated with sulfates and glucuronides (Wurtman, Axelrod, and Kelly 1968).

CHAPTER III

MATERIALS AND METHODS

Plant Selection and Preparation

Pencil pod black garden beans were soaked in a one percent solution of Chlorox Bleach for ten minutes to sterilize the seed coat before germination.

After rinsing, approximately fifty seeds were evenly spaced between dampened Whatman #1 filter papers in plastic petri dishes fifteen centimeters in diameter.

The closed petri dishes were placed in darkness at room temperature for seventy-two hours, to allow germination of the seeds. Four petri dishes were arranged in this way to accommodate 200 seeds.

Every healthy germinated seed was planted in an individual pot, ten centimeters in diameter, containing about 250 grams of sterilized soil. The soil consisted of dirt, vermiculite, and sand, in a 1:1:1 ratio. The seeds were covered with two centimeters of soil, and watered.

Each pot and plant was watered twice daily, and grown in a green house under natural sunlight, and mid-summer photo period. Two weeks later the plants were at the two true leaf stage, and suitable for study.

Healthy plants, with a chosen height of about twenty centimeters, with the third set of leaves emerging, were selected for

the study (See Figure 1). One hundred total plants were required to fill seven study groups. Plants were randomly placed within the study groups. Population size was fifteen plants for each experimental group, and the control cut group. Ten plants were used for an uncut control group.

Experimental Studies

Preparation of Experimental Plants

The test molecules for each study group were: indole acetic acid, 5-hyproxy indoleacetic acid, tryptophan, serotonin, and melatonin. The control groups were untreated uncut plants, and water treated decapitated plants.

Agar was prepared by boiling four grams of Difco Bacto agar powder in 100 milliliters of water for five minutes. The solution was allowed to stand for one hour to form a large gelatin block, one centimeter thick, that was cut into the appropriate sized test blocks.

The growing apical stems were removed with a cut at a ninety degree angle to the stem, one centimeter above the second set of leaves (Figure 1). Agar blocks about 1.5 x 1.5 x 1.5 millimeters were placed immediately over the end of the freshly cut plants.

Preparation and Application of Test Substances

The test molecules to be delivered to the plants were made at concentrations of 2×10^{-6} moles / 2γ, a concentration which

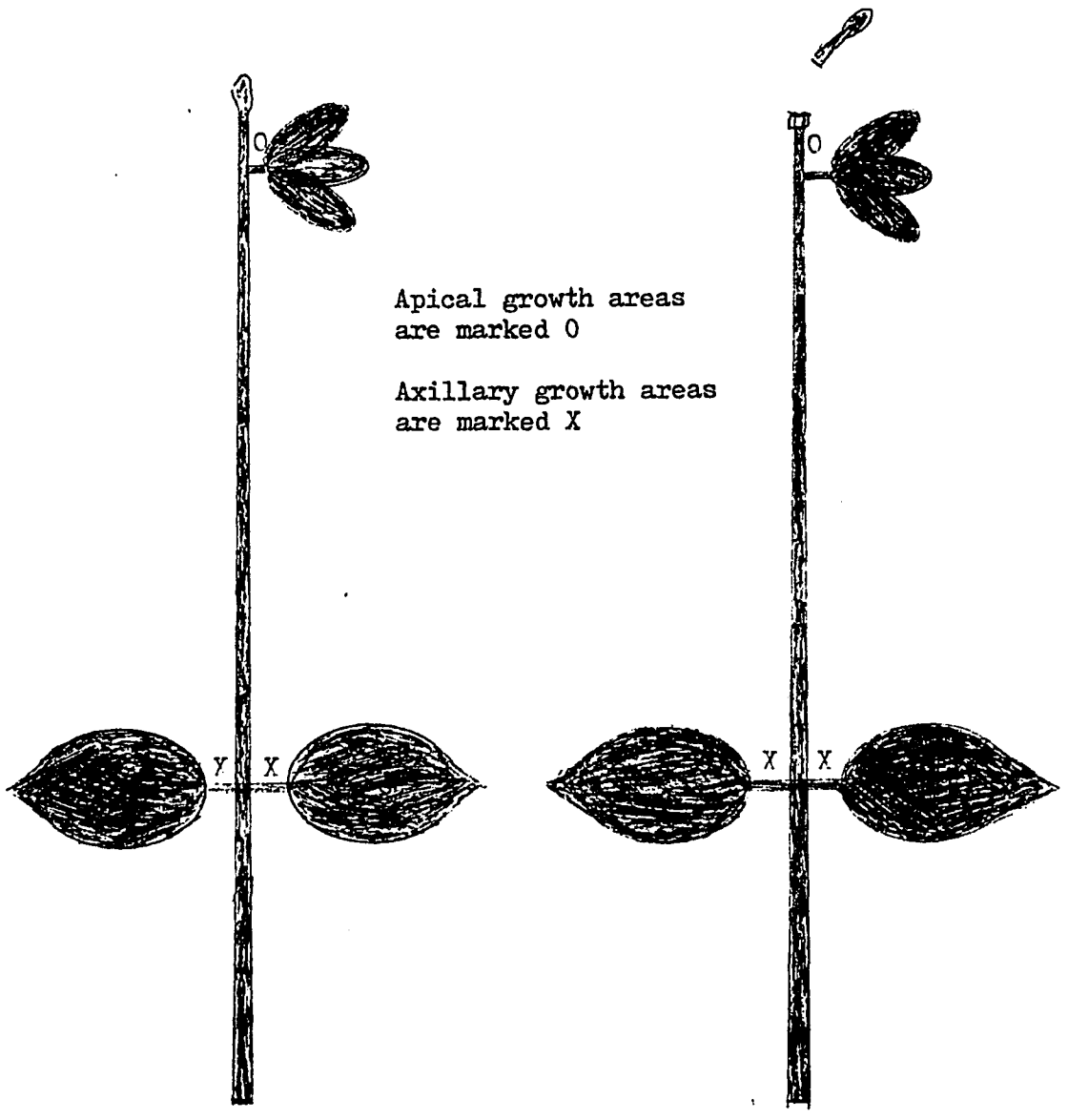


Figure 1. Test Plants Before and After Removal of Growing Tip.

promoted apical growth in indoleacetic acid treated cut plants (Leopold 1955). The solutions were placed in ampules, and sealed by flame under a nitrogen atmosphere to prevent oxidation, and frozen. Twenty vials for each test molecule were processed.

Application of the test molecules was accomplished using a Drummond Microcap micropipette, with a delivery of 2 γ. The cut control group was given 2 γ of distilled water.

The frozen test solutions were thawed, the ampules scored with a file, and broken open. A given solution was delivered to the agar block of each plant in the appropriate study group every three days throughout the study period.

Growth Measurements

Measurements were taken every three days. Areas of apical and axillary growth were measured to the nearest 0.1 centimeter. Plants were allowed to grow for three weeks.

After final measurements were taken, the plants were removed from their pots, placed between layers of newspaper and cardboard, and placed in a plant press to dry over heat for one day.

Dried plants were mounted on paper to study overall forms of plants, and comparisons between plant study groups.

Statistical Analysis

Quantitative analyses of apical and total axillary growth were made. Total axillary growth was found by totaling all growth from the axillary buds. Mean growth for each plant group was determined,

and tested for differences with an analysis of variance (ANOVA) using the students T test, to find whether or not there were any significant differences between the observed means.

Schematic figures were drawn to show qualitative and quantitative differences between groups (Figure 2). Each plant stick figure represented a group, with enhanced areas corresponding to mean apical, and mean shortest and longest axillary growths. The vertical scale was in centimeters, with each drawing based on a plant being decapitated at a height of twenty centimeters.

Plant groups were also compared by the degree to which they demonstrated apical dominance in Figure 3.

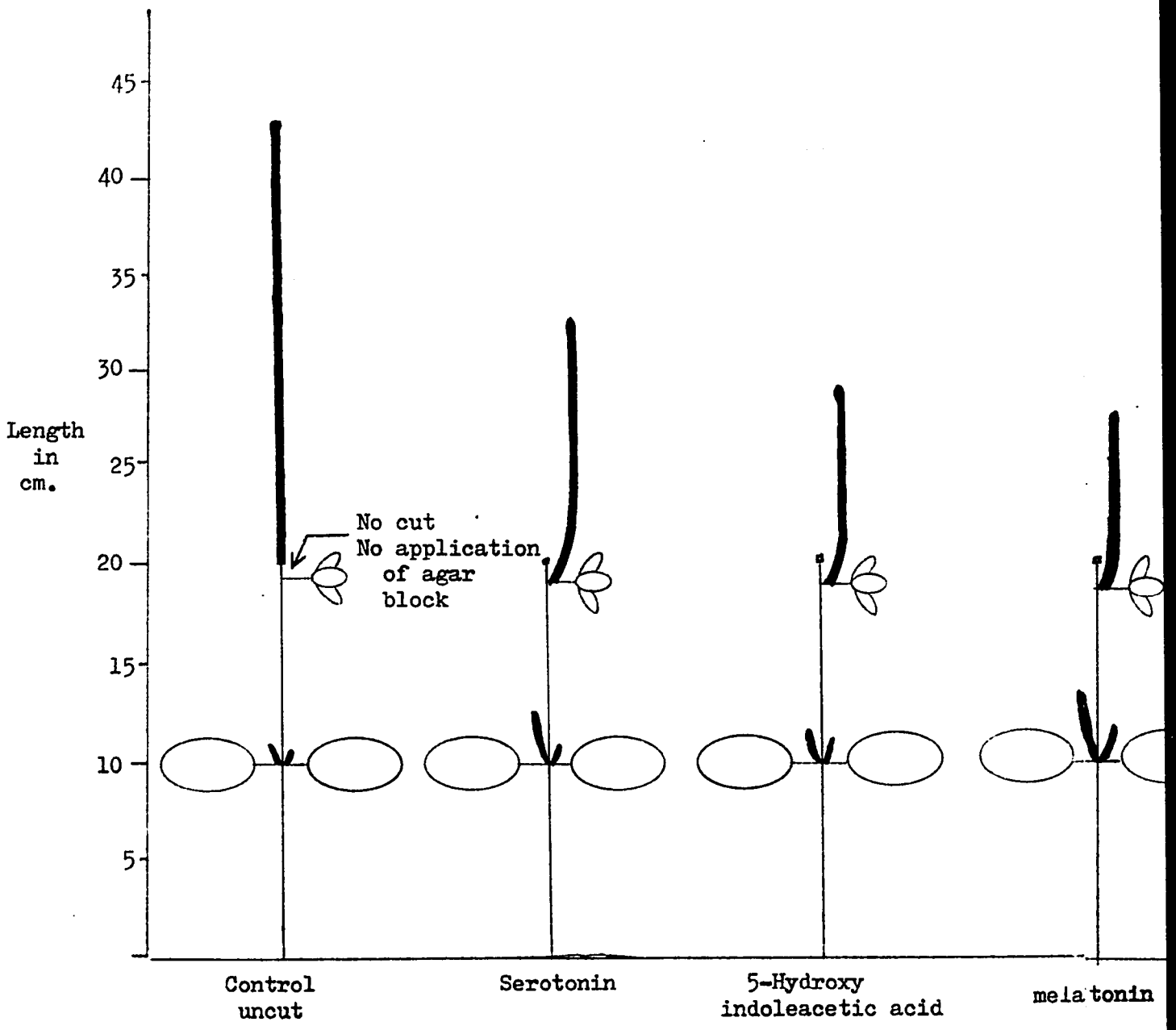
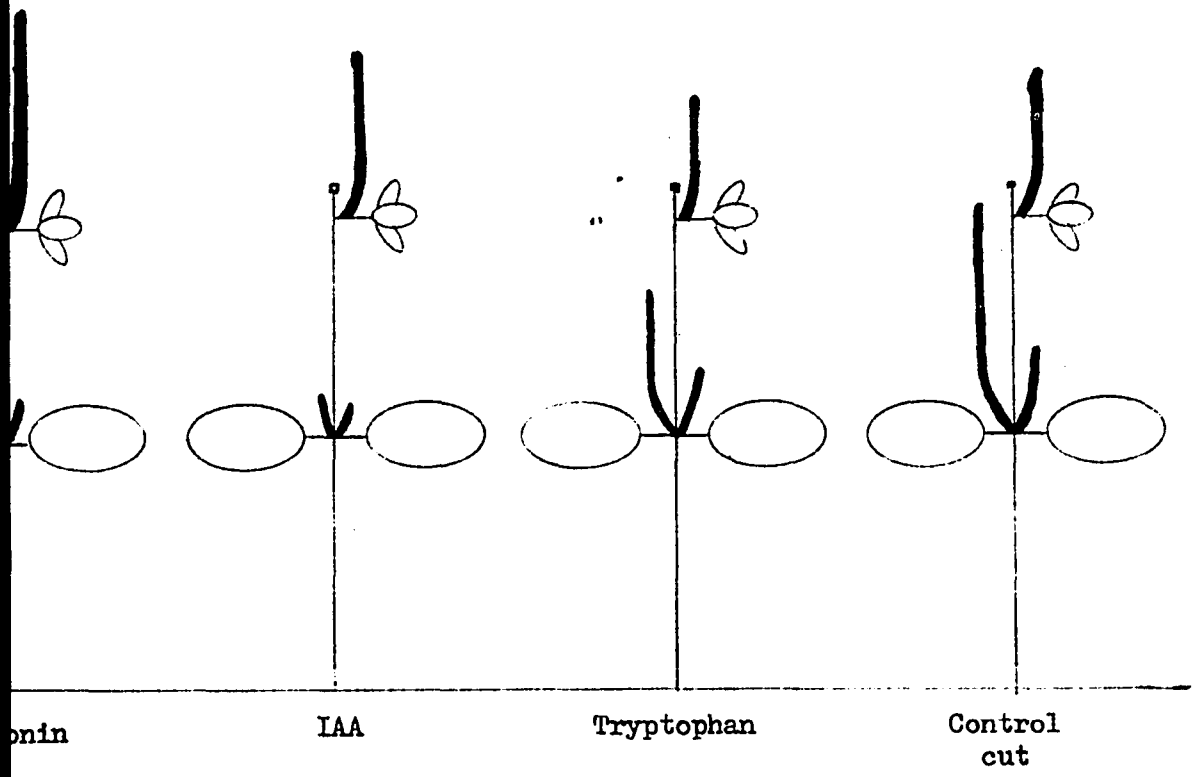


Figure 2. Comparisons of Mean Apical and Mean Axillary Growth between Plant



lant Groups

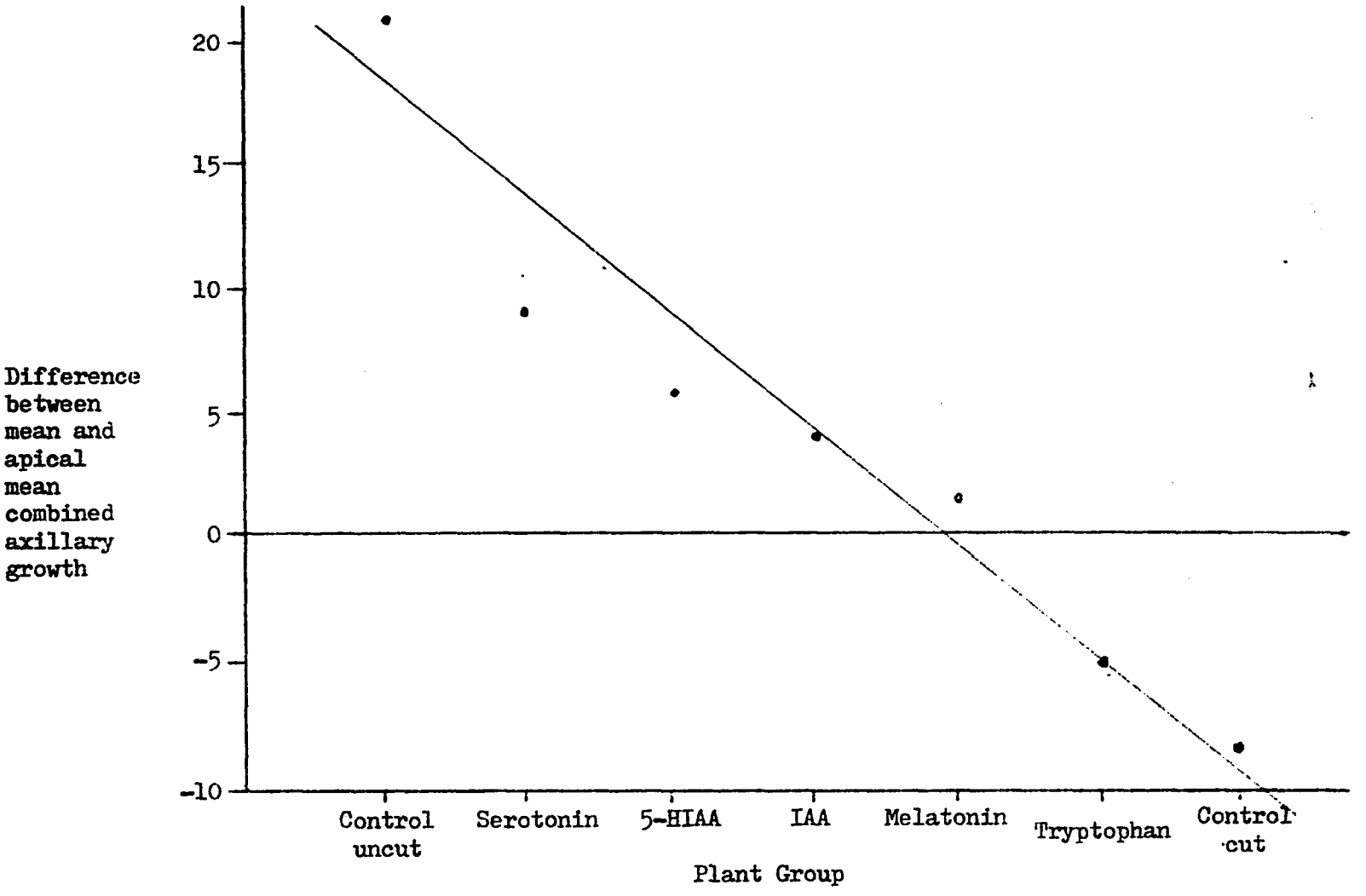


Figure 3. Relative Apical Dominance of Plant Group Treatments

CHAPTER IV

RESULTS

The means and standard deviations for areas of primary and secondary growth for each plant study group are listed in Table 1. Groups were arranged in order of greatest to least mean apical growth. The control uncut group represented a normal situation in which apical dominance occurred, characterized by large apical growth and relatively small axillary growth. Mean apical growth in the uncut group was 22.31 centimeters, compared to a mean combined axillary growth of 1.59 centimeters.

The remaining groups listed in Table 1 were tested with various substances following the removal of the apical growth center. The serotonin treated group demonstrated mean apical growth of 12.42 centimeters, and mean combined axillary growth of 3.52 centimeters.

The 5-HIAA treated plants produced mean apical growth of 8.91 centimeters, and mean combined axillary growth of 2.92 centimeters. The group treated with melatonin showed mean apical and mean combined axillary growths of 7.04 and 5.38 centimeters respectively.

The IAA treated group demonstrated mean apical growth of 6.21 centimeters and mean combined axillary growth of 2.77 centimeters. The control cut, water treated group, demonstrated a situation of lost apical dominance in which apical growth is reduced, while axillary growth greatly increased. This group showed only 5.04

Table 1

Apical and Axillary Growth in Bean Plants
Mean Values and Standard Deviations in Centimeters

Group	Apical	Shortest Axillary	Longest Axillary	Combined Axillary
Control Uncut	22.31 ± 6.83	.54 ± .36	1.05 ± .37	1.59 ± .66
Serotonin	12.42 ± 2.92	1.05 ± .56	2.47 ±1.82	3.52 ±2.21
5-HIAA	8.91 ±6.41	1.19 ± .9	1.73 ±1.34	2.92 ±2.09
Melatonin	7.04 ±4.95	1.63 ±1.64	3.75 ±3.48	5.38 ±4.71
IAA	6.21 ±4.79	1.24 ± .85	1.71 ±1.68	2.77 ±2.29
Control Cut	5.04 ±2.85	3.82 ±1.99	9.7 ±3.51	13.52 ±4.09
Tryptophan	4.09 ±3.47	2.53 ±1.33	6.75 ±4.00	9.29 ±4.20

centimeters of mean apical growth, while mean combined axillary growth increased to 13.52 centimeters.

The tryptophan treated group showed an even lower amount of mean apical growth, 4.09 centimeters, while demonstrating a mean combined axillary growth of 9.29 centimeters.

Figure 2 shows a pictoral qualitative and quantitative comparison of the mean apical and axillary growth areas. The figures were drawn to enhance the areas of the growth studied. For the qualitative results the two bilateral axillary growth areas were treated separately. In the quantitative results the individual axillary growth areas were combined (Table 1).

The drawings were generally arranged from highest to lowest mean apical growth. The qualitative results showed a pattern in which decreases in mean apical growth were somewhat related to increases in axillary growth. The groups positions, then, could be related to their promotion of apical dominance.

Apical growth was resumed in all the plant groups with the exception of the tryptophan and control cut groups. None of these treated plants produced as much apical growth as that which occurred in plants that were not decapitated.

Serotonin was the most effective treatment for restoring apical growth. Serotonin, 5-HIAA, and melatonin were all more effective in promoting apical growth than the endogenous plant auxin IAA.

Axillary growth patterns that resulted were such that similar responses could be paired. The 5-HIAA and IAA groups show a

similarity in their effects on growth. Both stimulated apical growth, and inhibited axillary growth.

The serotonin and melatonin groups were also similar. While these compounds promoted apical growth, they also partially released axillary growth inhibition.

There were also similarities between the tryptophan and control cut groups. Both show a loss of apical dominance with much greater mean axillary growth, and less apical growth.

The control uncut, IAA, and 5-HIAA groups all stimulated apical growth, while greatly inhibiting axillary growth. The serotonin and melatonin groups also promoted apical growth, but partially released the inhibition of axillary growth. With the tryptophan and control cut groups, there was very little apical growth, and a great increase in axillary growth.

Figure 3 shows a comparison of relative apical dominance between plant groups based on differences between mean apical and mean combined axillary growth. Values used were derived by subtracting mean total axillary growth from mean apical growth. Groups showing a substantial positive difference between mean apical and axillary growth indicated the presence of apical dominance. Those groups with a relatively small positive difference, or a negative difference indicated the absence of apical dominance.

Groups showing large positive differences in comparative growth were control uncut (+22.02), serotonin (+8.9), 5-HIAA (+5.99), and IAA (+3.44). The remaining groups, melatonin, control cut, and

tryptophan showed values of (+1.66), (-5.2), and (-8.52) respectively.

Based on this comparison, the control uncut, serotonin, 5-HIAA, and IAA groups all demonstrated apical dominance. The melatonin treated group did promote apical dominance, but significantly released axillary buds from inhibition. This group, then, exhibited partial apical dominance. The control cut and tryptophan groups showed a loss of apical dominance.

ANOVA tests of mean apical and mean combined axillary growth were made between plant groups. Confidence intervals were calculated using the students T test to show that the compared means were significantly different at the 95 percent confidence interval. Any calculated confidence interval less than 95 percent indicated that the compared means were not significantly different.

Statistical comparisons between groups for mean apical and mean combined axillary growth are shown in Figures 4 and 5. In Figure 4 groups were arranged along the baseline from lowest to highest mean apical growth. The distance on the line from one group to another was relative to significant differences between their means. Above the baselines, the groups were arranged vertically, with each group showing areas of significance compared to the baseline.

For example, the melatonin group in the vertical column was compared to the baseline to determine which groups had significantly different mean apical growth. The area of the baseline covered by a solid bar (▬▬▬) included all the groups whose means were not significantly different from melatonin. The area of baseline covered

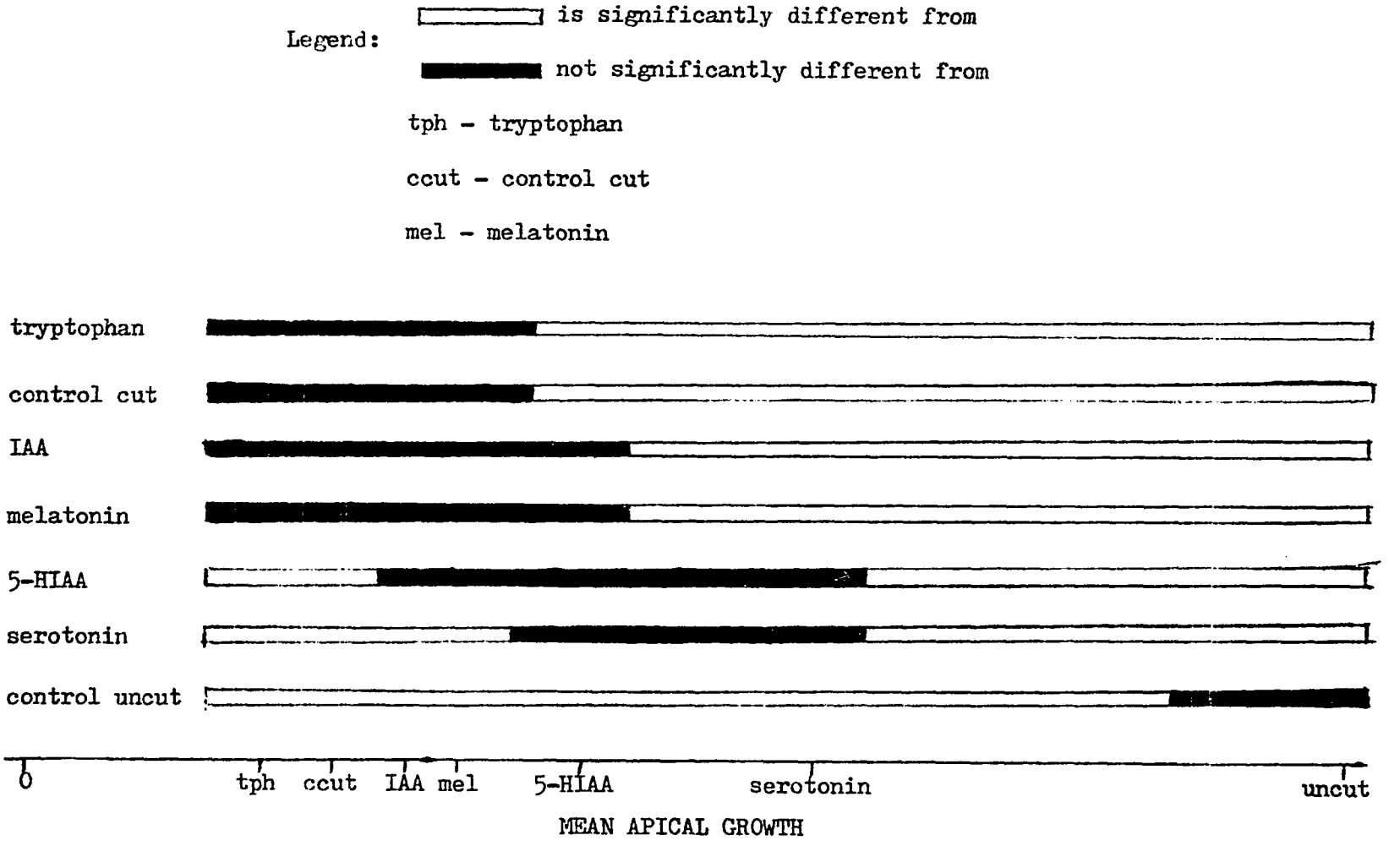


Figure 4. Statistical Comparisons Between Groups for Mean Apical Growth

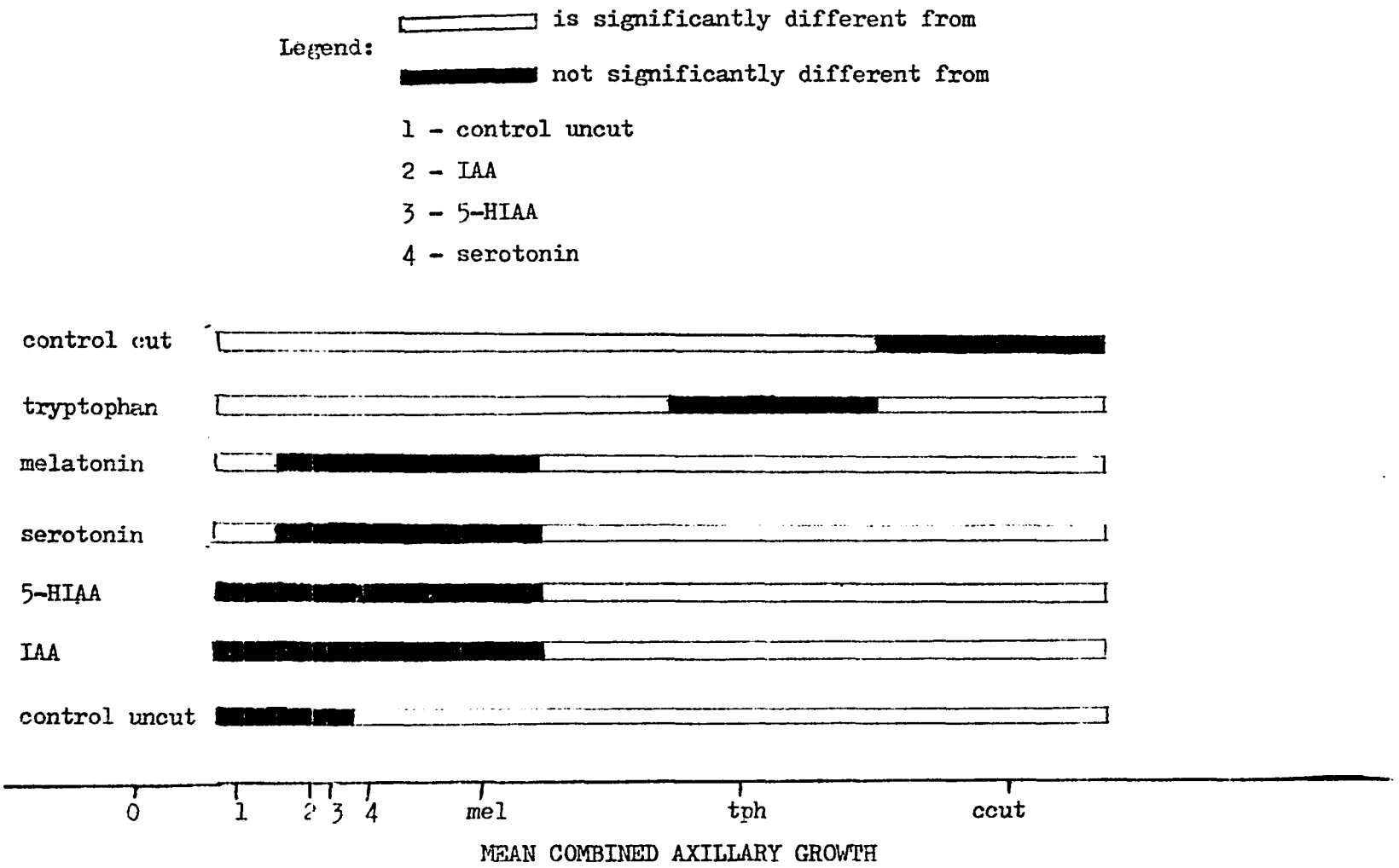


Figure 5. Statistical Comparisons Between Groups for Mean Combined Axillary Growth

by a clear bar (▭) contained those groups whose means were significantly different from melatonin. In this case, mean apical growth for melatonin was significantly different from the serotonin and control uncut groups, and not different from the remaining groups. The uncut group had mean apical growth that was significantly different from all other groups. Mean apical growth for the serotonin group was significantly different from the tryptophan, control cut, and control uncut groups, but not different from the 5-HIAA group. The mean apical growth of the 5-HIAA group differed from that of the tryptophan, control cut, and control uncut groups, while being statistically equal to the IAA, melatonin, and serotonin groups. The IAA group had mean apical growth which was significantly different from the serotonin and uncut groups, and not different from the remaining groups. Means for the control cut and tryptophan groups were significantly different from the 5-HIAA, serotonin, and control uncut groups.

The control cut and tryptophan groups were identical in their comparisons to other groups. The IAA and melatonin groups were also identical. The 5-HIAA and serotonin groups were also related.

The mean combined axillary growth comparisons, also based on 95 percent confidence intervals, are shown in Figure 5. The control uncut group was significantly different from the serotonin, melatonin, tryptophan, and control cut groups, and not significantly different from the IAA, and 5-HIAA groups. The IAA and 5-HIAA groups were identical in their comparisons to other groups. Both were significantly different from only the tryptophan and control cut groups.

The serotonin and melatonin groups were also identical in their comparisons, and were quite similar to those of IAA and 5-HIAA, being statistically different from only the tryptophan, control cut, and control uncut groups. The tryptophan and control cut groups had mean combined axillary growth that was significantly different from all other groups, including each other.

An analysis of variance test was used to show whether or not the observed means from the test and control groups were the result of the treatments to the respective groups. Comparisons were made for both mean apical and mean combined axillary growth. The results, based on a 95 percent confidence interval indicated that the observed results were directly related to the treatments given.

CHAPTER V

DISCUSSION OF RESULTS

5-HIAA and serotonin were more effective than IAA in promoting apical dominance in this test situation. The literature review produced no knowledge that 5-HIAA was an endogenous plant growth hormone, but 5-HIAA fulfills the requirements of a ring with a double bond, an adjacent side chain, and a carboxyl group given by Bonner and Varner (1976) for producing effects similar to IAA. 5-HIAA was structurally very similar to IAA, with a hydroxyl group at the fifth carbon being the only difference. Therefore, its activity was probable.

Serotonin produced greater stimulation of apical dominance than 5-HIAA. Serotonin, however, lacked the structural requirements of Bonner and Varner (1976), lacking a terminal carboxyl group.

Serotonin conversion to 5-HIAA or some other active plant growth substance is a possibility. If a plant contains the enzyme monoamine oxidase, serotonin could be converted to 5-HIAA. Serotonin was shown by Nissau and associates (1959) to be active in the Avena coleoptile test, and promoted apical growth in corn. Serotonin also occurs naturally in plants, including the genus Phaseolus. The formation pathway of serotonin and 5-HIAA in animals was quite similar to IAA formation in plants. The only major difference was an enzyme to hydroxylate tryptophan at the fifth carbon position, providing the precursor to serotonin. Since serotonin occurs

naturally in plants, it seems possible that the same enzymes might be present in plant tissue. Serotonin was also very closely related to tryptamine, which was enzymatically changed to IAA in plants. The same, or some closely related enzyme could oxidize serotonin to 5-HIAA.

Melatonin seemed to fail to significantly promote apical dominance. Evidently the small structural differences from serotonin were enough to produce significantly different growth patterns.

The similarity between the control cut and tryptophan groups was expected since tryptophan was not removed by decapitation, and not concentrated in growth areas. The control cut group showed that the removal of the growing tip of the plant resulted in a loss of the plant's ability to produce normal growth. The literature has always suggested that the apical growth substance lost in decapitation was IAA.

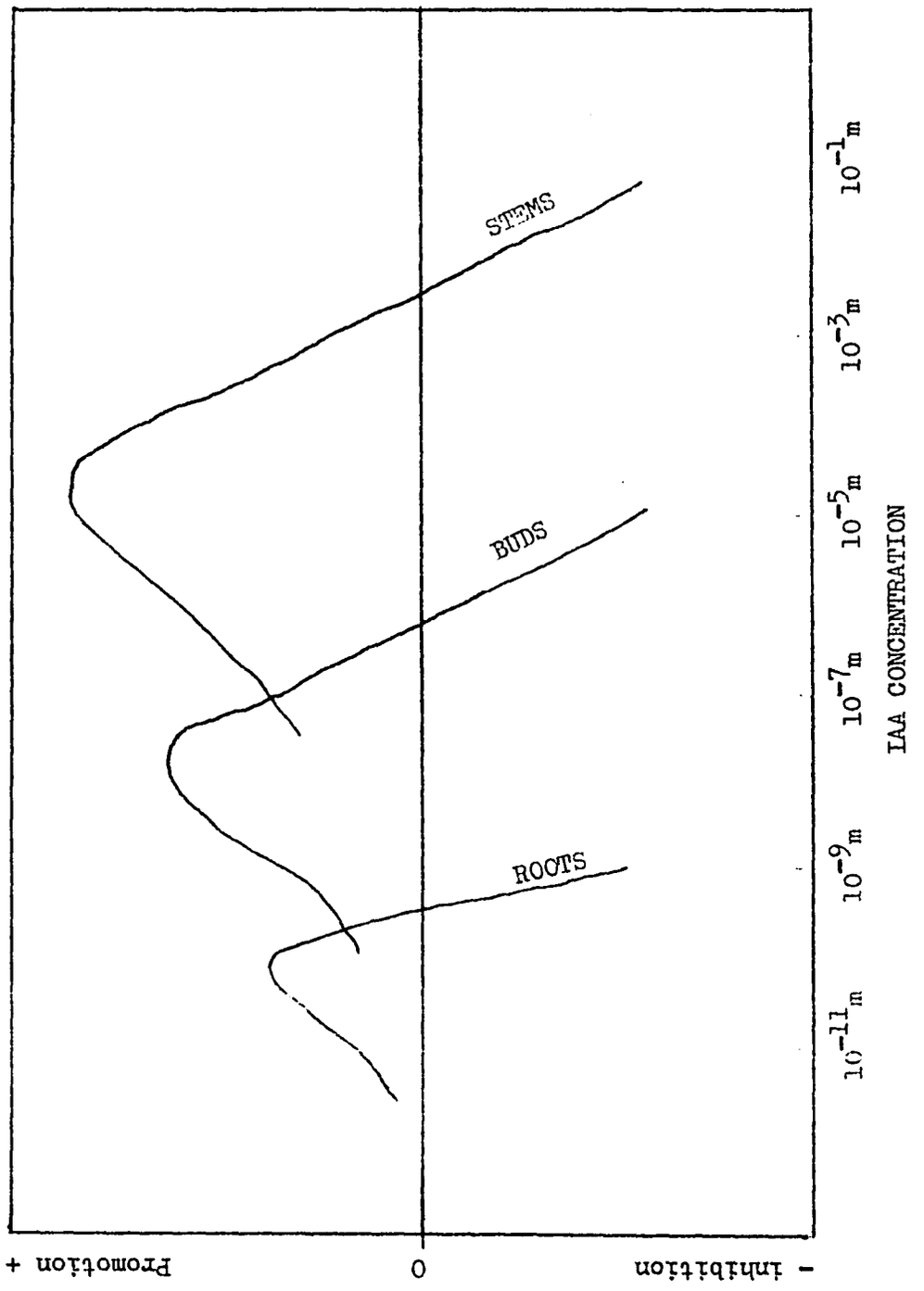
The IAA treated group displayed apical dominance by inhibiting lateral bud growth. But it did not promote apical growth that was statistically greater than the control cut group. The IAA plant group showed a large variation in apical growth which served to nullify any true growth differences. All IAA treated plants did produce more growth than the water treated plants.

Some of the test compounds did show a definite ability to restore apical dominance in decapitated bean plants. It is reasonable to assume that 5-HIAA is active in promoting apical dominance without any altering of structure. The serotonin treated plants did show the ability to use serotonin as a growth regulator. This was

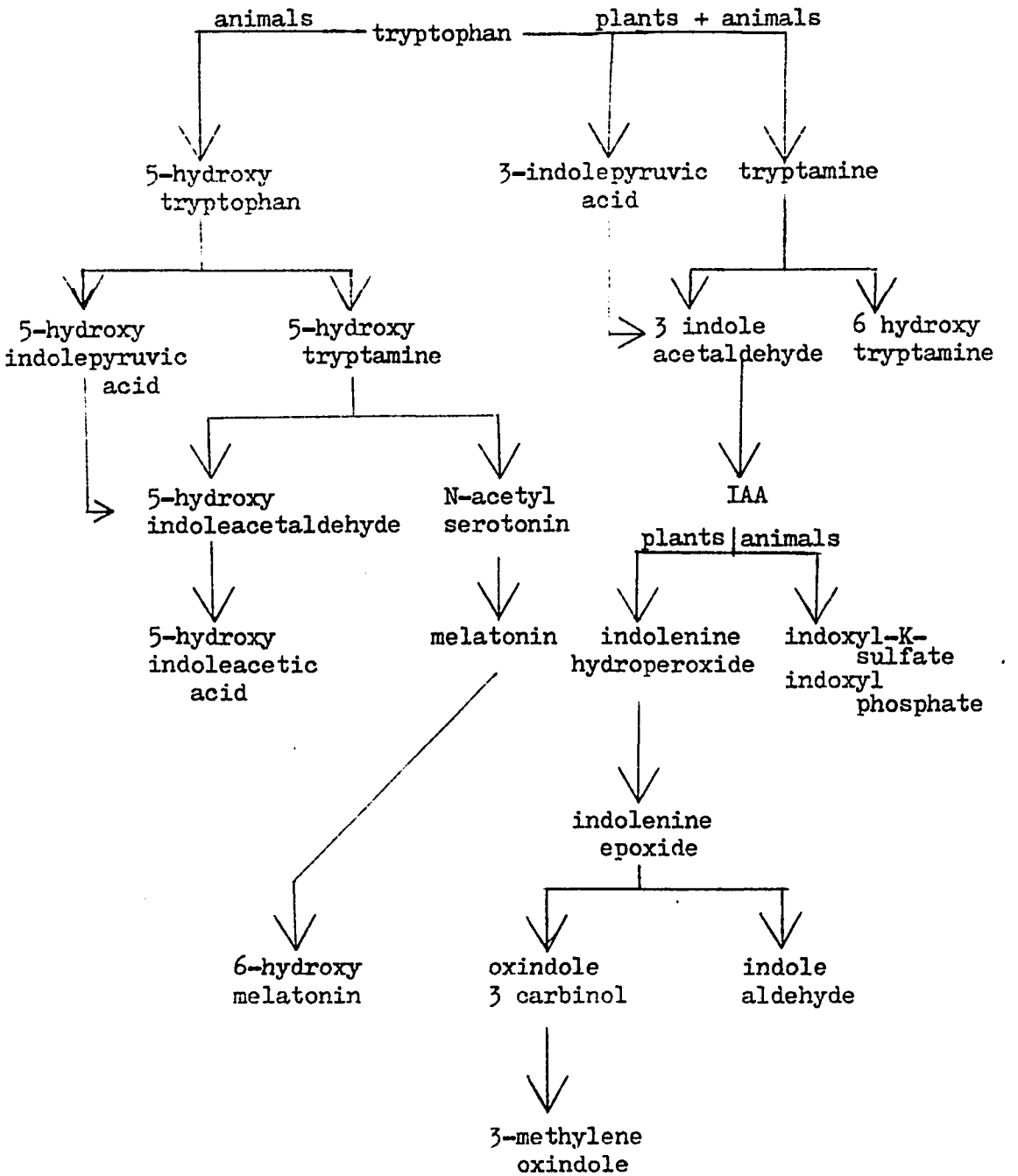
done either directly, or by altering the serotonin molecule to an active substance, quite possible 5-HIAA.

This study showed that several chemically related compounds can replace IAA, and promote apical dominance. It would be interesting to know if serotonin, known to occur naturally in plants, acts as a plant growth regulator in nature.

Appendix A. Auxin Content and Growth Relationships

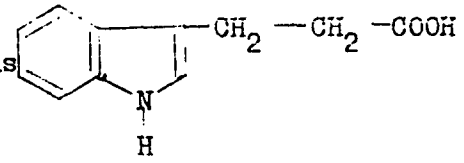


Appendix B. Synthesis and Metabolism of Test Substances

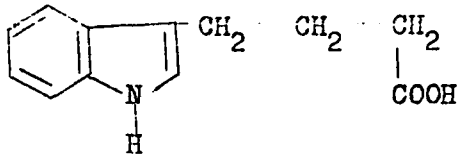


Appendix C. Examples of Types of Synthetic Auxins

indole acids

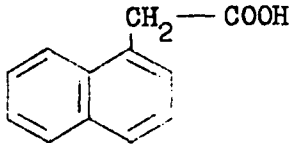


Indole Propionic Acid

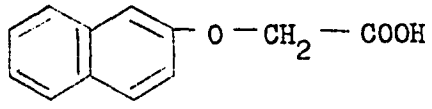


Indolebutyric Acid

naphthalene acids

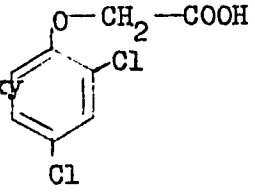


Naphthalenacetic Acid

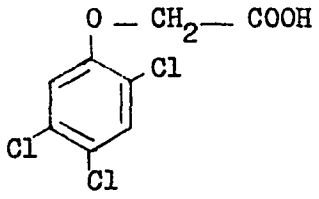


Naphthoxyacetic Acid

chlorophenoxy acids

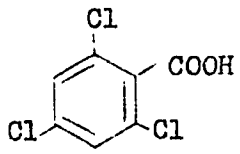


(2,4-D)

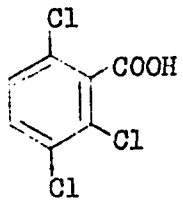


(2,4,5-T)

benzoic acids

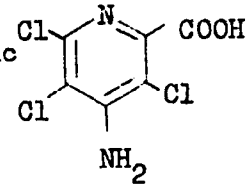


2,4,6 Trichloro-Benzoic Acid



2,3,6 Trichloro-Benzoic Acid

picolinic acids



4-amino-3,5,6 Trichloropicolinic Acid

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