SOME EFFECTS OF HERBICIDAL OILS ON BEANS

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

Mark G. Wiltse

1955

This is to certify that the

thesis entitled

Some Effects of Herbicidal Oils

on Beans

presented by

Mark G. Wiltse

has been accepted towards fulfillment
of the requirements for

Ph. D. degree in Botany

B. H. Grigsby
Major professor

Date Nov. 22, 1955

O-169

SOME EFFECTS OF HERBICIDAL OILS ON BEANS

By

Mark G. Wiltse

A THESIS

Submitted to the School of Graduate Studies of Michigan
State University of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Botany and Plant Pathology
School of Science and Arts

1955

ACKNOWLEDGMENTS

The author wishes to express his sincere thanks and appreciation to Dr. B. H. Grigsby for his assistance, advice and encouragement throughout the course of this work.

The author also expresses his appreciation to the Standard Oil Company of Indiana for the grant-in-aid which made this work possible and for the herbicidal oils which they supplied.

He particularly wishes to thank his wife, Elaine, whose aid, patience and encouragement made this work possible.

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ABSTRACT

The use of oils as herbicides dates back to the early 1900's. Research workers found that certain oil fractions could be used as selective herbicides. Oils were later used as directed sprays on onions, cotton and soybeans.

A study of the effects of oils upon soybeans (Glycine max, variety Hawkeye), field beans (Phaseolus vulgaris, variety Michelite), lima beans (Phaseolus lunatus, variety Fordhook Dwarf), wax beans (Phaseolus vulgaris, variety Pencil Pod Wax), green beans (Phaseolus vulgaris variety Tendergreen Bush) and weeds was undertaken in the fall of 1952 and field and greenhouse tests were conducted until the spring of 1955. Thirty-two experimental oils were tested in an effort to obtain an oil that was non-toxic to the bean stems but would give good weed control.

A power driven sprayer was designed and built to apply oils in the field as a directed spray, in a 6 inch band, at the base of the bean stems. A small DeVilbis sprayer unit was used for greenhouse oil application. All oils were applied in an amount equivalent to that of 6 inch band treatments in 22 inch rows.

Yields of beans in the field, dry weight of the beans in the greenhouse, observations of effects, injury ratings, microscopic examination, and weed counts were used to evaluate the effects of oil spray applications.

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Year 1955

Approved B. H. Grigsby

The following experimental oils gave good weed control with little injury to the bean stems:

a. LS-0133 (90% mineral spirits, 10% Indocene 70)
b. LS-0150 (90% mineral spirits, 10% Indosolvent 2)
c. LS-0152 (85% mineral spirits, 15% Indocene 70)
d. LS-0155 (40% mineral spirits, 40% Alkylate, 20% Indosolvent 2)
e. LS-0237 (Heavy naphtha)

No significant reduction in yield occurred following oil application in the field and about 75 per cent weed control was obtained. Grasses were controlled better than broadleaved weeds. Ragweed (Ambrosia artemisiifolia L.) appeared to be resistant to oil spray.

The typical oil injury on beans was characterized by a wilting of the plant similar to that of a plant in drought conditions. The treated area was water soaked in appearance and, later, turned a dark brown. Microscopic examinations of bean stems treated with oil revealed that toxic oils may cause a breakdown of cells in the epidermis, cortex, phloem and vascular cambium, and initiate, in cells adjacent to the injured cells, a reversion to meristematic activity.

Ten gallons per acre of a herbicidal oil gave better weed control than 5 gallons per acre and less injury to bean plants than 20 gallons per acre. A repeat application of a herbicidal oil gave slightly more injury but did not decrease the yield. The resistance of bean stems to oils appeared to decrease with age. However, for ease and accuracy of mechanical application, and for weed control, the best stage for spraying was the first trifoliate leaf stage. Applications of a herbicidal oil in a 60° F. temperature gave less injury than applications in 70 and 80° F. temperatures. Application of a herbicidal oil to bean stems with closed stomata gave less injury than when applied to bean stems with open stomata.

The types of beans arranged in order of decreasing oil resistance are: Field beans, soybeans, wax beans, green beans and lima beans.

INTRODUCTION

Oils have been used as herbicides for many years. The control of all vegetation by the application of oil to roadsides, railway roadbeds, and storage yards dates back to the early 1900's. Results obtained by applying oils from different sections of the country indicated that certain oil fractions were more phytotoxic than others. The need for a non-phytotoxic oil in insecticidal sprays stimulated research in oil fraction toxicity. Certain oil fractions were found to possess low phytotoxicity while others possessed high toxicity.

In more recent years it was found that certain plants, such as members of the Umbelliferae family, were resistant to oils while numerous broad-leaved weeds and grasses were killed by oil sprays. This led to the use of oils as selective herbicides. Herbicidal oils also were used as pre-emergence treatments to kill the weeds before the crop emerged. These new uses again stimulated research into the toxicity of various oil distillates. The knowledge obtained from this research found immediate application in the development of oil spray methods for weed control in several crops. Data from numerous tests indicated that plants were more resistant to oil when it was applied at certain stages in their growth and when the spray was directed at the base of the plant rather than at the terminal growing point. After spraying equipment for directed sprays had been developed, the use of herbicidal oils as a basal treatment was tested on several crops. The Stoddard solvent type of oil gave little injury with excellent weed control.

Chemical weed control in beans has not been as successful as in many other crops. Pre-emergence treatments have proved successful with some chemicals, but no post-emergence treatments have proven of value. Chemical treatments that are applied before the crop is up are not accepted readily by many growers because of their reluctance to treating the soil before the extent of the weed infestation is known. An economical method for the chemical control of weeds in beans with post-emergence treatments is needed.

Bean plants have a form of growth that permits the placement of sprays at the base of the stem during the early stage of growth. Many annual weeds present in bean fields are susceptible to herbicidal oils in their early stages of growth.

The studies reported here were undertaken in order to determine the effects of different oil fractions upon bean plants and weeds and in an attempt to devise a method for the chemical control of weeds in beans with post-emergence sprays.

REVIEW OF LITERATURE

The phytotoxic properties of crude oil or heavy oil fractions have been known for many years (17,20,67)*. Many workers attempted to isolate the toxic fractions of oil so that an oil could be obtained which was non-phytotoxic and could be used as a base for insecticidal sprays.

De Ong, Knight and Chamberlin (16) found a relatively high correlation between aromatic content and toxicity when oil from a single source was analyzed. Allen and Carpenter found that fractions derived from napthenic crude oils were more toxic than fractions refined from paraffinic crude oil (3). In 1932, Green (23) reported that aromatic content alone was not a reliable guide to phytotoxic effects of oils. He also found no correlation between toxicity and density, viscosity, surface tension, and flash point.

Later workers reported that the aromatic content of oil was correlated with toxicity (12,21,25,31,42,49,47). The aromatic fraction was analyzed to determine what factor caused the increase in toxicity (5,12,13,25,28,29,44,80). Crafts and Reiber (12) reported that toxicity increased with the number and size of substituted groups on the benzene ring up to tetraisopropylbenzene. Bell and Norem (5) stated that toxicity increased with side chains until the side chain molecular weight equaled the molecular weight of the benzene ring. Currier (13) working with oil vapors reported an increase in toxicity in the order of benzene, toluene,

*Numbers in parenthesis refer to the literature cited on page 62.

xylene, and trimethylbenzene. Leonard and Harris (44) also reported this order of activity and further stated that isomers in the side chain gave no change in toxicity. Havis (29) reported a reduction in toxicity with an increase in side groups. Van Overbeek and Blondeau (80) reported higher toxicity from the smaller molecules. They further stated that the smaller molecules appear less toxic when applied in liquid form because they evaporate faster. Griffiths (25) stated that aromatic fractions of more than ten carbon atoms are non-selective in toxicity. Havis (29) reported that the herbicidal properties of many of our oils possibly come from naphthalene aromatics.

Many components other than aromatic content have been suggested as the cause of toxicity in oils (5,12,14,44,45,49). Among these in the order of decreasing toxicity are: aromatics, naphthenes, olefins, and paraffins (5,28,29,35,46,80). A double bond appears to increase toxicity (29,44,49) while molecular branching decreases toxicity (45,80). Leonard and Harris (44) reported that an increase in chain length increases toxicity up to a certain chain length. They also found that the time required for injury to appear on plants increased with the chain length. Several workers reported an increase in toxicity when the oil was stored in light or was oxidized (12,29,36,80). Olefins, under these conditions, increased in toxicity more than did other fractions (29). Crafts and Reiber (12) reported that the increased toxicity was caused by peroxides which formed in the oil. Johnson and Hoskins (36) demonstrated that acids in the oils caused an increase in toxicity. Van Overbeek and Blondeau (80) stated that the increase in toxicity was due to undissociated acids and that the smaller the number of carbons in the acid molecule the greater the toxicity.

The toxicity of an oil can be predicted by determining its boiling range (12,49). Crafts and Reiber (12) reported that the higher the boiling range the larger the size of the oil molecules, and that an oil with a low boiling range will cause acute injury while an oil with a high boiling range will cause chronic injury. They described acute injury as occurring rapidly in the plant tissue and causing death of the cells within 48 hours, while chronic injury was characterized by a slow yellowing of the tissue with complete kill occurring several days after treatment.

Some research has indicated that the bromine absorption number, iodine value, aniline point and refractive index value gave an indication of the toxicity of the oil (5,13,29). Other workers found that surface tension and viscosity determine the rate of oil penetration and thus indirectly indicate toxicity (13,50). Emulsions of certain fractions have proved more toxic and less selective than straight oil sprays (12,15,29,81).

Several reports (13,22,26,39,40,49) stated that oil enters the plant through the stomata and cuticle, while others indicate that the stomata are the main points of entry (14,78,80). Dallyn and Sweet (15) stated that toxic oils enter the plant indiscriminately while non-toxic oils enter only through the stomata. Greater penetration in an area with open stomata than in an area with closed stomata was observed by Dallyn (14) and also by van Overbeek and Blondeau (80). Penetration of tissue was not the reason for difference in susceptibility in carrots and in beans as reported by Dallyn (14). Plants with a waxy cuticle resist penetration of oil other than through the stomata (80).

Most research has indicated that oil fills the intercellular spaces after entry (13,26,40,50,80,89,90). Two reports (31,40) stated that oil is then able to enter the vascular bundles; however, neither Dallyn (14) nor van Overbeek and Blondeau (80) were able to confirm this theory. Some reports stated that the oil enters living cells (40,41,54,89,90), but Minshall and Helson (50) and Rohrbaugh (66) stated that there was no penetration. Havis (29), and van Overbeek and Blondeau (80) found no penetration of living cells by non-toxic oils but observed penetration by toxic oils. Crafts and Reiber (12) found that oil would creep on the leaves of grass as much as six inches from the point of application.

Several studies have been made on the effect of oils upon transpiration, respiration, and photosythesis (24,31,37,38,40,50). Transpiration was sharply reduced in all treated plants but returned to a normal rate in the resistant plants (38,40,50). Helson and Minshall (31) reported that the reduction in transpiration rate is caused by interruption of the water supply to the tissue. Respiration increased and then later decreased in oil treated plants according to three reports (24,40,50). Minshall and Helson (50) observed that in susceptible plants respiration after treatment with oil decreased to zero with no recovery, while in the resistant plants respiration decreased but returned to normal. Knight, Chamberlin, and Samuels (40) found that, in plants treated with oil, photosynthesis was stopped immediately. Minshall and Helson (50) found that photosynthesis was stopped in susceptible plants that were sprayed with oil and in high light intensity the chlorophyll was rapidly broken down. The theory was advanced that the interruption of the supply of water was responsible for the cessation of photosynthesis (15,31,50). Dallyn and Sweet (15) added the idea that oils may cause a mechanical interference with gas exchange necessary for photosynthesis. Minshall and Helson (50) reported that the amount of oil influenced the degree of photosynthesis stoppage. The theory that photosynthesis is stopped by the rupture of the membranes of the chloroplasts has been advanced by Dallyn and Sweet (15) and van Overbeek and Blondeau (80).

Currier (13), Dallyn (14), and van Overbeek and Blondeau (80) have found that the semi-permeable membranes in the cells have been made permeable by treating with a toxic oil. Van Overbeek and Blondeau (80) proposed the theory that the plasma membranes consist of a lipoid fraction and a protein fraction. The lipoid fraction is composed of two layers of lipoid molecules with their polar ends together and the lipoid layers are surrounded by protein molecules. Toxic oils, according to this theory, act to disrupt the lipoid fraction and render the membranes permeable. Numerous reports stated that oil injury is associated with an interference of water transfer in the tissue (10,14, 15,31,49,50). Dallyn (14) and Helson and Minshall (31) observed that oils have altered the action of stomata. Dallyn (14) further observed that oil injury allowed the entry of a fungus into plant tissue.

Several ideas have been advanced with respect to reasons for selectivity of oils. Because most members of the Umbelliferae family have a high natural oil content and because the family is notably resistant to oils, the theory has been advanced that the presence of the natural oils render the plant resistant to toxic oils (15,29). That the natural oils may dilute the toxic oils or that the natural oil ducts may act as reservoirs for the toxic oils have both been mentioned as possible methods of providing resistance by Havis (29). Dallyn and Sweet (15) suggested that the resistance that has been shown by carrots and parsnips may be caused by the thick compact parenchyma that surrounds the vascular core. Crafts (10) stated that resistance to oil was caused by a difference in the protoplasm of resistant and susceptible species. Currier (13), Dallyn and Sweet (15), and van Overbeek and Blondeau (80) have suggested the reasons for selectivity as being a difference in the composition of the plasma membranes.

Environmental factors influence the amount of injury obtained by treatment of plant tissue with oil. At low temperature less injury occurred according to Eliason (18), but Dallyn (14) found temperature may affect only the speed of injury. Low humidity leads to greater injury and at low light intensity less injury was observed by Dallyn and Sweet (14,15). Dallyn (14) also observed that hardened plants and starved plants exhibited more injury than normal plants when treated with oil. Currier (13) described characteristic injury on plants as a darkening of tips of the youngest leaves due to a leakage of sap into intercellular spaces. The darkening spread to the older leaves and was followed by a loss of turgor and drooping of stem and leaves. The plants exhibited strong odors similar to that of macerated tissues. In bright sunlight chlorophyll was destroyed, sometimes resulting in complete bleaching of the affected portions. Addicott (1), and Minshall and Helson (49) described injury to leaf tissues as a collapse and shrinkage of the entire cell, including the cell wall and, later, a more or less complete cytolysis.

The application of oils prior to planting (11), pre-emergence (2,11,30,32,43,52,65,87), and post-emergence treatments have been reported in numerous papers. Post-emergence sprays have been used as selective sprays on tree nursery seed beds (8,18,19) and on crops in the Umbelliferae family (2,10,42,74). Eliason (18) mentioned an increase in injury when pine seedlings were sprayed when the soil moisture was low and the seedlings exhibited reduced turgor pressure. Lachman (42) reported that oils were more toxic in carrot fields when the plants were wet.

Post-emergence oil sprays have been used in crops as directed sprays. Wooten (88) designed a floating spray shoe with a laterally directed nozzle which placed the herbicidal oil at the base of the stems of the crop being sprayed. Other reports mentioned the use of spraying equipment very similar to Wooten's design (50,77,91). Wilson and Bruner (85,86) used directional spray equipment that employed a floating shield to protect the crop plant. They obtained good weed control using this equipment on snap beans. Shielded nozzles have also been used on onions (57). Directed sprays can be used on plants when a certain region of the plant is more resistant. The waxy covering on the stem of the cotton plant renders them more resistant to herbicidal oils (60,75). Mueller and Loomis (51) stated that leaves and herbaceous stems are covered with a special protective layer a few microns thick, known as cuticle. They further stated that the cuticle is assumed to be composed of pectin, a group of waxes known collectively as cutin, and possibly some cellulose. Many plants show an accumulation of various waxy materials on the surface of the cuticle. This resistant cuticle on the stems of plants has been the subject of much directed spray research.

Antognini (4) used herbicidal oils as a stem spray on onions. Hardcastle and Stemper (27) used herbicidal oils as directed sprays on sugar cane but they obtained injury. Talley (75) reported that low volumes of herbicidal oils could be used as directed sprays on cotton. McWhorter and Holstun (48) obtained good weed control with five gallons per acre of herbicidal oil applied to the base of the cotton stems in a band eight to ten inches wide on rows planted forty inches apart. Williams and Hinkle (83) observed injury when nine gallons per acre of a herbicidal oil was used on cotton. Ratcliff, et al. (61) obtained injury when a herbicidal oil was used at ten gallons per acre as a directed spray on cotton. Most workers (48,60,61,75) agree that herbicidal oils should be applied early to cotton in order to obtain good weed control with a minimum of injury to the crop. McWhorter and Holstun (48) and Talley (75) reported that oils can be applied to cotton five days after emergence. McWhorter and Holstun (48), Palmer and Ennis (55), and Ratcliff, et al. (61) reported that injury will occur if herbicidal oils are applied to cotton after bark forms on the stem. Holstun et al. (33,34) found that certain varieties and hill planted cotton gave less injury from oil treatments. Several reports (33,71,83) stated that oils applied by directing the nozzles parallel with the rows of cotton gave less cotton injury than nozzles directed across the rows but they obtained less weed control (33,83). Holstun, et al. (34) reported that the best weed control was obtained with herbicidal oils when the cotton was grown on beds approximately two inches high. Talley (75) found that the petroleum naphthas gave the best results on cotton of the herbicidal oils. Both the aromatic content (34,75,76) and the naphthenic content (75) is important in herbicidal oils. Talley, et al. (76) obtained poor weed control when they used hexane. Numerous reports (9, 58,62,63,64,71,75) indicated that satisfactory weed control was obtained by using several different oils. The use of herbicidal oils in pre- and post-emergence combinations have shown promise in cotton (9,26,48,53,63,82,84). Williams and Hinkle (83) obtained better grass control in cotton by fortifying the herbicidal oil, but no better broad leaf weed control. Fortifying oils have shown little promise for use in cotton (33,34,75).

Leonard and Harris (44,45,46) reported several experiments conducted in the greenhouse and in the field with directed oil application on soybeans and cotton. They found that the hypocotyls of cotton and soybeans were more resistant to oils than the stems of grass (45). Soybean hypocotyls were somewhat resistant to oils but they were more susceptible than cotton hypocotyls (45). VM&P Naphtha (boiling range 250° - 290° F.) selectively removed small annual weeds when applied at the base of the stems of soybeans at the rate of two and one-half gallons per acre to a narrow band in the rows planted forty inches apart (45). Octane also gave good weed control with no soybean injury (45). Lion Herbicidal Oil No. 1 gave some injury when applied at seven gallons per acre to soybeans (44,46). Young soybean plants showed little injury from one application of 12.5% and 25% benzene, toluene, xylene, and trimethylbenzene in dispersol (44). Old soybean plants showed less injury than the young plants and withstood two applications of the aromatic oils (44). Aliphatic oils in the six to ten carbon range caused a burning of the hypocotyl, the severity of which increased as the number of carbons increased (44). Dodecane caused most injury at the base of the hypocotyl (44).

Peek and Hinkle (56) applied a herbicidal oil to soybeans as a spray directed at the base of the stems. They sprayed a ten inch band in the forty inch rows at five gallons per acre. The first application was applied fourteen days after emergence. Two applications gave excellent weed control without serious bean damage.

Smith and Slife (68) applied herbicidal oil to soybeans in the first trifoliate leaf, fourth trifoliate leaf, and eighth trifoliate leaf stage in 1953. The soybeans were treated with five, seven and one-half, and ten gallons per acre applied in a narrow band in the forty inch rows. Two areas of the bean stem were used as application points: ground level, and between the primary leaves and the first trifoliate leaf. High placement of the spray gave the most damage. The fourth trifoliate leaf stage exhibited the most injury. Less injury and better weed control was obtained with the early treatment. There was no significant difference in yields between treatments. Stem burning, killing of the plants, and lodging were the characteristics of oil injury. In 1954, Smith and Slife (70) tested the same herbicidal oil at the same rates but applied them at the first trifoliate leaf, third trifoliate leaf, fifth trifoliate leaf, and seventh trifoliate leaf stages. Injury was about the same at the different stages of growth but recovery was better when the plants were treated early. Ten gallons of oil per acre caused more injury than the lower volumes. They recommended that oil sprays be applied one to two weeks after planting. Less bean injury and better weed control was obtained at this time of application.

Chappell and Camper (6,7) used Stoddard solvent at five gallons per acre as a directed band spray on soybeans. They obtained little weed control and no injury to the soybeans.

Upchurch (79) applied twenty gallons per acre (broadcast rate) of a herbicidal oil as a directed band spray on soybeans twenty days after planting. He obtained good weed control. A single oiling plus one cultivation gave the highest yield. One, two, and three oilings spaced one week apart gave good weed control without appreciable soybean injury.

Sweet, *et al*. (72,73) used various herbicidal oils as directed band sprays on snap beans, lima beans and field beans. They used twenty-five and fifty gallons per acre (broadcast rate) applied five weeks after planting. Good weed control was obtained with no difference in yields. When four applications were applied three days apart, a reduction in yield was obtained; however, when the interval was five days no reduction in yield occurred. They found that when the epidermis was killed the injury never penetrated beyond the phloem.

MATERIALS AND METHODS

Herbicidal oils furnished by the Standard Oil Company of Indiana were used in various tests in an attrmpt to find an oil that was relatively non-toxic to the stems of bean plants but was still sufficiently toxic to kill weeds. A list of the various experimental oils used and the available information on their components and properties is given in the appendix, page 69.

Several small screening tests were conducted in the Plant Science Greenhouse at Michigan State University during the winter of 1952-53. The undesirable oils were dropped from further tests while the desirable oils were carried on through several series of tests. The screening test consisted of growing soybean (Glycine max, variety Hawkeye) and field bean (Phaseolus vulgaris, variety Michelite) plants in pot culture. Three plants were grown per pot in unsterilized clay loam soil. The oils were applied to the surface of the soil in the pot and one inch of the stem of each bean plant at rates of one and two milliliters per twelve inch pot. A small DeVilbis sprayer was used to apply the oil. This same type of sprayer is used in entomological studies in the Peak-Grady test for toxicity of insecticides. Air was supplied to the sprayer from a three gallon compressed air sprayer tank. The sprayer was rinsed between treatments with 95% ethyl alcohol. The oils were applied when the first trifoliate leaf had emerged on the test plants. Ratings were made on the toxicity of the oil to the bean plants and on the weeds present three weeks after spraying. The rating scale used was: 1 - no injury, 12 - complete kill.

A power driven sprayer was modified so that herbicidal oils could be applied as directed-sprays to the base of the stem of bean plants under field conditions. A Planet Jr. 1 1/2 horsepower garden tractor was used for the power unit. A 1/4 inch Oberdorfer gear pump with a pressure regulator and pressure gauge was mounted on the front of the tractor and a V-belt was used to transfer the power from the engine to the pump. A one-gallon can was mounted on the front of the tractor for the spray solution tank. Two nozzles were arranged on the cultivator shanks behind the tractor and were connected to the pump unit by 1/4 inch Neoprene hose. The nozzles could be rotated in all directions and adjusted for height. Two free-floating shields made of 20 gauge galvanized sheet metal, mounted on a forward runner and a rear runner, were attached to the cultivator shanks to stand between the nozzles and the bean plants. The front of the shield was two inches and the rear of the shield one inch above the ground. The fan type nozzles were directed to spray horizontally underneath the shields into the row so that the spray pattern from one nozzle did not interfere with that from the opposite nozzle. A 6 inch band in the row was sprayed as well as about 1 inch of the lower part of the bean stem. The sprayer was rinsed out with 95% ethyl alcohol between treatments. Photographs of the sprayer are in the appendix, figures 17, 18, and 19.

Field tests were conducted on the Botany Department plots at East Lansing, Michigan in the summer of 1953. The clay loam soil was plowed and disced on June 9, 1953, and soybeans, field beans, lima beans (Phaseolus lunatus, variety Fordhook Dwarf), wax beans (Phaseolus vulgaris, variety Pencil Pod Wax), and green beans (Phaseolus vulgaris, variety Tendergreen Bush) were planted in 22 inch rows on June 10, 1953, with a small garden drill. Two rows of beans were planted for each treatment and the rows were divided into 3 plots, 2 rods long. Nine herbicidal oils that showed promise in the previous screening tests, or otherwise indicated that they could be used on beans, were applied with the power sprayer. Nozzles with teejet tips, size 730067, were used with 20 pounds per square inch pressure and the power sprayer traveled at about 2 miles per hour which applied 10 gallons per acre. Rates of application, in gallons per acre, expressed in this report are based on 6 inch band treatments in 22 inch rows. The oil sprays were applied on July 7, 1953, when the beans had developed their second trifoliate leaf and some of the weeds were two inches high. The soybeans were sprayed the second time on July 18 when the sixth trifoliate leaf had developed and the plants were about 14 inches high. The soybeans were cultivated on June 30 and again on July 7 while the other beans were cultivated only once, on July 18. Counts of grasses and broad-leaved weeds were made in the field, lima, wax, and green beans on July 25. Weed counts were made in a 4 inch band on 100 inches of row in 2 rows of each plot. All plots were hand-hoed to remove the weeds after the weed counts were completed. Observations on the effect of the oil upon the beans were made throughout the growing season. Pieces of stems that had been treated with oil were randomly selected from each plot fixed, sectioned, stained with Conant's quadruple stain and examined under the microscope for anatomical injury. Photomicrographs were made of some of the sections which had oil injury. Yield data were taken from all plots. Four pickings were made on the wax and green beans and two pickings on the lima beans. Two replications were harvested from the field beans because the third replication was flooded out at harvest time. One treatment in the field beans was removed accidently and thus the yield data were not available.

Field beans were drilled in, August 6, 1953, on muck soil, located near East Lansing, Michigan, that previously had been disced and floated. Two rows were planted per treatment and each treatment was divided into three replications. Twelve herbicidal oils were applied at a rate of 10 gallons per acre with the power sprayer as a directed basal stem spray on August 27, when the beans had developed one trifoliate leaf. A second treatment was applied on September 3 to those plots that showed no oil injury on the beans but still had weeds in the treated area. The beans had three trifoliate leaves at this spraying. Bean and weed injury ratings and weed counts were made on September 14.

Observations made of the effect of oils on vegetation grown under field conditions, when compared with observations of the effect of oils on vegetation grown under greenhouse conditions, indicated that screening tests under greenhouse conditions were not reliable. Therefore, a field screening test was set up on the muck soil plots. Field beans, lima beans, wax beans, and green beans were planted in 22 inch rows on August 6, 1953 with a small garden drill. Nineteen different herbicidal oils were applied to each kind of bean with the DeVilbis sprayer, on August 27, when the beans had developed their first trifoliate leaf. Five milliliters of the oil were used for each treatment. The sprayer was hand directed and the oil applied to a 3 inch band in the row and 1 inch of the bean plant stem. Each treatment was applied to at least 3 bean plants. Bean and weed injury ratings were made on September 10.

Greenhouse tests were conducted in the winter of 1953-54. Soybeans were planted in 12 inch pots in steam sterilized, sandy loam soil on December 16, 1953 and later thinned to three bean plants per pot. The experimental oils that had shown promise in the field tests were applied with the DeVilbis sprayer on December 30 to 3 randomized replications. Twenty gallons per acre of the herbicidal oils were applied as a basal stem treatment. The bean plants were harvested by cutting the stem at the ground line and drying the entire above-ground portion of the plant in a drying oven for 2 days before weighing. Bean injury ratings were made prior to harvest on February 6, 1954.

Soybeans were planted in unsterilized clay loam soil in 12 inch pots on January 23, 1954 for an oil screening test. The same methods were used as were described in the previous test. Seven oils were applied on February 13. Bean and weed injury ratings were made and the number of plants surviving was recorded before the beans were harvested and dry weights determined on March 20.

Two tests were conducted in the greenhouse to determine the stage of growth that was least susceptible to oil injury. Soybeans and field beans were seeded in 12 inch pots on March 6, 1954 in an unsterilized clay loam soil. The bean plants were thinned to three plants per pot before treatment. Three experimental herbicidal oils at a rate of 20 gallons per acre were applied with the DeVilbis sprayer to the stems of the bean plants and surface of the soil at different stages of growth. Applications were made on March 13 (3 days after emergence), March 23 (first trifoliate leaf), and April 2 (third trifoliate leaf). One series of pots received an application on all three dates. Bean injury ratings were made and the number of plants surviving was recorded before the beans were harvested and dry weights were determined on April 22.

Soybeans were planted in 12 inch pots on February 7, 1954, in unsterilized sandy loam soil. LS-0237 was applied 0, 3, 6, 13, 19, 27, and 32 days after emergence of the bean plants at 20 gallons per acre to pots containing 4 plants each. The standard greenhouse screening procedure used in the other tests was used. The 3 randomized replications were rated for oil injury and the dry weights were determined on April 8, 1954.

A test was conducted to determine if the amount of oil applied or the temperature at the time of application affected the amount of injury obtained. Soybeans were planted in an unsterilized clay loam soil in 12 inch pots on January 31, 1954. The plants were grown under greenhouse conditions (68°-70° F.) until they had developed the first trifoliate leaf. At this stage they were randomly divided into groups of 12 pots and transferred to greenhouse areas of 60, 70, and 80° F. temperatures. The pots remained in these temperature areas for 2 days before they were sprayed with the herbicidal oil. The DeVilbis sprayer was used to apply 20, 30, and 40 gallons per acre of LS-0237 to the surface of the soil and base of the stems of the soybean plants on February 13. The treatments were randomized in triplicate. The soybean plants remained in the temperature areas for 18 hours after spraying before they were returned to regular greenhouse conditions. Injury ratings and observations on the surviving plants were made 3 weeks after treatment. The soybeans were harvested and dry weights determined on March 20.

Repeat application of oils on beans was tested in the greenhouse. Soybeans were drilled in 22 inch rows in a clay loam soil in a greenhouse bed on January 11, 1954. The rows were divided into 3 replications. A spray boom was built with drop nozzles to direct the spray horizontally at the base of the bean stems. The boom was attached to a 3 gallon compressed air sprayer. The operator moved the boom sprayer slowly enough to thoroughly wet the bean stems. The first treatment of herbicidal oil LS-0237 was applied on January 31 after the beans had developed their first trifoliate leaf. Additional treatments were made one week apart on some of the rows until 1, 2, and 3 treatments had been applied to similar rows. Two weeks after the last treatment injury ratings were made. Six bean plants were randomly selected from each treatment replication on March 6 and tested for stem strength and later dried and weighed.

An apparatus was designed and built to measure the resistance to bending that the bean stems possessed. Three inches of the plant stems were cut from the bean plants and were clamped to a flat surface with

1 1/2 inches of the stem extending beyond the edge of the clamp. A protractor was mounted behind the clamp with the center located at the edge of the clamp. A crossarm with two small pulleys attached was suspended above the clamp. A string with a bottle attached to one end was run through the pulleys and tied to the free end of the bean stem. Water was added to the bottle until the bean stem was bent in a 90 degree angle from its original horizontal position. Two observations were made with this apparatus: (1) Number of grams required to bend the stem 90 degrees; (2) the resilience in degrees from the original position the stem exhibited one minute after the weight was released. A drawing of this apparatus is in the appendix, figure 20.

In the summer of 1954 additional field tests were made. The 3 tests made were a field screening test, a rate of application test, and a time of application test. The general methods were the same for all of these tests and very similar to the field tests conducted in the summer of 1953. The 5 kinds of beans were drilled in on the Botany Department plots in 22 inch rows on a clay loam soil that had been plowed, disced, and dragged 1 day before planting. Each treatment consisted of 2 rows which were divided into 3 replications 1 rod long. The oils were applied with the power sprayer used in the 1953 field tests and the oils were directed at the base of the bean plant stems. Weed counts were made on July 1 on the screening and rate tests by counting the weeds present in 4 inches of the treated band in two 100 inch sections of row for a total of 200 inches of row per plot. All plots were cultivated on July 1 and hand hoed July 2-8. Treated stems were randomly selected for sectioning in all of the plots on July 25. The sections were fixed in Farmer's fixative, sectioned, and stained with Conant's quadruple stain and examined under a microscope for anatomical oil injury. Observations on the oil injury were made on August 29. Yields were taken from the soybean and field bean plots by weighing the dry beans. Yields were taken from the lima, wax, and green bean plots by taking the green weight of the 3 pickings that were made.

The field screening test was planted on June 7 and sprayed on June 23, when the bean plants had developed their first trifoliate leaf, with 7 different oils. One treatment consisted of spraying on June 23 with LS-0237 followed by another apolication on July 1. Ten gallons of oil per acre were applied.

The rate of application tests were planted on June 9 and sprayed on June 23 when the bean plants had just developed their first trifoliate leaf. The herbicidal oil LS-0237 was used in all of the treatments. Five, ten and twenty gallons per acre were applied by using Teejet tips sizes 730038, 730067, and 8001 respectively with 20 pounds pressure per square inch and traveling at about 2 miles per hour.

The time-of-application plots were planted on June 7 and sprayed at different stages in the growth of the bean plants. Herbicidal oil LS-0237 was used in all of these tests at 10 gallons per acre. The oil sprays were applied on the following dates: June 15 (first true leaf), June 23 (first trifoliate leaf), July 1 (third trifoliate leaf), and July 21 (budding and blossoming). In addition, one plot received an application on both June 15 and June 23.

Further testing was conducted in the Plant Science greenhouse in the winter of 1954-55. Soybeans, field beans, lima beans, wax beans, and green beans were planted in 12 inch pots in unsterilized clay loam soil on January 14, 1955. Five experimental oils that had given good results in the field tests were applied with the DeVilbis sprayer at 20 gallons per acre on January 28 when the beans had developed their first trifoliate leaf. Each treatment was made in triplicate and randomized. One day before treatment the bean plants were thinned to four plants per pot and after treatment the soybean, field beans, and lime bean plants were thinned to three plants per pot while the wax and green bean plants were thinned to 2 plants per pot. Weed and bean injury ratings were made on February 5. Photographs were taken of some of the stems showing oil injury. The bean plants were harvested on March 4 by washing the soil away from the roots of the plants with running water. The stem was cut off at the soil line and dry weights of the stems and roots were determined. The nodules on the roots of the green bean plants were counted.

On February 14, 1955, soybeans were planted in unsterilized clay loam soil in 12 inch pots. Prior to treatment the plants were thinned to six plants per pot. When the plants had developed their first trifoliate leaf, the pots were randomly divided into 2 groups. One group of pots remained under ordinary conditions but the other group was placed under a fluorescent lamp about 4:00 P.M. on March 7. The fluorescent lamp did not increase the temperature of the air but gave light conditions comparable to daylight. At 10:00 P.M. on March 7 the plant stems were sprayed with herbicidal oil LS-0237 at 20, 40, and 60 gallons per acre. The oil was applied with the DeVilbis sprayer and each treatment was randomized in 3 replications. The epidermal cells of the stems of some of the plants under the light and dark conditions were stripped off and emersed in absolute ethyl alcohol. These strips were later examined under the low power lens of a microscope to check the size of the stomata opening. The light was removed from the pots 1/2 hour after treatment and the pots were placed together and randomized 12 hours later. Bean injury ratings were made on March 12 and the number of surviving plants was recorded. The number of plants in the 20 gallon per acre treatments and check were reduced to 2 per pot on March 8. The dry weights were determined for the surviving plants in the 20 gallon per acre treatment and the check pots on April 14.

The effect of the oils upon some weeds commonly present in bean fields wes investigated in the greenhouse in 1955. LS-0237 was applied at various rates to weeds growing in greenhouse flats. LS-0237 was applied to the flats of weeds on January 10, 1955. The oil was applied at 5, 10, and 20 gallons per acre. The weeds varied from seedlings to a maximum height of 1 inch. Weed counts were made on January 15. Five other experimental oils also were applied to weeds grown in flats. The oils were applied at 10 gallons per acre when the weeds were in the seedling or first leaf stage. Weed counts were made on March 13.

In both of these experiments the weeds were grown from volunteer seeding in unsterilized clay loam soil in 3 weeks. The oil treatments were applied with the DeVilbis sprayer. All treatments were randomized with four replications. Weed counts were made by counting individual species in the entire flat.

EXPERIMENTAL RESULTS

The purpose of the oil screening tests made in the winter of 1952-53 was to find an oil that was not toxic to the stems of bean plants but was toxic to weeds. Table I is a compilation of injury ratings obtained from several small oil screening tests made on soybeans and field beans. The tests indicated that field beans were more resistant to oil stem sprays than were soybeans. The oils, LS-0132, LS-0133, LS-0150, LS-0151, LS-0152, LS-0153, L-6319, and L-7565 gave quite severe injury and were dropped from further testing at that time. Oils LS-0147, LS-0154, LS-0155, LS-0178, L-3388, L-6581, L-7710, L-7718, and L-8712 appeared to be less injurious to the stems and were investigated further as to their weed injury ratings. A new lot of L-3388 gave less injury than a year-old sample and consequently, new samples were used on all further testing. L-8712 was not toxic on weeds.

Typical oil injury on the bean plants was characterized by a wilting of the entire plant similar to a plant suffering from the lack of water. The leaves were wilted and the stems were weak. The treated area of the stem had a water soaked appearance. If the plant was not killed by the oil, the stem tissue in the treated area was severely browned and the plant appeared to be slightly stunted. Some of the oils caused a slower reaction on the plant and little injury was noted until 4 days after treatment. A few of the heavier oils produced injury only at the ground line.

TABLE I

INJURY RATINGS MADE ON SOYBEANS, FIELD BEANS, AND WEEDS FOLLOWING APPLICATIONS OF HERBICIDAL OILS AS BASAL STEM TREATMENTS

Oil Used	Bean Injury Rating[1]		Weed Injury Rating[1]
	Soybeans	Field Beans	
LS-0132	12	4	
LS-0133	12	10	
LS-0147	7	2.7	11.2
LS-0150	12	8	
LS-0151	9	5	
LS-0152	12	11	
LS-0153	12	12	
LS-0154	2.7	11	7
LS-0155	4.2	4.3	10
LS-0178	4.5	1.7	6.5
L-3388 (new)	7	3.3	9.8
L-3388 (old)	6.5	7	12
L-6319	10	10	12
L-6581	2	3.5	9.5
L-7565	12	5	
L-7710	5.5	3	11
L-7718	3.5	3	10.5
L-8712	3	3	3

[1]Injury ratings: 1 = no effect, 12 = complete kill.

Because of the limited time and space available for field work, only the best oils from the screening tests were used in the field tests in the summer of 1953. Some additional oils that had shown promise for other workers were obtained for field testing. Octane (LS-0235) and VM&P naphtha (L-6580) had been mentioned by Leonard and Harris (44,45) as promising oils for weed control in soybeans. A very toxic oil, L-7297, was included in the field test. Bean yields obtained after the various oils were applied to 5 kinds of beans in the 1953 field tests as directed sprays at the base of the stems of the bean plants are presented in Table II. A significant reduction in yield occurred only when LS-0147

TABLE II

YIELDS OBTAINED FOLLOWING APPLICATION OF HERBICIDAL OILS

Oils Used	Yield in Pounds Per Acre				
	Soybean[1]	Field Bean	Lima Bean	Green Bean	Wax Bean
LS-0147	2050	926	1889	2926**	4296
LS-0154	2350	778	1667	6037	3778
LS-0155	2250	963	2111	4333	4630
LS-0178	2250	630	1222	6889	4556
LS-0235	2350	778	1185	5778	4667
LS-0237	2300	1037	1852	5778	5296
L-6580	2350	1111	1630	6111	5074
L-7297	2250	---	1815	6815	3815
L-7710	2000	963	1889	4370	4556
Untreated	2350	519	926	5852	3630
LSD 1%				2741	
LSD 5%				2000	

[1]Two applications of oil were made on all soybean plots.

was applied to the green beans. This probably can be attributed to experimental error because no injury was noticed on the bean plants during the growing season. Observations made after the oil was applied indicated that moderate injury occurred in all of the plots that had been sprayed with L-7297. Later in the season many of the stems in the L-7297 plots broke off at the ground line. L-7710 caused slight injury in all of the plots and some of the stems were very weak at harvest. LS-0237 gave slight injury to the stem of lima and green beans.

Some injury was noted in the examinations of the cross sections of the treated stems. Surface injury was noted in several of the sections and was characterized by causing a break-down of the cells in the epidermis and cortex. The cells adjacent to the injured cells reverted to meristematic activity and a periderm layer was formed around the injured tissue. Internal injury was noted in a few of the sections and was characterized by a break-down of the cells in the epidermis, cortex, phloem and vascular cambium. The cells adjacent to the injured tissue reverted to meristematic activity and a protective layer, similar to a periderm, was formed. Photographs of this injury is shown in the appendix, figures 5-15. Surface injury was observed when L-7710 and L-7297 was applied to all 5 kinds of beans. LS-0154, LS-0237 and L-6580 caused slight surface injury when applied to the lima, wax and green beans. Internal injury was observed in the soybeans, field, and green bean stems when L-7297 and L-7710 were used. Internal injury was also noted in the green bean stems when LS-0237 was used.

Table III gives the results of the weed counts made on the 1953 field oil screening tests. The main grasses present were green foxtail (<u>Setaria viridis</u> (L.) Beauv.), yellow foxtail (<u>Setaria lutescens</u> (Weigal) F. T. Hubb), large crabgrass (<u>Digitaris sanguinalis</u> (L.) Scop), and barnyard grass (<u>Echinochloa crusgalli</u> (L.) Beauv.). The main broad-leaved weeds present were lamb's quarters (<u>Chenopodium album</u> L.), pigweed (<u>Amaranthus retroflexus</u> L.), and purslane (<u>Portulaca oleracea</u> L.).

TABLE III

NUMBER OF WEEDS FOLLOWING APPLICATION OF HERBICIDAL OILS

Oil Used	Number of Weeds Per Square Foot							
	Field Bean		Lima Bean		Green Bean		Wax Bean	
	Grass	Broad-leaf	Grass	Broad-leaf	Grass	Broad-leaf	Grass	Broad-leaf
LS-0147	0.7	7.5**	1.0	8.5**	2.6	18.6	0.5**	7.5**
LS-0154	0.8	18.2	0.8	23.2	.6	17.5*	2.1**	21.8
LS-0155	0.2*	8.6**	0.6	7.5**	1.0	7.9	0.7**	6.4**
LS-0178	2.4	16.8*	0.4	21.7	.5	16.4*	0.7**	18.2**
LS-0235	0.2*	15.1**	0.8	17.1*	.2	12.5**	0.5	16.8**
LS-0237	0.0*	5.7**	0.4	3.3**	.7	5.7**	0.1**	3.6**
L-6580	0.0*	7.1**	1.2	8.8**	.2	6.1**	0.8**	5.7**
L-7297			0.0	4.4**	.7	3.2**	0.0**	5.7**
L-7710	0.4*	4.5**	1.0	2.4**	.6	5.4**	0.5**	4.3**
Untreated	1.7	23.2	3.3	29.4	1.1	27.1	5.2	28.6
LSD 1%	1.8	7.3		13.1		11.9	2.3	9.4
LSD 5%	1.3	5.3		9.5		8.7	1.6	6.8

The number of grasses per square foot was not significantly different between treatments in the lima and green bean plots. The lack of a significant difference is probably due to the low grass population in all of the plots and the germination of most of the grasses after treatment. The number of grasses per square foot showed a significant difference between treatments in the field and wax bean plots. All treatments were significantly lower than the untreated except in the LS-0147, LS-0154, and LS-0178 treatments applied to the field beans. The number of broad-leaved weeds per square foot showed a highly significant difference between treatments in all 4 kinds of beans. All treatments except LS-0154 and LS-0178 gave a highly significant decrease and LS-0178 gave a significant decrease in the number of broad-leaved weeds compared with the untreated plots in the field beans. All treatments except LS-0154, LS-0178, and LS-0235 gave a highly significant decrease and LS-0235 gave a significant decrease in the number of broad-leaved weeds compared with the untreated plots in the lima beans. All treatments except LS-0147, LS-0154 and LS-0178 gave a highly significant decrease and LS-0154 and LS-0178 gave a significant decrease in the number of broad-leaved weeds compared with the untreated plots in the green beans. All treatments except LS-0154 gave a highly significant decrease in the number of broad-leaved weeds compared with the untreated plots in the wax beans. LS-0237, L-7297, and L-7710 gave the greatest and most consistent decrease in the number of broad-leaved weeds of any of the oils and this is significant in comparing them with LS-0154, LS-0178, and LS-0235 in most of the comparisons.

Further field trials were conducted with field beans using the power sprayer on muck soil to determine the effects of oils on different weed species and also the effects of the other oils on the bean stems.

Table IV shows the results of the injury ratings made and the number of weeds per square foot after basal stem treatment of field beans with 12 herbicidal oils applied at the rate of 10 gallons per acre. The most

TABLE IV

NUMBER OF WEEDS AND BEAN INJURY RATINGS FOLLOWING APPLICATIONS OF HERBIDICAL OILS

Oils Used	Number of Treatments	Bean[1] Injury Rating	Weed[1] Injury Rating	Number of Weeds Per Square Foot	
				Grass	Broadleaf
LS-0147	2	2	8	1.1**	17.6**
LS-0153	2	2	7	4.8**	22.9**
LS-0154	1	3	8	5.2**	13.1**
LS-0155	1	4	10	1.5**	5.8**
LS-0178	2	2	2	9.0**	53.0
LS-0235	2	1	6	3.7**	27.0**
LS-0237	2	1	8	2.5**	14.5**
LS-0238	2	1	6	5.7**	24.2**
L-3388	2	2	5	5.4**	36.7
L-6580	2	1	8	3.3**	12.1**
L-7297	1	6	9	3.3**	5.4**
L-7710	2	5	10	1.0**	4.5**
Untreated	0	1	1	16.9	48.2
LSD 1%				4.5	19.6
LSD 5%				3.3	14.5

[1]Injury ratings: 1 = no effect, 12 = complete kill

abundant grasses in the plots were tickle grass (Panicum capillare L.), Kentucky bluegrass (Poa pratensis L.), and quack grass (Agropyron repens (L.) Beauv.): and the most abundant broad-leaved weeds were wormseed mustard (Erysimum cheiranthoides L.), ragweed (Ambrosia artemisiifolia L.) lamb's quarters (Chenopodium album L.) purslane (Portulaca oleracea L.), common chickweed (Stellaria media (L.) Cyrill), and mouse-ear chickweed (Cerastium vulgatum L.). All treatments gave a highly significant decrease in the number of grasses. The number of grasses was significantly higher in the LS-0178 treatment than in treatments LS-0147, LS-0155, LS-0235, LS-0237, L-6580, L-7297 and L-7710. All treatments except LS-0178 and L-3388 caused a highly significant decrease in the number of broad-leaved weeds. Oils LS-0155, L-7297, and L-7710 had significantly less broad-leaved weeds than LS-0153, LS-0178, LS-0235, LS-0238, and L-3388. LS-0235, LS-0237, LS-0238, and L-6580 after 2 treatments caused no noticeable injury to the stems of the field beans while all other treatments caused injury. LS-0154, LS-0155, and L-7297 caused bean stem injury after only 1 treatment. The weed injury ratings indicated that LS-0147, LS-0153, LS-0154, LS-0155, LS-0237, L-6580, L-7297, and L-7710 gave over 50% weed control.

Field screening tests with the manually operated DeVilbis sprayer unit were conducted to check the results obtained in the greenhouse test. Table V gives the injury ratings obtained by applying the experimental oils to the stems of 4 kinds of beans and weeds under field conditions. Oils LS-0132, LS-0151, L-6640, L-6840, L-7565, L-8949, L-8950, and L-8951 did not give enough weed kill to be useful as herbicidal oils in beans. Oils L-6319, L-6581, L-6639, L-6641, L-7718, and L-7934 caused excessive stem injury on the beans. Oils LS-0133, LS-0150, LS-0152, and L-8952 did not give excessive injury to the bean stems and gave good weed control.

TABLE V

INJURY RATINGS FOLLOWING APPLICATION OF HERBICIDAL OILS

Oils Used	Injury Ratings[1]								
	Field Bean		Lima Bean		Green Bean		Wax Bean		Average
	Bean	Weed	Bean	Weed	Bean	Weed	Bean	Weed	Weed
LS-0132	2	5	2	6	1	2	1	3	4
LS-0133	3	6	2	11	2	11	5	11	10
LS-0150	3	11	6	9	4	9	6	11	10
LS-0151	3	6	5	8	3	6	3	4	6
LS-0152	4	11	4	11	5	9	5	11	11
L-6319	12	12	9	12	10	12	12	12	12
L-6581	7	11	6	11	7	11	7	11	11
L-6639	7	11	7	11	7	11	7	11	11
L-6640	3	8	10	3	10	4	3	3	4
L-6641	7	11	6	11	6	11	10	12	11
L-7565	3	8	3	4	3	5	3	8	6
L-7718	7	12	9	12	7	12	8	12	12
L-7934	7	12	6	12	5	12	7	12	12
L-8949	1	3	1	1	1	1	1	3	2
L-8950	1	5	1	1	1	1	1	3	2
L-8951	1	3	1	2	1	2	1	4	3
L-8952	1	11	1	11	1	11	1	11	11

[1]Injury ratings: 1 = no effect, 12 = complete kill

In the winter of 1953-54 greenhouse screening tests were conducted. Table VI gives the dry weights and injury ratings obtained after basal stem treatment of soybean plants with 8 herbicidal oils at 20 gallons per acre. In pots treated with LS-0237 a significant increase in dry

TABLE VI

DRY WEIGHT AND INJURY RATINGS FOLLOWING APPLICATION OF HERBICIDAL OILS

Oils Used	Bean[1] Injury Rating	Dry Weight grams per pot
LS-0133	2	3.5
LS-0150	8	3.1
LS-0152	2	3.4
LS-0237	4	4.3*
LS-0238	3	3.0
L-6840	4	3.0
L-7934	10	2.6
L-8952	3	3.2
Untreated	1	2.4
LSD 1%		1.6
LSD 5%		1.1

[1]Injury ratings: 1 = no effect, 12 = complete kill.

weight per pot was found but no other significant difference between treatment dry weights occurred. LS-0150 and L-7934 gave considerable injury to the stem of the bean plants while the other oils gave only slight injury.

Another screening test was conducted in the greenhouse in the winter of 1953-54. Table VII gives the dry weight per pot, number of plants surviving and injury ratings obtained after basal stem treatment of soybean plants with 7 herbicidal oils at 20 gallons per acre. Treatments with LS-0133, LS-0150, LS-0152, LS-0237, and LS-0238 caused a highly significant decrease in the dry weight per pot. Extensive bean injury was noted in these same treatments and all of these pots had plants killed before they were harvested. Good weed kill was obtained in all treatments; however, treatments with LS-0152, LS-0237, and LS-0238 were outstanding.

TABLE VII

DRY WEIGHT, NUMBER OF SURVIVING PLANTS AND INJURY RATINGS FOLLOWING APPLICATIONS OF HERBICIDAL OILS

Oils Used	Number of Surviving Plants	Bean[1] Injury Rating	Weed[1] Injury Rating	Dry Weight Grams Per Pot
LS-0133	3.0	6	9	3.7**
LS-0150	3.3	3	9	5.6**
LS-0152	1.7	10	10	1.8**
LS-0237	1.0	11	11	3.8**
LS-0238	2.7	8	11	3.3**
L-6840	4.0	3	7	8.5
L-8952	4.0	5	8	10.2
Untreated	4.0	1	1	10.5
LSD 1%				4.52
LSD 5%				3.26

[1]Injury ratings: 1 = no effect, 12 = complete kill.

There seemed to be a difference between experiments in the amount of toxicity produced by an oil. Several experiments were made to investigate the cause for increased toxicity in some tests in an attempt to isolate the causes and adapt them to field experiments.

Table VIII gives the injury ratings, number of plants surviving, and dry weights obtained after basal stem treatments with 3 herbicidal oils were applied at 20 gallons per acre to soybeans and field beans at different stages of growth and a repeat application. According to the injury ratings, the soybean plants appeared to be more susceptible

TABLE VIII

INJURY RATINGS, NUMBER OF PLANTS SURVIVING, AND DRY WEIGHTS FOLLOWING APPLICATIONS OF HERBICIDAL OILS

Time of spraying and Stage of Growth	Oils Used	Bean Injury[1] Rating		No. of Plants Surviving		Dry Weight Grams/pot	
		Soybean	Field Bean	Soybean	Field Bean	Soybean	Field Bean
3 days after emergence (Unifoliate leaf)	LS-0147	5	1	3	3	2.6	4.9
	LS-0155	7	2	3	3	2.6	5.5
	L-7710	8	2	3	3	3.6	4.3
13 days after emergence (1st trifoliate leaf)	LS-0147	3	4	3	3	3.5	6.1
	L-7710	5	8	3	2	1.9	3.6
	LS-0155	3	4	3	3	3.5	4.7
23 days after emergence (3rd trifoliate leaf)	LS-0147	3	4	3	3	2.0	1.6
	L-7710	9	12	3	0	1.2	0
	LS-0155	2	4	3	3	1.8	5.3
Sprayed on all three dates	LS-0147	12	5	0	3	0	4.5
	L-7710	10	10	1	1	.9	1.6
	LS-0155	3	4	3	3	2.1	4.6
Untreated	Untreated	1	1	3	3	1.8	4.2

[1]Injury ratings: 1 = no effect, 12 = complete kill.

to oil injury in the unifoliate leaf stage than were field bean plants at a similar stage of growth. Soybean plants exhibited the least injury when the oil was applied after the plants had developed their first and third trifoliate leaves. The field beans were injured least when the oils were applied before the plants had developed their first trifoliate leaf.

The repeat treatments caused more injury to the soybean plants when LS-0147 and L-7710 were used. L-7710 appeared to be more toxic than LS-0147 and LS-0155. L-7710 killed some field bean plants when applied to the first and third trifoliate leaf stage of growth.

Table IX gives the injury ratings, number of plants surviving and dry weights per plant obtained when LS-0237 was applied to the stems of soybean plants at 20 gallons per acre at different stages of growth. The number of plants surviving and injury ratings indicate that the plant becomes more susceptible to oil in the later stages of growth. The plants appear to be most susceptible to oil injury when they have developed their first and second trifoliate leaves. The dry weights per plant gave no significant difference between treatments.

The effects of varying amounts of oil and different temperatures while spraying was investigated in greenhouse tests. Table X gives the injury ratings, number of plants surviving and dry weights obtained when LS-0237 was applied at 20, 30, and 40 gallons per acre to soybean plant stems in 60, 70, and 80° F. temperatures, under greenhouse conditions. Injury ratings indicate that less injury occurred when the oils were applied in 60° F. temperatures and that injury increased when

TABLE IX

INJURY RATINGS, NUMBER OF PLANTS SURVIVING AND DRY WEIGHTS FOLLOWING APPLICATIONS OF LS-0237

Time of Spraying and Stage of Growth	Bean Injury Rating[1]	Number of Plants Surviving	Dry Weights Grams Per Plant
Day of emergence (Bow)	1	4.0	1.5
3 days after emergence (beginning unifoliate leaf)	2	4.0	1.9
6 days after emergence (Full Unifoliate leaf)	2	4.0	1.7
13 days after emergence (First trifoliate leaf)	10	1.7	2.1
19 days after emergence (Second trifoliate leaf)	10	1.7	2.1
27 days after emergence (Beginning third trifoliate leaf)	8	3.3	1.6
32 days after emergence (Full third trifoliate leaf)	6	3.3	1.3
Untreated	1	4.0	2.2

No significant difference between yields.

[1]Injury ratings: 1 = no effect, 12 = complete kill.

the amount of oil was increased. The number of plants surviving indicate greater plant kill at the higher temperatures. Dry weights obtained indicate a highly significant difference between treatments and untreated except when 20 gallons per acre was applied at 70° F. At the 60 and 70° F. temperatures 40 gallons per acre caused a significant decrease in dry weights compared with the 20 gallon per acre rate. There was no significant difference in dry weights per pot between temperatures.

TABLE X

INJURY RATINGS, NUMBER OF BEANS SURVIVING AND DRY WEIGHTS FOLLOWING APPLICATIONS OF LS-0237

Temperature While Spraying Degrees F.	Gallons per Acre	Injury Ratings[1]	Number of Plants Surviving	Dry Weights Grams Per Pot
60	20	6	3.3	4.9**
	30	7	3.3	4.9**
	40	8	3.0	3.6**
	Untreated	1	4.0	7.3
70	20	6	3.3	4.8
	30	8	2.3	3.2**
	40	11	1.3	2.0**
	Untreated	1	4.0	6.0
80	20	8	2.7	3 0**
	30	10	2.0	2.7**
	40	9	2.7	3.2**
	Untreated	1	4.0	7.3
LSD 1%				2.24
LSD 5%				1.65

[1]Injury ratings: 1 = no effect, 12 = complete kill.

The effects of making repeated applications of herbicidal oils as stem treatments on beans was investigated by applying oil on soybeans planted in a bed in the greenhouse. Table XI gives the injury ratings, dry weights per plant, grams required to bend the bean stem 90 degrees, and the resilience (number of degrees from the original position that stems returned to 1 minute after release from a 90 degree bend) obtained when LS-0237 was applied 1, 2, and 3 times. The second and third applications caused an increase in injury as can

TABLE XI

INJURY RATINGS, DRY WEIGHTS, STRENGTH AND RESILIENCE OF STEMS FOLLOWING APPLICATION OF LS-0237

Number of Treatments	Injury Ratings[1]	Dry Weight Grams/Plant	Grams Required to Bend Stem 90 Degrees	Resilience Degrees from Original Position
1	3	2.2	46.2	12.5
2	6	2.1	52.3	12.2
3	8	2.2	39.3	15.3
Untreated	1	2.1	23.5	18.5

No significant difference between treatments in dry weight, grams required to bend stem on degrees, or resilience.

[1]Injury ratings: 1 = no effect, 12 = complete kill.

be noted in the injury ratings. There was no significant difference in the dry weights, grams required to bend the stem 90 degrees or the degrees in the resilience test. The treated stems appeared to require considerably more weight to bend them 90 degrees but the variability in stems eliminated a significant difference. The treated stems appeared to have greater resilience but this was not significant.

Further field testing was conducted in the summer of 1954 with oils that had shown promise in earlier field and screening tests. Table XII gives the yields per acre that were obtained from 5 kinds of beans grown under field conditions and treated with 7 herbicidal oils directed at the base of the stems at 10 gallons per acre. A significant difference between treatments was found in soybeans, field beans, lima beans, and green beans but no significant difference in wax beans.

TABLE XII

YIELDS FOLLOWING APPLICATION OF HERBICIDAL OILS

Oil Used	Yields in Pounds Per Acre				
	Soybeans	Field Beans	Lima Beans	Wax Beans	Green Beans
LS-0133	1857	1286	5714**	5000	8786
LS-0150	1929	1357	5714**	6000	6429
LS-0152	2000	1500	5571**	5643	9071
LS-0155	1857	1357	5786**	5429	9929*
LS-0237	2214**	1643*	4071	5571	8714
LS-0237+ LS-0237	2214**	1643*	4071	5571	9000
LS-0238	1020	1571*	4500*	4029	9357*
LS-6580	2000	1357	5714**	5357	9071
Check	1857	1286	2357	4357	7357
LSD 1%	327	357	2670		2671
LSD 5%	237	257	1021		1936

LS-0237 and 2 treatments of LS-0237 gave a highly significant increase in yield over the untreated in the soybean plots. LS-0237, 2 treatments of LS-0237, and LS-0238 gave a significant increase in yield in the field bean plots. LS-0133, LS-0150, LS-0152, LS-0155, and LS-6580 treatments gave a highly significant increase and LS-0238 gave a significant increase in yield over the untreated lima bean plots. LS-0155 and LS-0238 treatments gave a significant increase in yield over the untreated in the green bean plots. The increase in yield probably was caused by a decrease in yield in the untreated plots because of weed growth that was either not removed entirely or not early enough by the cultivation and hand hoeing. Observations made after treatment indicated that some injury occurred when two applications of LS-0237 was applied to the soybeans, lima beans, wax beans, and green beans. The lima beans were the most severely injured. Slight injury was noted when LS-0238 was applied to field, lima, wax and green beans. Slight injury was also observed when LS-0237 was applied in a single treatment to lima and green beans. LS-0152 showed slight injury on wax beans.

Examinations of stem cross sections indicated slight surface burning on some of the beans in the 1954 field treatments. The soybeans were injured slightly in the LS-0238 plots. The field beans were injured slightly in the LS-6580 plots. The lima beans were injured by the LS-0133, LS-0152, LS-0150, LS-0237, LS-0238 and LS-6580 treatments. The wax beans were injured with LS-0133, LS-0150, and LS-6580 treatments. The green beans were injured when LS-0133, LS-0150, LS-0152, LS-0237, LS-0238 and LS-6580 treatments were applied.

Table XIII lists the results of the weed counts in weeds per square foot and percent control obtained when 7 herbicidal oils were applied as basal stem treatments on 5 kinds of beans The weed counts were arranged in 5 different groups to determine if a difference in oil susceptibility existed between weed species. A highly significant reduction in the number of pigweeds, ragweed, and annual grasses was found in the treated plots. LS-0237 gave the highest percent control of pigweed and ragweed. The percent control obtained in the grasses was the highest of any of the weed groupings. LS-0133, LS-0150, and LS-0155 gave the highest percent control of grasses of the treatments. Highly significant reductions in the number of purslane and plantian plants were found in

TABLE XIII

NUMBER OF WEEDS AND PERCENT CONTROL FOLLOWING APPLICATIONS OF HERBICIDAL OILS

Oil Used	Weed Groupings[1] A No.per sq.ft.	A % control	B No.per sq.ft.	B % control	C No.per sq.ft.	C % control	D No.per sq.ft.	D % control	E No.per sq.ft.	E % control	Total No.per sq.ft.	Total % control
LS-0133	.87**	56	.15**	95	1.54**	73	.39	66	.09	48	3.05**	75
LS-0150	.96**	51	.16**	95	1.58**	72	.44	63	.17	4	3.31**	73
LS-0152	.70**	64	.39**	88	2.27**	60	.32	73	.07	60	3.75**	69
LS-0155	.98**	50	.24**	93	1.81**	68	.52	55	.05*	72	3.59**	71
LS-0237	.54**	72	.41**	88	2.34**	59	.52	55	.17	4	3.98**	65
LS-0238	.98**	49	.57*	83	2.32**	59	.57	52	.14	20	4.57**	63
LS-6580	1.10**	44	.52**	84	2.71**	53	1.57	0	.09	52	5.99**	51
Untreated	1.94		3.27		5.71		1.18		.18		12.27	
LSD 1%	.59		.98		2.64		1.19		.5		4.95	
LSD 5%	.44		.73		1.96		.89		.12		3.62	

[1]Weed Grouping:

A. Pigweed (*Amaranthus retroflexus* L.)
   Ragweed (*Ambrosia artemisiifolia* L.)
B. Annual grass (*Digitaria sanguinalis* (L.) Scop.)
   (*Setaria lutescens* (Weigel) F. T. Hubb)
   (*Setaris viridis* (L.) Beauv.)
   (*Echinochloa crusgalli* (L.) Beauv.)
C. Purslane (*Portulaca oleracea* L.)
   Plantian (*Plantago* spp.)
D. Lamb's quarter (*Chenonodium album* L.)
E. Miscellaneous weeds (*Oxalis stricta* L.)
   (*Polygonum persicaria* L.)
   (*Cirsium arvense* (L.) Scop.)

all treated plots. LS-0133 and LS-0150 gave the highest percent control of purslane and plantian. The lamb's quarters was not reduced significantly in the treated plots compared with the untreated but all treatments were less, significantly, than treatment LS-6580. LS-0152 gave the highest per cent control of lamb's quarters. Considering all weeds the treatments gave a highly significant decrease in the number of weeds. LS-0133 and LS-0150 gave the highest percent control of total weeds.

Table XIV gives the yields obtained when LS-0237 was applied at 10 gallons per acre as a basal stem spray to 5 kinds of beans at different stages of growth under field conditions. A significant reduction in yield occurred when 2 applications were made on the field beans and a significant increase in yield occurred when the application was made in the first trifoliate leaf stage of growth. Treatments at the time the

TABLE XIV

YIELDS FOLLOWING APPLICATION OF LS-0237

Stage of Growth	Yields in Pounds Per Acre				
	Soybeans	Field Beans	Lima Beans	Wax Beans	Green Beans
Unifoliate lead	1786	1143	3857	2643	4714
1st.trifoliate leaf	1429	1500*	5714	2786	7571
3rd.trifoliate leaf	1857	1143	3929	2214	5429
Flower Bud	1857	1000	3786	1786	5143
Unifoliate leaf + 1st.trifoliate leaf	1714	857*	4214	2071	5929
Untreated	1714	1214	5571	2571	6286
LSD 1%		393			
LSD 5%		279			

first trifoliate leaf had developed appear to have increased the yield in the lima, wax and green beans, but the differences were not statistically significant. The weeds were controlled better when the treatments were applied when the first trifoliate bean leaves had developed. Improved early weed control probably increased the yield even though the surviving weeds were removed by hoeing early in the season. Table XV gives the number of plants surviving the treatments at different stages of growth in the field and lima bean plots. The number of plants was significantly reduced in the field bean plots by all treatments except those applied in the first trifoliate leaf stage. There were more bean plants per row when the lima beans were treated at the first trifoliate leaf stage but this difference did not prove significant. The double application gave the greatest reduction in the number of plants.

TABLE XV

NUMBER OF PLANTS PER FOOT FOLLOWING APPLICATION OF LS-0237

Stage of Growth	Kind of Beans	
	Field Beans	Lima Beans
Unifoliate leaf	1.95*	.69
1st trifoliate leaf	2.54	.84
3rd trifoliate leaf	1.88*	.61
Flower bud	1.92*	.71
Unifoliate leaf + 1st trifoliate leaf	1.62*	.50
Untreated	2.42	.79
LSD 1%	.62	
LSD 5%	.44	

Observations made after spraying indicated that some of the bean seedlings were killed when sprayed in the unifoliate leaf stage. Observations made on August 29 indicated that some injury occurred in all 5 kinds of beans when the treatments were applied at the third trifoliate leaf and flower bud stages. Lima beans were injured when the oils were applied at the first trifoliate leaf stage. Spraying the bean stems without injuring the leaves at the later stages of growth was very difficult to accomplish in the field, lima, wax, and green beans.

Examination of stem cross sections showed that the double application caused injury on all kinds of beans. No injury was found in the other treatments in soybean, field, bean, and wax bean plots. Treatments at all stages of growth, except the flower bud stage, caused surface injury in lima, and green beans. Internal injury was found in sections of green bean stems sprayed in the unifoliate leaf stage and in lima bean stems sprayed in the third trifoliate leaf stage.

Yields obtained from 5 kinds of beans, basal stem treated with LS-0237 at 5, 10, and 20 gallons per acre, under field conditions are given in table XVI. There were no significant differences between yields

TABLE XVI

YIELDS FOLLOWING APPLICATION OF LS-0237

Treatment	Yield in Pounds Per Acre				
Gal./Acre	Soybeans	Field Beans	Lima Beans	Wax Beans	Green Beans
5	2071	1571	4929	5214	6714
10	2000	1357	5429	5786	6214
20	2000	1643	3714	4643	6786
Untreated	2000	1357	3714	4286	6571

No significant difference between treatments.

but observations made on August 29 showed that some injury occurred at the 20 gallon per acre plots in all beans. Severe injury was noted in the lima bean plot when LS-0237 was applied at 20 gallons per acre and some injury occurred in the 10 gallon per acre treatments.

Examination of stem cross sections showed surface injury in the 20 gallon per acre treatment in all beans except field beans. Injury was also noted in lima and green bean sections treated at the 10 gallons per acre rate.

Table XVII gives the number of grass and broad-leaved weeds per square foot and percent control after basal stem treatment with LS-0237 at 5, 10, and 20 gallons per acre on 5 kinds of beans. Highly significant reduction in the number of broad-leaved weeds was obtained with all treatments but there was no significant difference between rates. The percent control of broad-leaved weeds was highest in the 10 gallon per acre plots. The number of grasses was significantly reduced in the

TABLE XVII

NUMBER OF WEEDS AND PERCENT CONTROL FOLLOWING APPLICATION OF LS-0237

Treatment Gallons Per Acre	Weeds Per Square Foot and Percent Control			
	Grass	Percent Control	Broad Leaf	Percent Control
5	.32*	47	1.76**	41
10	.19**	66	1.16**	61
20	.21**	63	1.35**	55
Check	.57		3.00	
LSD 1%	.28		.85	
LSD 5%	.20		.61	

5 gallon per acre treatment and highly significantly reduced in the 10 and 20 gallon per acre treatments. The percent control was greater in the 10 gallon per acre treatment than in the 5 gallon per acre treatment.

The herbicidal oils that had given favorable results in field tests were used in greenhouse tests to further determine the effects of the oils upon the bean plants and weeds. Table XVIII gives the dry weights in grams per pot of stems and roots of beans grown in pots in the greenhouse and basal stem treated with 5 herbicidal oils at 20 gallons per acre. Neither the weight of the roots or stems gave a significant

TABLE XVIII

DRY WEIGHTS OF STEMS AND ROOTS FOLLOWING APPLICATION OF HERBICIDAL OILS

Oils Used	Dry Weights in Grams Per Pot									
	Soybeans		Field Beans		Lima Beans		Wax Bean		Green Bean	
	Stem	Root	Stem	Root	Stem	Soot	Stem	Root	Stem	Root
LS-0133	4.4	2.4	3.4	3.0	7.6	2.8	3.5	1.8	3.0	1.3
LS-0150	3.5	1.9	2.1	2.0	5.3	2.6	2.2	.9	2.8	.7
LS-0152	5.0	2.7	3.0	3.1	5.7	1.8	2.6	1.2	3.6	1.0
LS-0155	3.7	2.8	3.5	3.7	4.7	2.6	2.3	1.2	2.8	.7
LS-0237	3.3	2.6	3.1	2.7	5.4	2.4	2.4	.4	3.2	.6
Untreated	4.8	3.1	5.3	2.0	7.7	2.5	2.7	.6	2.9	.7

No significant difference between treatments.

difference between treated and untreated beans. Table XIX gives the bean and weed injury ratings for this same experiment and the number of nodules per pot for the green beans. Photographs of bean injury in this test are in the appendix, figures 1-4. LS-0155 appeared to injure the

TABLE XIX

INJURY RATINGS FOLLOWING APPLICATION OF HERBICIDAL OILS

Oils Used	Injury Ratings[1]										Green Bean Nodules /Pot
	Soybean		Field Bean		Lima Bean		Wax Bean		Green Bean		
	Bn[2]	Wd[3]	Bn	Wd	Bn	Wd	Bn	Wd	Bn	Wd	
LS-0133	7	12	6	12	6	12	4	12	4	10	48
LS-0150	8	9	8	7	7	12	3	12	5	12	39
LS-0152	6	12	4	10	5	9	3	12	4	12	30
LS-0155	4	12	2	9	2	12	1	12	2	8	20
LS-0237	2	11	7	12	8	12	9	12	5	12	21
Untreated	1	1	1	1	1	1	1	1	1	1	60

[1]Injury ratings: 1 = no effect, 12 = complete kill
[2]Bn = bean
[3]Wd = weed

field, lima, wax, and green beans less than the other oils. LS-0237 appeared to injure the soybeans least. There was little difference between treatments in the weed injury but LS-0237 and LS-0152 appeared to be slightly higher in weed toxicity. The number of nodules per pot of green beans appeared to be less in the treated pots but the difference was not statistically significant.

A greenhouse test was conducted to determine the effect of oil application to beans when their stomata were open, and again when the stomata were closed. The soybeans that were lighted at night had stomata that were 80 percent closed while the soybeans that were in the dark had mostly open stomata. The bean injury ratings, number of plants surviving and dry weights obtained when LS-0237 was applied at 20, 40, and 60 gallons per acre as a stem treatment to soybeans with open and closed stomata are given in Table XX. At the 20 gallons per acre rate the injury ratings indicated more injury occurred when the stomata were open during spraying and this proved significant. Fewer of the plants survived when they were sprayed with their stomata open. The dry weight per pot appeared to be less when the plants were sprayed with the stomata open but this was not statistically significant.

TABLE XX

BEAN INJURY RATINGS, NUMBER OF PLANTS SURVIVING FOLLOWING APPLICATION OF LS-0237

Amount of Oil Used	Bean[1] Injury Rating		Number of Plants Surviving		Dry Weight Grams Per Pot	
	Stomata		Stomata		Stomata	
Gals./Acre	Open	Closed	Open	Closed	Open	Closed
20	8.0*	4.5*	3.5	5.8	2.0	3.2
40	9.5	8.0	2.5	2.8		
60	10.5	10.5	2.2	1.2		
Untreated	1	1	6.0	6.0	4.0	3.6

[1]Injury ratings: 1 = no effect, 12 = complete kill.

Table XXI gives the number of weeds and percent control after treatment of 3 weeks old weeds in greenhouse flats with LS-0237 at 5, 10, and 20 gallons per acre. At the 5 gallon per acre rate, lamb's quarters, legumes, smartweed, and mouse-ear chickweed were the only weeds on which less than 90% control was obtained. At the 10 gallon per acre rate, lamb's quarters was the only weed not controlled to the extent of 90% or better. All weeds were killed at the 20 gallon per acre rate. When all weeds are considered, 5, 10, and 20 gallon per acre

TABLE XXI

NUMBER OF WEEDS AND PERCENT CONTROL FOLLOWING APPLICATION OF LS-0237

Kind of Weed[1]	Gallons of Oil Per Acre						
	Untreated	5		10		20	
	Number	No.	% control	No.	% control	No.	% control
Grass	13.19	1.18	91	.29	98	0.00	100
Lambs-quarter	15.15	4.71	69	1.62	89	0.00	100
Legume	3.24	1.32	61	0.00	100	0.00	100
Oxalis	1.47	0.15	90	0.00	100	0.00	100
Smart Weed	2.06	0.44	79	0.15	93	0.00	100
Mouse-ear Chickweed	.74	0.15	80	0.00	100	0.00	100
Bull Thistle	.44	0.00	100	0.00	100	0.00	100
Total	36.18	7.95	78%	2.06	94%	0.00	100%

[1]Kind of Weed: Grass (*Poa pratensia* L.)
(*Digitaria sanguinalis* (L.) Scop.)
(*Dactylis glomerata* L.)
(*Setaria* spp.)
Lamb's quarters (*Chenopodium album* L.)
Legume (*Melilotus*, *Medicago* and *Trifolium* spp.)
Oxalis (*Oxalis stricta* L.)
Smart Weed (*Polygonum Persicaria* L.)
Mouse-ear chickweed (*Cerastium vulgatum* L.)
Bull thistle (*Cirsium lanceolatum* (L.) Hill)

of LS-0237 gave 78, 94, and 100 percent control, respectively. Photographs of the treated flats are in the appendix, figure 16.

Table XXII gives the number of weeds per square foot and percent control obtained when 5 herbicidal oils were applied at 10 gallons per acre to 3 week-old weeds grown in flats in the greenhouse. The oils did not give a high percent of control of large crabgrass but this was probably due to additional germination after treatment. LS-0237 gave the

TABLE XXII

NUMBER OF WEEDS AND PERCENT CONTROL FOLLOWING APPLICATION OF HERBICIDAL OILS

Kind of Weeds	Untreated	LS-0133		LS-0150		LS-0152		LS-0155		LS-0237	
	No. of Weeds	No. of Weeds	% Control	No. of Weeds	% Control	No. of Weeds	% Control	No. of Weeds	% Control	No. of Weeds	% Control
Kentucky Blue Grass	18.1	5.1	72	6.3	65	4.3	76	10.4	42	2.9	80
Large Crabgrass	30.6	19.0	38	21.6	29	19.7	36	21.8	29	20.0	34
Foxtail	1.5	.9	40	.7	50	.7	50	.3	80	.6	60
Lambsquarter	31.9	5.9	84	7.8	76	3.7	86	12.5	61	1.8	94
Legumes	37.8	2.4	94	4.4	88	3.5	91	14.6	62	1.6	96
Pigweed	40.6	10.7	74	11.9	71	5.0	88	12.1	70	6.8	83
Ragweed	4.4	3.8	13	5.3	0	3.8	13	8.2	0	5.0	0
Smart Weed	19.0	4.3	78	4.9	74	3.7	81	5.1	73	5.0	74
Shepard's Purse	3.1	.7	76	.3	90	0.0	100	1.8	49	.3	90
Oxalis	3.7	1.0	72	1.3	64	1.3	64	.9	76	.4	88
Potentilla	3.2	.4	86	.7	77	.9	73	1.3	59	.4	86
Curled Dock	2.9	.6	80	.9	70	.1	95	0.0	100	.1	95
Yellow Rocket	1.5	.1	90	2.6	0	.6	60	.7	50	1.5	0
Dandelion	.6	0.0	100	0.0	100	0.0	100	0.0	100	0.0	100
White Cockle	1.6	0.0	100	.1	91	0.0	100	.3	82	0.0	100
Total of all Weeds	200.9	55.0	73	69.0	66	47.4	76	90.3	55	47.4	76

[1]Kind of Weed:

Kentucky bluegrass (Poa pratensis L.)
Large Crabgrass (Digitaria sanguinalis (L.) Scop)
Foxtail (Setaria spp.)
Lambsquarter (Chenopodium album L.)
Legumes (Melilotus, Medicago, and Trifolium spp.)
Pigweed (Amaranthus spp.)
Ragweed (Ambrosia artemisiifolia L.)
Smart weed (Polygonum Persicaria L.)
Shepherds Purse (Capsella Bursa pastoris (L.) Medic)
Oxalis (Oxalis stricta L.)
Potentilla (Potentilla recta L.)
Curled Dock (Rumex crispus L.)
Yellow Rocket (Barbarea vulgaris R.Br.)
Dandelion (Taraxacum officinale Weber)
White Cockle (Lychnis alba Mill.)

highest percent control of Kentucky bluegrass, lamb's quarters, legumes and oxalis. LS-0155 gave the best control of foxtail and curled dock. LS-0152 gave the best control of pigweed, smart weed and shepherd's purse. Ragweed appeared to be very resistant to oil treatments. LS-0152 and LS-0237 gave the best total weed control. LS-0150 and LS-0155 gave the poorest total weed control.

DISCUSSION

The use of oils as herbicides dates back to the early 1900's. Research workers found that certain oil fractions were phyto-toxic and oils were developed for selective weed control. Later, oils were used as directed sprays on onions, cotton, and soybeans.

Typical oil injury observed on the bean plants when a toxic oil was applied to the lower 1 inch of the stem was a wilting of the plant similar to that in a plant suffering from a lack of water. The leaves and stems were limp and the treated area appeared watersoaked. Apparently, the oil destroyed the semi-permeability of the cell membranes and interrupted the water transfer to the leaves. If the entire plant was not killed, the treated area was severely burned and turned a dark brown. Two toxic oils caused a weakening of bean stems in field tests. Examination of cross sections of beans stems treated in the field indicated that injury to the epidermis and cortex or an internal injury occurred. The surface injury was characterized by a breakdown of some cells in the epidermis and cortex and a reversion of the adjacent cells to meristematic activity with a formation of a periderm layer. The internal injury was characterized by a breakdown of cells in the cortex, phloem and vascular cambium with adjacent cells reverting to meristematic activity and forming a periderm layer. The internal injury was of the same type as the surface injury but was a result of deeper penetration into the stem.

The injury to the vascular cambium could cause an interruption in water movement within the plant.

Field tests conducted in 1953 and 1954 with basal stem directed oil applications gave no significant reduction in yield in the 5 kinds of beans tested. LS-0133 (90% mineral spirits, 10% Indocene 70), LS-0150 (90% mineral spirits, 10% Indosolvent 2), LS-0152 (85% mineral spirits, 15% Indocene 70), LS-0155 (40% mineral spirits, 40% alkylate, 20% Indosolvent 2) and LS-0237 (Heavy Naptha) gave good weed control with 1 treatment at 10 gallons per acre as 6 inch band treatments in 22 inch rows and gave little injury to the beans. LS-0152 and LS-0237 gave the best weed control but with slightly more injury to the beans. Grasses were controlled better than other weeds by oil treatments. Ragweed (Ambrosia artemisiifolia L.) was resistant to herbicidal oils. Lamb's quarters (Chenopodium album L.) was somewhat resistant to herbicidal oils and some tests indicated that if the oil spray did not reach the terminal growing points, the plants were not killed.

Experiments in the field and greenhouse, on the amount of oil to apply, indicated that additional bean injury occurred when 20 gallons per acre of the oil was applied compared with the 5 and 10 gallon per acre rates; however, no significant yield reduction was found. In the greenhouse tests, 5 and 10 gallon applications of LS-0237 gave 78 and 90 percent control, respectively, of all weeds. In field tests, 5 gallons per acre applications of LS-0237 gave 47 percent grass control and 41 percent broad-leaved weed control while 10 gallons per acre applications gave 66 percent grass control and 61 percent broad-leaved weed control. Twenty gallon per acre applications of LS-0237 gave no better weed control than the 10 gallon per acre rate. The rate of application tests indicated that if weeds were small, a low volume gave excellent control but larger weeds required a greater volume of spray to obtain satisfactory control.

Stage of growth experiments in the greenhouse and field indicated that susceptibility to oil injury increases with the age of the plant. No significant reduction in yield occurred when the beans were sprayed at different stages of growth. Before the plant had developed its first trifoliate leaves it was difficult, mechanically, to apply oil to the stems without causing leaf injury. After the field, lima, wax and green beans had developed their third trifoliate leaf, placement of the oil under the leaves was very difficult. The best weed control was obtained when the beans were sprayed in the first trifoliate leaf stage.

Repeated applications of LS-0237 did not cause a significant reduction in yield but more bean injury occurred than with single applications. Repeated applications did not cause significantly weaker bean stems in greenhouse tests.

Applications of LS-0237 in 60, 70 and 80° F. temperatures indicated that least injury occurred with the 60° F. application when 20 gallons per acre were applied as basal stem treatments in the greenhouse. Tests with LS-0237 applied as basal stem treatments to soybeans with stomata open and closed indicated that more injury occurred when stomata were open.

The beans were rated in order of decreasing oil resistance as follows: field beans, soybeans, waxbeans, green beans, and lima beans.

Heavy Naphtha (Boiling range 302-395^{o} F., 19% aromatics) and a mixture of 85% mineral spirits and 15% Indocene 70 show promise for use on beans as a basal stem spray for post-emergence weed control. Oils can be applied to stems of beans without injury to the leaves with a sprayer that has nozzles directed horizontally toward the base of the bean stem with a floating shield protecting the upper portion of the plant.

For the best weed control, and to facilitate application, oil sprays should be applied when the plant has the first trifoliate leaf. An additional application can be made a week or more later but applications without leaf injury may be difficult with field, lima, wax and green beans. Applications made in temperatures of 60^{o} F. give less bean injury. Ten gallons per acre applied in 6 inch bands on rows 22 inches apart will give 70-80 percent control of weeds. Grasses are controlled better than broad-leaved weeds Ragweed is not controlled by oil sprays and lamb's quarters has to be sprayed when less than 1 1/2 inches high to be effectively controlled.

Some burning of the bean stems occurs with oil application but there is no reduction in yield. Lima beans are injured more than other beans from oil sprays.

SUMMARY

1. Soybeans (Glycine max, variety Hawkeye), field beans (Phaseolus vulgaris, variety Michelite), lima beans (Phaseolus lunatus, variety Fordhook Dwarf), wax beans (Phaseolus vulgaris, variety Pencil Pod Wax), and green beans (Phaseolus vulgaris, variety Tendergreen Bush) were basal stem treated with herbicidal oils and the effect of the oil upon the beans and weeds was determined.

2. The herbicidal oils were applied manually in the greenhouse with a small DeVilbis sprayer and in the field with a power driven sprayer that was designed to apply the oil at the base of the bean stems.

3. The effects of the herbicidal oils were determined by yields of beans, dry weight of the bean plants in the greenhouse, injury ratings, microscopic examination, and weed counts.

4. Thirty-two experimental oils were screen tested for weed control and injury to the beans.

5. The following experimental oils gave good weed control with little injury to the bean plants when applied with the power driven directed spray sprayer.

a. LS-0133 (90% mineral spirits, 10% Indocene 70)
b. LS-0150 (90% mineral spirits, 10% Indosolvent 2)
c. LS-0152 (85% mineral spirits, 15% Indocene 70)
d. LS-0155 (50% mineral spirits, 40% alkylate, 20% Indosolvent 2)
e. LS-0237 (Heavy naphtha)

6. No significant reduction in yield occurred when the herbicidal oils were applied at 10 gallons per acre in a 6 inch band treatment

on rows 22 inches apart. Approximately 75% of the weeds were controlled.

7. Examinations of cross sections of the bean stems treated in the field indicated that oil injury may occur to the epidermis, cortex, phloem, and vascular cambium cells.

8. Oil injury from a toxic oil was observed as a wilting of the plant similar to that of a plant suffering from the lack of water. The treated stem area appeared watersoaked and later turned brown.

9. Grasses were controlled more readily than broad-leaved weeds with oil treatments. Ragweed (Ambrosis artemisiifolia L.) was resistant to oil and lamb's quarters (Chenopodium album L.) required complete coverage of the terminal growing point for control.

10. Twenty gallons per acre of LS-0237 caused some additional bean injury and gave no better weed control than 10 gallons per acre while 5 gallons per acre gave less weed control.

11. A repeat application of LS-0237 caused some additional injury but the yield was not reduced significantly.

12. Tolerance for oil spray in beans was greatest at the unifoliate leaf stage. Localized injury occurred on older beans but no reduction in yield was observed.

13. The first trifoliate leaf stage was best from the standpoint of mechanical application of oil and gave the best weed control.

14. Twenty gallons per acre of LS-0237 applied at 60° F. gave less bean injury than when applied at 70° and 80° F.

15. Twenty gallons per acre of LS-0237 applied to soybean stems gave significantly less injury when applied to stems with closed stomata.

16. The beans in order of decreasing oil tolerance are: field beans, soybeans, wax beans, green beans, and lima beans.

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APPENDIX

EXPERIMENTAL HERBICIDAL OILS AND DATA ON
THEIR COMPONENTS AND PROPERTIES

Code Numbers	Composition	Boiling Range Degree F.	Aniline Point Degree C.	Percent			
				Aromatic	Olefin	Naph-thene	Paraf-fin
LS- 0132	85% Mineral spirits, 15% Indosolvent 2			23.4			
LS-0133	90% Mineral Spirits, 10% Indocene 70			18.5			
LS-0147	El Dorado Heavy Naphtha	223-404		16.5	trace	18.5	65
LS-0150	90% Mineral Spirits, 10% Indosolvent 2			18.9			
LS-0151	80% Mineral Spirits, 20% Indosolvent 2			27.8			
LS-0152	85% Mineral Spirits, 15% Indocene 70			22.7			
LS-0153	80% Mineral spirits, 20% Indocene 70			27.0			
LS-0154	40% Mineral spirits, 40% Alkylate, 20% Indosolvent 2			23.8			
LS-0155	40% Mineral spirits, 40% Alkylate, 20% Indocene 70			23.0			
LS-0178	50% Mineral spirits, 50% Alkylate			5.0			
LS-0235	Octane						100
LS-0237	Heavy Naphtha	302-395		19.0	trace	19.5	61.5
LS-0238		306-384		21.5	trace	41.5	37.0

(Continued)

Code Numbers	Composition	Boiling Range Degree F.	Aniline Point Degree C.	Percent Aromatic	Olefin	Naphthene	Paraffin
L-3388	Stoddard Solvent	316-390					
L-6419	Indocene 90	400-475	16	79.2			
L-6580	VM&P Naphtha	205-325	55.8	14.0			
L-6581	High-flash VM&P Naphtha	295-372	56.1	13.0			
L-6639	Amyl benzene	316-390		100.0			
L-6640	N-Decane	316-390					100
L-6840	25% Amyl benzene 75% No. 10 base oil			25.0			
L-6841	25% mono amyl-benzene, 75% Regular oleum spirits			35.5			
L-7297	25% Indocene 70 75% Stoddard Solvent			32.0			
L-7565	Mineral Spirits	316-406	59.4	10.0			
L-7710	Indocene 70[1]	290-410	17.1	100.0			
L-7718	Indosolvent 2[2]	270-310	14.7	100.0			
L-7934	Emulsifiable Indocene 70			97.0			
L-8712	Dodecane						100
L-8949	10% trimethyl-benzene, 90% tetradecane			9.4			
L-8950	15% trimethyl-benzene, 85% tetradecane			14.1			

(Continued)

Code Numbers	Composition	Boiling Range Degree F.	Aniline Point Degree C.	Percent Aromatic	Olefin	Naph-thene	Paraf-fin
L-8951	10% tetramethyl-benzene, 90% tetradecane						
L-8952	15% tetramethyl-benzene, 85% tetradecane						
L-2988	No. 10 base oil	350-487	73.4	0.0			
L-246	Regular oleum spirits	310-425	59.7	12.5			

[1]Indocene 70
- 4% toluene
- 32% meta, para, and ortho xylene
- 21.5% 1,3,5, trimethylbenzenes
- 24.5% 1,2,4 trimethylbenzenes
- 6.5% 1,2,3 trimethylbenzenes
- 11.5% other aromatics

[2]Indosolvent 2
- 64% ortho, meta, and para xylenes
- 23% ethylbenzene
- 4% C_8 paraffins
- 9% Primarily aromatics

Figure 1 Pot on left: Green bean plants, basal stem treated with LS-0237 in the greenhouse, showing typical oil injury 2 months after treatment.

Pot on right: Untreated green bean plants.

Figure 2 Pot on left: Wax bean plants, basal stem treated with LS-0237 in the greenhouse, showing typical oil injury 2 months after treatment.

Pot on right: Untreated wax bean plants.

Figure 3 Pot on left: Lima bean plants, basal stem treated with LS-0237 in the greenhouse, showing typical oil injury 2 months after treatment.

Pot on right: Untreated lima bean plants.

Figure 4 The three soybean plants on the left were treated with LS-0237 in the greenhouse and show typical oil injury 2 months after treatment. Plant on right is untreated.

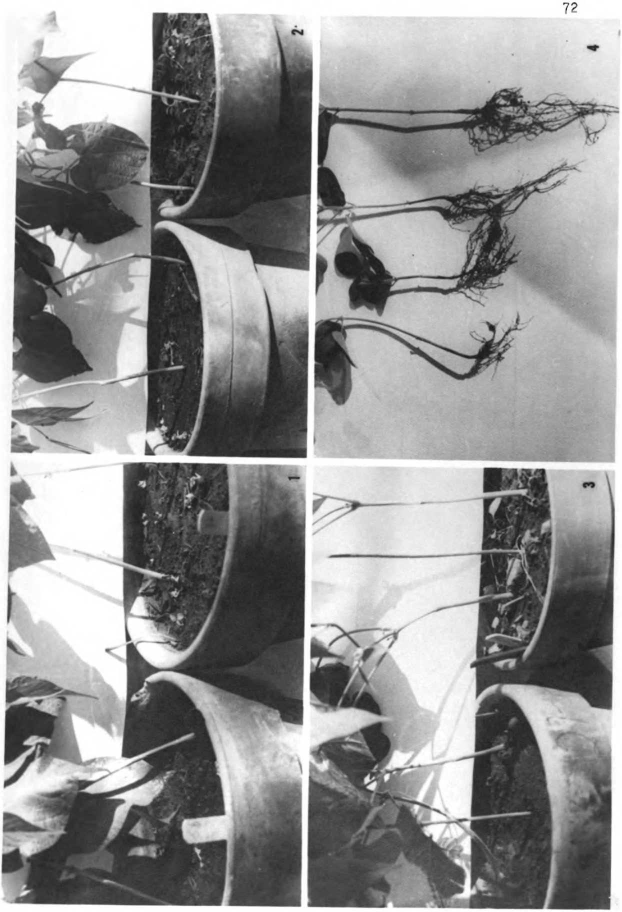
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Figure 5 Cross section of a stem of an untreated soybean plant (X 400)

Figure 6 Cross section of a stem of a soybean plant, basal stem treated with L-7710 in the field, showing typical surface oil injury. (X 400)

Figure 7 Cross section of a stem of an untreated lima bean plant. (X 400)

Figure 8 Cross section of a stem of a lima bean plant, basal stem treated with LS-0237 in the field, showing typical surface oil injury. (X 400)

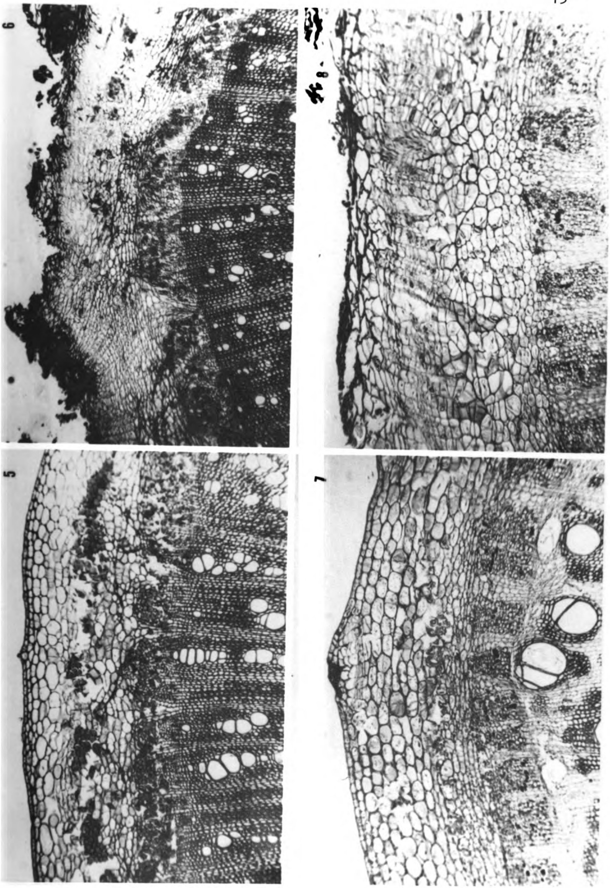
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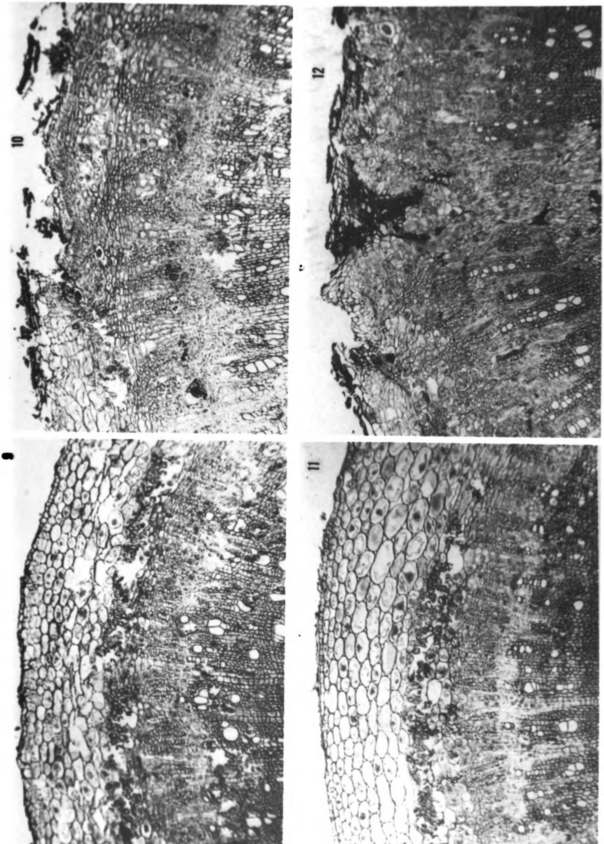
Figure 9 Cross section of a stem of an untreated wax bean plant. (X 400)

Figure 10 Cross section of a stem of a wax bean plant, basal stem treated with L-7710 in the field, showing typical surface oil injury. (X 400)

Figure 11 Cross section of a stem of an untreated green bean plant. (X 400)

Figure 12 Cross section of a stem of a green bean plant, basal stem treated with L-7297 in the field, showing internal oil injury. (X 400)



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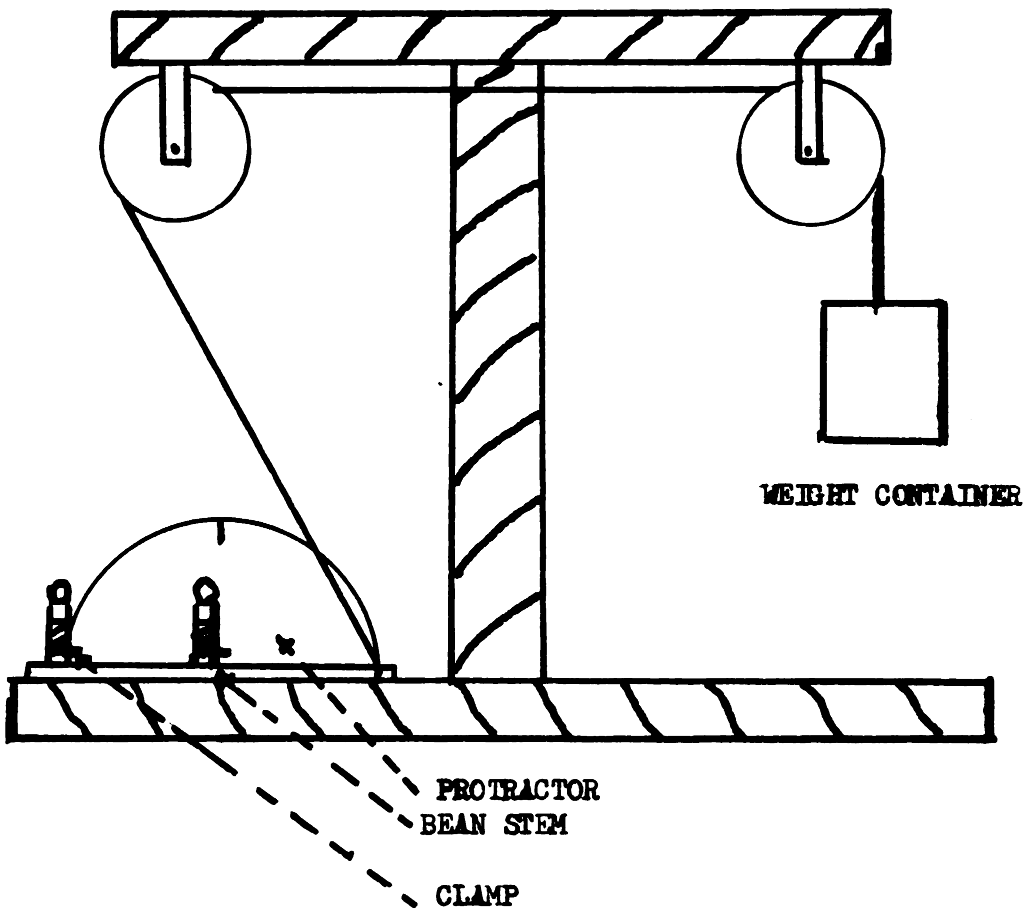

Figure 20 Apparatus to measure strength and resilience of bean stems.