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Title: ACTIVATED CARBON FOR IMPROVING DIURON SELECTIVITY IN BEANS

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Activated carbon is effective in protecting beans from herbicide injury. In a field study, diuron [3-(3, 4-dichlorophenyl)-1-1-dimethyl urea], linuron [3-(3, 4-dichlorophenyl)-1-methoxy-1-methylurea], fluometuron [1, 1-dimethyl-3-(α, α, α-trifluoro-m-tolyl) urea], and metobromuron [3,(p-bromophenyl)-1-1-methoxy-1-methyl urea] were used to determine the effectiveness of a one-inch band of activated carbon (Aqua Nuchar A) applied over the bean (Phaseolus vulgaris L.) row in protecting the crop from herbicide injury. Activated carbon was applied at 0, 150 and 300 pounds per acre, broadcast basis, while diuron, linuron, fluometuron and metobromuron were applied at rates of 1.0 and 2.0, 2.0 and 4.0, 1.0 and 2.0, and 1.0 and 2.0 lbs/acre, respectively. The results obtained showed that when activated carbon was used as a band treatment of one inch over the row (broadcast basis) at a rate of 150 pounds per acre, prior to herbicide application, good crop protection was obtained for all herbicide treatments at all

rates. However, the activated carbon also protected that weeds that germinated under the carbon band.

In the greenhouse, the influence of band width was determined by applying 0, 150 and 300 pounds per acre of carbon in bands of 1.0 and 3.0 inches in width. A carbon band of 1.0 inch provided adequate protection to the beans for all rates tested. No injury was observed in either the roots or the shoots, for all rates tested.

The effectiveness of activated carbon in protecting four plant species, beans, ryegrass (Lolium perenne Var. Linn L.), pigweed Amaranthus retroflexus L.) and barnyardgrass (Echinochloa crusgalli (L) Beauv) from diuron injury was also determined in a greenhouse experiment. It was found that activated carbon to diuron ratios of 100:1 were effective in protecting the four species tested.

Experiments with 2-gram "packets" of vermiculite with carbon showed that beans were protected from diuron injury only when the packet contained carbon. Application of activated carbon mixed in with a vermiculite "packet" was as effective as applying the carbon in a one-inch band over the row.

In an experiment involving alternate wetting and drying of activated carbon no decrease of the adsorptive capacity of the carbon was observed. In the laboratory the adsorption of diuron at 7, 10 and 20 ppm by four commercial types of activated carbon (Aqua Nuchar A, Darco-M, Gro-Safe and Pittsburg No. 3) was determined.

The results indicated that differences exist between different carbon sources. The greater the surface area of the carbon, the greater its adsorptivity. Desorption studies with diuron at 20 ppm and four different activated carbon sources showed that the degree of desorption also varied between the carbon sources.

Activated Carbon for Improving Diuron Selectivity in Beans

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INTRODUCTION

Oregon is one of the leading states in the production of snap beans (*Phaseolus vulgaris* L.) in the United States with 30,000 acres planted in 1971, yielding an average of 4.14 tons per acre. Of the various pests, weeds are a major pest for Oregon bean growers. In addition to decreasing yields substantially, weeds can affect the quality of the crop as well as increase the costs of production.

With selective herbicides the farmer has been able to control weeds effectively in bean crops. However, through the continued use of these herbicides, weeds of marginal resistance and those resistant to the herbicides being used have flourished. In order to control these weeds, either higher rates of the same herbicides being used or new herbicides will have to be developed. Another alternative is the use of other practices such as cultural and mechanical weed control.

Since many of the herbicides currently being used for weed control in beans are only relatively selective to this crop, higher rates could cause crop injury. New herbicides being developed are not currently available so a third option could be to devise methods by which currently available herbicides too toxic for direct use for weed control in beans can be used in this crop selectively.

A technique recently developed which allows higher rates of herbicides to be used or the use of herbicides of marginal selectivity involves the use of activated carbon. Selective placement of activated carbon over the crop seed or surrounding it creates a zone free of herbicidal activity since any herbicide coming in contact with the activated charcoal is immediately rendered unavailable to the crop seedling because of the adsorption of the herbicide to the surface of the material.

The use of activated carbon for crop protection has already been made feasible for some crops. In grass seed production, where high purity standards must be met in order to obtain maximum economic returns, activated charcoal has been used effectively over the seed row in order to protect the crop from otherwise toxic herbicides. In sugarbeets and alfalfa, the same concept has been developed, whereby a one-inch band of activated carbon is placed directly over the seed row (12, 14, 21, 23).

In addition to the direct benefits derived from increased selectivity, activated carbon also allows the use of less selective but cheaper and perhaps less persistent herbicides.

Since substituted ureas have marginal selectivity in beans and at times cause crop damage, experiments were conducted to determine the benefits that could be derived from the use of activated carbon for increased selectivity.

LITERATURE REVIEW

When herbicides are applied to soil systems, a number of factors determine their fate. Among the most important ones are chemical, microbial, and photochemical decomposition, volatilization, leaching, plant uptake, and adsorption by soil particles and soil organic matter (10). Adsorption, the theme of this study, is one of the main factors affecting the availability of a given herbicide to plants.

In order to visualize the behavior of a particular herbicide in the soil and in order to understand the effect of activated carbon on its performance, an understanding of the concept of adsorption is essential.

Adsorption is a surface phenomenon in which a force field displayed by a given surface exerts its influence on neighboring molecules or ions. The specific interaction between a given surface and a given molecule or ion can be brought about by ionic bonds, hydrogen bonds, covalent bonds or van der Waal forces. Since these bonds are the same as those that constitute chemical bonds, the phenomenon of adsorption can be considered a physical-chemical one which can be described in mathematical terms (10).

The main factors which determine the extent and strength of adsorption are (a) the nature of the adsorbing substance, including its number of charges per unit area, type of charges, and its porosity, shape and configuration; (b) the soil solution, in particular the pH and the relative proportion of the different molecules and ions present; (c) the temperature and (d) the nature of the molecule or ion in question, including its charge, hydration, formulation, and type of bonds it forms (10).

In soil systems there are four major solid components: sand, silt, clay and organic matter. Of these, because of their great surface area and charge per unit area, the clay and organic matter fractions are the primary constituents involved in the process of adsorption. This process is a natural phenomenon in soils, accounting for the retention and release of ions necessary for normal plant growth. The capacity to attract and retain ions in an exchangeable manner is called the ion exchange capacity and is usually expressed in milliequivalents of ions adsorbed per 100 grams of soil (13).

Of the mineral soil constituents responsible for adsorption, various major types of clay groups occur predominantly in the temperate regions of the world. These are represented by kaolinite, montmorillonite, illite and vermiculite. These differ in structure, composition, charge per unit area and surface available for adsorption. The cation exchange capacity, being related to all these factors, also varies considerably. Of these clays, vermiculite and montmorillonite have the greatest exchange capacity (100 to 150 and 80 to 150 meq/ 100 grams, respectively) while illite and kaolinite, in contrast, have a relatively low exchange capacity (10 to 40 and 3 to 15 meq/100 grams, respectively).

Of the organic soil constituents, humus is the primary one involved in adsorption (exchange capacity of 200 to 400 meq/100 grams). The relatively high adsorptivity of montmorillonite and vermiculite is due to their greater surface area, and hence, available charges. The humic portion of the soil has a high exchange capacity because of its high charge density (10, 15).

It was previously stated that the main forces involved in adsorption phenomena were due to ionic bonds, hydrogen bonds, covalent bonds and van der Waal forces. The strength and importance of each of these varies with the conditions at the time of adsorption and with the nature of the particle being adsorbed. In general, covalent bonds and ionic bonds are the strongest, followed by hydrogen bonds, and the weakest are interactions involving van der Waal forces. Ions or groups of opposite charge tend to be held by ionic bonds, while polar groups tend to be held together by covalent and hydrogen bonds. Van der Waal forces are important in the adsorption of nonpolar organic molecules such as ethylene glycol, glycerol and ring compounds (5).

Since herbicides applied to soils are subject to adsorption, it is important to know the degree of adsorption and the degree of desorption in order to provide enough available herbicide to perform its function and at the same time retain its selectivity towards the crop. One of the main criteria used when recommending rates of soil-applied herbicides is the adsorptive capacity of the soil. Higher rates are required to obtain weed control in soils of high organic matter and/or high clay content than in soils low in organic matter or of a sandy texture (31).

Activated carbon has many of the properties displayed by the various clays and by humus. It has a large surface area and hence a large capacity for adsorption. These properties allow it to be considered as a tool in such processes as purification of liquid systems whereby impurities are adsorbed by the activated carbon as the liquid filters through it (33).

The pores in the structure of activated carbon range in size from macropores to micropores. The micropores are arranged as tributaries to the macropores and are responsible for the large adsorptive capacity of the carbon. Large molecules are lodged in the macropores while the smaller molecules find their way to the micropores. The porosity of the activated carbon increases its surface area considerably (30).

The nature of the adsorptive forces of activated carbon are van der Waal forces. However, ionic bonds may also be involved since there are carboxyl, hydroxyl and carbonyl groups present (32).

Activated carbon does not occur naturally, at least not in commercial quantities. It must be produced from raw materials by certain specific processes which will give it the required properties. Activated carbon is a porous carbonaceous material of great adsorptive capacity which is made by a process involving carbonizing substances of biological origin and "activating" them. (Activation is a process by which the carbon is endowed with a greater surface area and pore volume giving it greater adsorptive power.) The most commonly used raw materials for the production of activated carbon are sawdust, wood, coconut shells, black ash, charcoal, lignite, petroleum coke and bituminous coal (27). Many processes for activation have been developed and these can be classified in two major groups: thermal activation and chemical activation.

Thermal activation involves heating the raw material to a high temperature (800-900^{o}C) in the presence of an oxidizing gas such as steam or carbon dioxide. The time required for oxidation varies from 15 minutes to several hours depending upon the desired pH and adsorptive power. Within limits, the longer the time of activation, the greater the adsorptive power. Excessive oxidation results in a loss of carbon (1, 17).

Chemical activation consists of heating the carbonaceous material in the presence of dehydrating agents such as sodium sulfate, sodium phosphate or dolomite (9, 33).

When considering an activated charcoal for a filtering process, several of its properties must be taken into account. Among these, the most important ones are adsorptive capacity, amount of extractable solubles, permeability and bulk density. The most important of these is the adsorptive capacity which determines the amount of material that can be retained by the carbon (17).

Permeability depends on the raw material used to make the activated carbon and is determined by particle shape and size. Permeability is an expression of how fast a given liquid can filter through the carbon.

Bulk density of the activated carbon is important because it affects the amount of liquid which a given amount of carbon retains when filterint (17).

With this as a brief background on activated carbon and its basic properties, a review of what has been done with activated carbon in relation to the application of herbicides will be presented.

Adsorption of Herbicides by Activated Carbon and Other Adsorbents

The use of charcoal or activated carbon for the adsorption of herbicides is not recent, having been recommended as far back as 1947 for decontaminating sprayers. Addition of a 1% carbon suspension to the tank of a spayer which had been used for applying 2, 4-D, (2, 4-dichlorophenoxy acetic acid) was effective in eliminating trace amounts of water-soluble forms of 2, 4-D, reducing the risk of damage to relatively susceptible crops sprayed with the same sprayer. Residues of oil formulations were found to be more difficult to eliminate by this method (25).

As the problem of herbicide residues in the soil increased, research was initiated to determine the most feasible methods by which these could be reduced to a nontoxic level. The most practical solution found was the addition and subsequent incorporation of activated carbon into the soil.

The effectiveness of activated carbon in reducing soil herbicide residues depends on the amount of herbicide to inactivated, the nature of the herbicide, the adsorptive capacity and the rate of the carbon applied, the crop to be seeded and the thoroughness of incorporation of the carbon (1, 3).

The thoroughness of incorporation is of utmost importance in determining the efficiency of the carbon. Incorporation with a disc harrow of the herbicide has given satisfactory results when done properly but when incorporation is deficient, herbicide injury results (8).

The nature of the herbicide also influences the degree of effectiveness of the carbon. A comparison of adsorption-desorption isotherms for diquat (1, 1'-ethylene-2, 2'-dipyridylium dibromide) pirazidiinium dibromide), paraquat (1, 1'dimethyl-4-4'-dipyridinium dichloride), prometone (2-methoxy-4, 6-bis[isopropylamino] -s - triazine) and 2, 4-D by charcoal and cation and anion exchange resins showed that prometone and 2, 4-D were adsorbed in greater amounts by charcoal and anion exchange resins than were diquat and paraquat (both cationic compounds) but when filtered through a cation exchange resin, diquat and paraquat were adsorbed in greater quantities than were prometone and 2, 4-D. When temperature was added as a factor, it was found that adsorption of diquat and paraquat increased with a corresponding increase in temperature (15, 31, 32). When clay was used (montmorillonite and kaolinite) it was found that both diquat and paraquat were adsorbed in greater quantities than were the other herbicides. Prometone, in fact, was adsorbed by montmorillonite but not by kaolinite. In general, when comparisons have been made between adsorption of herbicides by clay and activated carbon, more herbicide is adsorbed by activated carbon than by the clays (15, 31, 32).

Within a given family of herbicides, adsorptivity varies considerably. In studies done with phenoxyacetic acids, in addition to differences in solubility due to variations in chloride substitutions, the adsorptivity capacity was found to vary considerably. An increase in chlorine substitutions in the ring increased the adsorptivity of the molecule. Since for this family increased chlorination results in lower solubility in water, an inverse relation was found with adsorption. The less soluble the molecule, the more it is adsorbed (22).

The adsorption capacity of different activated carbons has been demonstrated with atrazine (2-chloro-4-[ethylamino] -6-isopropylamino-s-triazine) and diuron (3-[3, 4-dichlorophenyl] -dimethylurea) and was correlated with degree of activation. Nonactivated carbon was found to have a very low capacity for adsorption while activated carbon was highly adsorptive. Addition of a given amount of non-activated carbon to a 7 ppm diuron solution or to a 5 ppm atrazine solution resulted in only 2.5% adsorption of the herbicides while addition of the same amount of activated carbon to equivalent solutions resulted in 25 to 97% adsorption (19).

When activated carbon is used to detoxify soil herbicide residues the question arises concerning the fate of the herbicide with respect to time. Since the adsorbed herbicide is not available to plants, it follows that it may not be available for decomposition by soil microorganisms.

In studies involving endothal (3, 6-endoxohexahydrophthalmic acid) and DNOC (4, 6-dinitro-o-cresol), it has been shown that endothal is adsorbed weakly by charcoal and breakdown occurs at a normal rate. However, DNOC was found to be more firmly bound to the charcoal and its breakdown was delayed (6). Although the slower breakdown seems to be a negative effect, it appears that even though firmly adsorbed, its gradual release would allow its detoxification in such a manner that free toxic residues would not accumulate (6, 29).

The direct use of activated carbon to improve selectivity of herbicides has been the object of considerable study in the last few years. Interest in activated carbon has risen because it can afford many advantages such as the use of herbicides which are relatively nonselective toward the crop. These herbicides could offer the advantage of being cheaper, less residual and they may control a broader spectrum of weed species than currently used herbicides.

The effectiveness of the activated carbon is based on its ability to serve as a barrier by adsorbing herbicide molecules on its surface, hence rendering them unavailable to crop plants or seeds. Based on this concept, preplant root dips in activated carbon have been used effectively for protecting plants from herbicides. In 1948 it was reported that sweet potato (Ipomoea batatas Lam.) roots could be protected effectively from soil applications of 2, 4-D by dipping the roots in an activated carbon slurry prior to transplanting (7). Today, root dipping of ornamentals is a technique used to protect plants from toxic herbicides. Post-planting soil applications of simazine (2-chloro-4, 6-bis[ethylamino] -s-triazine) at rates from one to six pounds of active ingredient per acre have also been inactivated effectively by activated carbon. The degree of protection afforded, however, varies greatly with the crop and with the rate of simazine applied. Strawberry plants (Fragaria ananassa Duchnesne.) were completely protected by the activated carbon even when six pounds of simazine were used while tomatoes (Lycopersicon esculentum Mill.) were susceptible even to the one pound rate (2).

The carbon can be applied in the transplant water, the roots can be dusted or they can be immersed in a carbon slurry (1, 2, 3, 4). Dipping the roots in a slurry of activated carbon has been found to be more effective than applying the activated carbon as a powder or in the transplant water. This has been demonstrated with simazine and terbacil (3-tert-butyl-5-chloro-6-methyluracil) in strawberries. Young strawberry plant roots retain about one gram of carbon, this amount being sufficient to protect the plants from simazine at 1.5 pounds of active ingredient per acre (29). Scotch pine (Pinus silvestris L.) and white spruce (Picea glauca (Moench, Voss) seedlings have shown a marked increase in tolerance to dichlobenil and simazine, respectively, when their roots were dipped in a slurry prior to transplanting (4).

The activated carbon to herbicide ratio required for herbicide inactivation varies considerably. For simazine and atrazine this ratio is about 200:1 while for bensulide (0, 0-diisopropylphosphorodithioate-s-ester with N-[2-mercaptoethyl benzene sulfamanide]) it is 13:1. With propazine (2-chloro-4, 6-bis[isopropylamino]-s-triazine), ratios of 66:1 were sufficient to protect beans from injury while for picloram (4 amino-3, 5, 6-trichloro picolinic acid), ratios of 3600: 1 were required (11).

It is obvious, then, that although activated carbon will not provide absolute protection to all crops from all herbicides, they certainly broaden the safety margin for a number of them.

In 1956 a new technique was developed. It consisted of selective placement of activated carbon bands, in a subsurface application with special equipment. The experiments were conducted with sugarbeets (Beta vulgaris L.) and a number of herbicides were tested. The subsurface band placement of activated carbon was affected in protecting the beet seeds from injury from diuron, monuron (3-[p-chlorophenyl] - 1, 1-dimethylurea), propham (isopropyl carbanilate) and MCPA (2-methyl-4-chlorophenoxyacetic acid). Partial protection was provided against 2, 3, 6-TBA (2, 3, 6- trichlorobenzoic acid) (28).

Since subsurface band applications require special equipment and are complicated, experiments were conducted to determine the effectiveness of surface band applications of activated carbon compared to the effectiveness of the subsurface applications. In general, it was found that surface applications were equally effective, if not superior, to subsurface applications (12).

Another factor which contributed to the interest in subsurface versus surface applications of carbon were the findings concerning shoot and root entry of herbicides. Although absorption of preemergent herbicides takes place through both seedling roots and shoots, entry to one or the other zones is usually more effective. With subsurface applications, protection was being afforded primarily against herbicides absorbed by the seed and the roots while for those absorbed predominantly by the shoots, protection was erratic. Surface applications overcame this problem since the herbicide is retained at the soil surface and does not affect seedling roots or shoots.

The technique of surface band applications of activated carbon for crop protection against herbicides has gained in importance recently, primarily in the seed crop industry. High purity standards can only be obtained by absolute weed control and this has been nearly achieved by the use of highly active herbicides such as diuron and terbacil. Band applications have been found to be effective in protecting ryegrass (Lolium perenne L.), bluegrass (Poa pratensis L.) and Chewing's fescue (Festuca rubra Gaud.) from terbacil, simazine atrazine and diuron. Of these herbicides, diuron was the most readily inactivated and good weed control was obtained with all of the herbicide treatments (14, 21).

Using the same band technique, alfalfa (Medicago sativa L.) has been protected from broadcast applications of G-36393 (2-isopropylamino-4-[3-methoxypropylamino]-6-methylthio-s-triazine). However, it was found that a number of species were also protected within the band and these, if not controlled, became a serious problem (23).

In addition to surface band applications of charcoal, a technique involving spot treatments of carbon and vermiculite has been studied. In some direct-seeded crops, vermiculite-nutrient packets are used and activated carbon added. This method of protection has been found to be effective in protecting cucumbers (Cucumis sativa L.) from four pounds per acre of simazine and in protecting tomatoes from eight pounds of the same herbicide (20).

In direct-seeded rice (Oryza sativa L.) grown from seed, the rice pelleted in activated carbon was protected effectively from chloramben (3-amino-2, 5-dichlorobenzoic acid), butachlor (2-chloro-2', 6'-diethyl-N-[butoxymethyl] acetanilide), and RP 17623 (tertiobutyl-2-[dichloro-2, 4-isopropyloxy-5-phenyl] -4-oxo-5-oxadiazoline-1, 3, 4). No protection was afforded against diphenamid (N, N-dimethyl-2, 2-diphenylacetamide), diuron, atrazine, prometryne (2-methythio-4, 6-bis[isopropylamino] -s-triazine), ametryne (2-methylthio-4-ethyl-amino-6-isopropylamino-s-triazine), and norea (3-[hexahydro-4, 7-methanoindan-5-yl] -1, 1-dimethylurea) (26).

In order to fully capitalize on the usefulness of activated carbon for crop protection from herbicides, several questions need to be answered. It is obvious from the literature that although a general recommendation could be made for some crops by using a sufficiently high rate of activated carbon, the maximum economic benefit is through the use of optimum levels of carbon, suitable crop protection and effective weed control cannot be obtained until determinations are made regarding the specific characteristics of each carbon. These include the specific adsorptive capacity of the available activated carbons, the relative effectiveness of each with respect to specific herbicides, the level of tolerance or susceptibility of different weed species to different herbicide levels and the margin of safety afforded by each type of carbon to the different crops. For band applications, the required band width for a particular crop and for a given rate of a herbicide must be determined.

EXPERIMENTS

I. Protection of Bean Plants from Injury by Effects of Four Substituted Urea Herbicides with Activated Carbon

The objective of this experiment was to determine the effectiveness of a one-inch band of activated carbon (Aqua Nuchar A) over the seeded row for protecting beans (*Phaseolus vulgaris* L.) from injury from diuron, 3-(3, 4-dichlorphenyl)-1-methoxy-1-methylurea (linuron), 1, 1-dimethyl-3-(α, α, α-trifluoro-*m*-tolyl) urea (fluometuron), and 3-(p-bromophenyl)-1-methoxy-1-methyl urea (metobromuron). These herbicides were chosen because of their different physical and chemical properties such as solubility and molecular composition.

Materials and Methods

The rates of activated charcoal used were 150 and 300 pounds per acre (on a broadcast basis) and the herbicide rates were 1 and 2 pounds of active ingredient per acre of diuron, fluometuron and metobromuron and 2 and 4 pounds of active ingredient per acre of linuron.

The experiment was established on the Oregon State University Vegetable Research Farm, Corvallis, on May 21, 1971. The variety of beans used was OSU 949, the seeding rate per acre was 34 pounds and the seeding depth was 0.75 to 1 inch. The distance between rows was 2 feet. The beans were planted with a tractor-drawn planter and the activated carbon was applied as a slurry directly over the row at the time of seeding. This was accomplished by placing a nozzle immediately behind each press wheel of the planter.

The carbon was applied at a pressure of 5 pounds per square inch using 4004-E-T-Jet (Spraying Systems Co.) for the 150 pound rate and a 4008-E-T-Jet flat fan nozzle for the 300 pound rate. The carbon was suspended in water in a ratio of 1 pound of carbon in 2 gallons of water. The herbicides were applied as a broadcast application after seeding and after the application of the carbon.

The experimental design was a split-plot with four replications. The main plots were carbon rates and the herbicide treatments were subplots. Plot size was 8 feet by 12 feet.

The main criterion used to evaluate the effectiveness of the activated carbon was yield of green beans. Yields were taken from the center two rows of each plot.

In addition to yield data, degree of crop injury was evaluated visually using a rating scale of 0 to 10. A 0 rating represented no injury while a 10 rating represented total crop loss.

Weed control was determined by counts and by visual ratings. Weed counts were taken for pigweed (Amaranthus retroflexus L.) and groundsel (Senecio vulgaris L.), these two species being the dominant ones in the experiment. Counts were taken in the one-inch band of activated carbon and between rows. In the visual evaluation a rating of 0 to 100 was used in which 0 represented no control and 100, complete control (i. e., % control).

Results

In the absence of carbon, all herbicide treatments showed some degree of toxicity to the beans and this toxicity was reflected in yield reductions (Figure 1 and Appendix Table 1). In general, at the low rates, diuron caused the same degree of injury as did linuron, fluometuron, and metobromuron. At the high rates the four herbicides also caused equivalent yield reductions.

When a one-inch band of activated carbon was used over the seed row prior to herbicide application, yield reductions were not observed in any herbicide treatments. A one-inch band of the activated carbon at a rate of 150 pounds per acre (broadcast basis) was sufficient to afford the crop full protection.

Visual ratings of crop injury are in agreement with the yield data (Appendix Table 2). In the treatments where no carbon was used, injury was observed in terms of chlorosis and stand reduction. The injury ratings for the high rates of diuron and linuron were higher than for the low rates. For fluometuron and metobromuron, injury ratings were similar for the high and low rates.

Weed control between rows was more effective than in the row for all herbicide treatments where carbon was applied (Figures 2 and

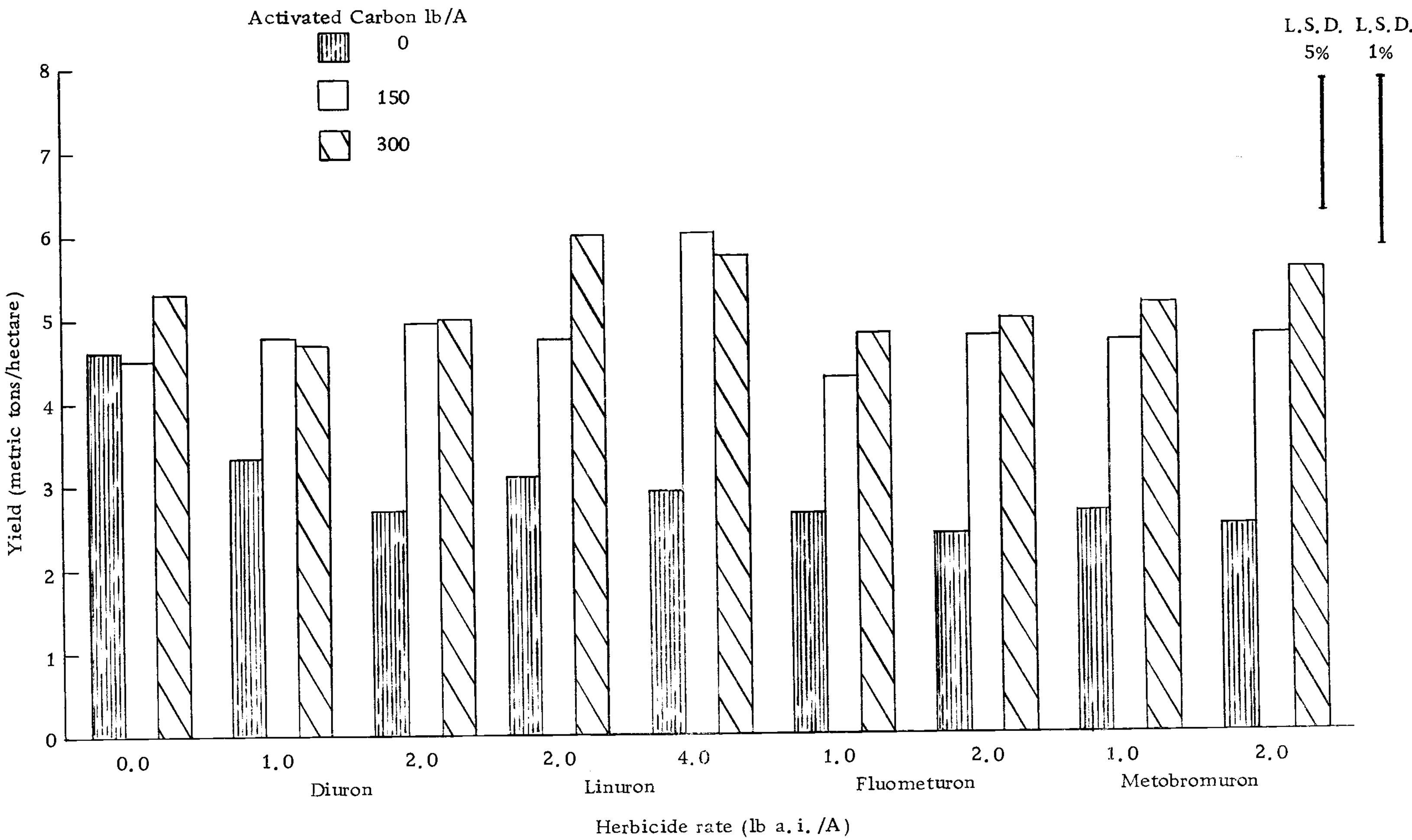

Figure 1. Effect of four substituted urea herbicides in the presence and absence of activated carbon on the yield of green beans (pods) four months after seeding.

3 and Appendix Tables 3-10). When activated carbon was used, pigweed was not controlled effectively in the row even at the high herbicide rates. The same degree of protection was afforded groundsel against diuron, fluometuron and metobromuron as was afforded to pigweed.

In general, it was found that 150 pounds of activated carbon per acre (broadcast basis) was effective in protecting the crop from herbicide injury. However, both pigweed and groundsel also were afforded a considerable amount of protection from the herbicides at this rate of carbon.

Although linuron appeared to be the most effective of the herbicides for the control of both weed species even the rate of 4 pounds was inactivated readily by 150 pounds of carbon. At the high rate of linuron, pigweed was not controlled while the control of groundsel was in the order of 75% when 150 pounds of activated carbon were used.

An experiment similar to the one conducted in the field was carried out under greenhouse conditions. The effectiveness of activated carbon applied in a one-inch band over the seed row for protecting germinating bean seeds from injury by four substituted ureas was evaluated.

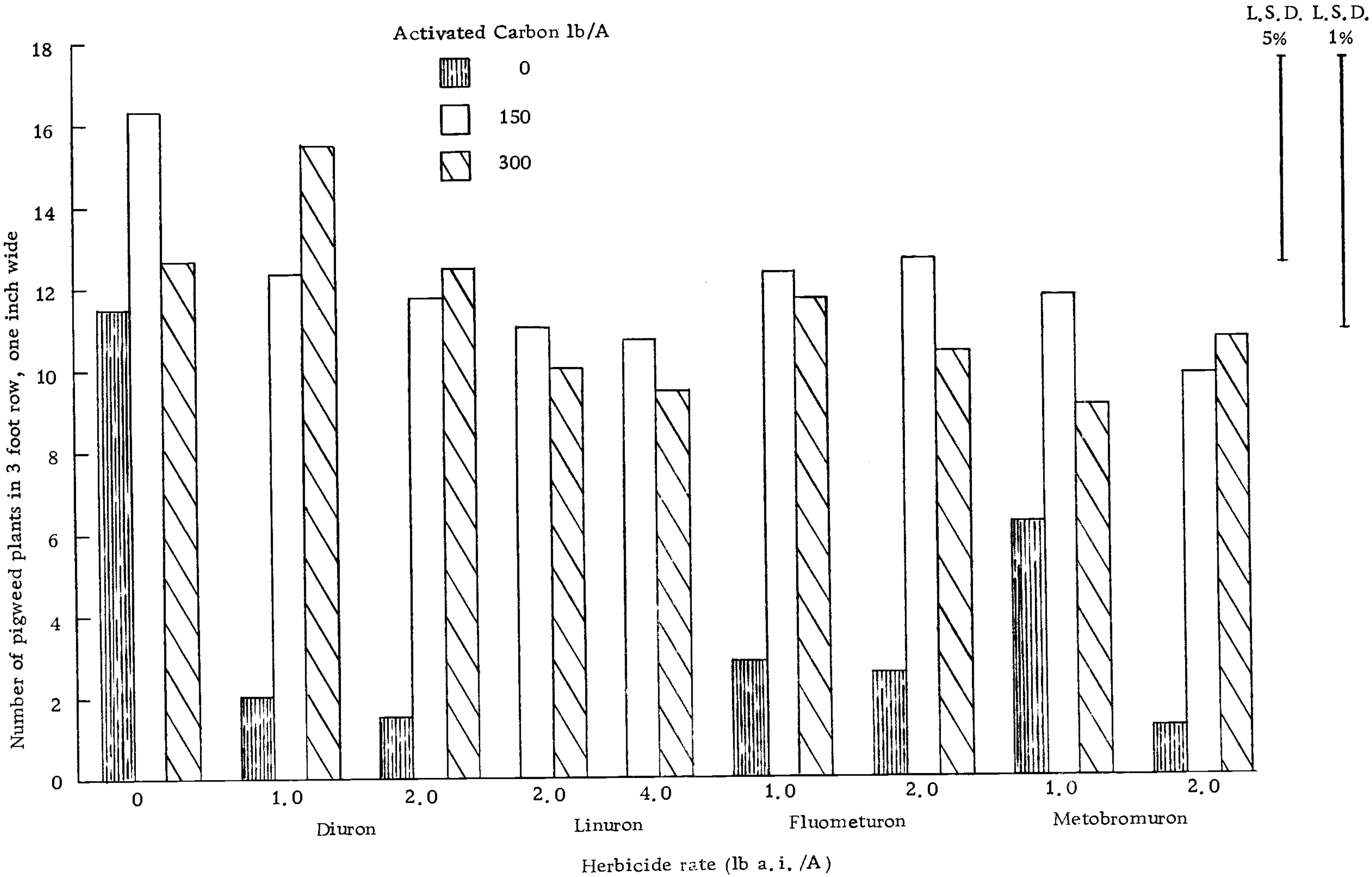

Figure 2. Effect of preemergence applications of substituted urea herbicides on pigweed in the rows in the presence and in the absence of activated carbon, two months after seeding.

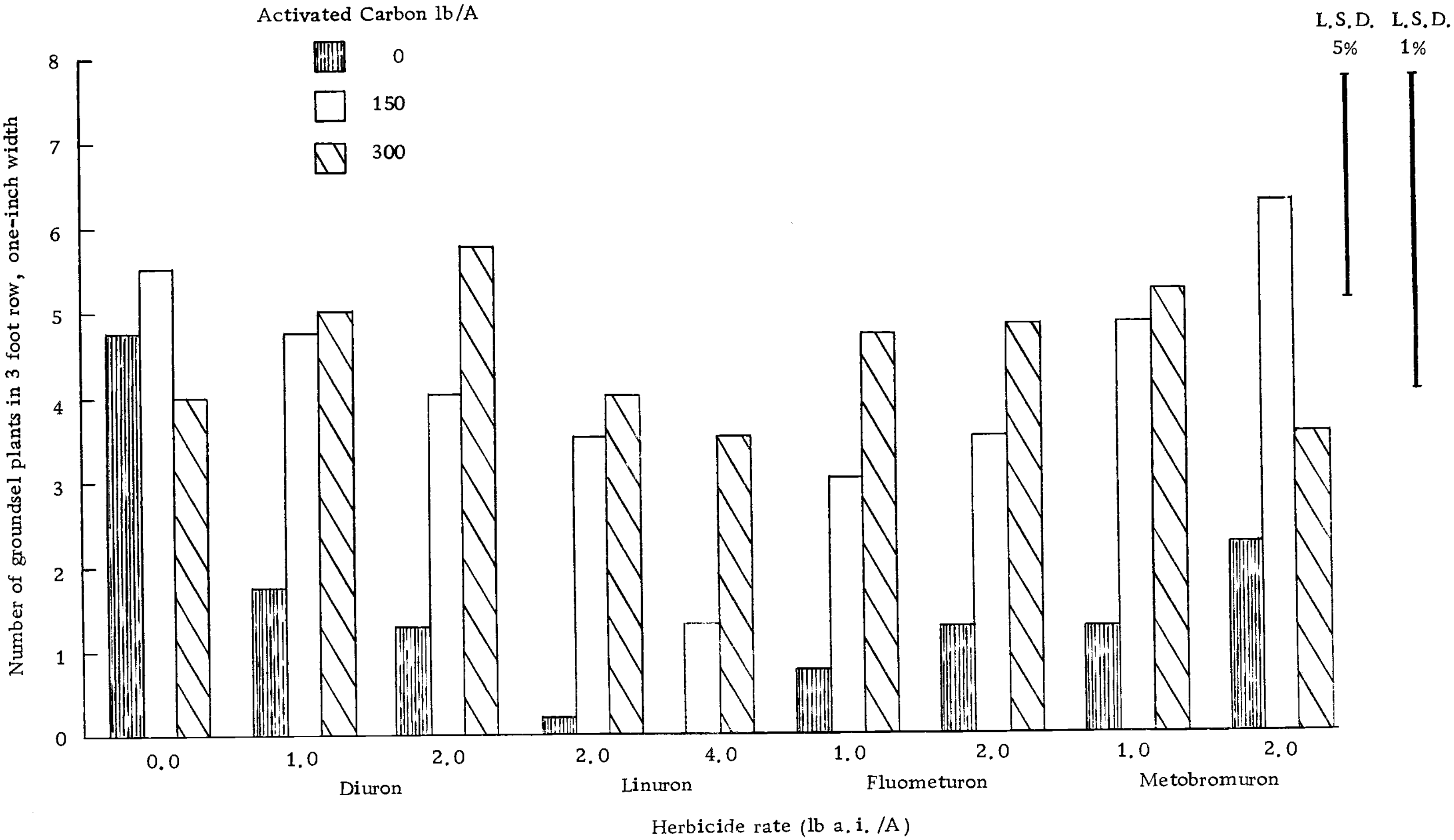

Figure 3. Effect of preemergence applications of substituted urea herbicides on groundsel in the rows in the presence and absence of activated carbon, two months after seeding.

Materials and Methods

Three rows of bean seeds were planted in pots 11 by 14 inches at a seeding depth of 0.75 inches. Each row was treated with a different rate of activated carbon: 0, 150 or 300 pounds per acre calculated on a broadcast basis. For the application of the different carbon band widths, templates were made with absorbent paper so that one-inch bands could be applied. The same herbicide rates were used as under field conditions.

Results were recorded 60 days after seeding by harvesting two plants per row and measuring fresh weight of the shoots.

Results

Results are shown in Figure 4 and Appendix Table 11. Results in the greenhouse confirmed those obtained in the field: activated carbon was effective in protecting bean seedlings from injury by the substituted ureas. In the absence of carbon, considerable injury to the beans was manifested. At the high herbicide rate, the beans were killed by diuron, linuron and fluometuron while at the high rate of metobromuron, the beans survived but green weight was decreased considerably. At the low herbicide rate, fluometuron was most injurious to the beans followed by linuron and metobromuron. Diuron was the least injurious to beans at the low rate in the absence of carbon.

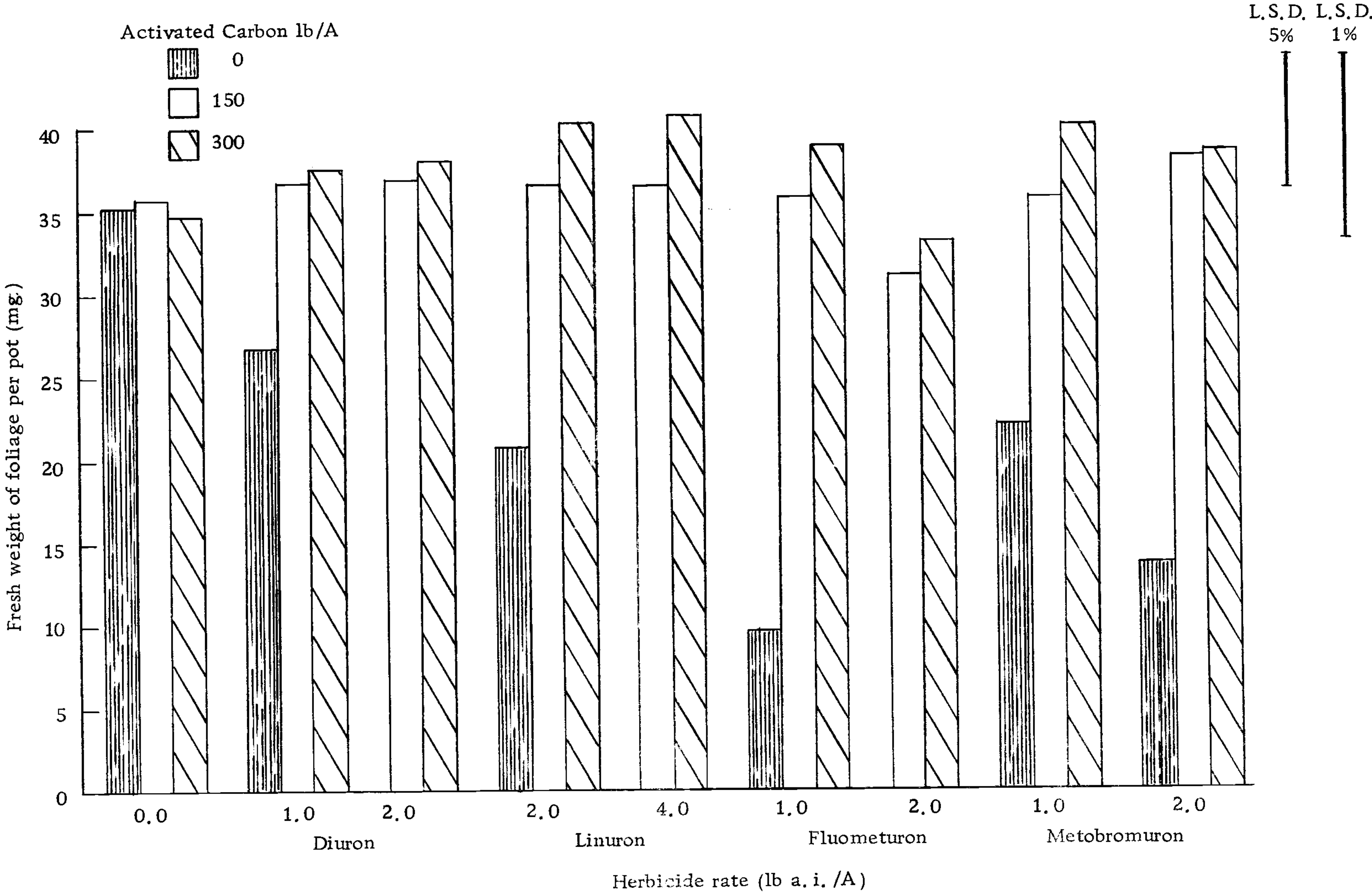

Figure 4. Effect of several substituted urea herbicides on the fresh weight of beans two months after application in the presence and in the absence of activated carbon.

In general, toxicity symptoms were more pronounced under greenhouse conditions than under field conditions.

In the presence of carbon, the beans were afforded complete protection from herbicide injury at both rates of herbicides.

II. Effect of Band Width on Root and Shoot Development

An experiment was designed to determine the effect of diuron on root and shoot development of beans and the protection afforded by different widths of activated carbon bands. The experiment was conducted in the greenhouse.

Materials and Methods

Diuron was applied at 1.5 and 3.0 pounds of active ingredient per acre and the charcoal was applied in bands of 1.0 and 3.0 inches at 0, 150 and 300 pounds per acre calculated on a broadcast basis.

Four bean seeds per pot were planted in a row. Each pot was four by four inches. Templates of absorbent paper were used to apply the different carbon band widths. After application of the carbon, diuron was applied as a broadcast treatment. The pots were arranged in a randomized block design in three replications and dry weight of the roots and shoots were taken 60 days after seeding.

Results

In the absence of carbon both roots and shoots were significantly reduced by diuron (Figures 5 and 6 and Appendix Tables 12 and 13). However, the application of a one-inch band or a three-inch band of activated carbon over the seed row at 150 pounds per acre, provided complete protection to the bean seedlings so that no negative effects were recorded on root growth.

The effect of diuron on shoot growth was not as clear-cut as the effect on root growth. However, the same results were obtained when measuring shoot growth. Statistically the herbicide had no effect on shoot growth as a result of herbicide treatment when carbon was present.

III. Effect of Rate of Activated Carbon on the Susceptibility of Four Plant Species to Diuron

An experiment was conducted to determine the relative degree of protection afforded by several rates of activated carbon from diuron injury to beans, ryegrass, barnyardgrass (*Echinochloa crusgalli* (L) *Beauv.*) and pigweed (*Amaranthus retroflexus* L.). Because of poor germination of the pigweed in the first experiment, susceptibility of this weed to diuron at different carbon rates was tested in a second experiment.

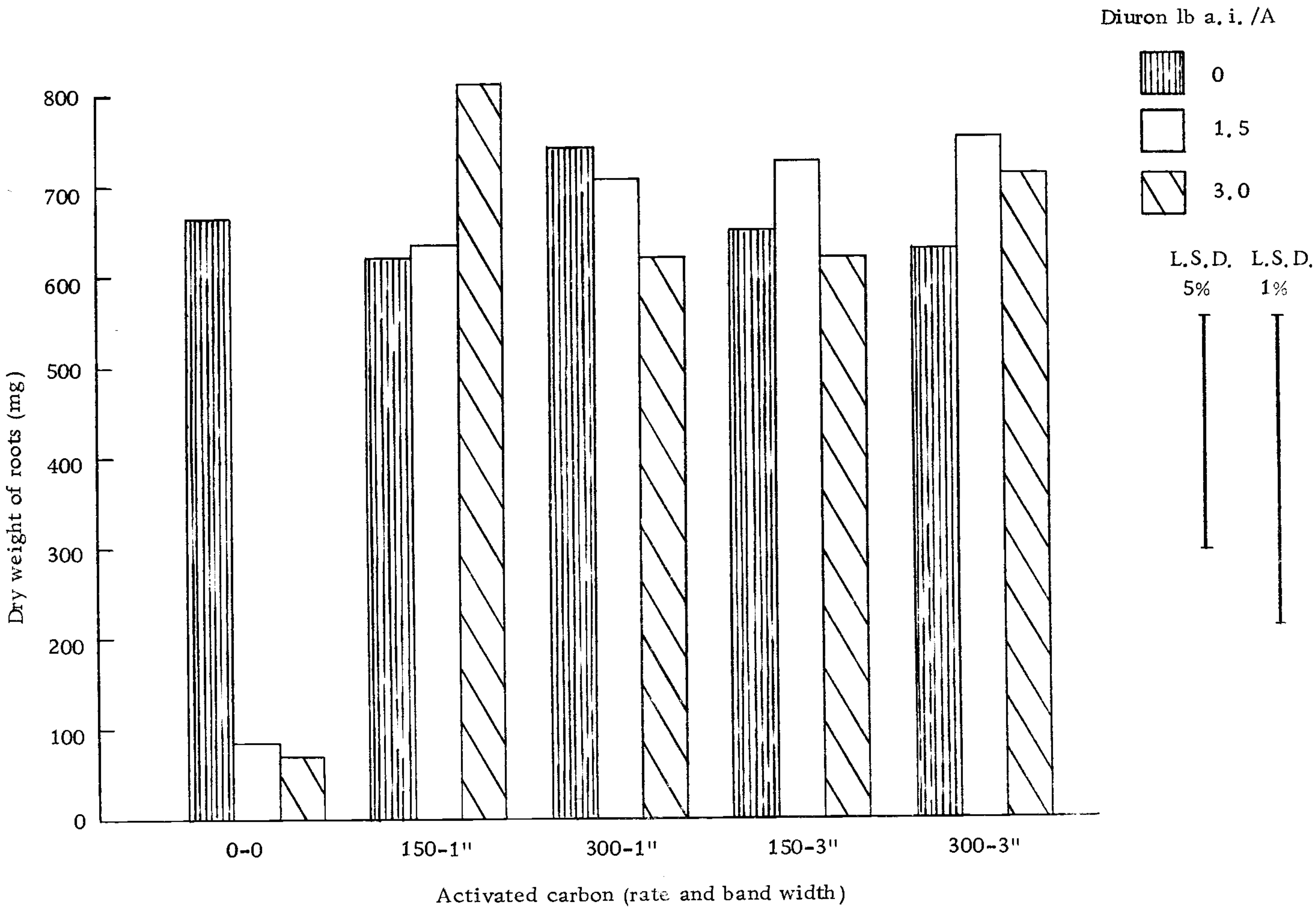

Figure 5. Effect of width of activated carbon bands on the root development of beans treated with diuron.

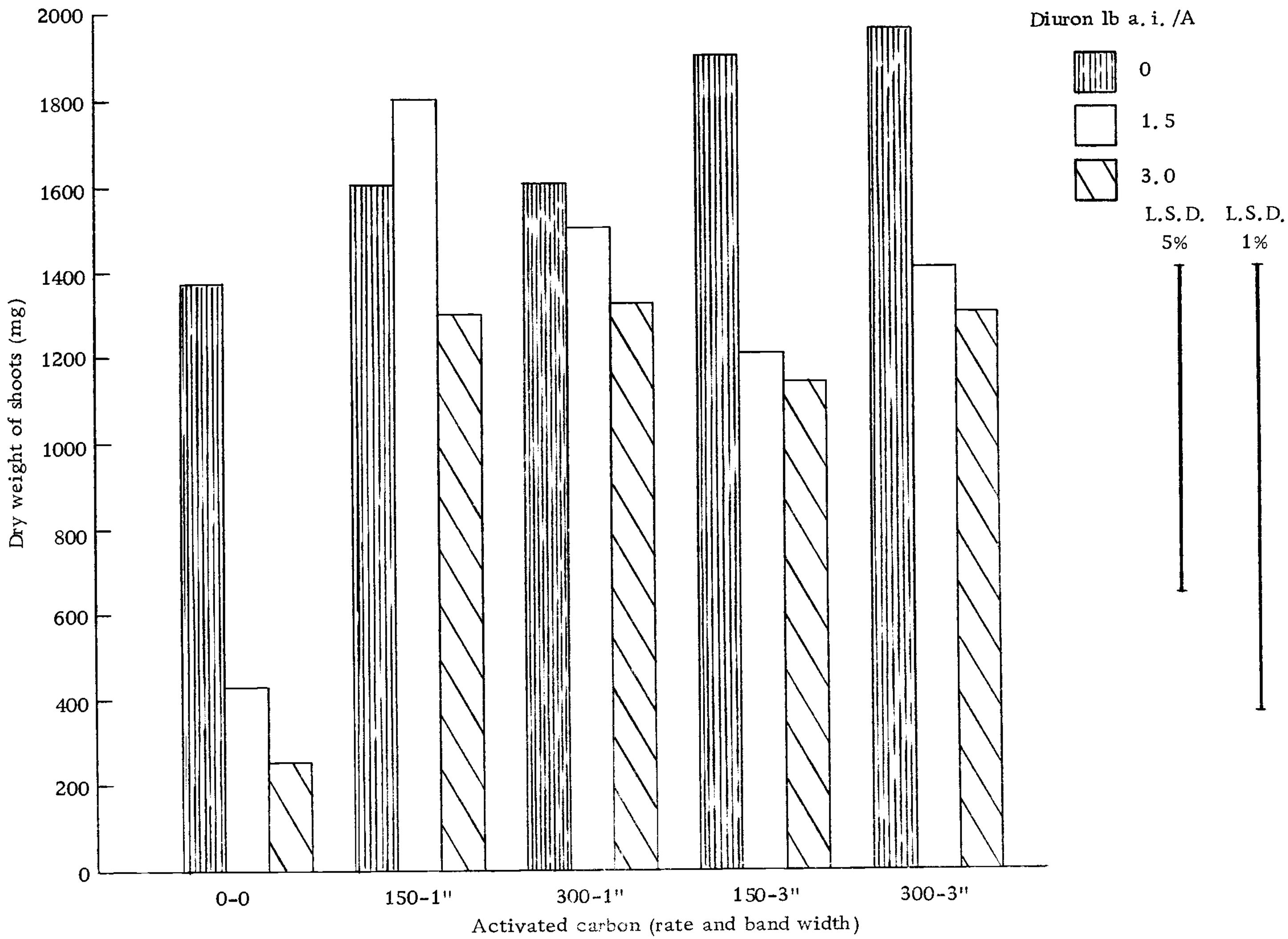

Figure 6. Effect of width of activated carbon band on the susceptibility of beans to diuron.

Materials and Methods

Beans, ryegrass and barnyardgrass were planted in separate 4 by 4 inch plastic pots. Seeding rates per pot were 2 seeds for beans and 15 seeds for ryegrass and barnyardgrass. After seeding, the seeds were covered with soil and the carbon was then applied over the soil. Diuron was applied on a broadcast basis at rates of 0.5, 1.0, 2.0 and 4.0 pounds of active ingredient per acre. In pigweed, the carbon rates were changed to 0, 150 and 300 pounds per acre and the diuron rates to 0, 0.75, 1.5 and 3.0 pounds of active ingredient per acre. One hundred seeds were planted per pot. Dry weight of the shoots was used to determine the toxic effect of diuron. Dry weight of shoot growth was measured 45 days after seeding.

Results

Beans: The average dry weight values obtained for beans are shown in Figure 7 and Appendix Table 14. In the absence of carbon, diuron caused a considerable reduction in dry weight of the shoots even at the low rate of 0.5 pounds per acre. Increasing the rate to 4 pounds did not result in a further significant decrease in dry weight.

At 50 pounds per acre of carbon, the beans were rendered safe from herbicide injury only at the 0.5 pound rate of diuron. In the presence of carbon and at diuron rates greater than 0.5 pounds per

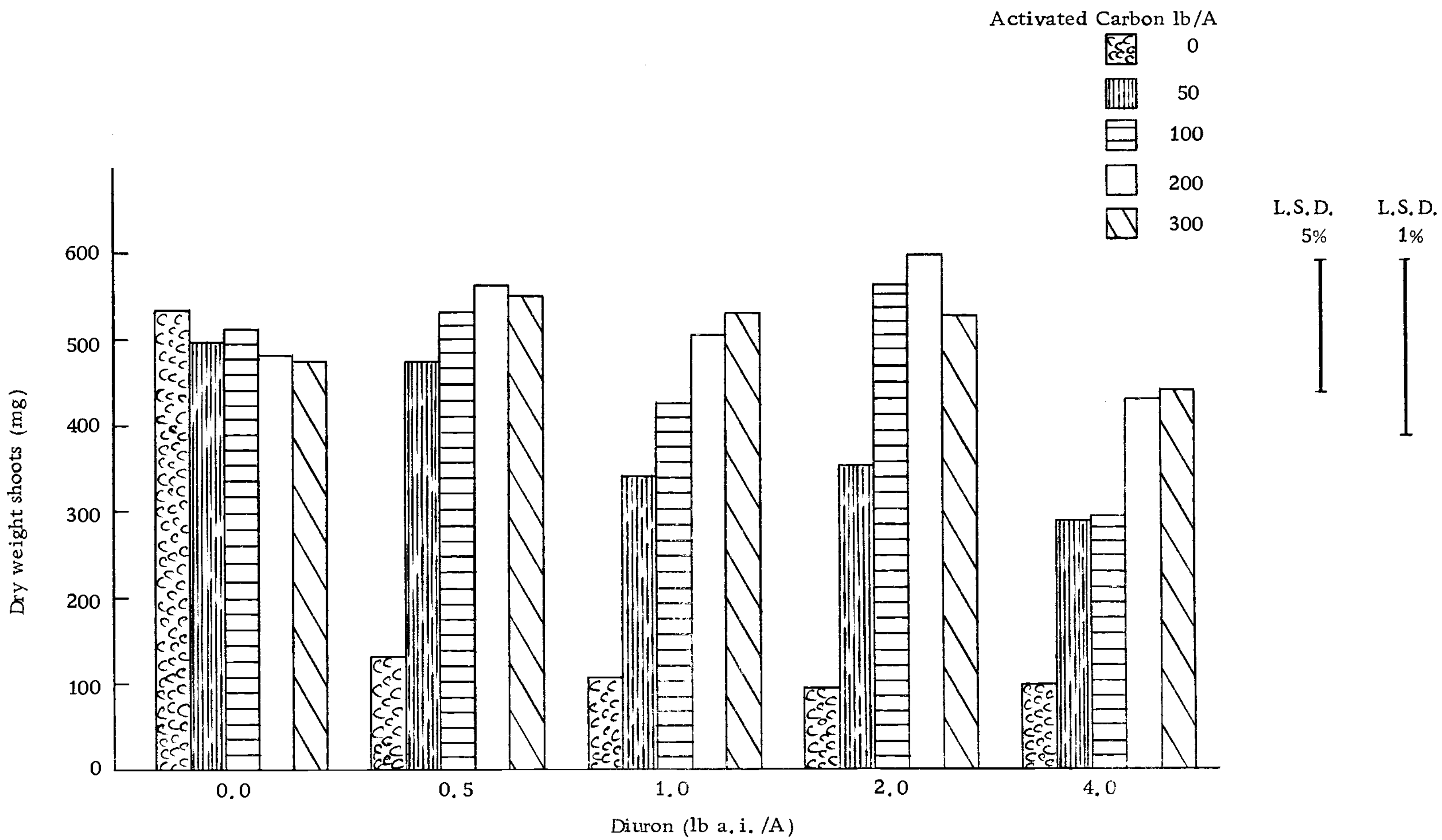

Figure 7. Effect of diuron on dry weight of bean shoots in the presence of several rates of activated carbon.

acre, dry weight was reduced although this reduction was not as great as that caused by 0.5 pounds of diuron in the absence of charcoal, indicating that carbon at 50 pounds per acre can afford a great deal of protection against diuron injury even at rates of 4 pounds of diuron per acre.

At carbon rates of 100 pounds per acre, protection against herbicide injury was evident at diuron rates of 0.5, 1.0 and 2.0 pounds per acre. At 4 pounds of diuron per acre considerable injury occurred.

Two and three hundred pounds per acre of activated carbon protected the beans from diuron injury up to rates of two pounds per acre. At four pounds per acre, dry weight was decreased at the 200 pound carbon rate.

There appears to be a direct relationship of the amount of activated carbon required to inactivate a given amount of the herbicide. This type of relationship has been reported by Linscott and Hagin (23) in alfalfa. Although not conclusive, it appears that for beans, 100 pounds per acre of activated carbon can inactivate the toxic effects of one pound of diuron to beans.

Ryegrass: When no carbon was used, ryegrass was affected adversely at all diuron rates (Figure 8 and Appendix Table 15). With increasing rates dry weight decreased. As with beans, 50 pounds of carbon were effective in protecting ryegrass from injury by 0.5 pounds of diuron but this rate of carbon was not effective against the one

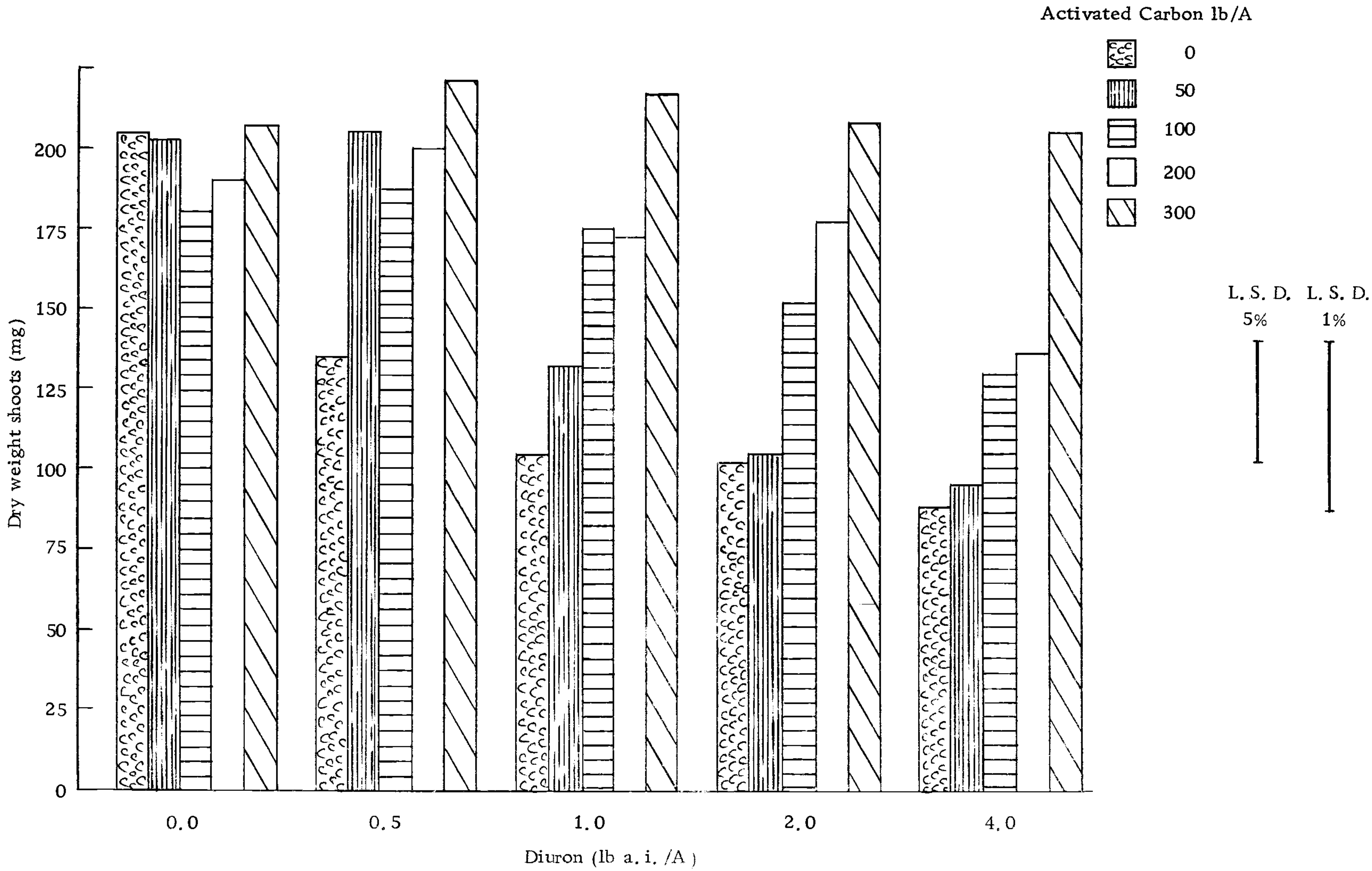

Figure 8. Effect of several activated carbon rates on the control of ryegrass by diuron.

pound rate.

One hundred pounds of carbon were effective in inactivating one pound of diuron but with two pounds, injury was present. Two hundred pounds of carbon were effective against two pounds of diuron and only the 300 pound rate of carbon was effective in inactivating four pounds of diuron.

According to the data obtained, ryegrass under the carbon band should be protected to the same degree as are beans. These results with ryegrass agree with results reported previously by Lee (21) and Burr (14). Diuron does not control ryegrass if the rates of carbon are high enough to protect the crop plant. They reported that 300 pounds of activated carbon provided protection to ryegrass from herbicidal rates of diuron.

Barnyardgrass: Barnyardgrass was more susceptible to diuron than were beans and ryegrass (Figure 9 and Appendix Table 16). In the absence of carbon, barnyardgrass was severely affected at all rates. In the presence of 50 and 100 pounds of carbon per acre, although not statistically significant, there appeared to be a slight reduction in dry weight of barnyardgrass with 0.5 and 1.0 pounds of diuron. At 2 and 4 pounds of diuron, 50 and 100 pounds of charcoal did not protect the grass. Two hundred pounds of carbon inactivated 2 pounds of diuron but not 4. Three hundred pounds of carbon were not sufficient to inactivate 4 pounds of diuron and dry weight was reduced.

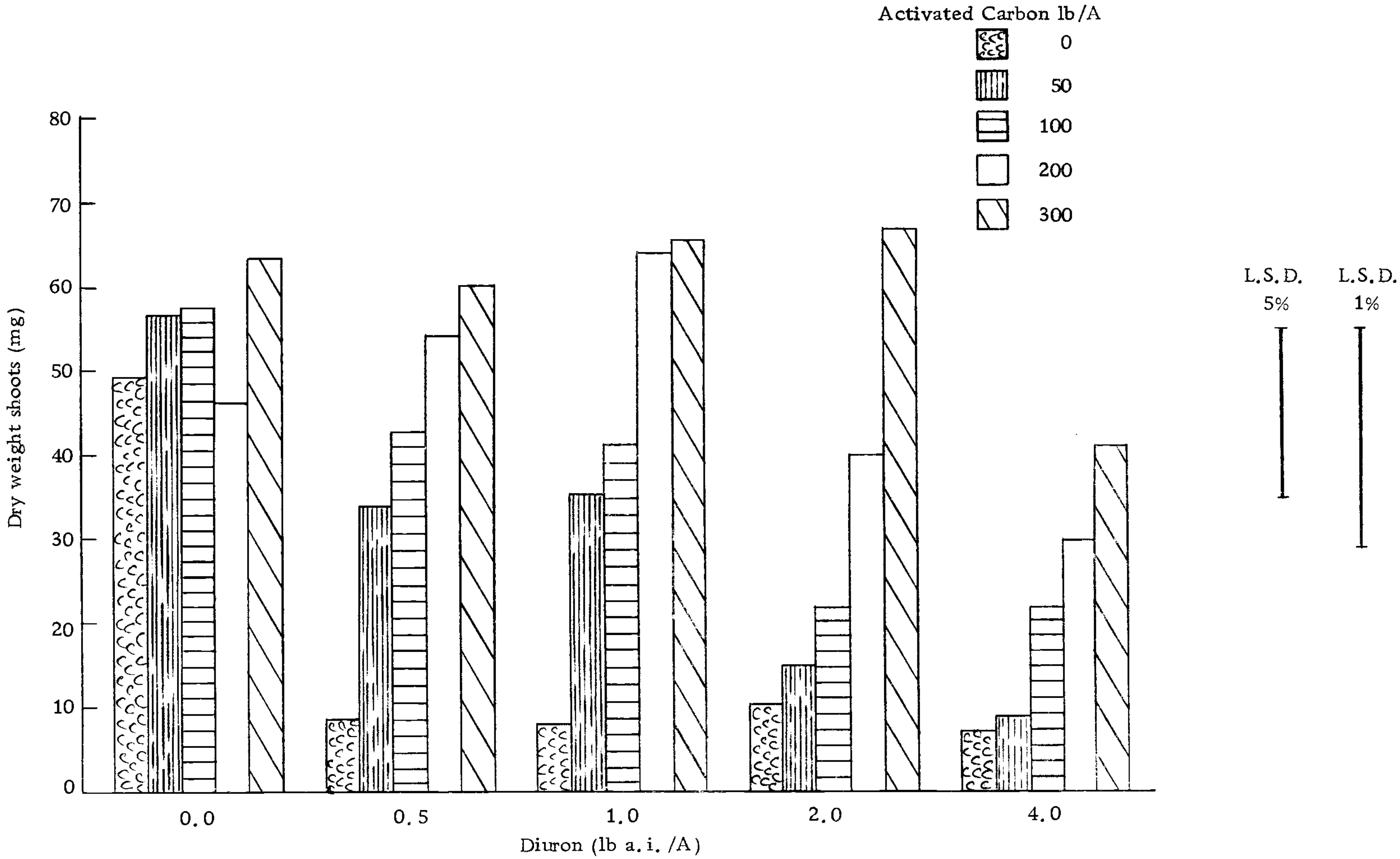

Figure 9. Effect of activated carbon on the control of barnyardgrass with diuron

Even though 200 pounds of carbon afforded satisfactory protection to barnyardgrass at 2 pounds per acre, 300 pounds were more effective.

The results obtained in this experiment showed that in the absence of carbon, diuron at rates as low as 0.5 pounds of active ingredient per acre caused injury to beans, ryegrass and barnyardgrass. Beans and barnyardgrass appeared to be more susceptible to diuron than ryegrass. In general, activated carbon: diuron ratios of 100:1 appeared to be effective in inactivating diuron. Three hundred pounds of activated carbon were sufficient to protect the ryegrass from 4 pounds of diuron, while for beans and barnyardgrass, the trend indicated that at least 400 pounds of activated carbon are required to inactivate diuron in order to prevent injury to beans and barnyardgrass. In beans, only a 35 pound difference in yield occurred between 0 and 4 pounds of diuron at the 300 pound carbon rate.

The results indicate that the degree of inactivation of diuron by activated carbon depends on the susceptibility of the plant species in question, the rate of the herbicide and the rate of carbon used.

Pigweed: Under field conditions, pigweed was the most predominant weed, therefore its susceptibility to diuron at different activated carbon rates was also tested. The results obtained with pigweed were very marked (Figure 10 and Appendix Table 17). In the absence of carbon, pigweed was susceptible to diuron at the 0.5

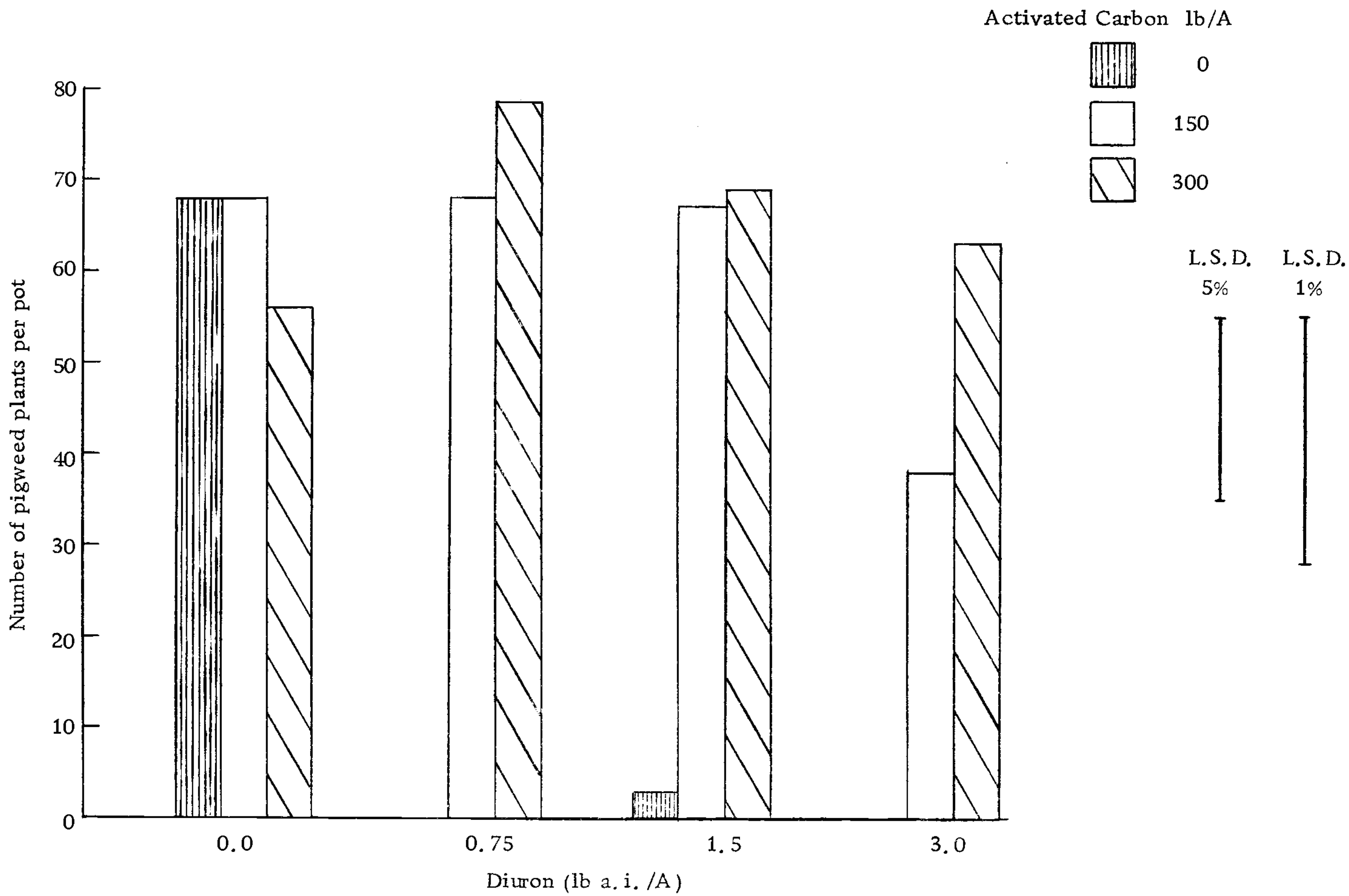

Figure 10. Effect of activated carbon on the control of pigweed by diuron.

pound rate. One hundred and fifty pounds of carbon were effective in inactivating 1.5 pounds of diuron but were not effective in inactivating 3 pounds. Three hundred pounds were effective in inactivating 3 pounds of diuron. As with beans, ryegrass and barnyardgrass, the activated carbon: diuron ratio required for inactivation was 100:1.

IV. Effectivness of Carbon in Vermiculite Packets for Protection of Bean Seedlings from Diuron Injury

The purpose of this experiment was to determine the effectiveness of an activated carbon-vermiculite mixture applied as a "packet" surrounding the seed for protection of bean seedlings from diuron injury. Also, a comparison was made with carbon applied alone in a band over the seed row.

Materials and Methods

The experiment was conducted in the greenhouse, with 2 seeds per plot planted at a depth of 0.75 inches. Diuron rates used were 0, 0.75, 1.5 and 3.0 pounds of active ingredient per acre. Aqua Nuchar A activated carbon was used. The vermiculite-activated carbon treatments consisted of:

(a) no vermiculite, no activated carbon;

(b) seeds planted in a hole 1 inch in diameter and 0.75 inches deep, the hole being filled with vermiculite (two grams per hole required);

(c) seeds planted in the 1-inch diameter, 0.75 inch deep hole and filled with a mixture of vermiculite and activated carbon at ratios of 200:1 and 100:1, activated carbon to vermiculite;

(d) activated carbon applied in a one-inch band over the row;

(e) seeds planted in hole, covered with vermiculite followed by a one-inch band application of carbon over the row.

The ratios used in part (c), above, were selected on the basis of field applications of 150 and 300 pounds of activated carbon, assuming that under field conditions, distance between plants is 6 inches.

The rates of activated carbon used were 150 and 300 pounds per acre. The carbon slurry consisted of 1 pound of activated carbon per 2 gallons of water and was applied as a spray, using templates and 8004-E-T-Jet and 8008 E-T-Jet nozzles (low and high rates of carbon, respectively). Three replications were used and the experimental design was a completely randomized design. Means were compared by Duncan's Multiple Range test. Dry weight of bean shoots and primary and secondary root length were measured to determine the effectiveness of the treatments. Measurements were taken 30 days after seeding.

Results

Results of this experiment are summarized in Table 1 and Appendix Tables 18 and 19. As in previous experiments, in the

Table 1. Effect of Activated Carbon-vermiculite Applied in Band and Mixed to Inactivate Diuron on the Root Length and Foliage Dry Weight

Diuron (lb/A)	Adsorbent Carbon (lb/A)	Vermiculite (gr/hole)	Method of Carbon Application*		Root Length (cm)	Foliage Dry Weight (mg)
			Band	Mix		
0	0	2			10. 87 abcde**	781 bcd
0. 75	0	2			5. 87 defghi	417 efg
1. 5	0	2			3. 93 hi	212 fg
3. 0	0	2			3. 30 i	183 fg
0	150	2	+		10. 00 abcdef	825 bcd
0. 75	150	2	+		8. 93 abcdfghi	758 cde
1. 5	150	2	+		8. 57 bcdefghi	1030 abc
3. 0	150	2	+		7. 10 bcdefghi	695 cde
0	300	2	+		11. 43 abcd	1045 abc
0. 75	300	2	+		9. 83 abcdfg	803 bcd
1. 5	300	2	+		11. 17 abcde	1016 abc
3. 0	300	2	+		8. 00 bcdefghi	950 abc
0	150	2		+	8. 90 bcdefghi	1040 abc
0. 75	150	2		+	12. 70 ab	1024 abc
1. 5	150	2		+	9. 90 abcdefg	1060 abc
3. 0	150	2		+	8. 93 abcdefghi	936 abc
0	300	2		+	9. 16 abcdefg	1149 a
0. 75	300	2		+	10. 97 abcde	957 abc
1. 5	300	2		+	11. 83 abcd	978 abc
3. 0	300	2		+	14. 33 a	1111 ab
0					8. 36 bcdefghi	1117 ab
0. 75					4. 70 fghi	334 fg
1. 5					4. 20 ghi	217 fg
3. 0					2. 83 i	126 g
0	150		+		9. 13 abcdefghi	971 abc
0. 75	150		+		8. 50 bcdefghi	758 cde
1. 5	150		+		6. 50 cdefghi	522 def
3. 0	150		+		4. 87 efghi	247 fg
0	300		+		9. 77 abcdefg	894 abcd
0. 75	300		+		11. 83 abc	908 abc
1. 5	300		+		11. 73 abcd	1047 abc
3. 0	300		+		11. 33 abcd	973 abc

* + indicates carbon was applied.

** Treatments with a common letter are not significantly different at 1% level.

absence of carbon, the beans were severely injured. The beans were protected from injury by bands of carbon and by mixtures of carbon and vermiculite. Vermiculite alone (without carbon) was not effective in protecting the beans from injury. The degree of protection varied with rate of diuron and rate of carbon used. In general, carbon mixed with the vermiculite appeared to be more effective in protecting the beans than the treatment where carbon was applied over the row, with or without vermiculite, particularly at the higher rate of diuron and at the 150 pound carbon rate. Comparisons between the treatments involving carbon applied as a band over the row with and without spot vermiculite "packets" indicated that vermiculite slightly increased the effectiveness of the carbon for protecting the beans, particularly at the 150 pound carbon rate. When 300 pounds of carbon were used, there was no difference between the treatments.

Results obtained for the effects on the roots were in accord to those obtained for effects on shoots.

V. Effect of Alternate Wetting and Drying on the Adsorptive Capacity of Activated Carbon

The purpose of this experiment was to determine the effect of alternate wetting and drying on the adsorption capacity of activated carbon with respect to diuron. Under field conditions, alternate wetting and drying could change the adsorptive capacity of activated carbon and hence decrease its effectiveness in protecting the beans from diuron injury.

Materials and Methods

Samples of activated carbon were washed and dried 1, 3 and 5 times and were then sprayed as a broadcast surface application at 150 and 300 pounds per acre. Washing and drying consisted of making a slurry with water in a carbon/water ratio of 1:2 (1 pound to 2 gallons respectively). The slurry was then sprayed on paper and allowed to dry at 20 C. For samples requiring more than one washing, the procedure was repeated.

After the application of the carbon, diuron was sprayed at 0.75, 1.5 and 3.0 pounds of active ingredient per acre. Two bean seeds had been planted in the pots and shoot dry weight was measured 45 days after planting. The experimental design was a randomized block with three replications.

Results

Results are presented in Table 2 and Appendix Table 20. At the carbon and diuron rates used, no significant differences were observed. In the absence of carbon, dry weight decreased as diuron rate increased. One hundred and fifty pounds of carbon were as effective as 300 pounds for inactivating diuron , although dry weight appeared to

Table 2. Effect of Alternate Washing and Drying on the Adsorptive Capacity of Activated Carbon

Diuron lb/A	Activated Carbon lb/A	No. of Washings	Dry Weight Shoots (mg)
0	0		778.67
0.75	0		478.33
1.5	0		295.00**
3.0	0		244.00**
0	150	1	804.33
0.75	150	1	825.00
1.5	150	1	880.00
3.0	150	1	717.00
0	300	1	762.33
0.75	300	1	644.00
1.5	300	1	767.00
3.0	300	1	647.00
0	150	3	771.33
0.75	150	3	721.33
1.5	150	3	645.33
3.0	150	3	782.33
0	300	3	757.67
0.75	300	3	860.33
1.5	300	3	714.33
3.0	300	3	784.00
0	150	5	765.00
0.75	150	5	701.33
1.5	150	5	720.00
3.0	150	5	800.00
0	300	5	759.67
0.75	300	5	824.00
1.5	300	5	751.33
3.0	300	5	692.67

** Significantly different from check at 1% level (LSD) be slightly reduced at the diuron rate of 3 pounds and carbon rate of 150 pounds. No differences were found in adsorption due to number of washings.

According to Leopold et al. (22), the adsorptive capacity of activated carbon in a slurry decreases with time. However, in this study, immediate alternate wetting and drying did not affects its adsorptivity.

VI. Adsorption and Desorption of Diuron by Several Activated Carbons

The purpose of this experiment was to determine the relative adsorptivity of four activated carbons with respect to diuron and also, the extent of desorption.

Materials and Methods

Four activated charcoals were used: Aqua Nuchar A (West Virginia Pulp and Paper Co.), Darco M (Atlas Chemical Industries, Inc.), Gro-Safe (Atlas Chemical Industries, Inc.) and Pittsburg No. 3 (Calgon Corporation). The technical specifications of each of the charcoals is shown in Table 3.

Table 3. Specifications of the Activated Carbons Tested

Activated Carbon	Particle Size	Surface Area m^2/gr	pH	Raw Material
Darco M	70 mesh	600	5-7	lignite
Pittsburg No. 3	65 mesh	800	5-7	bituminous coal
Aqua Nuchar A	100 mesh	650	6.1-8	vegetal
Gro-Safe	70 mesh	600	10-11	lignite

Adsorption Studies: Ten milligram samples of each activated carbon were suspended in 500 ml solutions of 0, 7, 10 and 20 ppmw of diuron, and were placed on an Eberbaken shaker for 24 hours. After shaking, the samples were centrifuged at 10000 X g for 20 minutes. Aliquots of the supernatant were taken for color development and the diuron concentration was determined colorimetrically.

Determination of diuron was accomplished by the colorimetric method described by Lowen and Baker (24). The method consists of subjecting diuron to acid hydrolysis and this yields p-chloraniline, which is then complexed with sodium nitrite, sulfamic acid and N-(1-naphthyl-ethylene diamine dihydrochloride) to form a violet solution.

Four milliliter aliquots of the centrifuged sample were placed in 500 ml boiling flasks and 5 ml of 95% ethyl alcohol were added to each flask. To this mixture, 6 ml of 4N HCl were added. The flask was fitted with an air condensor 60 cm long and the mixture was maintained at total reflux for 20 hours on an electric hot plate. Adequate air circulation to cool the condensor was provided in order to prevent losses during the reflux period.

After the reflux period, the contents were allowed to cool down and were transferred into a 25 ml volumetric flask. The sample was diluted to 20 ml with distilled water an 1 ml of 1% sodium nitrite was added. After 15 minutes (diazotization period) 1 ml of 10% sulfamic acid was added to the flask contents in order to get rid of the excess nitrite. After 15 minutes, 1 ml of N-(1-naphthyl)-ethylenediamine-dihydrochloride (NED) was added and the volume was brought up to 25 ml. After 15 minutes full color was developed which remained stable. The intensity of the color, which is directly proportional to the concentration of the material in solution was determined with a Beckman DB Spectrophotometer at a wavelength of 560 mμ. The concentration of diuron was obtained from a standard curve prepared from known quantities of diuron. The samples for the standard curve were given the same acid hydrolysis and color development treatment as were the treatments involving carbon. The amount of diuron adsorbed by the charcoal was obtained by calculating the difference between initial and final concentrations in solution.

Desorption Study: Diuron-charcoal suspensions were prepared as in the absorption studies. After 20 hours of shaking the samples were centrifuged and the supernatant was decanted. The carbon-diuron pellet was resuspended in 20 ml of distilled water and the samples were shaken for 24 hours. The samples were then centrifuged at 10000 X g for 20 minutes. Aliquots of the supernatant were taken and diuron was determined colorimetrically as described previously.

Results

In order to establish the quantitative nature of the adsorption process, adsorption of diuron was measured as a function of its initial concentration in solution relative to the final concentration, after exposure to activated carbon. The results obtained are presented in Table 4 and Appendix Tables 21 and 22.

Table 4. Adsorption and Desorption of Diuron

Charcoal	Diuron Adsorbed Concentration ppm			Diuron Desorbed Concentration ppm
	7	10	20	20
Pittsburg No. 3	4.97	5.50	6.41	1.56
Aqua Nuchar A	2.71	3.07	4.59	1,98
Darco-M	2.54	3.03	4.86	0.48
Gro-Safe	1.96	2.50	3.74	1.03

The adsorptive capacity of the four activated carbons varied considerably. Pittsburg No. 3 had the greatest capacity for adsorbing diuron (6.41 ppm) while Gro-Safe had the least (3.74 ppm). Aqua Nuchar A and Darco-M had an equivalent intermediate capacity to adsorb diuron. As the concentration of diuron was increased in the original solutions, so was the amount of diuron adsorbed by each of the carbons. This relationship was not linear, and the rate of increase was not the same for all carbons. Pittsburg No. 3 had a high initial absorptivity, 4.97 ppm, at an original solution concentration of 7 ppm but its capacity to adsorb greater amounts of diuron was not as great as that of the other carbons. Adsorption of diuron by Pittsburg No.3 carbon from solutions containing 20 ppm was 6.41 ppm, a 30% increase. Aqua Nuchar A, Darco-M and Gro-Safe had increases of 68, 88, and 92% respectively when the diuron concentration in the original solutions was increased from 7 to 20 ppm.

The results obtained can be partially explained by the particular characteristics of each carbon. Pittsburg No.3 has the greatest surface area and the greatest diuron adsorptivity. The other three carbons have the same surface area but Gro-Safe has a high pH. The similarities between Aqua Nuchar A and Darco-M may explain their adsorptivity likeness while the lower adsorptivity of Gro-Safe could be due to the high pH of the carbon. At high pH the attraction or nonrepulsion of diuron by the carbon could be reduced. Also, other particles may be adsorbed in preference to diuron at high pH.

Desorption studies indicate that there are definite differences in strength of adsorption between the different carbons. Desorption occurred to the greatest extent with Aqua-Nuchar (43%), followed by Gro-Safe (27%), Pittsburg No.3 (23%), and Darco-M (10%). With the exception of Aqua-Nuchar A, all the carbons showed a fairly low degree of desorption. The difference in degree of desorption between Aqua-Nuchar and Darco-M could be due to the slight difference in pH the source of the material and particle size.

DISCUSSION AND CONCLUSIONS

Experiments were conducted to determine the effectivness of activated carbon in protecting beans from preemergence applications of different substituted ureas and also, to determine the adsorptive and desorptive properties of four activated carbons.

A review of the literature indicates that activated carbon can afford protection to different crops. In fact, many seed producers in Western Oregon have used activated carbon on a commercial basis in order to increase the margin of selectivity of commercial preemergence herbicides to their crops.

Research reported in the literature indicates that adequate protection by carbon following herbicide treatment and effective weed control depend on many factors such as type of crop, weed species present, type and rate of herbicide and on the rate of carbon used (11).

The results obtained in the field and under greenhouse conditions showed that when activated carbon was used as a band treatment of one inch over the row at a rate of 150 lb/A, broadcast basis, prior to herbicide application, good crop protection was obtained in all herbicide treatments. In the absence of carbon all herbicide treatments showed some degree of toxicity to the beans and the injury was reflected in yield reductions. Similar results were obtained by Linscott and Hagin (23) in alfalfa. When they applied a narrow carbon band on the soil surface directly over the seeded row they found that a minimum of 100 lb/A of charcoal were necessary to protect the legume from 3.0 lb/A of G-36393. The carbon acts as a barrier protecting the crop from herbicide injury.

In addition to crop protection, the activated carbon also protects those weed seeds that germinte under the carbond band. Weeds that develop in the band are able to compete with the crop and their competitive effect can be as severe or more so than when no weed control is implemented. It was observed that when only the weeds between the rows were controlled, weeds in the row grew free from competition from other weeds and developed faster and larger than normal.

Since weeds germinating under the band are protected from herbicide injury, the band width should be minimized so that the weed population in the treated row is reduced. Greenhouse results indicated that the application of a one-inch band of activated carbon over the seed row was effective in protecting bean roots from diuron injury.

In a second experiment it was shown that a one-inch band of activated carbon over the seeded row was as effective as a three-inch band of activated carbon. No injury to the root system of the beans was observed in the presence of a one-inch band of activated carbon. The effect on shoot growth was not as clear-cut as the effect on root growth, but in general, no injury was evident.

Protection of beans from injury from diuron can be expected since diuron has a certain degree of selectivity towards beans and, in addition, is known to be adsorbed readily by activated carbon. A one-inch band of activated carbon allowed roots to develop without injury.

Since the weed species in the field were protected by the activated carbon in the row an experiment was designed in order to establish the relative susceptibility of four plant species to different diuron rates in the presence of different rates of activated carbon. When considering the benefits obtained by increasing the margin of selectivity of a given herbicide to a crop one should also consider the margin of selectivity towards the weed species present. Since it is known that different plant species have different thresholds of susceptibility, the ideal rate of carbon and herbicide would be that one which would allow an acceptable margin of selectivity to the crop and at the same time provide good weed control between and within rows.

A greenhouse study was conducted using different carbon rates to determine the relative susceptibility of four plants species to diuron. The results showed that 50 lb/A of activated carbon gave protection to beans, ryegrass, barnyardgrass and pigweed when 0.5 lb/A of diuron were applied. As the rate of diuron increased, the rate of activated carbon required to protect the four species increased. In general, it was observed that activated carbon: diuron ratios of 100:1 were effective in protecting the four species from herbicide injury. In the absence of carbon, all four species tested were susceptible to diuron. These results are in agreement with those reported by Lee (21) and Burr (14). They reported that a minimum of 300 lb/A of activated carbon, broadcast basis, were required for acceptable protection from diuron, 2 pounds/acre.

Varying the rate of carbon and diuron did not result in significant differences in susceptibility between the four species tested. The ratio of activated carbon to diuron of 100: 1 held true for all four species.

A possibility for reducing the number of weeds within the row is to spot treat the area surrounding the seed. Vermiculite "packets" have been used effectively to provide an optimum nutrient supply at seeding time and incorporation of activated carbon into the packet could be as effective as band treatments over the row. This technique has been reported by Kratky and Warren (20) for tomatoes and cucumbers using simazine. Protection was obtained even at simazine rates of 8 lb/A.

The results obtained by incorporating activated carbon into the vermiculite "packet" showed that beans are protected from injury by diuron only when the packet contained carbon. Carbon mixed in the vermiculite "packet" appeared to be slightly more effective than surface band treatments of carbon over the row.

The effect of alternate wetting and drying on the adsorptive capacity of activated carbon is important because it can influence the degree of selectivity rendered a given crop under different moisture conditions. Leopole et al. (22) reported that activated carbon kept in water lost adsorptive capacity with time. However, under field conditions alternate wetting and drying would be more likely to occur and therefore experiments were conducted to determine such effects. It was found that alternate wetting and drying of activated carbon did not decrease the gross adsorptive capacity of the carbon. After five washings the activated carbon still afforded total protection to the crop.

Another factor of importance in determining the relative effectiveness of a given activated carbon in providing crop protection is its adsorption and desorption characteristics. The greater the adsorptivity and the lesser the desorptivity, the better the carbon.

Specific characteristics of an activated carbon responsible for its adsorption of herbicides have not been reported (19). However, it seems very likely that degree of activation and surface area per unit weight are the most important criteria responsible for adsorptivity. Desorption could depend on pore size in relation to retention to specific molecules. In the present study involving four commercial types of activated carbon it was found that as the concentration of diuron was increased, the amount of diuron adsorbed by all carbons increased. Differences in adsorptivity between different carbon sources were evident. Carbon which adsorbed the greatest amounts of diuron at low concentrations did not adsorb more diuron in proportion to its original capacity. The greater the surface area of the carbon, the greater its adsorptivity. With carbons having the same surface area, adsorptivity appeared to be related to pH and possibly pore size.

In conclusion, activated carbon can be used effectively to protect beans from herbicide injury. For diuron the ratio of activated carbon to diuron required to provide such protection was 100: 1. However, the carbon was also found to provide the same degree of protection to weed seeds as to the crop. Carbon applied in vermiculite packets was as effective in protecting beans as was the surface band treatment. A one-inch band of carbon was as effective as a three-inch band in protecting the crop.

Alternate wetting and drying did not affect the adsorptive capacity of activated carbon. Adsorption by specific carbons varied with diuron concentration and surface area. The greater the concentration and the greater the surface area, the greater the adsorption. Desorption of diuron occurs in all carbons but apparently is not of importance under field conditions.

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APPENDIX

Appendix Table 1. Effect of substituted urea herbicides on the yield of green bean pods in ton/hectare (four months after seeding)

Herbicide	Rate of Herbicide (lb/A)	Rate of Carbon (lb/A)	Tons of Green Bean Pods per Hectare Replication I	II	III	IV	V
diuron	1	-	4.15	3.01	2.29	3.97	3.35
diuron	2	-	2.46	3.44	2.57	2.55	2.75
linuron	2	-	2.65	2.97	3.51	3.22	3.08
linuron	4	-	2.53	3.37	2.73	2.83	2.86
fluometuron	1	-	1.36	2.83	3.23	3.17	2.64
fluometuron	2	-	1.49	2.35	2.42	3.30	2.38
metobromuron	1	-	2.48	2.23	2.57	3.32	2.65
metobromuron	2	-	2.43	2.47	2.00	3.04	2.48
diuron	1	150	3.69	4.47	4.17	6.94	4.81
diuron	2	150	4.81	4.09	4.35	6.60	4.96
linuron	2	150	4.46	4.36	4.15	6.05	4.75
linuron	4	150	6.20	5.75	5.58	6.52	6.01
fluometuron	1	150	3.91	3.99	4.14	4.96	4.32
fluometuron	2	150	4.03	4.12	5.06	5.95	4.78
metobromuron	1	150	4.56	3.82	4.76	5.65	4.69
metobromuron	2	150	4.03	4.12	5.06	5.95	4.78
diuron	1	300	4.10	4.49	3.84	6.49	4.72
diuron	2	300	5.11	3.97	4.83	6.17	5.02
linuron	2	300	3.97	6.10	7.09	6.89	6.01
linuron	4	300	5.03	5.95	5.95	6.69	5.77
fluometuron	1	300	4.04	4.56	5.51	5.21	4.32
fluometuron	2	300	4.51	4.71	4.99	5.70	4.97
metobromuron	1	300	5.05	4.81	4.96	5.70	5.13
metobromuron	2	300	4.22	6.15	5.35	6.77	5.62
		150	4.49	4.34	4.12	5.10	4.51
		300	5.06	4.14	5.74	6.20	5.35
check			4.49	4.94	4.61	4.59	4.65

Analysis of Variance

Source of Variation	df		SS	MS	F Value
Replications	3		25.1806	8.3935	
Carbon rate	2		106.5619	53.2810	53.28**
Replications x carbon rate	6		6.0479	1.0080	
Herbicides	8		10.9348	1.3669	4.47**
Carbon rate x herbicides	16		18.0545	1.1284	3.69**
Replications x herbicides	24	72	21.9825	0.3053	
Rep. x carbon rate x herbicides	48				
Total	107		188.76229		

** Significant at 1% level.
C. V. = 12.6%
L. S. D. at .05 level = 1.56
L. S. D. at .01 level = 2.08

Appendix Table 2. Visual evaluation of bean injury (four months after seeding) (0 = no injury; 10 = total injury).

Herbicide	Rate of Herbicide (lb/A)	Rate of Carbon (lb/A)	Bean Injury per Plot Replication I	II	III	IV	Avg.
diuron	1	-	4	5	4	3	4.0
diuron	2	-	6	6	5	5	5.5
linuron	2	-	3	4	3	4	3.5
linuron	4	-	6	6	5	4	5.2
fluometuron	1	-	5	5	3	3	4.0
fluometuron	2	-	2	4	2	7	4.3
metobromuron	1	-	3	3	4	2	4.0
metobromuron	2	-	3	3	4	4	3.5
diuron	1	150	3	1	0	1	1.2
diuron	2	150	2	2	1	2	1.7
linuron	2	150	1	2	1	2	1.5
linuron	4	150	3	3	2	2	2.5
fluometuron	1	150	1	1	1	1	1.0
fluometuron	2	150	1	2	2	2	1.7
metobromuron	1	150	1	1	1	1	1.0
metobromuron	2	150	1	2	1	2	1.5
diuron	1	300	2	1	0	0	0.7
diuron	2	300	1	0	0	2	0.7
linuron	2	300	0	1	1	1	0.7
linuron	4	300	2	1	1	2	1.5
fluometuron	1	300	0	1	0	1	0.5
fluometuron	2	300	1	1	1	0	0.7
metobromuron	1	300	0	0	2	0	0.5
metobromuron	2	300	0	1	1	1	0.7
		150	2	1	1	0	1.0
		300	1	1	0	0	0.5
check	-	-	0	0	0	0	0.0

Appendix Table 3. Effect of preemergence applications of substituted urea herbicides in the presence and in the absence of activated carbon on pigweed in the row (two months after seeding).

Herbicide	Rate of Herbicide (lb/A)	Rate of Carbon (lb/A)	Number of Pigweed per Plot Replication I	II	III	IV	Avg.
diuron	1	-	1	4	2	1	2.0
diuron	2	-	0	2	3	1	1.5
linuron	2	-	0	0	0	0	0.0
linuron	4	-	0	0	0	0	0.0
fluometuron	1	-	2	4	4	1	2.7
fluometuron	2	-	2	8	0	0	2.5
metobromuron	1	-	10	8	5	2	6.2
metobromuron	2	-	4	1	0	0	1.2
diuron	1	150	17	12	18	2	12.2
diruon	2	150	8	14	19	6	11.7
linuron	2	150	15	13	12	4	11.0
linuron	4	150	10	20	13	0	10.7
fluometuron	1	150	23	12	8	6	12.2
fluometuron	2	150	14	16	12	8	12.5
metobromuron	1	150	15	14	16	2	11.7
metobromuron	2	150	14	4	12	9	9.7
diuron	1	300	21	15	20	6	15.5
diuron	2	300	5	16	24	5	12.5
linuron	2	300	16	12	10	2	10.0
linuron	4	300	15	12	8	3	9.5
fluometuron	1	300	16	12	15	4	11.7
fluometuron	2	300	10	12	12	8	10.5
metobromuron	1	300	17	10	12	5	11.0
metobromuron	2	300	16	13	10	4	10.7
		150	20	21	18	6	16.2
		300	17	18	11	5	12.7
check			14	16	8	9	11.5

Analysis of Variance

Source of Variation	df		SS	MS	F Value
Replications	3		1003.2130	334.4043	
Carbon rate	2		1829.4074	914.7037	20.05**
Replications x carbon rate	6		273.7037	45.473	
Herbicides	8		407.9630	50.9959	4.04**
Herbicides x carbon rate	16		232.7593	14.5475	1.15
Replications x herbicides	24	72	908.8333	12.622	
Rep. x herbicides x carbon rate	48				
Total	107				

** Significant at 1% level.

C. V. = 39.9%

L. S. D. at .05 level = 5.024

L. S. D. at .01 level = 6.68

Appendix Table 4. Effect of preemergence applications of substituted urea herbicides on groundsel in the row in the presence and in the absence of activated carbon (two months after seeding).

Herbicide	Rate of Herbicide (lb/A)	Rate of Carbon (lb/A)	Number of Groundsel per Plot Replications I	II	III	IV	Avg.
diuron	1	-	0	4	2	1	1.7
diuron	2	-	2	2	0	1	1.2
linuron	2	-	0	0	1	0	0.2
linuron	4	-	0	0	0	0	0.0
fluometuron	1	-	0	2	1	0	0.7
fluometuron	2	-	3	2	0	0	1.2
metobromuron	1	-	0	3	0	2	1.2
metobromuron	2	-	3	3	1	2	2.2
diuron	1	150	9	6	2	2	4.7
diuron	2	150	12	2	1	1	4.0
linuron	2	150	7	5	2	0	3.5
linuron	4	150	2	0	1	2	1.2
fluometuron	1	150	2	8	1	1	3.0
fluometuron	2	150	5	7	2	0	3.5
metobromuron	1	150	11	4	0	4	4.7
metobromuron	2	150	10	6	5	4	6.2
diuron	1	300	1	6	4	9	5.0
diuron	2	300	17	5	0	1	5.7
linuron	2	300	10	4	1	1	4.0
linuron	4	300	12	2	0	2	4.0
fluometuron	1	300	10	3	1	1	3.5
fluometuron	2	300	10	6	1	2	4.1
metobromuron	1	300	9	4	3	5	5.2
metobromuron	2	300	4	6	2	2	3.5
		150	9	4	0	9	5.5
		300	8	2	0	6	4.0
check			8	2	5	4	4.7

Analysis of Variance

Source of Variation	df	SS	MS	F Value
Replications	3	204.3241	68.108	
Carbon rate	2	133.1296	66.5648	5.33 **
Replications x carbon rate	6	74.8704	12.4784	
Herbicides	8	164.0185	20.5023	3.05 **
Herbicides x carbon rate	16	73.8704	4.6169	0.68
Replications x herbicides	72 24	484.5556	6.7300	
Rep x herbicides x carbon rate	48			
Total	107	1134.768519		

L.S.D. at 0.05 = 3.67 ** Significant at 1% level.

L.S.D. at 0.01 = 4.88

C.V. = 64%

Appendix Table 5. Effect of preemergence applications of substituted urea herbicides on pigweed between rows, in the presence and in the absence of activated carbon (two months after seeding).

Herbicide	Rate of Herbicide (lb/A)	Rate of Carbon (lb/A)	Number of Pigweed per Plot Replications I	II	III	IV	Avg.
diuron	1	-	5	2	3	2	3.0
diuron	2	-	0	3	5	2	2.5
linuron	2	-	0	3	2	0	1.2
linuron	4	-	0	0	0	0	0.0
fluometuron	1	-	2	5	2	1	2.5
fluometuron	2	-	8	6	14	0	7.0
metobromuron	1	-	10	10	2	4	6.5
metobromuron	2	-	3	3	2	1	2.2
diuron	1	150	8	3	3	2	4.2
diuron	2	150	1	2	5	0	2.0
linuron	2	150	0	0	0	0	0.0
linuron	4	150	0	0	1	0	0.2
fluometuron	1	150	6	5	1	2	3.5
fluometuron	2	150	4	6	1	0	2.7
metobromuron	1	150	10	12	2	4	7.0
metobromuron	2	150	5	5	1	1	2.7
diuron	1	300	7	6	12	3	7.0
diuron	2	300	0	4	5	1	2.5
linuron	2	300	4	1	0	0	1.2
linuron	4	300	0	3	0	0	0.7
fluometuron	1	300	3	6	0	1	2.5
fluometuron	2	300	6	3	3	0	3.0
metobromuron	1	300	8	10	7	2	6.7
metobromuron	2	300	7	5	1	1	3.5
		150	41	43	33	23	35.0
		300	44	38	36	27	36.2
check			45	47	38	20	37.5

Analysis of Variance

Source of Variation	df		SS	MS	F Value
Replications	3		388.2604	129.5401	
Carbon rate	2		10.0185	5.0093	0.96
Replications x carbon rate	6		31.2407	5.2068	
Herbicides	8		12086.3519	1510.7940	113.20**
Herbicides x carbon rate	16		94.9815	5.9363	0.44
Replications x herbicides	24	72			
Rep. x herbicides x carbon rate	48		960.8889	13.3457	
Total	107		13572.101852		

** Significant at 1% level C. V. = 53.8%

L. S. D. at .05 level = 10.33

L. S. D. at .01 level = 13.74

Appendix Table 6. Effect of preemergence applications of substituted urea herbicides on groundsel between rows in the presence and in the absence of activated carbon (two months after seeding).

Herbicides	Rate of Herbicide (lb/A)	Rate of Carbon (lb/A)	Number of Groundsel per Plot Replications I	II	III	IV	Avg.
diuron	1	-	0	11	3	7	5.2
diuron	2	-	0	3	0	2	1.2
linuron	2	-	1	0	0	0	0.2
linuron	4	-	0	0	0	0	0.0
fluometuron	1	-	2	2	2	0	2.2
fluometuron	2	-	3	8	0	0	2.7
metobromuron	1	-	10	2	1	3	4.0
metobromuron	2	-	5	6	2	2	3.7
diuron	1	150	10	6	0	7	5.7
diuron	2	150	4	3	1	1	2.0
linuron	2	150	0	0	0	0	0.0
linuron	4	150	0	0	0	0	0.0
fluometuron	1	150	0	3	0	0	0.7
fluometuron	2	150	2	0	2	0	1.0
metobromuron	1	150	10	6	1	3	5.0
metobromuron	2	150	3	6	3	3	3.7
diuron	1	300	0	2	2	9	3.2
diuron	2	300	3	2	0	1	1.5
linuron	2	300	1	0	0	0	0.2
linuron	4	300	0	0	0	0	0.0
fluometuron	1	300	0	5	0	1	1.5
fluometuron	2	300	5	0	1	0	1.5
metobromuron	1	300	1	1	2	3	1.7
metobromuron	2	300	3	10	2	4	4.7
		150	20	22	15	14	17.7
		300	18	21	22	19	20.0
check			23	18	16	12	17.2

Analysis of Variance

Source of variation	df	SS	MS	F Value
Replications	3	98.4074	32.8025	
Carbon rate	2	1.2047	0.6204	0.10**
Replications + carbon rate	6	36.5370	6.0895	
Herbicides	8	3043.6296	380.4531	63.94**
Carbon rate + herbicide	16	68.0926	4.2558	0.72
Replications + herbicides	24			
Replications + herbicides + carbon rate	72 / 48	72428.0556	5.9452	
Total	107	3675.962963		

** Significant at 1% level — C.V. = 61%

L.S.D. at .05 level = 6.90 — L.S.D. at .01 level = 9.17

Appendix Table 7. Visual evaluation of percent pigweed control in the row (four months after seeding).

Herbicide	Rate of Herbicide (lb/A)	Rate of Carbon (lb/A)	Percent Pigweed Control per Plot Replications I	II	III	IV	Avg.
diuron	1	-	80	60	75	65	70
diuron	2	-	80	90	80	80	82
linuron	2	-	95	98	100	95	97
linuron	4	-	100	100	100	100	100
fluometuron	1	-	90	60	50	70	68
fluometuron	2	-	90	80	80	70	80
metobromuron	1	-	40	55	75	50	55
metobromuron	2	-	70	80	90	70	77
diuron	1	150	10	10	10	10	10
diuron	2	150	25	15	10	10	15
linuron	2	150	15	15	20	30	20
linuron	4	150	50	50	15	15	32
fluometuron	1	150	20	5	15	5	11
fluometuron	2	150	30	20	15	10	19
metobromuron	1	150	15	10	10	0	8
metobromuron	2	150	20	10	10	10	12
diuron	1	300	10	10	0	10	7
diuron	2	300	10	10	10	15	11
linuron	2	300	10	15	20	15	15
linuron	4	300	12	22	20	20	19
fluometuron	1	300	10	0	0	10	5
fluometuron	2	300	30	20	20	10	17
metobromuron	1	300	10	15	10	0	9
metobromuron	2	300	10	10	10	10	10
		150	0	0	0	0	0
		300	0	0	0	0	0
check			0	0	0	0	0

Appendix Table 8. Visual evaluation of percent pigweed control between rows (four months after seeding).

Herbicide	Rate of Herbicide (lb/A)	Rate of Carbon (lb/A)	Percent Pigweed Control per Plot Replications I	II	III	IV	Avg.
diuron	1	-	80	60	75	55	65
diuron	2	-	80	90	85	75	82
linuron	2	-	98	100	100	95	98
linuron	4	-	100	100	100	100	100
fluometuron	1	-	90	60	55	65	68
fluometuron	2	-	50	80	90	85	76
metobromuron	1	-	50	60	75	40	56
metobromuron	2	-	60	70	80	85	74
diuron	1	150	60	60	50	60	58
diuron	2	150	75	85	80	70	78
linuron	2	150	95	100	100	100	99
linuron	4	150	100	100	100	100	100
fluometuron	1	150	95	55	60	70	70
fluometuron	2	150	50	70	95	90	76
metobromuron	1	150	40	55	70	45	52
metobromuron	2	150	60	65	80	80	71
diuron	1	300	50	80	60	50	60
diuron	2	300	75	80	80	85	80
linuron	2	300	95	100	100	95	98
linuron	4	300	100	100	100	100	100
fluometuron	1	300	95	60	50	70	69
fluometuron	2	300	60	75	100	90	81
metobromuron	1	300	40	60	75	55	55
metobromuron	2	300	70	70	80	80	75
		150	0	0	0	0	0
		300	0	0	0	0	0
check			0	0	0	0	0

Appendix Table 9. Visual evaluation of percent groundsel control in the rows (four months after seeding)

Herbicide	Rate of Herbicide (lb/A)	Rate of Carbon (lb/A)	Percent Groundsel Control per Plot Replications I	II	III	IV	Avg.
diuron	1	-	100	70	80	80	82
diuron	2	-	85	95	90	70	85
linuron	2	-	100	90	90	95	94
linuron	4	-	100	100	100	100	100
fluometuron	1	-	100	65	65	70	75
fluometuron	2	-	80	90	100	100	92
metobromuron	1	-	40	65	70	50	56
metobromuron	2	-	70	75	80	75	75
diuron	1	150	10	5	10	10	8
diuron	2	150	0	10	0	10	5
linuron	2	150	15	20	20	35	20
linuron	4	150	10	15	30	50	26
fluometuron	1	150	10	10	10	5	8
fluometuron	2	150	20	5	15	5	11
metobromuron	1	150	20	0	0	0	5
metobromuron	2	150	15	0	0	0	3
diuron	1	300	10	10	10	5	8
diuron	2	300	0	10	10	0	5
linuron	2	300	10	10	15	25	15
linuron	4	300	0	15	25	30	18
fluometuron	1	300	5	5	15	5	7
fluometuron	2	300	10	5	10	10	8
metobromuron	1	300	10	0	0	0	2
metobromuron	2	300	10	0	0	10	5
		150	0	0	0	0	0
		300	0	0	0	0	0
check			0	0	0	0	0

Appendix Table 10. Visual evaluation of percent groundsel control between rows (four months after seeding)

Herbicide	Rate of Herbicide (lb/A)	Rate of Carbon (lb/A)	Percent Groundsel Control per Plot Replications I	II	III	IV	Avg.
diuron	1	-	100	70	70	50	72
diuron	2	-	75	95	90	70	82
linuron	2	-	90	100	100	95	96
linuron	4	-	100	100	100	100	100
fluometuron	1	-	100	65	60	75	75
fluometuron	2	-	80	80	100	100	90
metobromuron	1	-	50	70	70	60	62
metobromuron	2	-	70	75	75	70	72
diuron	1	150	100	90	50	60	75
diuron	2	150	70	80	75	90	79
linuron	2	150	95	100	100	90	95
linuron	4	150	100	100	100	100	100
fluometuron	1	150	100	60	60	55	69
fluometuron	2	150	85	90	100	100	93
metobromuron	1	150	45	70	70	50	59
metobromuron	2	150	60	75	60	70	66
diuron	1	300	80	75	60	55	68
diuron	2	300	75	80	90	70	78
linuron	2	300	100	100	100	100	100
linuron	4	300	100	100	100	100	100
fluometuron	1	300	100	70	100	65	84
fluometuron	2	300	90	90	100	100	95
metobromuron	1	300	40	75	80	70	66
metobromuron	2	300	60	70	75	90	73
		150	0	0	0	0	0
		300	0	0	0	0	0
check			0	0	0	0	0

Appendix Table 11. Effect on the shoot fresh weight of beans of several substituted urea herbicides in the presence and in the absence of activated carbon (two months after seeding)

Herbicide	Rate of Herbicide (lb/A)	Rate of Carbon (lb/A)	Shoot Fresh Weight in grams per Pot Replications I	II	III	Avg.
diuron	1		29.50	22.20	29.28	26.97
diuron	2		0.0	0.0	0.0	0.0
linuron	2		22.05	20.80	19.60	20.80
linuron	4		0.0	0.0	0.0	0.0
fluometuron	1		10.00	8.25	10.45	9.53
fluometuron	2		0.0	0.0	0.0	0.0
metobromuron	1		20.50	20.00	25.31	21.93
metobromuron	2		10.55	15.46	13.58	13.20
diuron	1	150	31.40	37.50	37.27	35.40
diuron	2	150	38.00	39.25	32.55	36.56
linuron	2	150	35.01	35.04	40.20	36.73
linuron	4	150	35.30	39.55	35.15	36.63
fluometuron	1	150	33.55	38.60	37.25	36.43
fluometuron	2	150	36.24	35.10	36.23	35.83
metobromuron	1	150	29.75	29.85	33.64	31.00
metobromuron	2	150	33.08	38.75	35.23	35.67
diuron	1	300	37.25	32.40	43.00	37.53
diuron	2	300	34.49	38.00	35.15	35.87
linuron	2	300	38.90	35.15	39.27	37.76
linuron	4	300	37.00	39.46	38.10	38.20
fluometuron	1	300	36.10	37.63	47.36	40.36
fluometuron	2	300	37.50	39.83	44.83	40.70
metobromuron	1	300	36.42	36.77	42.64	38.60
metobromuron	2	300	33.10	35.20	31.70	33.33
		150	40.91	39.20	39.35	39.80
		300	34.00	39.05	40.80	37.93
check			37.00	35.00	32.35	34.76

Analysis of Variance

Source of Variations	df		SS	MS	F Value
Replications	2		42.0669	26.0335	
Carbon rate	2		9312.4625	4656.2312	1435.42**
Replications x carbon rate	4		12.9753	3.2438	
Herbicides	8		1552.1158	194.0145	24.79**
Herbicides x carbon rate	16		2710.5909	169.4119	19.70**
Replication x herbicides	16	48			
Rep. x carbon rate x herbicides	32		375.6244	7.8255	
Total	80		14015.835798		

** Significant at 1% level.

C. V. = 10%

L. S. D. at 0.05 level = 5.34

L. S. D. at 0.01 level = 3.99

Appendix Table 12. Effect of width of activated carbon band on the susceptibility of beans to diuron.

Rate of Diuron (lb/A)	Rate of Activated Carbon (lb/A)	Carbon Band Width in Inches			Foliage Dry Weight in mg/per Pot Replications			
		0	1	3	I	II	III	Avg.
0.0	0	+			1,055	1,909	1,147	1,370
1.5	0	+			346	320	628	431
3.0	0	+			385	315	369	356
0.0	150		+		1,652	1,785	1,632	1,689
1.5	150		+		1,564	1,991	1,847	1,800
3.0	150		+		1,665	1,248	1,017	1,310
0.0	300		+		1,651	1,595	1,548	1,598
1.5	300		+		1,678	1,447	1,401	1,508
3.0	300		+		1,288	1,298	1,390	1,325
0.0	150			+	2,260	1,755	1,723	1,912
1.5	150			+	903	1,506	1,195	1,201
3.0	150			+	1,129	1,361	1,013	1,167
0.0	300			+	1,852	2,724	1,329	1,968
1.5	300			+	1,482	1,289	1,449	1,406
3.0	300			+	1,354	1,273	1,276	1,301

Analysis of Variance

Source of Variation	df	SS	MS	F Value
Replications	2	271835.7344	135917.8672	
Herbicides	2	3012976.9336	1506488.4668	20.54**
Carbon-band	4	4732212.7559	1183053.1890	16.13**
Herbicides x carbon-band	8	1249847.5098	156230.9387	2.13
Error	28	2053304.2676	73332.2953	
Total	44	11320177.201172		

** Significant at 1% level

C. V. = 19.96%

L. S. D. at .05 level = 785.00

L. S. D. at .01 level = 1057.00

Appendix Table 13. Effect of width of activated carbon bands on the root dry weight of beans treated with diuron (two months after seeding).

Rate of Diuron	Rate of Activated Carbon (lb/A)	Carbon Band Width in inches 0	1	3	Dry Weight in mg per Pot Replications I	II	III	Avg
0.0	0	+			627.64	640.64	728.13	665.00
1.5	0	+			84.30	83.74	93.12	86.67
3.0	0	+			65.33	58.19	97.19	73.33
0.0	150		+		657.00	769.34	445.00	623.67
1.5	150		+		658.64	790.00	457.00	635.00
3.0	150		+		876.00	855.25	703.28	811.33
0.0	300		+		749.80	691.31	780.36	741.33
1.5	300		+		858.63	723.00	535.00	705.33
3.0	300		+		584.40	666.21	613.28	621.00
0.0	150			+	654.71	682.67	624.12	653.33
1.5	150			+	771.18	745.40	666.72	727.67
3.0	150			+	557.00	645.40	665.22	622.33
0.0	300			+	726.36	817.37	732.43	629.00
1.5	300			+	466.23	689.58	707.00	751.00
3.0	300			+	695.25	747.40	695.43	711.33

Analysis of Variance

Source of Variation	df	SS	MS	F Value
Replications	2	37757.6445	18878.8223	
Herbicides	2	161965.3777	80982.6888	10.58**
Carbon-band	4	1220732.5776	305183.1444	39.86**
Herbicides x carbon-band	8	659132.6223	82391.5778	10.76**
Error	28	214386.3560	7656.6556	
Total	44	2293974.577637		

** Significant at 1% level

C. V. = 18.5%

L. S. D. at .05 level = 253.68

L. S. D. at .01 level = 341.55

Appendix Table 14. Effect of diuron rates on dry weight of bean foliage in the presence of several rates of activated carbon (45 days after seeding)

Treatments		Dry Weight in mg per Pot			
		Replications			
Diuron (lb/A)	Carbon (lb/A)	I	II	III	Avg
0.5		106	108	192	135.3
0.5	50	390	523	512	475.0
0.5	100	521	586	492	533.0
0.5	200	580	587	560	575.7
0.5	300	574	594	480	549.7
1.0		107	102	115	108.3
1.0	50	322	333	352	336.0
1.0	100	386	380	512	426.0
1.0	200	480	482	560	507.7
1.0	300	483	497	610	530.3
2.0		104	84	93	93.7
2.0	50	320	377	364	353.7
2.0	100	553	582	555	563.7
2.0	200	650	581	556	596.3
2.0	300	554	546	475	525.3
4.0		108	73	75	85.7
4.0	50	320	298	245	287.7
4.0	100	380	212	274	289.0
4.0	200	430	464	400	431.7
4.0	300	390	462	452	435.3
	50	500	493	620	537.7
	100	490	568	431	496.7
	200	500	521	508	510.0
	300	447	575	401	474.3
check		424	444	553	473.7

Analysis of Variance

Source of Variation	df	SS	MS	F Value
Replications	2	2760.4268	1380.2134	
Herbicides	4	324169.7334	81042.4333	29.75**
Carbon rate	4	1063225.4666	265806.3666	97.57**
Herbicides x carbon rate	16	457918.1328	28619.8833	10.51**
Error	48	130768.9071	2724.3522	
Total	74	1978842.666748		

** Significant at 1% level

C.V. = 12.6%

L.S.D. at .05 level = 149.11

L.S.D. at .01 level = 199.30

Appendix Table 15. Effect of several activated carbon rates on the control of rye grass by diuron (45 days after planting)

Treatment		Dry Weight Foliage in mg per Pot			
Diuron	Carbon	Replications			
(lb/A)	(lb/A)	I	II	III	Avg.
0.5		115	112	108	111.7
0.5	50	185	168	188	180.7
0.5	100	140	185	183	169.7
0.5	200	180	173	176	176.7
0.5	300	183	185	220	196.0
1.0		86	75	73	78.7
1.0	50	106	108	107	107.3
1.0	100	140	163	150	151.0
1.0	200	166	154	122	147.6
1.0	300	194	186	196	192.0
2.0		89	71	73	78.0
2.0	50	87	77	80	81.7
2.0	100	125	133	128	129.0
2.0	200	149	172	137	152.7
2.0	300	193	186	174	184.7
4.0		87	51	54	64.0
4.0	50	82	60	72	71.7
4.0	100	105	102	109	105.3
4.0	200	120	108	107	111.7
4.0	300	171	184	191	182.0
	50	173	184	187	181.3
	100	181	169	182	177.3
	200	146	151	171	156.3
	300	191	142	161	164.6
check		156	195	200	183.7

Analysis of Variation

Source of Variation	df	SS	MS	F Value
Replications	2	104.5067	52.2533	
Herbicides	4	46751.2533	11687.8133	60.84**
Carbon rate	4	60516.7200	15129.1800	78.82**
Herbicides x carbon rate	16	28036.2134	1752.2633	9.12**
Error	48	92134.4933	191.9478	
Total	74	144622.186676		

** Significant at 1% level

C.V. = 9.79%

L.S.D. at .05 level = 39.58

L.S.D. at .01 level = 52.89

Appendix Table 16. Effect of activated carbon on the control of barnyardgrass with diuron

Treatment		Dry Weight Foliage in mg per Pot			
Diuron	Carbon	Replications			
(lb/A)	(lb/A)	I	II	III	Avg
0.5		9.4	11.6	4.7	8.7
0.5	50	33.9	35.1	33.5	34.2
0.5	100	45.3	40.0	43.3	42.7
0.5	200	60.2	52.7	47.2	53.3
0.5	300	58.1	62.2	60.1	60.0
1.0		8.0	6.0	7.8	7.3
1.0	50	29.5	39.2	35.4	34.3
1.0	100	47.6	40.0	30.0	41.0
1.0	200	72.0	60.2	58.1	63.3
1.0	300	70.0	64.9	62.3	65.7
2.0		10.0	10.0	10.8	10.3
2.0	50	9.9	13.6	17.9	14.0
2.0	100	27.4	18.9	19.6	22.0
2.0	200	38.7	38.9	41.2	39.7
2.0	300	86.3	58.6	59.7	67.7
4.0		13.6	4.8	5.4	7.7
4.0	50	9.2	11.3	7.2	9.0
4.0	100	27.3	22.0	16.0	21.7
4.0	200	30.0	27.3	31.8	29.7
4.0	300	43.7	40.4	40.1	41.3
	50	51.7	47.2	50.3	49.7
	100	54.1	59.6	55.4	56.3
	200	63.0	57.0	52.5	57.3
	300	47.4	45.5	44.6	45.3
check		47.4	92.8	51.9	63.7

Analysis of Variance

Source of Variation	df	SS	MS	F Value
Replications	2	215.7867	107.8933	
Herbicides	4	9051.2800	2262.8200	48.17**
Carbon rate	4	17128.0800	4282.0200	91.15**
Herbicides x carbon rate	16	5833.9200	364.6200	7.76**
Error	48	2254.88	46.9767	
Total	74	34483.94667		

** Significant at 1% level

C.V. = 18.5%

L.S.D. at .05 level = 19.58

L.S.D. at .01 level = 26.17

Appendix Table 17. Effect of activated carbon on the control of pigweed by diuron

Treatment		Dry Weight Foliage in mg per Pot			
Diuron (lb/A)	Carbon (lb/A)	Replications I	II	III	Avg.
0.75	0	0	0	0	0.0
1.5	0	4	3	3	3.3
3.0	0	0	0	0	0.0
0.75	150	70	75	60	68.3
1.5	150	73	48	81	67.3
3.0	150	43	33	38	38.0
0.75	300	86	83	68	79.0
1.5	300	65	82	51	69.0
3.0	300	66	60	62	62.7
	150	56	75	73	68.0
	300	56	50	66	57.3
check		72	64	68	68.0

Analysis of Variance

Source of Variation	df	SS	MS	F Value
Replications	2	13.7222	6.8611	
Carbon rate	2	14133.3889	8566.6944	173.47**
Herbicides	3	4331.5556	1443.8519	29.23**
Carbon rate x herbicides	6	8553.9444	1425.6574	28.87**
Error	32	1580.2778	49.3837	
Total	35	31612.888889		

** Significant at 1% level
C.V. = 14.5%
L.S.D. at .05 level = 20.27
L.S.D. at .01 level = 27.33

Appendix Table 18. Effectiveness of carbon, vermiculite and carbon-vermiculite mixtures in protecting bean shoots from diuron injury

Diuron	Adsorbent		Method of Carbon Application		Foliage Dry Weight in mg per Plot			
	Carbon	Vermiculite			Replication			
lb/A	lb/A	gr/hole	Band	Mix	I	II	III	Avg.
0	0	2			817	845	680	781
0.75	0	2			411	432	408	417
1.5	0	2			171	253	211	212
3.0	0	2			218	167	165	183
0	150	2	+		902	730	843	825
0.75	150	2	+		744	767	763	758
1.5	150	2	+		1,027	1,013	1,052	1,030
3.0	150	2	+		694	684	607	662
0	300	2	+		1,025	999	1,113	1,045
0.75	300	2	+		605	1,180	623	803
1.5	300	2	+		786	951	1,312	1,016
3.0	300	2	+		951	996	904	950
0	150	2		+	1,135	1,077	910	1,040
0.75	150	2		+	1,079	961	1,032	1,024
1.5	150	2		+	1,061	1,063	1,057	1,060
3.0	150	2		+	617	1,005	1,185	936
0	300	2		+	1,198	1,220	1,028	1,149
0.75	300	2		+	1,307	889	675	957
1.5	300	2		+	955	998	983	978
3.0	300	2		+	1,165	1,158	1,011	1,111
0					996	1,368	987	1,117
0.75					367	401	233	334
1.5					235	142	274	217
3.0					133	105	139	126
0	150			+	1,124	881	908	971
0.75	150			+	566	823	885	758
1.5	150			+	418	522	627	522
3.0	150			+	185	304	253	247
0	300		+		1,061	896	725	894
0.75	300		+		954	1,038	733	908
1.5	300		+		1,128	1,029	984	1,047
3.0	300		+		964	1,020	935	973

Analysis of Variance

Source of Variation	df	SS	MS	F Value
Replications	2	52525.1455	26262.5728	1.27
Treatments	31	10118360.6000	326398.7300	15.86**
Error	62	1275750.1900	20576.6160	
Total	95			

** Significantly different at 1% level. C.V. = 18.7%

Appendix Table 19. Effectiveness of carbon, vermiculite and carbon-vermiculite mixtures in protecting bean roots from diuron injury.

Diuron	Adsorbent		Method of Carbon Application		Root Dry Weight in mg/plot			
	Carbon	Vermiculite			Replication			
lb/A	lb/A	gr/hole	Band	Mix	I	II	III	Avg.
0.0	0	2			13.5	11.6	7.5	10.87
0.75	0	2			6.2	5.9	5.5	5.87
1.5	0	2			3.9	4.1	3.8	3.93
3.0	0	2			3.2	3.0	3.7	3.30
0.0	150	2	+		9.5	10.7	9.8	10.00
0.75	150	2	+		9.8	9.2	7.8	8.93
1.5	150	2	+		8.1	10.5	7.1	8.57
3.0	150	2	+		7.5	7.0	6.8	7.10
0.0	300	2	+		9.1	11.5	13.7	11.43
0.75	300	2	+		9.5	11.0	9.0	9.83
1.5	300	2	+		12.0	9.5	12.0	11.17
3.0	300	2	+		9.1	8.5	6.4	8.00
0.0	150	2		+	11.0	8.2	7.5	8.90
0.75	150	2		+	12.5	12.1	13.5	12.70
1.5	150	2		+	10.0	10.0	9.7	9.90
3.0	150	2		+	8.3	10.5	8.0	8.93
0.0	300	2		+	9.3	9.7	8.5	9.16
0.75	300	2		+	12.1	8.3	12.5	10.97
1.5	300	2		+	12.5	13.6	9.4	11.83
3.0	300	2		+	16.0	14.5	12.5	14.33
0.0					7.0	7.9	10.2	8.36
0.75					4.7	4.3	5.1	4.70
1.5					4.0	4.0	4.6	4.20
3.0					4.0	2.0	2.5	2.83
0.0	150		+		8.5	8.5	10.4	9.13
0.75	150		+		8.0	8.5	9.0	8.50
1.5	150		+		6.0	7.0	6.5	6.50
3.0	150		+		4.8	4.0	5.8	4.87
0.0	300		+		7.8	11.3	10.2	9.77
0.75	300		+		12.6	11.2	11.7	11.83
1.5	300		+		10.3	15.0	9.9	11.73
3.0	300		+		11.0	13.5	9.5	11.33

Analysis of Variance

Source of Variation	df	SS	MS	F Value
Replications	2	4.50187516	2.25094	1.0839
Treatments	31	798.876563	25.77021	12.4089**
Error	62	128.758125	2.07674	
Total	95	932.136563		

** Significant at 1% level

C.V. = 16%

Appendix Table 20. Effect of alternate washing and drying on the adsorptive capacity of activated carbon

Diuron lb/A	Activated Carbon lb/A	No. of Washings	Dry Weight Shoots (mg) Replications I	II	III	Avg.
0.00	0		808	705	823	778.67
0.75	0		440	563	432	478.33
1.50	0		255	298	332	295.00
3.00	0		253	251	228	244.00
0.00	150	1	1,028	723	662	804.33
0.75	150	1	773	916	786	825.00
1.50	150	1	980	862	798	880.00
3.00	150	1	659	712	780	717.00
0.00	300	1	624	996	667	762.33
0.75	300	1	731	732	469	644.00
1.50	300	1	664	826	812	767.00
3.00	300	1	589	632	721	647.00
0.00	150	3	798	807	709	771.33
0.75	150	3	745	731	688	721.33
1.50	150	3	584	785	567	645.33
3.00	150	3	705	980	662	782.33
0.00	300	3	745	797	731	757.67
0.75	300	3	1,050	827	704	860.33
1.50	300	3	652	611	880	714.33
3.00	300	3	808	960	584	784.00
0.00	150	5	829	605	861	765.00
0.75	150	5	931	773	400	701.33
1.50	150	5	696	793	671	720.00
3.00	150	5	587	1,068	745	800.00
0.00	300	5	640	859	780	759.67
0.75	300	5	778	800	894	824.00
1.50	300	5	830	761	663	751.33
3.00	300	5	627	775	676	692.69

Analysis of Variance

Source of Variation	df	SS	MS	F Value
Replications	2	105225.0713	52612.5356	
No. of washings	6	1034226.1660	172371.0277	11.18**
Diuron rates	3	137738.1426	45912.7142	2.98
No. of washing x diuron rates	18	584785.3574	32488.0754	2.10
Error	54	832772.2627	15421.7086	
Total	83	2694747.0000		

* Significant at 5% level ** Significant at 1% level

L.S.D. at 0.05 level = 351.25

L.S.D. at 0.01 level = 467.16

C.V. = 17.5%

Appendix Table 21. Adsorption of diuron by four carbon sources (ppm)

Herbicide rate in ppm	Observations 1	2	3	Avg.	Observations 1	2	3	Avg.
	Aqua Nuchar				Gro-Safe			
7	2.68	2.76	2.69	2.71	2.02	1.90	1.93	1.95
10	3.06	3.10	3.06	3.07	2.56	2.46	2.48	2.50
20	4.54	4.62	4.61	4.59	3.70	3.71	3.81	3.74
	Darco-M				Pittsburg No. 3			
7	2.52	2.52	2.58	2.54	4.96	5.04	4.90	4.97
10	3.06	3.00	3.04	3.03	5.52	5.51	5.47	5.50
20	4.92	4.76	4.90	4.86	6.46	6.39	6.38	6.41

Appendix Table 22. Desorption of diuron by four carbon sources (ppm)

Source of Activated carbon	Diuron Desorption (ppm)* 1	2	3	Avg.
Aqua Nuchar	1.95	1.97	2.02	1.98
Gro-Safe	1.08	1.00	1.00	1.03
Darco-M	0.51	0.47	0.46	0.48
Pittsburg No. 3	1.52	1.56	1.60	1.56

* Original concentrate in solution 20 ppm