Relation of Structure to Phytotoxicity of *s*-Triazine Herbicides on Cotton and Weeds

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Thirty substituted *s*-triazine compounds, representing several substituent groups, were comparatively evaluated in sand-nutrient culture for pre-emergence activity on cotton, brachiaria, and crabgrass. Attempts were made to ascertain the effect of structural differences on phytotoxic activity and to select compounds with promise as selective pre-emergence or preplanting herbicides for cotton. Chloro derivatives were low in selectivity and low to moderate in activity against the two weeds. Only methylmercapto or methoxy derivatives had both high activity on weeds and low activity on cotton. Amido derivatives were generally high in selectivity, but all were very low in activity. Alkylamino substituents were present in active, inactive, selective, and nonselective compounds.

Chemical, physical, and structural properties of herbicides are very important in determining plant response to pre-emergence herbicides; soil and plant properties are equally important. Considerable research on these properties has been reported with reference to the pre-emergence use of *s*-triazine herbicides. Reviews on the herbicidal properties of *s*-triazines in general have been made by several authors (*1*, *2*, *6*, *7*).

Pre-emergence applications of *s*-triazines to plants in sand-nutrient cultures (*4*, *5*), and in soil (*6*, *7*) have indicated certain generalities with respect to plant response. Corn appeared highly tolerant to chloro derivatives, but susceptible to methylmercapto and methoxy derivatives. Cotton appeared more tolerant of methylmercapto derivatives than of methoxy or chloro substituted *s*-triazines. Soybeans appeared more tolerant of methoxy and methylmercapto derivatives than of chloro derivatives. Two annual grasses (crabgrass and brachiaria) were more susceptible in general to methylmercapto and methoxy derivatives than to chloro derivatives.

The primary objective of the present investigation was to determine some effects of molecular structure of 30 *s*-triazine herbicides on the response of cotton and two weeds to the herbicides applied pre-emergence with minimum interference from the media in which the plants were grown.

Materials and Methods

The plants used were cotton [*Gossypium hirsutum* L. (DBES 8274)], brachiaria [*Brachiaria platyphylla* (Griseb.) Nash], and crabgrass [*Digitaria sanguinalis* (L.) Scop.]. Previous work (*5*) indicates that brachiaria is generally resistant to *s*-triazines as compared with other annual weeds while crabgrass is generally susceptible to many herbicides.

Waxed cartons were filled to within 1 inch of the top with masonry sand. Nine concentrations, including a zero level, of 30 *s*-triazine herbicides (chemical structures are presented in Table II) were prepared using full-strength Nutrient Solution 2 described by Hoagland and Arnon (*3*) as the diluent. Each herbicide concentration was twice that of the next concentration in descending order. About 200 ml. of the appropriate herbicide solution, emulsion, or suspension was applied to the surface of the sand in each container. Approximately half of this amount was excess and drained out through holes 1 inch from the bottom of the carton. Response data used in classification of herbicide activity came from cartons treated with solutions for 25 of the herbicides, including the standard herbicide diuron. Utilized data for the remaining six *s*-triazines included data from some cartons treated with suspensions or emulsions, and these data are included in the group presented as possible minima or maxima rather than as point estimates. After the herbicides were applied, seeds were added (one species per carton) and covered with a measured amount of dry, untreated sand appropriate for the desired depth of planting. After emergence, the cotton was thinned to two plants per carton, but the grasses were not thinned. Thereafter, the cartons of sand were sprinkled as needed to maintain moisture without drainage loss, but no herbicide or nutrient solution was added.

Because it was not practical to include all herbicides, plant species, and rates in a single experiment, 3-(3,4-dichlorophenyl)-1,1-dimethylurea (diuron) was used as a reference material or standard for herbicidal activity in each of five subexperiments. In these subexperiments, a few herbicides, one of which was always diuron, were applied to all species at all concentrations in two replications.

Visual ratings of plant response were recorded 2 to 3 weeks after planting when the appearance of new injury symptoms appeared to have ceased. Graphs of plant response versus concentration were made for each herbicide. ED_x values for each herbicide (concentration of herbicide in p.p.m. by weight necessary to reduce growth of plant by x per cent) were determined from the graphs and used to prepare selectivity and activity indices in a manner similar to that reported in 1958 by Upchurch (*8*). The selectivity index for each herbicide was prepared by dividing the ED_{30} for cotton by the ED_{70} for weeds. Thus, a herbicide which reduced weed growth by 70% at a concentration which reduced cotton growth by 30% would have a selectivity index value of 1.0. Weed control activity indices were computed by dividing the ED_{50} for diuron (within the same subexperiment) by the ED_{50} for the triazine. Thus, if four times as much of a triazine as of diuron was required to reduce growth of a weed species by 50%, the index value of the triazine would be 0.25.

Selectivity index values below 0.99 and activity values below 0.25 were considered low, and values above these were considered high. Thus, a compound with a selectivity index of 1.8 for cotton versus brachiaria and an activity index of 0.8 for brachiaria would be more promising for control of brachiaria in cotton than one with corresponding index values of 0.9 and 0.4. All data in the tables have been rounded to the nearest tenth to reduce implications of significance to small difference between treatments. Index values below 0.1, being of doubtful interest, are presented merely as being less than 0.1. In a few instances, the highest concentrations used failed to cause the desired levels of response, and the related data are also presented as minima or maxima. Unless otherwise specified, all statements referring to selectivity for weed control and activity refer only to cotton and the weeds included.

Results and Discussion

Diuron, the standard herbicide, was highly selective and active at low concentrations (Table I). Activity of each *s*-triazine on the weeds was calculated as a percentage (w./w.) of the activity of diuron within the same subexperiment to provide a basis for comparisons between *s*-triazines in different subexperiments. Variability from one subexperiment to another, as measured by diuron performance, was normal for greenhouse experiments conducted over an extended period. Selectivity and activity of the standard herbicide varied approximately 100% among the five subexperiments (Table I). Differences between *s*-triazines considered significant exceeded 100% with a few minor exceptions, and exceeded 200% in most comparisons.

Table I. ED_{50} Values and Selectivity Indices for Diuron

Subexperiment No.	ED_{50} (P.P.M.)[a] Brachiaria	ED_{50} (P.P.M.)[a] Crabgrass	Selectivity Index,[b] Cotton Versus Brachiaria	Selectivity Index,[b] Cotton Versus Crabgrass
1	0.11	0.04	2.0	5.8
2	0.08	0.04	1.2	3.0
3	0.12	0.04	1.8	7.1
4	0.18	0.05	1.2	4.3
5	0.11	0.07	2.1	3.5
Av.	0.12	0.05	1.7	4.7

[a] Concentration in p.p.m. required to reduce growth by 50%.

[b] $\frac{ED_{30}\text{ for cotton}}{ED_{70}\text{ for weed}}$ For example, in subexperiment 1, twice as much diuron was required to injure cotton 30% as to injure brachiaria 70%.

Selectivity and activity ratings of all *s*-triazines are presented in order of decreasing activity on brachiaria within groups of high and low selectivity between cotton and brachiaria (Table II).

Generally, crabgrass was much more susceptible than brachiaria to the triazines. Of the triazines which were as much as 25% as active as diuron on brachiaria, only one had a crabgrass ED_{50} lower than the brachiaria ED_{50}. Except for simetone, therefore, *s*-triazines classified as active against brachiaria would also control crabgrass if used in a concentration effective against brachiaria. Thus, for interpretation of the data to identify maximum-activity compounds, the crabgrass activity index can largely be ignored.

Six of the compounds evaluated appeared highly selective and sufficiently active to warrant field evaluation as pre-emergence or preplanting herbicides for cotton. These were ametryne, simetone, prometryne, isotryne, simetryne, and ipatone. Considerable activity and selectivity, particularly on crabgrass, were exhibited by prometone and 2-isopropylamino-4-methylamino-6-methoxy-*s*-triazine. All other compounds appeared low in selectivity, activity, or both. Review of the data in Tables I and II should, in addition to aiding selection of compounds, provide information as to how each chemical should be studied in the future. For instance, compounds high in selectivity should be evaluated as soil-incorporated herbicides as well as surface-applied herbicides. Compounds high in activity and moderate in selectivity such as prometone would probably perform more effectively in clay or soils high in organic matter than in sandy soils low in organic matter. In sandier soils, more reliance would have to be placed on differential placement of the herbicides for selectivity.

Structural effects on phytotoxicity were studied by rearrangement of the data of Table II into groups with one constant and two variable substituents. Since there are 15 different substituents involved, 15 groups of one to 17 compounds each are possible. For example, 17 of the *s*-triazines are isopropylamino derivatives and one of the 30 is an allylamino derivative. Such an arrangement of data involves much repetition and is omitted in this report. Formation of groups containing one constant and two variable substituents were used, however, in developing the remainder of the results and discussion.

Allylamino and Propylamino Derivatives. Only one allylamino and only one propylamino derivative were included in this study. Both were low in activity and selectivity.

Chloro Derivatives. All chloro derivatives were low in selectivity between brachiaria and cotton. Four derivatives had selectivity between crabgrass and cotton, but all four were low in activity. All but two of the chloro derivatives, simazine and 2-chloro-4-ethylamino-6-(3-methoxypropylamino)-*s*-triazine, were relatively low in activity.

Diethylamino, Ethylamino, Isopropylamino, and Methylamino Derivatives. Presence or absence of a diethylamino, ethylamino, isopropylamino, or methylamino substituent was not necessary for selectivity or activity. Each appeared in at least one of the compounds that were high in both activity and selectivity. All of the active and selective compounds contained at least one of these substituents, but each of these substituents was also present in compounds that were either relatively inactive or nonselective with respect to both weeds. All except the ethylamino substituent appeared in compounds that were low in both activity and selectivity.

Ethoxy, Trichloromethyl, and Amido Derivatives. All compounds containing one or more of the ethoxy, trichloromethyl, or amido substituents were low in activity. All of these except 2-ethylacetamido-4-isopropylacetamido-6-methoxy-*s*-triazine were highly selective.

Methylmercapto Derivatives. All compounds containing a methylmercapto substituent were high in selectivity and activity. Alkylamino methylmercaptos tended to be more selective than the corresponding alkylamino methoxys.

Methoxy Derivatives. Methoxy compounds were present in both selective and nonselective groups. Activity on weeds was high except where amido substituents were present.

3-Methoxypropylamino Derivatives. Two of the three compounds containing the 3-methoxypropylamino substituent were high in activity, but all were low in selectivity.

Table II. Selectivity and Activity Indices for s-Triazine Herbicides in Relation to Cotton and Weeds in Sand-Nutrient Cultures

Compounds arranged in order of descending toxicity to brachiaria within selectivity groups

s-Triazines			Name or Code No.	Selectivity Index[a] Cotton Versus		Activity Index[b]	
High Selectivity, Cotton vs. Brachiaria							
2	4	6		Brachiaria	Crabgrass	Brachiaria	Crabgrass
Ethylamino	Isopropylamino	Methylmercapto	Ametryne	1.6	3.3	1.2	0.8
Ethylamino	Ethylamino	Methoxy	Simetone	2.3	1.3	1.0	<0.1
Isopropylamino	Isopropylamino	Methylmercapto	Prometryne	1.6	10.0	0.7	1.3
Isopropylamino	Methylamino	Methylmercapto	Isotryne	1.0	3.1	0.4	0.4
Ethylamino	Ethylamino	Methylmercapto	Simetryne	1.1	2.0	0.3	0.4
Diethylamino	Isopropylamino	Methoxy	Ipatone	1.7	2.5	0.3	0.2
Ethylamino	Ethylamino	Trichloromethyl	34041	>8.0	> 6.0	0.1	<0.1
Ethylbenzamido	Ethylbenzamido	Methoxy	34675	1.6	6.0	<0.1	0.1
Ethylacetamido	Ethylacetamido	Methoxy	34035	>1.0	> 1.7	<0.1	<0.1
Ethylamino	Ethylamino	Isopropylamino	34451	1.3	2.9	<0.1	0.1
Ethoxy	Isopropylacetamido	Isopropylacetamido	34472	>8.0	> 9.0	<0.1	<0.1
Diethylamino	Isopropylacetamido	Methoxy	34405	>4.0	>12.0	<0.1	<0.1
Low Selectivity, Cotton vs. Brachiaria							
2	4	6					
Isopropylamino	Isopropylamino	Methoxy	Prometone	0.7	1.0	0.9	0.9
Ethylamino	Isopropylamino	Methoxy	Atratone	0.3	0.7	0.6	0.5
Methoxy	(3-Methoxypropylamino)	(3-Methoxypropylamino)	34690	0.2	0.4	0.6	0.2
Isopropylamino	Methylamino	Methoxy	32292	0.2	1.0	0.4	0.7
Chloro	Ethylamino	Ethylamino	Simazine	0.1	0.3	0.4	0.2
Chloro	Ethylamino	(3-Methoxypropylamino)	34696	0.1	0.6	0.3	0.4
Chloro	Ethylamino	Isopropylamino	Atrazine	<0.1	1.0	0.1	0.2
Chloro	Isopropylamino	(3-Methoxypropylamino)	34698	<0.1	0.7	<0.1	0.2
Ethylamino	Isopropylamino	Methylamino	34365	0.6	1.7	<0.1	<0.1
Chloro	Diethylamino	Ethylamino	Trietazine	0.7	4.6	<0.1	<0.1
Chloro	Isopropylamino	Methylamino	30026	<0.1	0.4	<0.1	0.2
Ethylacetamido	Isopropylacetamido	Methoxy	34572	0.3	0.5	<0.1	<0.1
Chloro	Isopropylamino	Propylamino	30451	0.1	0.3	<0.1	<0.1
Chloro	Diethylamino	Diethylamino	Chlorazine	<0.4	<0.4	<0.1	<0.1
Ethylamino	Isopropylamino	Isopropylamino	34453	>0.7	>1.6	<0.1	<0.1
Allylamino	Chloro	Isopropylamino	34361	<0.1	0.2	<0.1	<0.1
Chloro	Diethylamino	Isopropylamino	Ipazine	0.1	1.3	<0.1	<0.1
Chloro	Isopropylamino	Isopropylamino	Propazine	<0.1	1.7	<0.1	0.2

[a] $\frac{ED_{30}\text{ cotton}}{ED_{70}\text{ weed}}$ For example, prometryne was much more selective than prometone with respect to control of crabgrass and brachiaria in cotton.

[b] $\frac{ED_{50}\text{ diuron}}{ED_{50}\text{ triazine}}$ For example, prometone was approximately twice as toxic as isotryne to crabgrass and brachiaria, but was only 90% as effective as the standard herbicide diuron.

The data obtained in this study are in general agreement with those of other related investigations (*4*, *5*, *7*). Some of the few exceptions are in regard to compounds intermediate in selectivity or activity, and may be the result of residual experimental errors. Other differences among the various investigations are undoubtedly the result of intentional variables among experiments which would influence adsorption by the experimental media, absorption by the experimental plants, and volatility of the herbicides. All these investigations indicate that classification of the *s*-triazines by a single substituent can be misleading. For instance, methoxy derivatives cannot be classified as active because methoxy derivatives which are also amido derivatives are very inactive as pre-emergence herbicides.

Several general and accurate statements about the effect of structure on activity and selectivity can be made as follows:

All *s*-triazines which contain a chloro substituent were low in selectivity and low to moderate in activity against the two weeds.

All methylmercapto and some methoxy derivatives were selective and active.

All *s*-triazines containing amido substituents were very low in activity against the two weeds, and all but one were very selective.

Alkylamino substituents were present in active, inactive, selective, and nonselective compounds.

Obviously, these four general statements must be restricted to cotton, crabgrass, and brachiaria. Extreme caution should be used in even theoretical extension of these statements to include similar *s*-triazines not included in this study. Further, all of these general indications would vary with environmental factors such as soil type, temperature, humidity, soil moisture, rainfall, and others. Although these restrictions must be observed, the data obtained should facilitate the selection of *s*-triazines for evaluation experiments and provide preliminary data for studies on modes of action.

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