Peroxidizing Herbicides (II): Structure-Activity Relationship and Molecular Design
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\textbf{Introduction}

The \textit{p}-nitrodiphenyl ethers (DPEs) and cyclic imides (Cyls), here called peroxidizing herbicides of the first generation (1965–1980), induce inhibition of chlorophyll biosynthesis and phototoxicative destruction of plant membranes affecting photosynthetic pigment contents. The detailed mechanism of action of the peroxidizing herbicides has been outlined in the first part of this review (Böger and Wakabayashi, 1995). The immediate physiological response of the plant against these herbicides is a halt of chlorophyll biosynthesis and photodynamic destruction of cellular constituents. The old light-dependent herbicidal-action theory of DPEs is accompanied by an abnormal accumulation of protoporphyrin-IX (proto-IX or a derivative thereof), which acts as a photosensitizer in the light and induces radical formation with subsequent destruction of cellular constituents. The old light-dependent herbicidal-action theory of DPEs and Cyl compounds (Matsunaka, 1969; Matsunaka, 1976; Suzuki \textit{et al}., 1975; Wakabayashi \textit{et al}., 1979; Fedtke, 1982) can now be discussed on the basis of this principle.

The substantial steps made forward in recent years to elucidate the mechanism of action gave a strong impetus to molecular design of the second generation (since 1980) of peroxidizing herbicides. At least 20 different herbicide candidates including Cyls, pyrazoles, triazoles, triazolidines, thiazolidines and oxazolidines with an N-(2-fluoro-4-chloro-5-substituted)phenyl moiety, 2-chloro-4-trifluoromethylphenyl 3'-substituted-4'-nitrophenyl ethers, and certain pyridine derivatives are currently in development and more may be investigated (Fig. 1; Wakabayashi and Böger, 1993, 1994). The basic structures of peroxidizing herbicides including those of 1st and 2nd generation can now be classified into five larger groups: (1) diphenyl ethers, (2) cyclic imides, (3) N-aryl-diazoles, (4) N-heterocyclic five-membered compounds without N-aryl linkage, and group (5) including compounds with a pyridine-carboxamide or a carbamate moiety (Fig. 2). Oxyfluorfen and SUAM-16476 of group 1 are representatives of the most active DPE peroxidizers. Within the five groups, the Cyl class (group 2) is most flourishing in designing new peroxidizing herbicides, starting from modification of the old parent compound, chlorophthalim, as outlined by Fig. 3. To design Cyl-type peroxidizers, the N-(2-fluoro-4-halogen (Cl or Br)-5-substituted) aryl moiety is essential to produce highly active compounds (Wakabayashi \textit{et al}., 1979; Wakabayashi, 1988). Herbicides of group 3 and 4 of Fig. 2 are the immediate family of Cyl peroxidizers. It should be noted that in the pyrazole series of group 3 a 2,4,6-substituted aryl moiety proved to be effective. More recent N-heterocyclic five-membered peroxidizers (group 4) without an N-aryl linkage to the heterocycle should be emphasized (Miura \textit{et al}., 1993; Miura \textit{et al}., 1994; Hamper \textit{et al}., 1995), indicating that N-aryl linkage, although dominant in peroxidizers, is not mandatory. The active compounds of this series include the C-(2-fluoro-4-halogen-5-substituted) aryl moiety, which markedly contrib-
Fig. 1. Development of peroxidizing herbicides: Two generations since 1965.

Fig. 2. Peroxidizing herbicides: The basic structures can be arranged in five groups.

Molecular design of peroxidizing herbicides has been integrated into other scientific disciplines.
Consideration of the First Generation of Peroxidizing Herbicides

The DPEs and Cyls, exhibiting the so-called light-dependent herbicidal action and bleaching activity related to photooxidative destruction of thylakoid and cell membranes, are now verified as peroxidizing herbicides (Wakabayashi and Böger, 1993; Böger and Wakabayashi, 1995). Several key studies sorting new leads have been introduced and are discussed here.

I. SAR studies of DPE and Cyl peroxidizers

Diphenyl ethers: Various analogues have been assayed to find a correlation between chemical structures, their peroxidizing activity and protox inhibition (Lambert et al., 1983; Nandihalli et al., 1992). Many 2-chloro-4-trifluoromethylphenyl 3'-substituted-4'-nitrophenyl ethers exhibit protox inhibition and light-induced peroxidation. 3'-Substituents, such as COOCH₃, OCH₃, OC₂H₅, NHC₂H₅ and CONHCH₃, enhance the peroxidizing activity. A free carboxyl group in 3-position will reduce activity, its esterification generally markedly increases activity. Activity will be generally enhanced by substituents with positive Hammett σ parameters at 2- or 4-position at the phenyl ring not bearing a nitro group. Neither protox inhibition nor initial phytotoxic activity is changed by substituting 4'-chloro for a 4'-nitro group. The phytotoxic activity is completely lost when the CF₃-group is moved from 4- to 5-position. Compounds with S, SO, SO₂ or an NH-linkage between the two phenyl rings are herbicidally inactive. The promising structures of peroxidizing herbicides are shown in Fig. 4 (left part).

Cyclic imides: It has already been considered that the peroxidizing activity of Cyls is extremely high amongst compounds whose structures conform to the following rule (see Fig. 4, right part; Wakabayashi et al., 1979; Wakabayashi, 1988;
2. QSAR studies on peroxidizing herbicides

For a large number of compounds, it has been established that their herbicidal efficiency in greenhouse tests and growth-inhibition activity against *Echinochloa* can be quantitatively correlated with high significance through the peroxidative phytotoxic parameters obtained from autotrophic *Scenedesmus* cells (Böger and Wakahayashi, 1995; Wakahayashi et al., 1988; Watanabe et al., 1992; Böger and Sandmann, 1994). Those are growth inhibition, decrease of chlorophylls and carotenoids, short-term accumulation of proto-IX and light-induced ethane formation, even the protox inhibition using corn etioplasts can be now combined with this network. A reliable quantitative correlation has been established with the six parameters mentioned. For example, QSARs of the peroxidizing compounds can be accomplished either with the *Echinochloa* root-growth inhibition test, by measuring light-induced ethane formation, or with decrease of chlorophyll content in sensitive green microalgae. The investigator may choose any one of the six parameters, whichever he can handle best in the laboratory.

The QSARs between structures and phytotoxic parameters obtained from 40 N-aryl-3,4,5,6-tetrahydrophthalimides have been analyzed using physico-chemical parameters and regression analysis (Ohta et al., 1980; Wakahayashi, 1988; Sato et al., 1992). The results shown in Table I indicate that the position-specific steric effect of aromatic substituents, as presented by the STERIMOL values of para-substituents, are highly important in determining the phytotoxic potency of cyclic imide...
Table I. Quantitative structure-activity relationship of cyclic imide peroxidizers (N-aryl-3,4,5,6-tetrahydrophthalimides).

<table>
<thead>
<tr>
<th>PI_{50}</th>
<th>Structure</th>
<th>( K )</th>
<th>( L_p )</th>
<th>( B_{5p} )</th>
<th>( n )</th>
<th>( r )</th>
<th>( s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echinochloa</td>
<td>( 4.062 \pm 0.197 )</td>
<td>( -0.876 \pm 0.383 )</td>
<td>( 2.086 \pm 0.336 )</td>
<td>( -0.370 L_p^2 - 1.079 B_{5p} )</td>
<td>( 40 )</td>
<td>( 0.912 )</td>
<td>( 0.345 )</td>
</tr>
<tr>
<td>Scenedesmus</td>
<td>( 5.595 \pm 0.252 )</td>
<td>( -0.944 \pm 0.487 )</td>
<td>( 2.652 \pm 0.427 )</td>
<td>( -0.471 L_p^2 - 1.380 B_{5p} )</td>
<td>( 40 )</td>
<td>( 0.912 )</td>
<td>( 0.439 )</td>
</tr>
<tr>
<td>Chlorophyllum</td>
<td>( 5.738 \pm 0.264 )</td>
<td>( -1.174 \pm 0.513 )</td>
<td>( 2.768 \pm 0.450 )</td>
<td>( -0.508 L_p^2 - 1.390 B_{5p} )</td>
<td>( 40 )</td>
<td>( 0.909 )</td>
<td>( 0.462 )</td>
</tr>
<tr>
<td>Carotenoid</td>
<td>( 5.688 \pm 0.258 )</td>
<td>( -1.155 \pm 0.502 )</td>
<td>( 2.737 \pm 0.441 )</td>
<td>( -0.505 L_p^2 - 1.412 B_{5p} )</td>
<td>( 40 )</td>
<td>( 0.914 )</td>
<td>( 0.452 )</td>
</tr>
<tr>
<td>Ethane</td>
<td>( 5.200 \pm 0.171 )</td>
<td>( 0.772 \pm 0.307 )</td>
<td>( -0.041 L_p^2 - 0.304 B_{5p} )</td>
<td>( 13 )</td>
<td>( 0.914 )</td>
<td>( 0.453 )</td>
<td></td>
</tr>
<tr>
<td>Protox</td>
<td>( 5.417 \pm 0.443 )</td>
<td>( 2.172 \pm 1.104 )</td>
<td>( -0.195 L_p^2 - 0.947 B_{5p} )</td>
<td>( 16 )</td>
<td>( 0.900 )</td>
<td>( 0.493 )</td>
<td></td>
</tr>
</tbody>
</table>

\( PI_{50} \) values were determined by a root growth inhibition assay with *Echinochloa utilis* in a light/dark regimen (Eqn. (1)), growth inhibition of autotrophic *Scenedesmus acutus* (Eqn. (2)), decrease of chlorophyll and carotenoids in autotrophic cultures (Eqns (3), (4)), light-induced ethane formation by *Scenedesmus acutus* (Eqn. (5); the \( PI_{50} \) value is the “activity value” as explained in Böger and Wakabayashi, 1995). Eqn. (6) represents the structure-activity relationship of STERIMOL parameters with the inhibition of isolated protoporphyrinogen oxidase from corn (*Zea mays*), \( o = 2 \) (Hammett constants of substituents). \( L_p \) is the STERIMOL parameter for the length along the bond axis connecting C(para) and the atom of the para-substituents. \( B_{5p} \) is the largest one among the STERIMOL width parameters of para-substituents. \( n \) is the number of experimental data, \( s \) the standard deviation, and \( r \) the correlation coefficient. Figures in parentheses are the 95% confidence intervals.

Peroxidizers. In Eqns (1) to (6), the phytotoxic activities are satisfactorily delineated by taking into account the combined electronic effect expressed as \( \Sigma \sigma \) as well as the steric influence of para-substituents, although the \( \sigma \) term is not significant in Eqns (5) and (6) due to insufficient number \( n \) of data available on ethane formation and protox inhibition. There exists an optimum length of para-substituents for protox inhibition in a series of Cyls as shown in Eqn. (5), where the length effect is represented by a parabolic function of the \( L_p \) parameter. The smaller the width of the para-substituent, the more feasible will be the interaction with the target enzyme. The QSAR study of other series of Cyl class of peroxidizers, namely N-aryl-1,5-tetramethylene-hydantoins, 4-aryl-1,2-tetramethylene-1,2,4-triazolidine-3,5-diones and their thiocarbonyl analogues, also have been demonstrated using STERIMOL parameters and Hammett \( \sigma \) constants (Wakabayashi, 1988; Sato et al., 1992). The herbicidal activity of N-(2-fluoro-4-substituted-5-methoxy)phenyl-3,4,5,6-tetrahydrophthalimides has recently been discussed in relation to hydrophobicity constants, inductive and resonance parameters, and molar refractivity (Lyga et al., 1991). It is concluded that the 4-position of the N-phenyl moiety should be occupied by a small, hydrophobic and electron-negative group for optimum activity.

The QSARs between molecular properties of 24 DPEs and their effects on protox and herbicidal activity have been reported (Nandihalli et al., 1992). The QSARs indicate that the electronic (partial charge, superdelocalizability, dipole moment) and hydrophobic properties account for the variation in protox inhibition, and molecular bulk and overall electronic potentials are responsible for the herbicidal effect.

3. Peroxidizing activity and X-ray structures of peroxidizers

Nandihalli et al. (1992) have reported the molecular similarity between protoporphyrinogen-IX (protox) and acifluorfen by comparing their molecular size as derived from semiempirical molecular orbital (MO) calculation. Such a comparison is feasible since protox inhibitors compete with the
substrate at the target enzyme (cf. our review, part I). They reported that the maximum length (12.29 Å) and width (5.53 Å) of acifluorfen matched closely with the full length and one-half width of protogen molecule. In addition, the torsion angle of acifluorfen at the ether oxygen matched with the angle at the methylene bridge between two neighboring pyrrole rings (Fig. 5: left upper part). In our crystallographic studies, the longest length of KPP-314 (see also Fig. 2), chlorophthalim and of oxyfluorfen were 12.56 Å, 11.37 Å and 12.31 Å, respectively (Kohno et al., 1993). These values indicate that the molecular size of three peroxidizing herbicides is about the same. The values 11–13 Å may indicate the length of the receptor size of protox. The torsion angles of KPP 314 and oxyfluorfen, which show good phytotoxic activity, were found approx. 65–85° also in X-ray analysis. It appears that both length and angle of the molecules have some bearing on peroxidizing activity and may contribute a steric factor to match with protox. Recent calculations based on molecular orbitals of our group have shown that cyclic imides (chlorophthalim. Fig. 5. left part. bottom) and triazolidine-type inhibitors do not match with the (b) and (c) pyrrole rings of protoporphyrinogen (as does acifluorfen), but favorably match with the (c) ring and the propanoic acid part (e). (Fujii et al., 1995). The different fitting of inhibitors with protoxen obviously points to different amino acid residues of protox functioning as the binding partners of these inhibitors. Lack of substantial cross-resistance between oxyfluorfen and chlorophthalim corroborates this assumption (Watanabe, 1992). Recently, Hagiwara and Nakayama (1994) have also reported the molecular similarity of three peroxidizing herbicides, namely 1,2,4-triazolin-3-one-3,4,5,6-tetrahydrophthalimide (S-23142 in Fig. 1) and 1,2,4-thiadiazole derivatives with a 2-fluoro-4-chloro-5-propargyl oxyphenyl group (NS-1556 in Fig. 9) through conformational analysis for the rotation of the phenyl ring of these compounds. We strongly suggest that molecular properties of a peroxidizing inhibitor have to be compared with those of protogen, the substrate of the enzyme. Comparison of different
inhibitors alone (e.g. DPEs and cyclic imides) is not sufficient to give a clue for possible molecular design (comp. Akagi and Sakashita, 1993).

4. Structural conversion of peroxidizing herbicides in plants

The DPEs are relatively stable in the bioassay medium as compared to cyclic imides. N-Aryl-3,4,5,6-tetrahydrophthalimides (imides) and N-3,4,5,6-tetrahydrophthalamic acids (amide-acids) are interconverted to each other during incubation with seedlings of *Echinochloa utilis* (Sato *et al.*, 1991). N-Aryl-3,4,5,6-tetrahydroisophthalimides (isoimides), which show strong peroxidizing activity like imides, are transferred to amide-acids, and then the amide-acids are cyclized to imides and/or hydrolyzed to the corresponding anilines and 3,4,5,6-tetrahydrophthalic acid during a bioassay in the presence of *Echinochloa* (Fig. 6; Hoshi *et al.*, 1993). The most effective phytotoxic structures of imides, isoimides and amide-acids are now considered to be *imides* formed through the (inter)conversion mentioned above. Analogous experiments have been carried out using several sets of isomeric peroxidizing herbicides, namely 5-arylimino-3,4-tetramethylene-1,3,4-thiadiazolidine-2-ones and 4-aryl-1,2-tetra-methylene-1,2,4-triazolidin-3-one-5-thiones, exposing them to *Echinochloa* seedlings, *Scenedesmus*, or to a spinach homogenate (Hoshi *et al.*, 1992; Sato *et al.*, 1994a). The former compounds were readily converted into triazolidines, during incubation in the presence of the plants or the homogenate, however, the opposite conversion of triazolidines into thiadiazolidines was not observed. Accordingly, the most powerful phytotoxic principle of the thiadiazolidin peroxidizers appears to be due to formation of the triazolidines in the presence of plants; the triazolidines are more potent herbicides than the thiadiazolidines. Recently, it has been reported that the conversion of thiadiazolidines into triazolidines rapidly proceeds with glutathione S-transferase and SH-compounds present such as glutathione, dithiothreitol and others (Iida *et al.*, 1994a, b; Sato *et al.*, 1994b; Shimizu *et al.*, 1994, 1995). This reaction apparently reflects a new functional property of a certain glutathione S-transferase isoenzyme (Nicolaus *et al.*, 1995). The compounds, like isoimides and thiadiazolidines, can be referred to as pro-herbicides with the intention that a more active phytotoxic molecule is formed within, or in the vicinity of, plant cells, preferably at the targeted chloroplast.

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![Fig. 6. Structural conversion of cyclic imide compounds (left part) and thiadiazolidines (right part) in the presence of *Echinochloa utilis* seedlings. Seedlings were cultured with the chemicals for 7 days in darkness according to Sato *et al.* (1994a). Conversion of the compounds to other structures was analyzed by HPLC.](image-url)
The Second Generation of Peroxidizing Herbicides

The first generation of peroxidizing herbicides, such as oxadiazon, chlorophthalim and oxyfluorfen, have handed down their unique phytotoxic properties to more than 20 different peroxidizing herbicides or candidates of a second generation including DPEs, Cyls, pyrazoles, triazoles, triazolidines, thiadiazolidines, oxazolidines and so on, which have been developed mostly in the second half of the 1980's (Figs. 7, 8 and 9). By studies in our laboratories many of these compounds have experimentally been confirmed to be peroxidizing herbicides by inhibiting protox, causing photooxidative ethane formation and a strong bleaching effect in the light, although their structures are quite different. Some candidates, e.g. KPP-300, KPP-314, S-23142, flumipropyn, flumioxazin, fluthiacet-methyl (KIH-9201), NS-1556, thidiazimin, ET-751, PPG-1013 and SUAM-16476, are currently developed as practical herbicides. In Figures 7 to 9 these and further structures of candidates for peroxidizing herbicides are illustrated for the reader's information. Also a compilation of compounds with possible peroxidative properties written by Anderson et al. (1994) should be consulted.

Experiments are under way to determine in detail the peroxidizing characteristics of these compounds in our laboratories.

Design for Future Peroxidizing Herbicides

The general characteristics of these herbicides are attractive features to develop a number of new target products by herbicide design. These characteristics are nowadays obtained mostly by mechanism of action studies. The inhibition of chlorophyll biosynthesis is an important mechanism of the peroxidizing action which results in decrease of plant pigments via radical reactions started by sensitized tetrapyrroles in the light. Obviously, protox is a favorable target, although it is inhibited competitively and reversibly. The low inhibitor constants for plant protox in combination with an apparent rapid turnover of proto IX to generate

![Diagram of peroxidizing diphenyl ether herbicides]

Fig. 7. Peroxidizing diphenyl ethers (A) and peroxidizing herbicides with new structures (B).
Fig. 8. Recent structural modifications of peroxidizing compounds belonging to the cyclic imide class: pyrrolidinones, pyrazoles, triazolones, pyrimidinones, pyridazinones and their analogues. For some compounds the dates are indicated when they were first patented (see also Fig. 9).

Fig. 9. Recent structural modifications of peroxidizing compounds belonging to the cyclic imide class: oxazolidines, triazolidines, thiadiazolidines and cyclic imides with new aryl moieties.
radicals lead to amazingly low use rates. These are
down to some grams per hectare (e.g. 10–20 g/ha
for flumipropyn or 5–10 g/ha for flutiacet-
methyl; formulas in Figs. 8 and 9, respectively),
which makes such herbicidal compounds interesting
candidates for future ecology-oriented chemical
weed control. Leaching problems are minor
ones; many of the peroxidizing herbicides in devel-
opment (see Fig. 1 in Böger and Wakabayashi,
1995) exhibit a reduced persistence in soil. A vari-
ety of compounds with different core structures
are good protox inhibitors giving the synthetic
chemist a fair chance to find more. Prospects are
good that this chance will be improved by more
knowledge of the biochemistry of the peroxidation
reaction system and of the enzymology involved.
“Me-Too” design as well as the development of
compounds with new core structures and substi-
tuents, should be based on rational approaches
using advanced biochemical investigations.

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Akagi T. and Sakashita S. (1993). A quantum chemical
**48c**, 345–349.

Anderson R. J., Norris A. E. and Hess F. D. (1994). Syn-
thetic organic chemicals that act through the porphy-
rin pathway. In: Phorphyric Pesticides (S. O. Duke and
C. A. Rebeiz, eds.). ACS Symp. Ser. no. 559, Amer.
Chemical Soc., Washington, D. C., pp. 18–33.

Böger P. and Sandmann G. (1993), Pigment biosynthe-
sis and herbicide interaction. Photosynthetica **28**,
481–493.

Böger P. and Wakabayashi K. (1995), Peroxidizing herbi-
159–166.

Fedtke C. (1982), Diphenyl ether herbicides. In: Bio-
chemistry and Physiology of Herbicidal Action.
Springer Publ., Berlin.

Fujii H., Koura S., Takusuka S., Uraguchi R., Iida T.,
Sato Y., Nicolaus B., Böger P. and Wakabayashi K.
(1995), Protoporphyrinogen oxidase inhibition and
molecular structures of cyclic imide herbicides. Ab-

Hagiwara K. and Nakayama A. (1994), Molecular simi-
larity of peroxidizing herbicides: Biososterism in Δ2-
1,2,4-thiadiazolines and related heterocyclic com-

Hamper B. C., Leschinsky K. L., Massey S. M., Bell
3-Aryl-4-substituted-5-(halo)alkylisoxazoles. Design,
synthesis, and herbicidal activity of a unique class of pre-
and postemergent herbicides. In: Synthesis and
Chemistry of Agrochemicals IV (D. R. Baker, J. G.
Fenyes, G. S. Básarab, eds.). ACS Symp. Ser. 584,

Hoshi T., Sato Y., Kohno H., Wakabayashi K. and Böger
P. (1992), Hydrolysis and phytotoxic activity of cyclic
imides. Proceedings, 6th China-Japan Symposium Pes-

Hoshi T., Koizumi K., Sato Y. and Wakabayashi K.
(1993), Hydrolysis and phytotoxic activity of N-aryl-
3,4,5,6-tetrahydroisophthalimides. Biosci. Biotechn.
Biochem. (Japan) **57**, 1913–1915.

Iida T., Takasuka S., Ihara T., Sato Y., Wakabayashi K.
and Böger P. (1994a), Mechanism of action of thiadia-
zolined herbicides: Comparison of phytotoxicities
between herbicidal 1,3,4-thiadiazolidin-2-ones and
1,3,4-triazolidine-2-thiones. Abstract, 19th Annu.
Meeting Pesticide Society Japan, Sapporo, p. 89.

Iida T., Senoo S., Sato Y., Nicolaus B., Wakabayashi K.
and Böger P. (1994b), Isoomerization of thiadiazoli-
dine-herbicides and their phytotoxic principle. Ab-
stract, 29th Annu. Meeting Society Chemical Regula-

Iida T., Senoo S., Sato Y., Nicolaus B., Wakabayashi K.
and Böger P. (1995), Isoomerization and peroxidizing
phytotoxicity of thiadiazolidine-thione compounds. Z.

Kohno H., Hirai K., Hori M., Sato Y., Böger P. and
Wakabayashi K. (1993), New peroxidizing herbicides:
Activity compared with X-ray structure. Z. Natur-

Lambert R., Sandmann G. and Böger P. (1983), Correla-
tion between structure and phytotoxic activities of ni-

Lyga J. W., Patera R. M., Theodoridis G., Halling B. P.,
Hotzman F. W. and Plummer M. J. (1991), Synthesis
and quantitative structure-activity relationship of her-
icidal N-(2-fluoro-5-methoxyphenyl)-3,4,5,6-tetrahy-

Matsunaka S. (1969), Acceptor of light energy in photo-
activation of diphenyl herbicides. J. Agric. Food

Matsunaka S. (1976), Diphenyl ethers. In: Herbicides:
Chemistry, Degradation and Mode of Action (P. C.
Kearney and D. D. Kaufman, eds.). Marcel Dekker

Miura Y., Ohnishi M., Mabuchi T. and Yanai I. (1993),
ET-751: A new herbicide for use in cereals. Brighton
Crop Protection Conference, Weeds, BCPC Publ.,

Miura Y., Tsuchata K., Ohnishi M. and Mabuchi T.
(1994), Study on new herbicide, ET-751, for cereals.
Abstract, 19th Annu. Meeting Pesticide Science Soci-
ety Japan, Sapporo, p. 52.


