International Journal of Agricultural Sciences ISSN 2167-0447 Vol. 10 (11), pp. 001-009, November, 2020. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Aclonifen: The identikit of a widely used herbicide

Özgür Kilinç

Laboratoire d'Ecologie Alpine (LECA, UMR 5553), Equipe Pollution Environnement Ecotoxicologie Ecoremédiation, Domaine Universitaire de Saint-Martin d'Hères. 2233, rue de la piscine Bât D Biologie, BP 53, 38041 Grenoble Cedex 9, France.

Accepted 05 September, 2020

Aclonifen is a herbicide with a diphenylether nucleus which has been authorized for agronomic use in France and Europe in 1983 (Corn, 1 kg.ha^{-1} and sunflower, 2.7 kg.ha^{-1} in pre-emergence) and in Turkey since 1994 (sunflowers, 1.8 kg.ha^{-1} and lentils, chickpeas, 0.75 kg.ha^{-1}). This a.i. shows several characteristics which differ from the other members of its chemical family, especially its two complementary modes of action and a very high conjugation potential in sunflower. These features explain its high selectivity for sunflower and also explain that, after pre-emergence treatment, the a.i. was readily transformed into polar derivatives which remain segregated inside the roots. Thus, the chemical derivatives issued from the use of this a.i. are absent from the sunflower leaves and, consequently, from the flowers and the seeds. The modes of action, uptake, transfer and conjugation of this a.i. in sunflower, as compared to the weeds associated to this culture; show that not only pre-emergence treatments are possible for this a.i. but also post-emergence application.

Key words: Aclonifen, herbicide, diphenylether, modes of action, selectivity, metabolism.

INTRODUCTION

Since the beginning of the 20th century, chemicals have been used for agronomical purposes, such as soil mineral nutrition, the control of fungal diseases or pests and also the control of adventitious weeds (Cabanette, 1986; Hascoet and Bourdin, 1988). The first chemicals used as herbicides were minerals and the longest one in use was sulphuric acid, used until the middle of the 20th century as an efficient selective dicotyledonous weed killer in cereal cultures (Castillo and Barcelo, 1988; Tissut et al., 2006). Until the Second World War, organic compounds of the nitrophenols family acting as powerful phosphorylation uncouplers were used with the same purpose as H_2SO_4 (Bourdin, 1983; Gauvrit, 1996).

After this step, a large number of new herbicides appeared, all fulfilling two determinant conditions:

1. To have a strong herbicidal efficiency on the whole adventitious flora associated to a certain type of cultivated plant.

2. To have no toxicity for the culture itself.

From a practical point of view, the first condition was often fulfilled through the use of a mixture of two or more a.i. or through several treatments with different a.i.. For instance, the herbicidal strategy for corn culture was carried out for years in Europe through a first pre-emergence treatment associating atrazine and alachlor and a second post-emergence one, using bentazone (Coleman et al., 1997; Coleman et al., 2001; Tissut et al., 2006). Among the huge crowd of new chemical compounds having a herbicidal activity, few lead to an effective agronomical use. They are selected through intensive experimental screening mainly aimed at widely spread cultures such as wheat, corn, rice, sugar cane, vine, potato, sunflower and soya.

Figure 1 tentatively illustrates the screening method for selecting herbicides being potentially useful in agronomy. The number of commonly used herbicides nowadays is probably under 400 belonging to fewer than 20 chemical families. The known biochemical sites of action of these a.i. are certainly fewer than 15, with the main sites corresponding to uncoupling of ATP synthesis, photosynthetic electron transfer, synthesis of fatty acids,

*Corresponding author. E-mail: ozgur.kilinc@yahoo.fr. Tel: +33 (0) 4-76-51-46-80. Fax: +33 (0) 4-76-51-44-63.

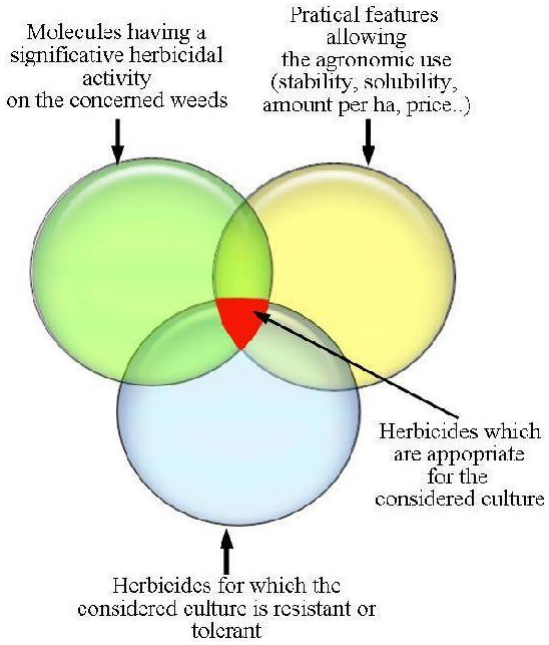


Figure 1. Theoretical scheme illustrating the choice of a new herbicide.

chlorophyll, carotenoids or different amino acids and phytohormonal control (Duke, 1990; Böger and Sandmann, 1992; Devine et al., 1993; Tissut et al., 2006; Tomlin, 2006). The theoretical bases supporting the selectivity of a herbicide towards some botanical species or some cultures are of different types:

1) A specific biochemical resistance of the cellular target (that is atrazine resistant weeds due to an unusual structure of the D1 protein);
2) The presence of active and specific detoxification mechanisms involving for instance P450 or conjugation enzymes;
3) The presence of specific anatomical structures hampering the herbicide uptake by the plant;
4) The use of an agronomic strategy which avoids the contact between the a.i. and its biochemical target (spatial or chronological separation).

In the present report, we will try to illustrate, in more details concerning biochemistry and physiology, how the diphenylether aclonifen can play the role of a very efficient and selective weed killer in sunflower culture and consequently, differ from the other members of the diphenylether family.

MATERIALS AND METHODS

Plant material

Five plant species including *Helianthus annuus* L. var Extrasol, *Zea mays* L. var Furio, *Alopecurus myosuroides* Hudson, *Sinapis alba* L. and *Bassica napus* L. var napus were concurrently cultivated. The weed seeds were supplied by Arbiotech, 35590 Saint Gilles, France.

Chemicals

^{14}C aclonifen (1167 Bq.nmol^{-1}) was a generous gift from Bayer CropScience AG Wuppertal Germany. Unlabelled aclonifen was extracted from the commercial product “Challenge 600” (Bayer CropScience) containing 600 g/L of a.i. The acetonic extract was fractionated with petrol ether (40 to 60°C). The latter solution was evaporated to dryness, dissolved in the minimal amount of acetone and stored at 4°C until crystallization. This process was repeated three times and gave pure aclonifen as controlled by TLC chromatography and spectrophotometry.

The pre-emergent treatments were comparatively carried out either with pure aclonifen dispersed in water + 2% dimethylsulfoxide or with the formulated preparation Challenge 600 dispersed in water (30 ml m^{-2}). The formulated preparation Challenge 600 (with surfactant and other formulating agents) was used as a preplant treatment at different doses, among which 2.7 kg a.i/ha which is the conventional concentration for agronomic uses in France. All solvents and reagents were purchased from Sigma Chemical Co.

Culture conditions

Two culture conditions were experimented: culture chamber (day: 16 h, 25°C; night: 8 h, 18°C R.H. 80%) and greenhouse. In the greenhouse, temperature was bound to the external climatic conditions with artificial heating when temperature decreased under 10°C and the addition of artificial light for 12 h each day (200 µE.m^{-2}.s^{-1}.PAR). Greenhouse cultures were carried out between September and November. The seeds were soaked for 8 h in aerated tap water at 25°C. The imbibed seeds were planted in

plastic pots containing 25 kg of a mixture composed of sand, clay and organic compost 1:1:1 (v/v/v) pH 7.

Plant treatments

Pre-emergence treatments were carried out on the soil surface of the pots, using a laboratory sprayer containing the amount of aclonifen flowable suspension corresponding to the conventional doses (270 $mg.m^{-2}$ in 30 ml water) or at other doses. Concurrently, pure aclonifen with 2% DMSO was also used in the same conditions.

^{14}C concentrations determination

Plant fresh samples (aerial and underground parts separately) were submitted to three successive extractions with acetone. The acetonic solutions were evaporated to dryness and redissolved in 70% EtOH. An aliquot of the dry residual pellet was dissolved with 10 ml of mineralization mixture, H_2O_2/perchloric acid/H_2O (1/1/1, v/v/v), in closed polyethylene flasks. After 2 to 3 days of mineralization at 25°C, the radioactivity of the mineralization mixture as well as that of ethanol 70% solutions were measured through scintillation counting (1414 Winspectral EG&G Wallac), using PerkinElmer ULTIMA GOLD AB liquid. During the mineralization step, the absence of $^{14}CO_2$ leaching from the flasks was controlled using a KOH trap.

RESULTS

Herbicides with a diphenylether structure

The diphenylether family is composed of members having a diphenylether nucleus, bearing lipophilic substituents such as CF_3, NO_2 or Cl, with in some cases, a free acidic function as in acifluorfen. Structure and agronomic uses of the major diphenylether herbicides are shown in Table 1. All these compounds have a common herbicidal mode of action through the inhibition of an enzyme involved in chlorophyll and cytochromes synthesis, which is protoporphyrinogen-oxidase (E.C.1.3.3.4). One major site of action of this enzyme is the structuring plastid under light, giving the photosynthetically active chloroplast (Matringe et al., 1988; Becerril and Duke, 1989; Matringe et al., 1990; Duke et al., 1991; Jacobs et al., 1991; Graham, 2005).

The visible symptom of such a biochemical effect might be suspected to be bleaching due to a lack of chlorophyll. However, it is not the case as the main symptom is a rapid light-dependent cell necrosis resulting from the presence of high amounts of protoporphyrin IX in the cytoplasm. This protoporphyrin IX, when excited by light, leads to the formation of high amounts of toxic $^1O_2$ (Duke et al., 1990; Scalla and Matringe, 1994; Hess, 2000). In the case of aclonifen, which possesses a very specific substitution pattern (2-chloro-6-nitro-3-phénoxyaniline), we previously demonstrated that, it had the same mode of biochemical action on protoporphyrinogen oxidase, leading to cell destruction for a concentration (0.5 mM) which was slightly higher than for acifluorfen taken as a reference (0.1 mM) (Kilinc et al., 2009). However, we demonstrated that, at the same concentration, carotenoid biosynthesis was also strongly inhibited (Kilinc et al., 2009). This last effect was responsible for bleaching of the aerial parts as the previously synthesised chlorophyll was no longer protected by the carotenoids.

The biochemical mode of action of aclonifen

Figure 2 is a scheme, which summarizes the complex herbicidal mode of action of aclonifen. Two biochemical sites are affected concurrently that contribute to the same physiological function: the structuration and functionality of the photosynthetic apparatus in the chloroplast. Aclonifen, through the inhibition in chlorophyll and cytochrome biosynthesis, allows the cytoplasmic accumulation of high amounts of toxic $^1O_2$. At the same time and at the same concentration, aclonifen deeply decreases the formation of the membrane pigments (the carotenoids) which protect this membrane against the free radicals and against $^1O_2$. As a whole, the two biochemical effects of aclonifen seem to be complementary and probably, really synergistic. Such a typical dual activity seems not to have any equivalence among the other well-known herbicides. The inhibitory activity of aclonifen on carotenoid biosynthesis, which is absent in the other diphenylethers, seems to depend on the specificity of the substitution pattern of the nucleus, probably mostly on the presence on the 1–NH_2.

Location of the aclonifen target space in plant

For many types of herbicides acting on photosynthesis (that is phenylureas, triazines, paraquat), on chlorophyll synthesis (diphenylethers) or carotenoid biosynthesis, (aminotriazole, diflufenicanil, norflurazon) the target space inside a plant is exclusively located inside the aerial parts, not inside the roots (Tissut et al., 2006). For aclonifen, the double mode of action involves chloroplast structuration and requires light for protoporphyrin IX excitation. Consequently, the target space for this a.i. is clearly limited to the plant's aerial parts. Moreover, the most sensitive step in this herbicidal action is the seedling stage when the plantlet is only composed of a limited number of cells and when there is no previous accumulation of chlorophyll and carotenoids at the level of the future aerial parts.

At this stage of maximum sensitivity, two parameters which are likely to be characteristic of each botanical species can be measured using ^{14}C aclonifen:

1. The "critical concentration" inside the target space which is the lowest internal concentration able to kill the plant and expressed as $nmol.g^{-1}$ fresh weight;
2. The "critical content" per plant, which is the minimum

Table 1. Structure and agronomic uses of the major diphenylether herbicides.

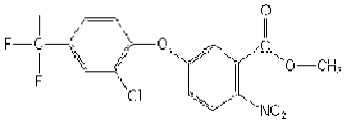
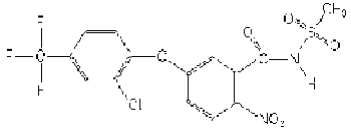
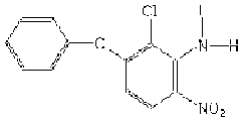
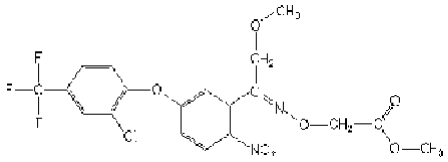
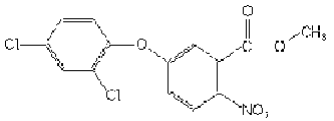
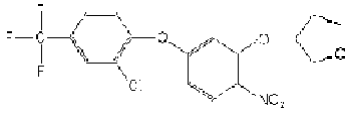
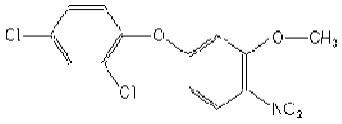
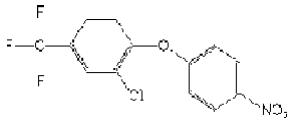
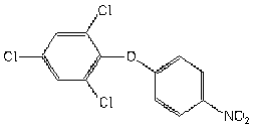
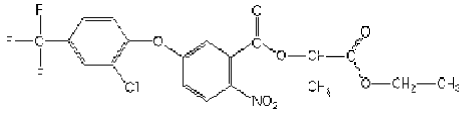
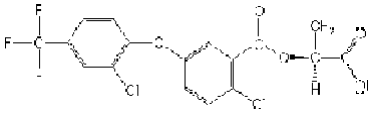
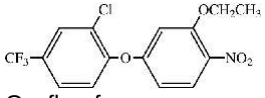
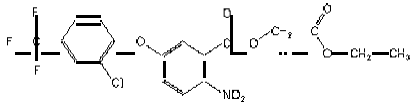
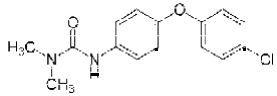
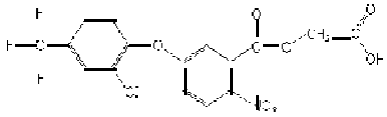
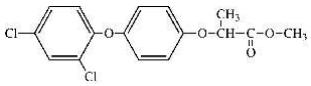
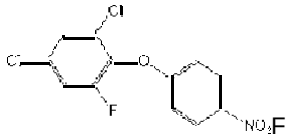
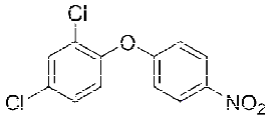
Chemical structure	Uses	Chemical structure	Uses
 Acifluorfen-methyl	Soyabeans, peanuts, rice	 Fomesafen	Soya beans, phaseolus, leguminous crops
 Aclonifen	Wheat, corn, legumes, potatoes, sunflowers, carrots, chickpea, and vegetables	 Fucaomi	Wheat, barley, rice, soya and peanuts
 Bifenox	Winter wheat and winter barley	 Furyloxyfen	Sugarcane
 Chlomethoxyfen	Rice	 Nitrofluorfen	Non authorized
 Chlornitrofen	Rice and dry farmland	 lactofen	Cotton, soya beans and snap beans
 Ethoxyfen (HC-252)	Soybean, peanut, english pea,winter wheat and winter barley	 Oxyfluorfen	Fruit trees , vines, nuts, cereals, maize, soya, beans, nuts, rice, cottons, bananas, peppermint, onions

Table 1. Contd.

 Fluoroglycofen-ethyl	Wheat, barley, oats, peanut, rice and soya beans	 Chloroxuron	Soya beans
 Fluoroglycofen	Wheat, barley, oats, peanuts, rice, soya beans	 Diclofop-methyl	Wheat, barley, rye, triticale, leguminous crops and flax
 luoronitrofen	Sunflower, forest seedlings and rice	 Nitrofen	Non authorized

amount of a.i. per seedling for which this seedling was killed (nmoles per plant).

Table 2 shows the values of these two parameters in the case of several plants.

The pre-emergence strategy optimizing the access of aclonifen to its target space

In order to reach the critical concentration in the aerial parts of the seedlings of the weeds early, the best way is to load the roots, from a soil previously treated. As the roots are insensitive to aclonifen, they can ensure a rapid uptake from the soil water solution in equilibrium with the aclonifen adsorbed on the clay/humus complex. The aclonifen stored inside the roots is then transferred to the aerial parts in the xylem sap but also through diffusion from cell to cell as the distance from root to shoot is very small at this stage. For this pre-emergence strategy, aclonifen has to be distributed uniformly on the soil under the form of a concentrated suspension or flowable concentrate (SC).

Aclonifen selectivity towards sunflower

In the studied weeds, the critical concentration in their aerial parts was found to range from 38 to 90 µM (Table 2). In sunflower growing on a soil treated with twice or 3 times the agronomic doses, only a very small concentration reaching less than 4 µM was found in the aerial parts, although there was a huge concentration inside the roots (300 µM). As a matter of fact, an autoradiography of a treated sunflower seedling showed that, ^{14}C was mainly concentrated inside the roots (Figure 3). These roots were repeatedly extracted by EtOH 50% and the extract submitted to TLC with 2 appropriate solvents allowing to efficiently separate the lipophilic aclonifen from derivatives of increasing polarity (Figure 4).

Figure 4 demonstrates that 88% of ^{14}C aclonifen was transformed inside sunflower roots into very polar derivatives which can be hydrolyzed for giving lipophilic compounds closely related to aclonifen (Rf value on TLC and UV spectrum). Furthermore, similar polar derivatives of aclonifen can be formed *in vitro* with ^{14}C aclonifen, acetonic powder of sunflower root and 10 mM glutathione. Without the addition of glutathione, these polar derivatives were not formed. As a whole, these experiments on sunflower demonstrate that aclonifen was submitted to a powerful conjugation process, giving highly polar derivatives and which were supposed to result from a GST specific activity occurring inside the roots. We demonstrated also that aerialparts acetonic

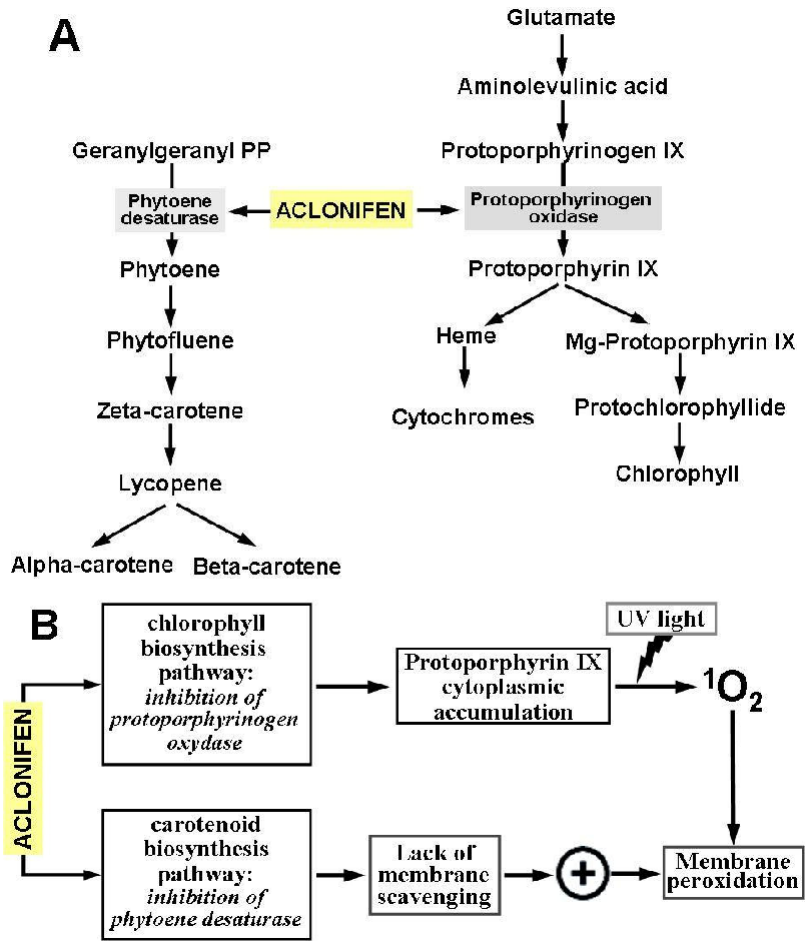


Figure 2. Complementary biochemical effects of aclonifen on plant aerial parts under light. A) Biochemical pathways affected by aclonifen. B) Herbicide effect.

Table 2. Critical concentration and critical content per plant in several plant species cultivated under standard conditions in the greenhouse.

Species	Critical concentration[a]	Fresh weight (mg)	Critical content per plant[b]
Alopecurus myosuroides	90±34	4± 2	0.4 ± 0.1
Sinapis alba	38±14	38±0.4	1.4 ± 0.3
Brassica napus	60±35	11 ± 3	0.7 ± 0.2
Zea mays	50±18	190 ±36	9.5 ± 1.5
Helianthus annuus	not obtained	156 ± 17	-

[a]Critical concentration indicates the concentration in aerial parts for which the herbicidal effect was obtained. Data are expressed as nmol.g^{-1} fresh weight ± S.E of ten plants. [b]Critical content per plant: Critical concentration / fresh weight of aerial parts (mg).

powder was able to readily transform aclonifen into polar derivatives.

DISCUSSION

Sunflowers show a huge capacity of aclonifen conjugation, giving hydrophilic derivatives without herbicidal activity. The conjugation potential is to be found in the whole plant. From a theoretical point of view, the polar derivatives might be transformed again into new compounds (Korte, 2000; Schröder and Collins, 2002) which could be endowed with some herbicidal activity (Langebartels and Harms, 1985). However, in pre-emergence treated sunflower, the polar derivatives remain trapped in the roots during more than 5 weeks.

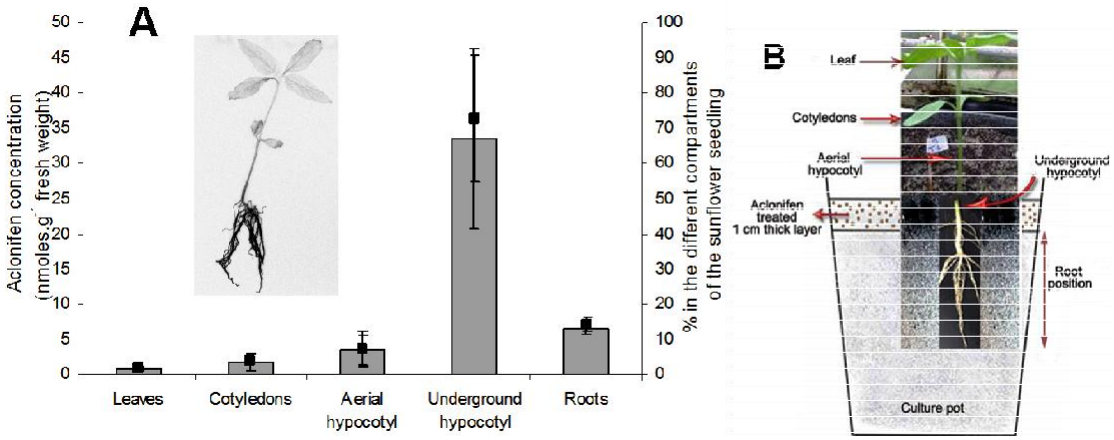


Figure 3. A: ^{14}C autoradiography and ^{14}C distribution for a sunflower seedling at 5 weeks submitted to a soil pre-emergence treatment at 2.7 kg a.i/ha. B: Experimental device.

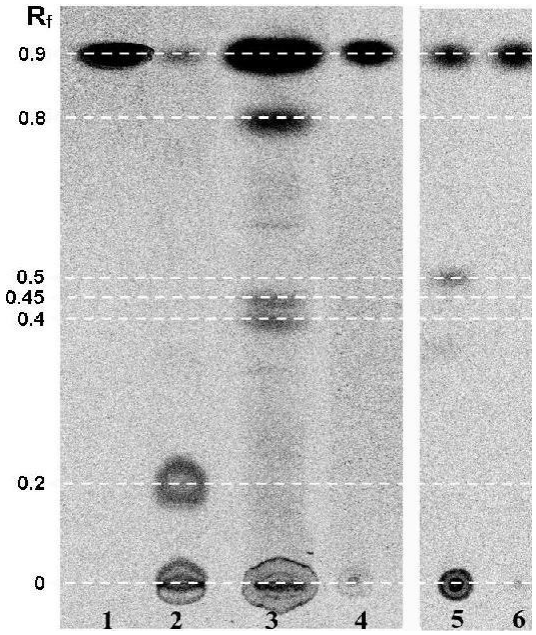


Figure 4. TLC autoradiography of aclonifen metabolites in sunflower. 1) Pure aclonifen, 2) Internal root extract of treated sunflower plants (35 days), 3) Hydrolysis product of the polar derivatives (Et2O extracted hydrolysis products of this extract), 4) Ethanolic solution obtained from root superficial washing, 5) Aclonifen derivatives obtained from the reaction of aclonifen with sunflower root acetonic powder and glutathione, 6) Same as line 5 but without glutathione, TLC with 2 successive solvents, solvent 1: petrol ether/dichloroethane/EtOH/ acetonitrile (4/4/2/1), solvent 2: dichloroethane/ EtOH/acetonitrile/H2O (4/4/2/0.1).

Thus, this conjugation potential seems to be responsible for the fact that, almost no free aclonifen can reach the target space under our conditions (Figure 5).

Furthermore, when sunflower leaves were directly treated by aclonifen, an intense uptake occurred but the a.i. was immediately conjugated. As a consequence, the

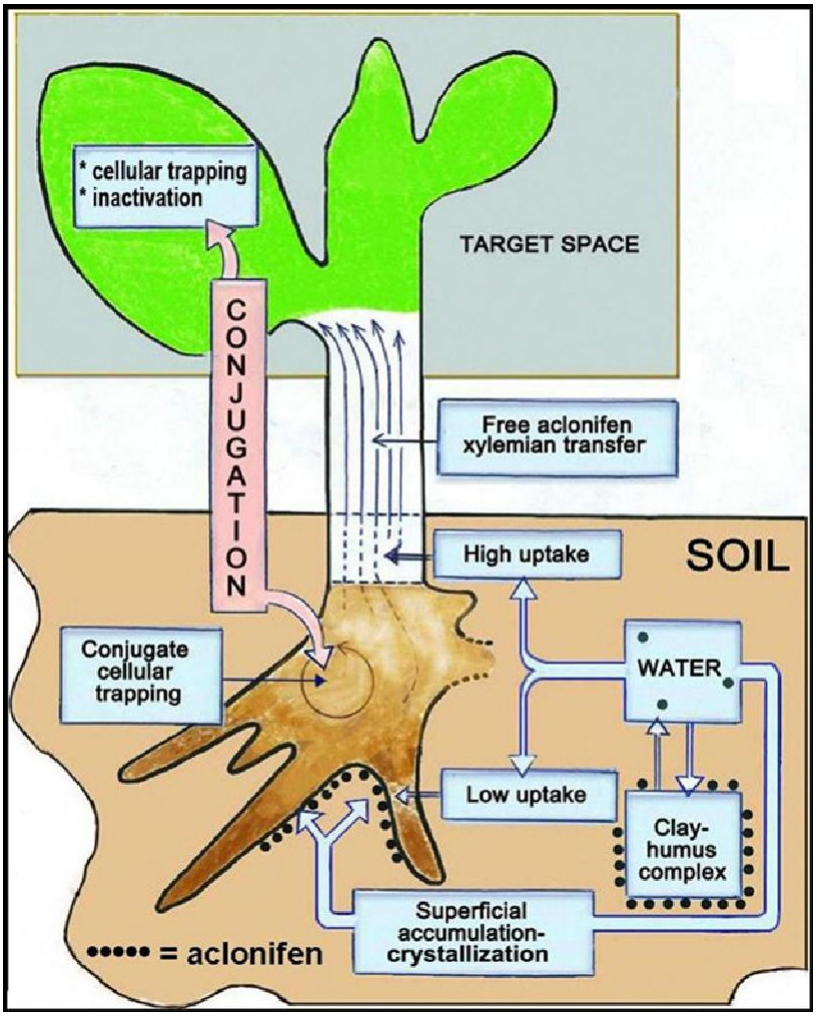


Figure 5. Factors playing a role in sunflower selectivity for aclonifen. General scheme of aclonifen transfer inside the whole plant.

critical concentration in the target space cannot be obtained. On the whole, the group of detoxifying enzymes present in sunflower includes one conjugating isoenzyme with a high substrate specificity for aclonifen, which is powerfully expressed in this plant, in marked contrast with the main weeds able to grow in sunflower cultures, which are very sensitive to this herbicide. This feature confers a high tolerance to sunflower under pre-emergence conditions but it may also have the same result. Under post-emergence conditions with an appropriate formulation. The structure of the polar derivatives resulting from this conjugation is currently under study.

The substrate specificity of the involved isoenzymes for different types of diphenylethers is also now an object of great interest. Different conjugations have been described for other diphenylethers in different plant species acifluorfen in wheat (Pascal et al., 2000) and soybean (Frear et al., 1983), fluorudifen in *Picea abies*, (Lamoureux et al., 1991), in corn, sorghum (Hatton et al., 1996), in peas (Frear and Swanson, 1973) and in peanut (Shimabukuro et al., 1973) and fomesafen metabolism in soya (Evans et al., 1987). All these results are required to be compared to the sunflower situation and the aclonifen transformation. From the same point of view, the selectivity of aclonifen for other cultures (corn, cicer, pisum…..), which leads to agronomic uses, especially in Turkey, requires to be investigated and compared to sunflower for the biochemical ways of detoxification, rates of inactivation and for the nature of the genes involved in these mechanisms. On the whole, aclonifen is a good illustration of the fact that, among a chemical family such as diphenylethers, the nature and positions of the substituents can lead to deeply different biological effects controlling the possible agronomic uses. Consequently, a tentative classification of herbicides, based on the chemical structure of the nucleus (that is phenylureas, phenylcarbamats, diphenylether…) will often deeply differ from a classification based on the biological efficiency (uncouplers, PSII inhibitors, cell division inhibitors…).

REFERENCES

Becerril J, Duke SO (1989). Protoporphyrin IX content correlates with activity of photobleaching herbicides. Plant physiol., 90: 1175-1181.

Bourdin J (1983). Evolution des produits phytosanitaires et des techniques d'application. Phytoma, 353 : 6-11.

Böger P, Sandmann G (1992). Target assays for modern herbicides and related phytotoxic compounds. (ed) Lewis Publishers, Florida, USA.

Cabanettes JP (1986). Herbicides. Plus d'un demi-siècle d'histoire. *La France agricole*, 5 sept. 1986, pp. 5-6.

Castillo M, Barcelo D (2000). Chapter 12. Determination of organic pollutants in industrial wastewater effluents. Techniques and Instrumentation in Analytical Chemistry. Elsevier, 21: 537

Coleman JO, Blake-Kalff MM, Davies ET (1997). Detoxification of xenobiotics by plants: chemical modification and vacuolar compartmentation. Trends Plant Sci., 2: 144-151.

Coleman JO, Frova C, Schröder P, Tissut M (2001). Exploiting plant metabolism for the phytoremediation of persistant herbicides. Environ Sci. Pollut. Res., 9: 18-28.

Devine M, Duke SO, Fedtke C (1993). Physiology of Herbicide Action. (ed) Prentice Hall, New Jersey, USA.

Duke SO (1990). Overview of herbicide mechanisms of action. Environ. Health Perspect., 87: 263-271.

Duke SO, Lydon J, Becerril JM, Sherman TD, Lehnen LP, Matsumoto H (1991). Protoporphyrinogen oxidase inhibiting herbicides. Weed Sci., 39: 345-352.

Evans JDHL, Cavell BD, Hignett RR (1987). Fomesafen – metabolism as a basis for its selectivity in soya. Proc. Brighton Crop Prot. Confer., 1: 345-352.

Frear DS, Swanson HR (1973) Metabolism of substituted diphenylether herbicides in plants. I. Enzymatic cleavage of fluorodifen in peas (*Pisum sativum* L.). Pestic. Biochem. Physiol., 3: 473-482.

Frear DS, Swanson HR, Mansager ER (1983) Acifluorfen metabolism in soybean: Diphenylether bond cleavage and the formation of homoglutathione, cysteine, and glucose conjugates. Pestic Biochem. Physiol., 20: 299-310.

Gauvrit C (1996) Efficacité et sélectivité des herbicides. INRA, Ed., Paris, p. 158.

Graham MY (2005). The diphenylether herbicide lactofen induces cell death and expression of defense-related genes in soybean. Plant Physiol., 139: 1784-1794.

Hascoet M, Bourdin J (1988). Evolution des produits antiparasitaires et situation actuelle. Phytoma, 400: 68-73.

Hatton PJ, Dixon D, Cole DJ, Edwards R (1996). Glutathione transferase activities and herbicide selectivity in maize and associated weed species. Pestic. Sci., 46: 267-275.

Hess FD (2000) Light-dependent herbicides: an overview. Weed Sci., 48: 160-170.

Jacobs JM, Jacobs NJ, Sherman TD, Duke SO (1991). Effect of diphenylether herbicides on oxidation of protoporphyrinogen to protoporphyrin in organellar and plasma membrane enriched fractions of barley. Plant Physiol., 97: 197-203.

Kilinc Ö, Reynaud S, Perez L, Tissut M, Ravanel P (2009). Physiological and biochemical modes of action of the diphenylether aclonifen. Pestic Biochem. Physiol., 93: 65-71.

Korte F, Kvesitadze G, Ugrekhelidze D, Gordeziani M, Khatisashvili G, Buadze O, Zaalishvili G, Coulston F (2000) Organic toxicants and plants. Ecotoxicol. Environ. Saf., 47: 1-26.

Lamoureux GL, Rusness DG, Schröder P, Rennenberg H (1991) Diphenyl ether herbicide metabolism in a spruce cell suspension culture: The identification of two novel metabolites derived from a glutathione conjugate. Pestic. Biochem. Physiol., 39: 291-301.

Langebartels C, Harms H (1985) Analysis for non-extractable (bound) residues of pentachlorophenol in plant cells using a cell wall fractionation procedure. Ecotoxicol. Environ. Saf., 10: 268-279.

Matringe M, and Scalla R (1988) Studies on the mode of action of Acifluorfen-Methyl in nonchlorophyllous soybean cells: Accumulation of tetrapyrroles. Plant Physiol., 86: 619-622.

Matringe M, Clair D, Scalla R (1990). Effects of peroxidizing herbicides on protoporphyrin IX levels in non-chlorophyllous soybean cell culture. Pestic. Biochem. Physiol., 36: 300-307.

Pascal S, Gullner G, Komives T, Scalla R (2000). Selective induction of glutathione S-transferase subunits in wheat plants exposed to the herbicide acifluorfen. Z. Naturforsch., C: Biosci., 55: 37-39.

Scalla R, Matringe M (1994). Inhibitors of protoporphyrinogen oxidase as herbicides: diphenyl ethers and related photobleaching molecules. Rev. Weed Sci., 6: 103-132.

Schröder P, Collins C (2002). Conjugating enzymes involved in xenobiotic metabolism of organic xenobiotics in plants. Int. J. Phytorem., 4: 247-265.

Shimabukuro RH, Lamoureux GI, Swanson HR, Walsh WC, Stafford LE, Frear DS (1973). Metabolism of substituted diphenylether herbicides in plants. II. Identification of a new fluorodifen metabolite, S-(2-Nitro-4-Trifluoromethylphenyl)-glutathione in peanut. Pestic Biochem. Physiol., 3: 483-494.

Tissut M, Delval JM, Ravanel P (2006) Plantes, herbicides et désherbage ACTA, Paris, France.

Tomlin CDS (2006). The pesticide manual. Fourteenth Edition. Published by BCPC (British Crop Production Council). Hampshire, UK.