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Soil Amendment: A Technique for Soil Remediation of Lactofen

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Abstract Lactofen, a member of the diphenyl ether chemical family, shows great potential for the control of broadleaf weeds associated with leguminous crops. It presents a high degree of selectivity when applied post-emergence to soybean and peanut crops. This paper presents the persistence of lactofen under a soybean crop under various conditions, including without remediation techniques, under soil solarization with polyethene sheets, and soil solarization followed by straw amendment. The results indicate that dissipation is faster when using the soil solarization technique (set II) compared to no treatment (set I) and is further enhanced by tstraw amendment, where almost 90% dissipation was recorded (set III). The dissipation followed first-order kinetics with a half-life that varied from 30 to 10 days. The half-life of lactofen was 15 days in treatments of soil solarization and straw amendments alone, indicating that both techniques have to be used in combination to achieve successful remediation of soil. Use of biodegradable polythene/substitute material will make this process a popular technique and may also improve its commercial viability.

Keywords Lactofen · Soil · Amendment · Wheat straw · Mulching

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Lactofen (1-carboethoxy) ethyl 5- (2- chloro - 4 - (trifluoromethyl)phenoxy) -2-nitrobenzoate, (Fig. 1) is a member of the diphenyl ether chemical family (PPG Industries Inc. 1985/86, US EPA, 1995). This product has been developed by PPG Industries and shows great potential for the control of broadleaf weeds associated with leguminous crops. Lactofen is a restricted-use pesticide in Environmental Protection Agnecy (EPA) toxicity class I. Lactofen is slightly or practically non-toxic by ingestion; reported oral LD50s for it are 2,400 mg/kg (EPA, 1995) to greater than 5,000 mg kg^{-1} in rats (Meister, 1994). It is applied as a foliar spray on target weeds. It is commonly used to control broadleaf weeds in soybeans, cereal crops, potatoes, and peanuts. It presents a high degree of selectivity when applied post-emergence to soybean and peanut crops. It is available as an emulsifiable concentrate 2EC as a commercial product. The doses commonly used post-emergence vary from 0.1 to 0.2 kg. a.i. ha^{-1} and in pre-emergent applications from 0.2 to 0.4 kg. a.i. ha^{-1}. Some of the species generally controlled by lactofen are: Bidens spp., Solanum rostratum, Ambrosia artemisifolia, Richardia scabra, Physalis wrightii, Sesbania exaltata, Datura stramonium, Amaranthus spp., Mollugo verticilata, Portulaca oleracea, Xanthium spp., Acalypha spp., Commelina spp., Ipomoea spp., Cucumis spp., Sida spp., Abutilon theophrasti, Euphorbia spp., Hibiscus spp., Asclepias spp., Helianthus annus, and Anoda cristata.

Lactofen is practically non-toxic to the majority of bird species. The reported oral LD_{50} value is greater than 2,510 mg/kg for the bobwhite quail (Herbicide Handbook, 1989). An LD_{50} of greater than 160 μg bee^{-1} is reported for the technical compound in honeybees, indicating low toxicity for this species (US EPA, 1987).

Lactofen is readily absorbed through the foliage, but translocation is limited in most species of broadleaf plants

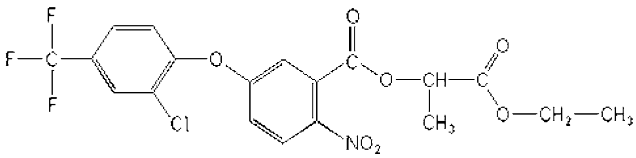

Fig. 1 Lactofen (1-carboethoxy) ethyl-5- (2-chloro-4–trifluoromethyl)phenoxy) -2-nitrobenzoate

(Herbicide Handbook, 1989). It is readily metabolized, with detectable residues absent after 24 hours. Lactofen is of low persistence in most soil types (US EPA, 1987; Rose and Raibov, 1985; Wauchope et al., 1992). Reported field half-lives range from 1 to 7 days (US EPA, 1987; Wauchope et al., 1992; US EPA, 1993). It is rapidly degraded, mainly by microbial activity rather than hydrolysis (Herbicide Handbook, 1989), although hydrolysis is more likely at pH 9 and above, which is unlikely in soil environments (Herbicide Handbook, 1989; US EPA, 1993). Aerobic conditions speed the rate of microbial breakdown of lactofen (Herbicide Handbook, 1989; US EPA, 1987; Wauchope et al., 1992). Photolysis (breakdown bythe energy of sunlight) and volatilization loss are thought to be minimal (Herbicide Handbook, 1989). Lactofen is tightly bound to most soils (Herbicide Handbook, 1989), and is therefore likely to be immobile in most cases. The primary degradation product, acifluorfen, is, however, mobile to highly mobile in soils, depending on soil type and organic matter content, and may also be moderately persistent (Kidd et al., 1991).

Lactofen has very low water solubility and is tightly bound to soil, so it is therefore not expected to be prevalent in surface waters. One possible source of infiltration into surface waters would be surface runoff. In this event, the compound would most probably remain bound to the solid particle and settle to the bottom. Lactofen is stable at pH 5 to 7 but will readily undergo hydrolysis at pH 9 and above (Herbicide Handbook, 1989; US EPA, 1987). Reported half-lives for lactofen in water are 5–10 days (Rose and Raibov, 1985). Lactofen is readily absorbed through the foliage, but translocation is limited in most species of broadleaf (Herbicide Handbook, 1989; US EPA, 1993).

This herbicide is used in early post-emergence; however it has some pre-emergent action. Lactofen is aabsorbed by various soil particles. Strictly in pre-emergence, the effectiveness of its absorption by weeds depends on the texture, structure, and organic matter content of the soil. When it is applied post-emergence, a non-ionic surfactant must be included (Triton, etc.) to improve its effectiveness. Some studies indicate that this product is resistant to lixiviation, but tends to dissipate rapidly after application. It has also been noted that the biological action of some microorganisms in the soil leads to the degradation of the product. Lactofen has a mean lifespan of 1–2 months. This product is applied post-emergence, when weeds have two to six leaves (two or three weeks after the sowing of legumes). Some residual pre-emergent effect has been observed in post-emergent applications.

Lactofen has proven very effective for the control of broadleaf weeds in soybeans (Taylor, 1985). In field trials conducted over two years (1994–1995), acetolactate synthase (ALS)-inhibiting herbicides and herbicides with different mechanisms of action were tested individually and in combination for control of ALS-resistant Palmer amaranth in soybeans. ALS-inhibiting herbicides did not control the resistant Palmer amaranth. Lactofen at 210 g/ha and acifluorfen at 560 g ha^{-1} gave the best post-emergence control. However tank mixes of lactofen with imazethapyr or chlorimuron plus thifensulfuron did not significantly increase control over lactofen alone. Sequential treatment with a soil-applied herbicide, either SAN 582 [dimethenamid] or pendimethalin, followed by lactofen post-emergence, controlled weeds best (by >85%), (Gaeddert, 1997).

The presence of excessive residues of herbicides in soil often hinders the germination of the next crop. Pesticides applied to the soil to control weeds and soil-borne insects are often mobile and, on irrigation or rain, leach down and find their way into ground water. This may result in the pollution of rivers, lakes, and even drinking water. In an attempt to remediate herbicide residues from the soil a multidisciplinary approach has been attempted. Recent trends in remediation are bioremediation, i.e., the use of soil microbes, or photoremediation techniques, i.e., the use of plants that are able to detoxify the contaminated site. The other common cultural practices involve the use of charcoal, ploughing the field crop residues, use of fly ash, neem cake, and even farmyard manure.

In this paper we present the persistence of lactofen under different soil remediation techniques: soil solarization, soil solarization followed by amendment with straw, under field conditions. Four sets of experiments were conducted wherein the dissipation of lactofen was recorded under different conditions; (i) lactofen under a soybean crop, (ii) lactofen with soil solarization, (iii) lactofen with soil amendment, and (iv) soil solarization coupled with soil amendment with straw.

Materials and Methods

Field experiments were conducted on soybean (Glycine max L. Merrill) variety Pusa 22 during June to September (Kharif season) at the farm of the Indian Agricultural Research Institute, New Delhi.

Four sets of experiments were carried out. Soybean was sown in all the plots under study. In set I only lactofen was applied in the field without any soil soal-

Table 1 Residues of lactofen in soil following different treatments

Sampling Days	Residues (mg kg^{-1})			
	Lactofen (No soil amendment)	Soil solarization	Straw amendment	Solarization + straw amendment
0 (1 hr)	15.94 (0.06)	15.28(0.03)	15.25(0.05)	15.73(0.05)
16	9.76(0.04) (38.74)	7.33(0.04) (52.00)	6.41(0.03) (57.99)	6.21(0.05) (60.52)
26	7.85(0.03) (5.076)	4.23(0.03) (72.28)	3.15(0.06) (79.32)	2.15(0.05) (86.31)
32	5.35(0.04) (66.46)	3.27(0.05) (78.58)	2.34(0.04) (84.61)	1.33(0.05) (91.54)
Soybean grains	0.001	0.001	0.001	0.001

Table 2 Regression equation and half-life

Treatment	*Y*	Half-life (days)	Correlation coefficient *R*
Lactofen	3.23–0.01x	30.1	0.95
Lactofen with solarizaion	3.2028–0.02x	15.05	0.99
Lactofen with straw amendment	3.19–0.02x	15.05	0.99
Lactofen under solarizaion and straw amendment	3.25–0.03x	10.03	0.98

rization and amendment, in set II soil solarization followed by lacofen was applied, in set III straw amendment followed by the application of lactofen was used, and in set IV the regime was soil soalrization coupled with soil amendment with straw followed by lactofen application. The experiment was carried out in triplicate in 16 plots including a set of control plot for each treatment. Lactofen (Cobra 2 EC) was applied at 100 g a.i. ha^{-1} in four plots (set I). In another four plots straw was amended and left for one month before the application of lactofen at 100 g a.i. ha^{-1} (set III). Eight plots were covered with polythene sheets with a thickness of 100 μm and left for 30 days. After one month of solarization the herbicide, lactofen (Cobra 2 EC) was applied at 100 g a.i. ha^{-1} (set II). Soil solarization and straw amendment (one month) followed by application of lactofen was used in the plots from set IV. Soil samples were collected after 0, 8, 16, and 26 days, and soybean grains were also harvested. A representative air-dried and sieved sample of soil (50 g) was extracted in a Soxhlet extractor using a hexane-acetone mixture (1:1, 350 mL) for six hours. The extract was filtered, concentrated under vacuum, and subjected to a column cleanup.

Soybean samples at harvest were extracted in a Soxhlet extractor for four hours with 300 mL of a mixture of hexane and acetone (1:1).

The extracted grain sample was evaporated completely under vacuum, dissolved in hexane (40 mL) and then exchanged into acetonitrile (3 x 40 mL), to remove the oil from the grains. The acetonitrile portion was further diluted with saline water (2%, 600 mL) and then partitioned into dichloromethane (3 x 30 mL).

A glass chromatographic column (1.5 i.d. x 150 cm) was packed with neutral alumina (2 g) and Florisil (1 g) sandwiched between two layers of activated anhydrous sodium sulfate (2 g). The concentrate was transferred to the column, which was pre-washed with hexane (25 mL). The column was eluted with 150 ml 1:1 (v/v) of the acetone–hexane mixture. The eluate was concentrated to dryness using a rotavapor and the residue was dissolved in 10 ml hexane before analysis by gas liquid chromatograph (GLC) using an electron-capture (EC)detector.

The quantitative estimation of lactofen was carried out using a Hewlett Packard gas liquid chromatograph series II (model 5890) equipped with a Ni 63 electron-capture detector. The BP-5 megabore column (12mx 0.52 mm i.d. x 1 μ) was used for the estimation of lactofen in the soil samples. Another column (megabore BP-5, 30m x 0.52 mm i.d. x 1 μ) of varying length but the same polarity was used, to ascertain the identity of the pesticide. The concentration of lactofen was calculated on the basis of the peak area from the calibration curve. Standard solutions of concentrations 0.1, 0.2, 0.5, 1.0, 1.5, and 2.0 g mL^{-1} of lactofen were injected into the GLC and a calibration curve was drawn by plotting the peak area versus concentration. Each injection was carried out thrice for all the concentrations to obtain the linearity range of the pesticide.

The GLC column temperature was 250°C and the injector port and detector were set at 270°C and 300°C, respectively. Lactofen eluted in 5.23 min under these conditions. The temperatures conditions maintained for the confirmation were 280°C for the column, 290°C for the injector port, and 350°C for the detector. The retention time of lactofen was 3.73 min.

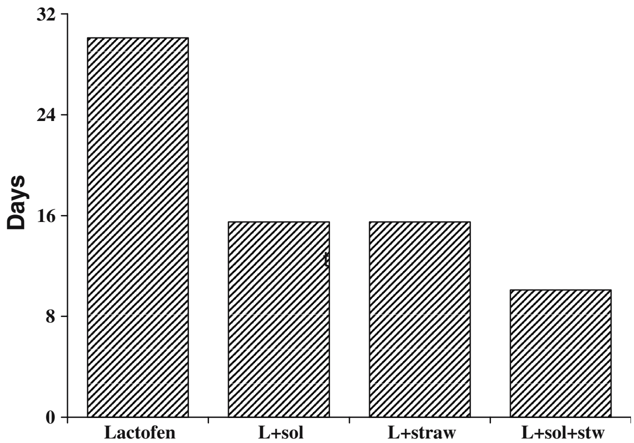

Fig. 2 Half-life of lactofen under different treatments

Results and Discussion

Initial residues of lactofen were 15.94, 15.28, 15.25, and 15.73 mg/kg, for the four treatments: no amendment, lactofen under soil solarization, straw amendment, and soil solarization and straw amendment, respectively (Table 1). The residues dissipated to 38.7, 52.0, 57.9, and 60.5% of the initial values by day 16 in the sets I, II, III, and IV, respectively (Table 2). This data indicates that lactofen dissipated faster in the treatment with straw coupled with soil solarization, followed by straw amendment alone and finally soil solarization alone. This leads to the conclusion that straw amendment plays a significant role in soil remediation. By day 32 the lactofen levels had decreased tos 66.5, 78.5, 84.61 and 91.5% of the original values for the four treatments, respectively. However the data also reveals that, although the amended biomass is able to generate organic matter, which enhances the dissipation of lactofen, biomass amendment alone is not effective in remediation of soil. The process of amendment must be used in combination with other compatible techniques lsuch as soil mulching, for use in contaminated sites.

The dissipation followed first-order kinetics with a half-life that varied from 30 to 10 days (Fig. 2). The half-life of lactofen was 15 days under the treatments by soil solarization and straw amendments alone, indicating that these two techniques must be used in combination to achieve successful remediation of soil lactofen levels. Similar results have been reported during soil soloarization of quinalphos (Gopal et al., 2000). This technique holds promise as a soil remediation method. Use of a suitable biodegradable substitute for the polythene material will make this process a popular and commercially viable approach.

Conclusions

The results indicate that dissipation is faster using the soil solarization technique (set II) compared to no treatment (set I) and is further enhanced by the straw amendment, with almost 90% dissipation recorded (set III). The dissipation followed first-order kinetics with a half-life that varied between 30 and 10 days. The half-life of lactofen was 15 days in the treatments with soil solarization and straw amendments alone, indicating that the two techniques must be used in combination to achieve successful remediation of soil lactofen levels.

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