

Adsorption and leaching of novel fungicide pyraoxystrobin on soils by ^{14}C tracing method

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Abstract Pyraoxystrobin, (*E*)-2-(2-((3-(4-chlorophenyl)-1-methyl-1*H*-pyrazole-5-yloxy)methyl)phenyl)-3-methoxyacrylate, is a newly developed strobilurin fungicide with high antifungal efficiency. It has high potential to enter soil environments that might subsequently impact surface and groundwater. Therefore, ^{14}C -labeled pyraoxystrobin was used as a tracer to study the adsorption/desorption and migration behavior of this compound under laboratory conditions in three typical agricultural soils. The adsorption isotherms conformed with the Freundlich equation. Single factor analysis showed that organic matter content was the most important factor influencing the adsorption. The highest adsorption level was measured in soil with low pH and high organic carbon content. Once adsorbed, only 2.54 to 6.41% of the adsorbed compound could be desorbed. In addition, the mobility results from thin-layer chromatography and column leaching studies showed that it might be safe to use pyraoxystrobin as a fungicide without causing groundwater pollution from both runoff and leaching, which might be attributed to its strong hydrophobicity. High organic

matter content enhanced pyraoxystrobin adsorption and desorption because of the rule of similarity (lipid solubility). In the column leaching study, 95.02% (minimum value) of the applied ^{14}C remained within the upper 4.0-cm layer after 60 days.

Keywords Pyraoxystrobin · Adsorption · Desorption · Mobility behavior · Soil

Introduction

With the extensive use of pesticides in the natural environment, pesticides occupy a unique position among the chemicals encountered in soils and groundwater (Boivin et al. 2004). The fate of pesticides in soils is of great concern, as they pose a major threat to the environment (Boivin et al., 2005a). Adsorption and desorption are key processes affecting the interactions between pesticides and the soil solid phase (Linn et al. 1993; Chen et al., 2017; Arthur et al. 2017). It is necessary to obtain more information on the migration of pesticides to predict their mobility and fate in the soil environment and to understand their transport in soil or soil-groundwater (Gao et al. 1998). The desorption of pesticides is also of great concern because it determines the release rate and the potential mobility of pesticides in soil (Huang et al., 1998). Several studies have noted the occurrence of hysteresis in the adsorption-desorption reactions in soils (Gao et al. 1998; Yue et al. 2017). The hysteresis phenomena is characteristic of the adsorption-desorption process in soil, but the exact mechanisms of hysteretic

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adsorption/desorption of anionic, basic, and neutral pesticides remain largely unknown (Ding et al. 2002). Hysteretic adsorption/desorption suggests that adsorption of pesticides occurs with a limited degree of reversibility depending upon both the physicochemical properties of the molecules and the soils involved.

Because pesticides can easily migrate to groundwater through overland runoff/leaching by rainfall or irrigation water, they are one of the main sources of groundwater pollution (Laabs et al. 2000). Previous studies indicated that the mobility of pesticides is influenced by many factors like climate, hydrology, chemical properties of the pesticide, soil type, farming methods, and others (Redoudo et al., 1997). The mobility characteristics of each pesticide should be studied to determine the potential for transport to water sources.

Strobilurins are among the most important classes of fungicide with high germicidal activity. In recent years, with their rapid application around the world, strobilurins have become a hot topic in fungicide research. Pyraoxystrobin, (E)-methyl-2-(3-((3-(4-chlorophenyl)-1-methyl-1H-pyrazol-5-yl)oxy)methyl)phenyl)-3-methoxyacrylate, is a novel fungicide developed by the ShenYang Research Institute of Chemical Industry, China. Previous studies have indicated that this novel fungicide exhibits strong fungicidal activities against *Pyricularia oryzae*, *Phytophthora infestans*, *Pseudoperonospora cubensis*, *Erysiphe graminis*, and *Magnaporthe grisea* (rice blast). So far, several countries and regions, e.g., China, the USA, and Europe, have authorized and widely used this type of fungicide, demonstrating its promising market potential. Temporary registration for the compound has also been obtained in China for application on cucumber downy mildew at a rate of 80–100 g active ingredient per hectare (Li et al. 2010; Wang et al. 2008). As pyraoxystrobin is a novel fungicide, it is necessary to study its behavior in soil as there is limited information available to date. Therefore, there is an urgent need to investigate the adsorption/desorption and mobility characteristics of pyraoxystrobin in soils to determine the potential for transport and groundwater contamination.

The aim of this study was to investigate the adsorption/desorption and migration behavior of pyraoxystrobin in three tested agricultural soils and to identify the main factors influencing these processes. Adsorption and desorption experiments were carried out with standard batch equilibration experiments together with radiochemical statistical methods. The

migration study was conducted by soil thin-layer chromatography (TLC) and column leaching methods to get a better understanding of the leaching/runoff potential of pyraoxystrobin in soils.

Materials and methods

Pyraoxystrobin and reagents

Radioactive pyraoxystrobin was used in the present study. ^{14}C -labeled pyraoxystrobin was synthesized in our previous work (Liu et al. 2011). Selected characteristics of ^{14}C -labeled pyraoxystrobin at 25 °C are listed in Table 1. Scintillation cocktails were prepared using 2,5-diphenyloxazole (PPO) and 1,4-di-[2-(5-phenyloxazolyl)]-benzene (POPOP) of scintillation grade. Scintillation cocktail A contained the following ingredients: 5.0 g PPO, 0.5 g POPOP, 350 mL glycol-ether, and 650 mL dimethyl benzene. Scintillation cocktail B contained the following ingredients: 5.0 g PPO, 0.5 g POPOP, 175 mL ethanolamine, 225 mL glycol-ether, and 600 mL dimethyl benzene. Dimethyl benzene, methanol, dichloromethane, and other reagents were all analytical grade.

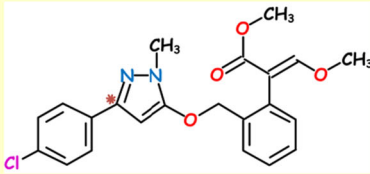
Soil samples

Three soil types not containing pyraoxystrobin were collected from the 0–15-cm surface layer in Zhejiang, China. All three soils (S1: loamy soil, S2: red clayey soil, and S3: coastal saline soil) were air-dried, ground, and sieved through a 2-mm mesh sieve prior to use. The basic physicochemical properties of the three soils were determined using standard methods (Nelson and Sommers 1982; Gee and Bauder 1986; Table 2).

Adsorption/desorption experiments

Adsorption isotherms were plotted using the standard batch equilibrium method (OECD 2000). In the adsorption experiment, to ensure the water saturation of soil samples, the calcium chloride (CaCl_2) solutions (0.01 M, 10 mL) were mixed into 50-mL sealed glass centrifuge tubes with 5.0 g of air-dried and sieved soil with three replicates. The tubes were oscillated with a rotary agitator (100 rpm) for 2 h at 25 ± 2 °C in the dark and then centrifuged at 6000 rpm for 30 min. After that, ^{14}C -labeled pyraoxystrobin in solution was added into

Table 1 Selected properties of pyraoxystrobin at 25 °C (supplied by ShenYang Research Institute of Chemical Industry, China)

ISO Common name	Pyraoxystrobin
Chemical structure	 <p>The chemical structure of Pyraoxystrobin is shown. It consists of a pyrazole ring substituted with a methyl group (CH₃) at the 1-position, a (E)-3-methoxyacrylate group at the 5-position, and a 3-((4-chlorophenyl)-1-methyl-1H-pyrazol-5-yloxy)methyl group at the 2-position. The pyrazole ring is also substituted with a methyl group (CH₃) at the 1-position. The acrylate group has two methoxy groups (O-CH₃) attached to the double bond. The phenyl ring of the acrylate group is substituted with a methoxy group (O-CH₃) at the 3-position. The pyrazole ring is substituted with a methyl group (CH₃) at the 1-position and a (E)-3-methoxyacrylate group at the 5-position. The pyrazole ring is also substituted with a methyl group (CH₃) at the 1-position. The acrylate group has two methoxy groups (O-CH₃) attached to the double bond. The phenyl ring of the acrylate group is substituted with a methoxy group (O-CH₃) at the 3-position.</p>
Chemical name	<p>* 14-Carbon labeled site</p> <p>(E)-methyl-2-(3-((3-(4-chlorophenyl)-1-methyl-1H-pyrazol-5-yloxy)methyl) phenyl)-3-methoxyacrylate</p>
Chemical formula	C ₂₂ H ₂₁ ClN ₂ O ₄
Molecular weight (g mol⁻¹)	412.12 (IUPAC 2001)
Octanol/H₂O partition coefficient	Log Po/w =3.93
Melting point (°C)	124~126
Solubility	Slightly soluble in water; Soluble in N, N - dimethyl formamide acetone, ethyl acetate, methanol, etc.
Stability	Stable in room temperature
Toxicity (mice acute oral toxicity)	LD50/LC50: 1022.24 mg/kg (female), 999.95 mg/kg (male)

the tubes; while the prepared CaCl₂ solution was added to reach the solution volume of 25 mL. The ultimate concentrations of pyraoxystrobin were 0.2, 1.0, 2.0, and 4.0 µg/mL. Based on previous kinetic studies, the adsorption equilibrium could be reached within 5 h (Supporting Information Fig. S1). After oscillating the mixed solution using the thermostatic oscillator (G-33, New Brunswick Scientific Co. Inc., USA) at the rate of 200 rpm for 5 h, the sample was collected and

centrifuged for 10 min at 8000 rpm. An aliquot of 1.0 mL of supernatant was transferred into 10 mL of scintillation cocktail A to measure the radioactivity on the liquid scintillation counter. The difference between the initial and equilibrium concentrations was assumed to be the adsorption amount onto soil.

Desorption experiments were conducted immediately after the adsorption experiments. Fresh CaCl₂ solution (0.01 M, 25 mL) was added into each tube and the

Table 2 Basic physicochemical properties of the soil samples

Soil type	pH (H ₂ O)	OM ^a (%)	Silt (%)	Sand (%)	Clay (%)	CEC ^b (meq/100 g)
Loamy soil (S1)	6.95	2.11	20.98	36.32	42.70	10.65
Red clayey soil (S2)	5.36	2.65	21.01	33.25	45.75	8.93
Coastal saline soil (S3)	8.20	1.23	26.32	31.32	42.36	11.77

^a Organic matter

^b Cation exchange capacity

soil residue was stirred with a glass rod. Then, the tubes were oscillated at 25 ± 2 °C for 5 h. During preparation of the different replicates, the tubes were stored at 4 °C to avoid biodegradation. The suspensions were subsequently centrifuged; meanwhile, the radioactivity of the supernatant was measured (similar to the adsorption experiments). The desorption process was repeated using the above procedure until no radioactivity was detected in the supernatant.

Migration studies

Soil TLC study

Soil TLC was conducted according to previously reported methods (Guo et al. 2003). Soil was passed through a 0.25-mm mesh sieve and then a soil–water slurry was prepared with the fine fraction and distilled water. The slurry was spread as a 5-mm thick layer over 20×15 -cm glass plates with the aid of a TLC spreading device. The coated plates were dried and stored at 60% humidity for further use.

In this section, three prepared soils (i.e., S1, S2, and S3) were used. On each plate, a 5 μ L (about 5.1×10^6 Bq) droplet of 14 C-pyraoxystrobin methanol solution was applied 2.0 cm away from the bottom edge of the TLC plate. The plates were placed in closed chromatographic chambers ($22 \times 5 \times 18$ cm) using 0.01 M CaCl_2 solution as the developer at a height of 0.5 cm. After the CaCl_2 solution migrated to a distance of 12 cm from the base, the plates were taken out, dried at room temperature, and developed. After contacting with the imaging plate for 2 h, an autoradiogram was obtained by reading the imaging plate in an Image Reader (BAS-1800II, Fujifilm, Japan).

Column leaching study

The soil used for the column leaching study was S1. The experiment was conducted in a fallow field plot with polyvinyl chloride (PVC) cylinders (50 cm length, 5.5 cm i.d.). The average temperature during the experimental period was 18.5 °C and the total rainfall was more than 400 mm. The method was followed according to the previous study by Weber (1986). First, the cylinders were packed with 700 g dried soil and the soil was moistened by standing in a water tank until water reached the top of the column. Then, the columns were removed from the water tank and left undisturbed for

2 days to drain to allow the soil to reach field capacity. For each cylinder, 10.0 g soil was treated with a preblended solution of 10 μ L of methanol and 5.1×10^7 Bq of 14 C-labeled pyraoxystrobin, which was then applied to the soil surface in the cylinder. Afterwards, it was covered with about 10.0 g of blank soil to minimize photo decomposition and moistened with the nature rainfall. Cylinders were sampled every 10 days over a 2-month period. The cylinder was sectioned from the top of the soil surface at intervals of 2 cm until no fungicide could be detected. After being dried at 40 °C, 0.5 g soil sample was subjected to combustion on a Biological Oxidizer (OX-600, R. J. Harvey Instruments, Hillsdale, NJ, USA) in triplicate, while the evolved $^{14}\text{CO}_2$ was trapped by 10 mL scintillation cocktail B. Samples were analyzed by liquid scintillation counting for radioactivity measurement.

Data evaluation

All of the experiments were conducted in triplicate, and the standard deviations presented in the text were calculated from the repeated measurements. For the adsorption assay, the isotherm parameters were determined for each soil using the Freundlich equation (Eq. 1):

$$X/m = K \cdot C^{1/n} \quad (1)$$

Where, X is the amount of pesticide adsorbed by the adsorbent (μg), m is the weight of the adsorbent (g), C is the concentration of pyraoxystrobin in the solution under equilibrium status ($\mu\text{g/g}$), K is the adsorption coefficient of soil, and $1/n$ is the adsorption coefficient.

The Freundlich isotherm can also be expressed in linear form after logarithm linearization and the values of K and n can be obtained by plotting $\log X$ versus $\log C$ (Eq. 2)

$$\log \frac{X}{m} = \log K + \frac{1}{n} \log C \quad (2)$$

The change in soil adsorption in terms of Gibbs free energy (ΔG) is also an important parameter, which can reflect the soil adsorption capacity. According to the changes in ΔG , it can infer the soil adsorption mechanisms. When $|\Delta G| \leq 40$ kJ/mol, it is physical adsorption; whereas when $|\Delta G| \geq 40$ kJ/mol, it is chemical adsorption. The soil adsorption ΔG for pesticides can be calculated by Eq. (3):

$$\Delta G = -RT \ln K_{om} \quad (3)$$

Where, ΔG is the change in Gibbs free energy in the process of soil adsorption, R is a constant ($R = 8.314 \text{ J}/(\text{K};\text{mol})$), T is kelvin temperature (K), K_{om} is the adsorption constant of soil organic matter (SOM) per unit ($K_{\text{om}} = K/\text{SOM content} \times 100$).

In the soil TLC study, the R_f value was calculated to evaluate migration as follows:

$$R_f = \frac{R_1}{R_2} \tag{4}$$

Where, R_1 (cm) is the frontal distance migrated by pyraoxystrobin and R_2 (cm) is the distance migrated by the solution (herein, $R_2 = 10 \text{ cm}$).

Results and discussion

Adsorption/desorption behaviors of pyraoxystrobin in agricultural soils

Sorption isotherms were used to describe the equilibrium of the pesticides between the aqueous solution and the solid phase. Depending on the nature of the sorption system, the isotherm model can determine the maximum sorption capacity and several thermodynamic parameters that can be used for a better understanding of the binding mechanisms.

The recoveries of pyraoxystrobin in soils S1, S2, and S3 were $101.4 \pm 2.63\%$, $92.2 \pm 3.12\%$, and $89.5 \pm 1.79\%$, respectively, which indicated that the method was adequate for the experiment. The amount of pyraoxystrobin adsorbed by the three agricultural soils under equilibrium status was described by the Freundlich adsorption isotherm. The Freundlich adsorption isotherm has been applied to describe the adsorption of pesticides by soil, organic matter, and clay minerals (Sánchez-Camazano et al. 2000; Ren et al. 2011). The values of K and $1/n$ are provided in Table 3. The K parameter is an empirical constant of the Freundlich model expressing soil sorbent capacity for a given range of pesticide concentration. In this study, the K values ranged from 36.28 to 71.33 and the observed adsorption decreased in the order: $S2 > S1 \gg S3$. The largest K value was obtained in S2 with high organic matter content and low pH. In many studies, organic matter content and soil pH also appear to be the dominant factors influencing the adsorption of pesticides such as the herbicide 2,4-dichlorophenoxyacetic acid (Spark

and Swift 2002; Boivin et al. 2005b). However, the behavior of atrazine, isoproturon, and paraquat was dominated by the solid-state soil components and the presence of dissolved organic matter had little effect (Spark and Swift 2002). This means that adsorption of pesticides by soil could also be influenced by other properties, such as pH, cation exchange capacity, and clay content. The differences in absorption behavior might be explained by differences in the interaction between the chemical and the soil solid phase. The correlations among adsorption parameters and soil properties can be used to determine the dominant factors in the adsorption of pesticides on different soils; this will also provide supporting information for soil remediation strategies in case of soil pesticide contamination.

The soil adsorption ΔG of ^{14}C -pyraoxystrobin was negative for all three soils (Table 3), indicating that their adsorption behaviors were exothermic reactions. Thus, decreasing temperature improves pyraoxystrobin adsorption by soils. The adsorption ΔG values were all below 40 kJ/mol, indicating that physical adsorption was the primary adsorption mechanism resulting in the adsorption mainly occurring in the surface soil (i.e., topsoil).

The correlation coefficients (r^2) between the Freundlich adsorption constant and different soil properties, including pH, organic matter, and cation exchange capacity, are shown in Table 4. The r^2 values for organic matter ranged from 0.79 to 0.96, which indicated that organic matter was the dominant factor influencing pyraoxystrobin adsorption. High soil organic matter content leads to high pyraoxystrobin adsorption by soils. The adsorption capacity was negatively correlated with pH, indicating that, when pyraoxystrobin is applied in acidic soils, it might be susceptible to redistribution within the soil profile, sim-

Table 3 Freundlich constants and ΔG for soil adsorption of ^{14}C -pyraoxystrobin

	S1	S2	S3
Freundlich equation			
K	64.91	71.33	36.28
1/n	0.97	0.99	0.90
Changes of free energy			
K_{om}	3.08×10^5	2.69×10^5	3.19×10^5
ΔG (kJ/mol)	-8.09	-8.03	-8.11

Table 4 Freundlich constants (*K*) and correlation coefficients (*r*²) as influenced by soil physicochemical properties

Soil property	Coefficient equation	<i>K</i>	<i>r</i> ²
pH	139.36–11.97 <i>x</i>	– 11.97	0.83
OM	6.71 + 25.45 <i>x</i>	25.45	0.96
CEC	178.92–11.62 <i>x</i>	– 11.62	0.79

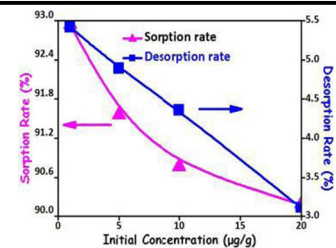
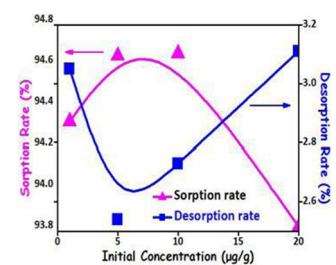
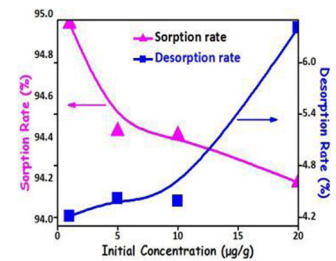
ilar to previous studies (Carrizosa et al. 2000, 2001; Dubus et al. 2001). At low soil pH, part of the pyraoxystrobin exists in the neutral form. Thus, pyraoxystrobin adsorption might be more sensitive to soil pH variations because of different ionization states in different soils. Adsorption of the ionized form is

stronger than that of the neutral form because of repulsion between electronegative charges of soil constituents and those of the ionized molecules.

Desorption is also a key process affecting pesticide molecule behavior in soils. Desorption controls the predisposition of a pesticide to be degraded and/or leached at different stages (Dur et al. 1998). In addition, after adsorption experiments, it is important to assess the desorption process since it might reflect the interactions involved between the chemical and different soil types. The adsorption and desorption rates in the three soils with different initial concentrations are shown in Table 5. S1 and S2 had similar adsorption rates that were not related to the initial concentration of pyraoxystrobin. The

Table 5 Sorption and desorption rate of ¹⁴C-pyraoxystrobin in different soils

Soil type	Initial concentration (µg/g)	Sorption rate (%)	Desorption rate (%)
S1	1.0	94.98±4.32	4.21±0.23
	5.0	94.46±2.52	4.42±0.23
	10.0	94.44±2.36	4.39±0.05
	20.0	94.21±6.03	6.41±0.84
S2	1.0	94.33±5.21	3.05±0.28
	5.0	94.65±5.36	2.54±0.33
	10.0	94.66±6.11	2.73±0.36
	20.0	93.82±5.21	3.11±0.09
S3	1.0	92.94±6.66	5.42±0.33
	5.0	91.56±9.36	4.89±0.47
	10.0	90.77±5.32	4.36±0.62
	20.0	90.19±1.20	4.25±0.24



average adsorption rate of these three soils was about 94.44%. Pyraoxystrobin was not readily desorbed from soils with 0.01 M CaCl₂ solution, with only 2.54 to 6.41% of adsorbed pyraoxystrobin desorbed. However, bentazone and atrazine had a very high desorption rate of more than 91.1% (Boivin et al. 2005a). When compared with pyraoxystrobin, bentazone and atrazine might be absorbed on weak energetic sites; while a large amount of both molecules might be leached through soil via mobile water. S2 had the smallest desorption rate among the soils tested. The soil pH seems to influence the release of pyraoxystrobin molecules. According to the above analysis, it is noteworthy that pyraoxystrobin has very low water solubility, which might lead to a close affinity with the solid phase.

Mobility of pyraoxystrobin in agricultural soils

The R_f values were measured on the radio chromatograms for the soil TLC study. The R_f values were small, with values of 0.19 ± 0.01 , 0.23 ± 0.01 , and 0.36 ± 0.02 for S1, S2, and S3, respectively, indicating that pyraoxystrobin is not very mobile in these soils. The mobility results confirm that pyraoxystrobin was strongly adsorbed by the tested soils, in accordance with the desorption results. Soil can be treated as a mixture of different components: (1) poorly adsorbed compounds, such as sand and pebbles; (2) mineral components with adsorption properties, such as clays, possibly including mineral ions; and (3) organic compounds, such as insoluble humin, traces of water-soluble humic and fulvic acids, and native plant organic compounds. The chemical constituents of soil particles can affect the pesticide movement (Ravanel et al. 1999). The relationship between the R_f values and soil properties is shown in Table 6. Organic matter was the dominant soil property related to the R_f values, followed by soil pH. This result is consistent with the effect of the soil properties on the Freundlich constants. However, clay and cation exchange capacity had lower correlation coefficients with the R_f value.

The soil column study was conducted under simulated field conditions. The ¹⁴C radioactivity in the soil profile was analyzed every 10 days after initiation of the experiment to monitor the mobility of pyraoxystrobin. The total amount of pyraoxystrobin

Table 6 Relationship between R_f value and soil properties

Soil property	Correlation coefficient (r^2)	P value
pH	0.47	0.52
OM	0.67	0.39
CEC	0.41	0.56

recovered in the columns ranged between 90 and 96% of that applied. The mobility of pyraoxystrobin in S1 was shown in Fig. 1. Most of the applied ¹⁴C-pyraoxystrobin and its metabolites were detected in the upper layer (0–10 cm). About 96.03% of ¹⁴C-pyraoxystrobin and its metabolites were detected in the upper 4-cm layer on the 10th day, with 95.02% detected on the 60th day. No ¹⁴C-labeled component was detected in the leachates, indicating that the rainwater leaching solution did not transport pyraoxystrobin into the deep soil layers. These results indicate that after the application of pyraoxystrobin, the majority will be adsorbed and strongly retained in the surface soil and that the risk of its pollution in groundwater is minimal.

Both clay and organic carbon are important in the binding of organic compounds in soils (Worrall et al. 2001; Spark and Swift 2002; Cox et al. 1997). An increase in the concentration of dissolved organic matter can increase pesticide mobility. Hydrophilic pesticides are generally highly mobile in soils. When 2 mg of the pesticides carbofuran and atrazine were added separately into surface soil, a 200-mm simulated shower brought the peak value of carbofuran down to 25–30 cm in depth and that of atrazine to 15–20 cm in depth (He et al. 2006). However, our results suggest that the leaching of pyraoxystrobin is different to that of other hydrophilic pesticides. Pyraoxystrobin, carbofuran, and atrazine are all hydrophilic pesticides, but their leaching behaviors are largely different, indicating that water solubility of the pesticides might not be the main reason for the differences in mobility. High organic matter content favors the enhancement of pyraoxystrobin adsorption and decomposition because of the rule of similarity (lipid solubility). The possible mechanism of high soil organic matter (SOM) content and low pH leading to limited water solubility and contributing to the adsorption capacity of pyraoxystrobin (good lipid solubility) in the tested soils is shown in Fig. 2.

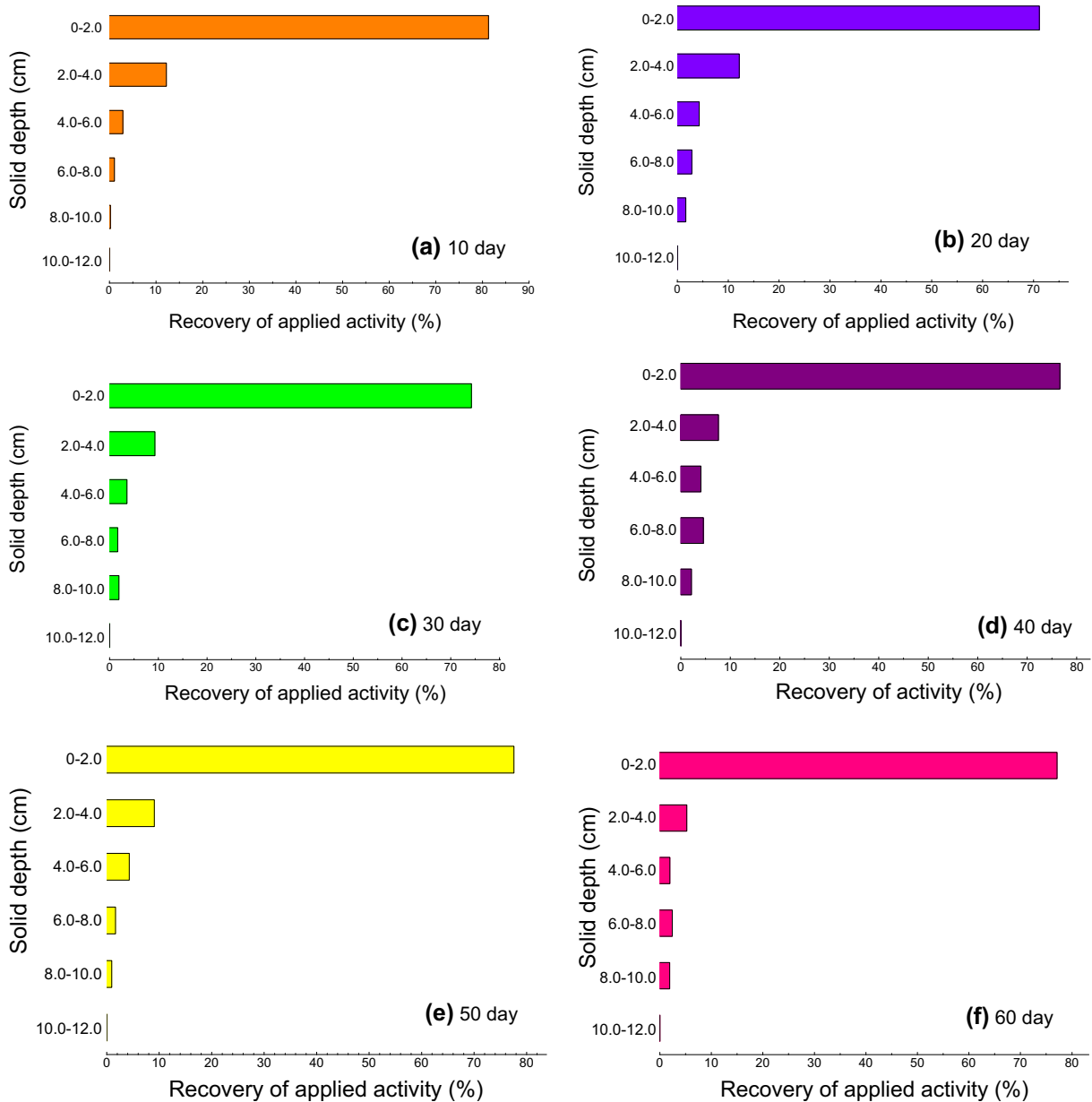


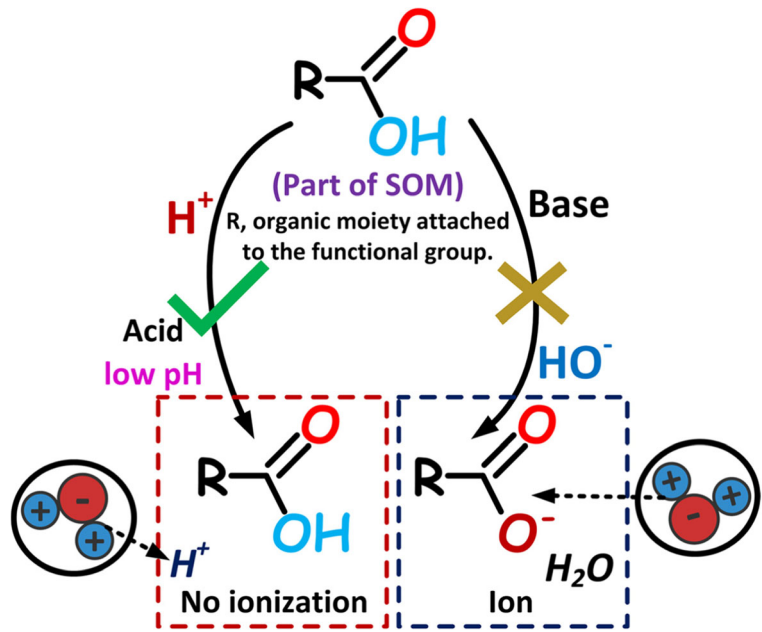
Fig. 1 Soil column leaching study in S1 with ^{14}C -pyraoxystrobin under field conditions. **a** to **f** corresponding to the samples collected every 10 days after treatment within 2 months

Conclusions

High organic matter content and low pH contributed to the adsorption capacity of pyraoxystrobin in the tested soils. Pyraoxystrobin is not readily desorbed from soils and soil pH seems to influence the rate of release. The mobility results from the TLC and column leaching

studies showed that it might be safe to use pyraoxystrobin as a fungicide without causing groundwater pollution, because of its strong hydrophobicity and limited mobility. High organic matter content favors the enhancement of pyraoxystrobin adsorption and desorption because of the rule of similarity (lipid solubility). In particular, the addition of organic wastes to soil

Fig. 2 Schematic of soil organic matter (SOM) by addition of a proton does not ionize the carboxyl groups (left); consequently, the attraction of water molecules operates only through polarity leading to limited water solubility; or strong base ionizes the carboxyl groups (right), creating strong attraction of water molecules contributing to formation of a hydration shell and leading to increased water solubility



would likely enhance the absorption of pyraoxystrobin. However, studies on the life cycle, biocompatibility, and biodegradation of pyraoxystrobin are warranted if large doses are used.

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