

# Spinosad Adsorption on Humic and Clay Constituents of Lacustrine Egyptian Soils and Its Leaching Potential

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## ABSTRACT

Adsorption of pesticides on soils is a key process for the assessment of their fate and transport in the environment. The kinetics and adsorption/desorption isotherms of spinosad on Abis soil and its clay and humic acid (HA) soil fractions were studied using batch experiments. Equilibrium time was investigated at 10 mg l<sup>-1</sup> spinosad initial concentration in 0.01M CaCl<sub>2</sub> background solution. Adsorption isotherms were carried out at different initial spinosad concentrations (0.1, 0.5, 1, 5, 10, 50 and 100 mg l<sup>-1</sup>). Desorption experiment was started immediately after adsorption equilibrium was reached through two successive dilution steps with 0.01M CaCl<sub>2</sub> solution. Equilibrium time of spinosad adsorption was at 24 h. Soil clay fraction had higher affinity to adsorb spinosad than HA and Abis soil had the least affinity. Adsorption data were successfully fitted to the Freundlich equation. Slopes of the linearized Freundlich equation,  $1/n_{ads}$  were 1.11, 1.54 and 1.49 and the intercepts,  $K_{ads}$  were 2.09, 5.02 and 9.21 for Abis soil, HA and clay fractions, respectively. Spinosad was not completely desorbed from the sorbents tested and the coefficient of hysteresis was 0.68 for Abis soil. Spinosad had  $K_{OC}$  of 1050 l kg<sup>-1</sup>. The calculated groundwater ubiquity score (GUS) index of spinosad in Abis soil ranged from 0.93 to 1.20 and from 2.16 to 2.35 indicating spinosad very low to low and moderate leaching potential under aerobic and anaerobic conditions, respectively.

**Keywords:** kinetics, adsorption, desorption, GUS index, leaching potential, spinosad.

## INTRODUCTION

The production and application of pesticides are increasing worldwide day by day. When pesticides are applied to the field, only small portion reaches to its target and the large remaining part is released into the environment. That may lead to some problems, such as toxicity to non-target organisms, leaching, and accumulation. Polluted soil, surface and ground waters involve risk to the environment and also to human health due to possible direct or indirect exposures. (Bajeer *et al.*, 2012).

Spinosad is a naturally derived insecticide (Dow Agrosciences LLC) that represents a new generation of biorational products developed for the agricultural industry that have a reduced spectrum of toxicity compared with the synthetic insecticides that were

developed previously (Williams *et al.*, 2003). Spinosad is a mixture of two neurotoxic macrolide compounds spinosyn A (85%) and spinosyn D (15%) that are active mainly by ingestion (Fig. 1). Spinosyns are produced by fermentation of the actinomycete *Saccharopolyspora spinosa* Mertz and Yao isolated from a Caribbean soil sample (Bret *et al.*, 1997). Spinosyns A and D are highly toxic to Diptera, Lepidoptera, Thysanoptera, and some species of Coleoptera, but they have extremely low toxicity for mammals; therefore, spinosad is classified by the U. S. Environmental Protection Agency as a reduced-risk material (Thompson *et al.*, 2000).

Potential groundwater contamination by a pesticide depends on its mobility. Mobility assessment of a pesticide may involve either direct or indirect approaches. Direct estimation involves the application of these compounds in the field or to soil columns, soil sampling from different depths and analysis by intensive and expensive routine analytical laboratory work. Indirect estimation is based on measurement of an indicator parameter, which is used as an index for the relative ranking of mobility (Green and Karickhoff, 1990). The sorption coefficient ( $K_d$ ) and the sorption coefficient normalized to soil organic carbon (OC) content ( $K_{oc}$ ) have been the most frequently used coefficients for this estimation. Indirect estimation has been used with variable success for different classes of herbicides, depending on whether they are a weak acid, a weak base, or neutral chemically (Oliveira Jr *et al.*, 2001).

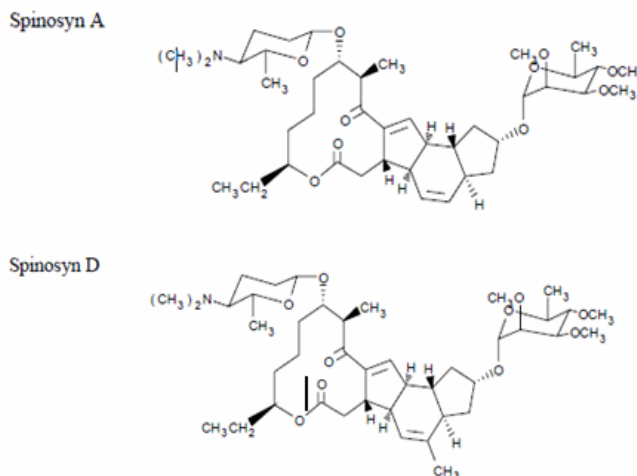
Previous studies suggested that adsorption of herbicide to the soil is the key process that affects their ecotoxicological impact, environmental mobility and the rate of degradation (Singh *et al.*, 2004; Liu *et al.*, 2010; Singh and Cameotra, 2013;). The desorption process of herbicides is also important since it determines the release rate and the potential mobility of herbicides in the soil (Liu *et al.*, 2010). The adsorption-desorption process of pesticides is influenced by several factors like organic matter content, clay type, and content, soil texture, pH, temperature, etc. (Singh *et al.*, 2004; Flores *et al.*, 2009; Liu *et al.*, 2010; Wu *et al.*, 2011).

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**Fig. 1. Chemical structure of Spinosyn A and D**

The risk of a pesticide entering the surface and ground waters mainly comes from the adsorbed pesticide present in the soil. To protect surface and groundwater from pesticide contamination and evaluate their impact, extensive knowledge concerning degradation and sorption–desorption processes in the environment is required (Flores *et al.*, 2009; Wu *et al.*, 2011).

A scoring methodology was suggested by Gustafson (1989) to estimate the potential of pesticides to contaminate groundwater. The groundwater ubiquity score (GUS) score is calculated using the persistence of pesticides and their adsorption strength to soil particles. The numerical GUS values was calculated from the following expression:

$$GUS = \log_{10}(t_{1/2}) \times [4 - \log_{10}(K_{OC})]$$

where,  $t_{1/2}$  is the half-life time of pesticide, the time in days needed for the degradation of the half of the applied pesticide to the soil and  $K_{OC}$  is the rate at which the pesticide is bound to the soil organic fraction, can be derived from the distribution coefficient of adsorption isotherm ( $K_d$ ), and the organic carbon content of the soil (% OC). The higher the GUS value, the higher the potential for pesticides to move towards groundwater.

**Table 1. A relative ranking of the leaching potential of pesticides based on GUS values (Pfeiffer, 2010)**

GUS values	Leaching Potential
< 0.1	Extremely Low
0.1 - 1.0	Very Low
1.0 - 2.0	Low
2.0 - 3.0	Moderate
3.0 - 4.0	High
> 4.0	Very High

A relative ranking of pesticides for their potential to leaching based on the GUS values was suggested by Pfeiffer (2010) as listed in Table (1). Databases of USDA-NRSDB (2006) and PPDB (2009) for different soils and pesticides, respectively were utilized to make the ranking scale of several pesticides used.

Little information is known concerning the behavior of spinosad in Egyptian soils and environments. Therefore, the objective of this study was to evaluate the adsorption-desorption of spinosad on a lacustrine Egyptian soil of Abis region, Alexandria and estimate its leaching potential to shallow groundwater in the region.

## MATERIALS AND METHODS

### 1- Soil Sampling and characterization

Five surface soil samples (0-20 cm) were collected from different locations at the Research Farm of Agriculture College, Abis region, east of Alexandria governorate (31° 12' 43" N, 29° 58' 53" E). Abis region is an agricultural area having a lacustrine soil (*Typic torrifluvents*) with shallow, fluctuating watertable ranging from 60-110 cm (Atta, 2010). No history of spinosad treatments was indicated in Farm's records at the selected sample locations. The soil samples were air-dried, grounded (porcelain mortar with rubber pestle) and passed through 2-mm sieve, mixed thoroughly to obtain a composite soil sample to be used in this study. Soil texture was determined by the hydrometer method (Gee and Bauder, 1986). Soil pH was measured in 0.01 M CaCl<sub>2</sub> in 1:2.5 w/v soil extract. Organic matter content was determined by the Walkley-Black wet digestion method (Nelson and Sommers, 1982). Cation exchange capacity (CEC) for tested soil was determined by the barium chloride compulsive

exchange method (Gillman and Sumpter, 1986). Other soil physical and chemical properties were determined according to Page *et al.* (1982). Selected main characteristics of the tested soil are shown in Table (2).

**Table 2. Main physical and chemical characteristics of Abis lacustrine soil**

Soil characteristics	Value
pH*	7.78
EC, dS m <sup>-1</sup>	1.73
Total carbonate, %	7.8
Organic carbon, %	0.54
CEC, cmol <sub>(+)</sub> kg <sup>-1</sup>	25.6
Clay, %	24.1
Silt, %	12.1
Sand, %	63.8
Soil textural class	Sand clay Loam

\* in 0.01M CaCl<sub>2</sub> extract.

## 2- Fractionation of soil components:

### A- Humic Acid Fraction (HA):

The humic fraction was extracted from soil sample with 0.5M NaOH as described by Velasco *et al.*, (2004). Briefly, five flasks, each containing 80 g air-dried soil were mixed with 800 ml of 0.5M NaOH at a ratio of 1:10 (w/v) in a one-liter volume flasks. Flasks were tightly stoppered to reduce exposure to air and shaken for 24 h at 130 rpm on a rotary shaker. The slurry was left for 1 day to settle in the dark at room temperature, then centrifuged at 10,000 rpm for 10 min to separate the supernatant containing both humic acid (HA) and fulvic acid (FA). The supernatant was acidified to pH 1.0 with 6M HCl and allowed to stand for 24 h in order to separate the HA as a precipitate from the soluble FA in the supernatant. Supernatant (FA) was discarded after centrifugation for 30 min at 10,000 rpm. The precipitated dark colored HA fraction was purified by suspension in a mixture of 0.1M HCl & 0.3M HF solution in a plastic container and shaken overnight at room temperature followed by centrifugation. It was then washed with distilled water 5 times through centrifugation until the test for chloride with silver nitrate was negative. The product was dried at a temperature below 40 °C until constant weight and stored until used.

### B- Soil clay fraction:

The clay fraction of the soils (< 2µm particle size particles) was obtained by sedimentation method (Kunze and Dixon, 1986). Briefly, a soil sample was air dried and treated with 30% H<sub>2</sub>O<sub>2</sub> at room temperature and then at 80 °C to remove soil organic matter. The treated sample was suspended and dispersed by shaking overnight with 0.1 M Calgon solution (sodium hexametaphosphate). Soil suspension was left to settle for about 7 h. The < 2 µm fraction (supernatant) was

decanted and exposed to washing several times with distilled water to remove any chloride until no Cl<sup>-</sup> was detected by 0.005M AgNO<sub>3</sub> solution. Clay slurry was dried at 105 °C for 16 hr, ground and stored until use.

## 3- Quantification of Spinosad:

Analytical spinosad (99.9% purity; water solubility 235 ppm at 25 °C, pH 7) was obtained from the El-Help Company, Egypt. Stock standard spinosad solution (200 mg l<sup>-1</sup>) was prepared by dissolving the required amount of the compound in redistilled water and stored at 4°C under dark condition. To obtain the optimum wavelength for spinosad photometric determination, a stepwise forward spectral scanning (range: 200-400 nm) was tested for 10 mg l<sup>-1</sup> spinosad aqueous solution using a UV-Vis Spectrophotometer (Thermo Corporation, Nicolet, evolution 100). A spectral density curve (S-D curve) was established for optical density, O.D., versus wavelength from which the optimum wavelength of spinosad ( $\lambda_{max}$ , the wavelength for maximum O.D.) was detected. The calibration standard curve (C-D curve) of spinosad was obtained by plotting triplicates of six different concentrations ranging from 1 to 100 mg l<sup>-1</sup> at the obtained  $\lambda_{max}$ .

## 4- Kinetics of spinosad adsorption experiment:

The equilibrium time was determined according to the adsorption kinetics study and previous studies of the spinosad adsorption (Thompson *et al.*, 2002; Hui-jun *et al.*, 2013; Singh and Cameotra, 2013). Batch adsorption kinetics experiment was carried out in 25-mL polypropylene centrifuge tubes at an initial spinosad concentration of 10 mg l<sup>-1</sup> prepared in a background of 0.01M CaCl<sub>2</sub>. Calcium chloride solution was used as a background electrolyte in order to minimize ionic strength changes and to promote flocculation. The experiment was performed in triplicate sets of centrifuge tubes containing 1.0 g of soil and 10 ml of spinosad solution. Soil suspensions were shaken at 200 rpm by (Orbital shaker SO1, Stuart) for different time intervals (15, 30, 45, 60, 90 min and 3, 6, 12, 18, 24, 36, 48 and 72 h) in the dark at room temperature (25±1°C). Suspensions were then centrifuged at 4000 rpm for 15 min (Centrifuge, Kokusan) and spinosad final concentration was measured in the supernatant. The concentration of spinosad in the supernatant was calculated against its standard curve. The amount of spinosad sorbed, *S* (mg kg<sup>-1</sup>) at each time interval was calculated as the difference between its initial and final concentrations. The amount of spinosad adsorbed was plotted against reaction time intervals for graphical determination of the equilibrium time for the tested sorbents.

### 5- Spinosad adsorption experiment:

Adsorption of spinosad on soil, clay and humic acid fraction was quantified using the batch equilibration technique. Duplicates of 1:10 of sorbent to solution ratio were equilibrated with 10 ml of aqueous solutions of different initial spinosad concentrations ( $C_i$ ) (0.1, 0.5, 1, 5, 10, 50 and 100 mg l<sup>-1</sup>) prepared in the same way as in the kinetics experiment described above. For the soil and clay fraction, 1 g was equilibrated with 10 ml of the aqueous solution while 0.25 g of HA fraction was equilibrated with 2.5 ml of aqueous solution of spinosad. Suspensions were shaken at 200 rpm for the previously determined equilibrium time at room temperature (25±1°C). At equilibrium, the supernatant was obtained as previously described and the equilibrium concentration ( $C_e$ ) of spinosad was measured. Control samples (no spinosad) containing only sorbent substances and 0.01M CaCl<sub>2</sub> were used for each series of experiments. Blanks with no sorbent indicated that adsorption of spinosad to the reaction vessels was insignificant. The amount of spinosad sorbed,  $S$  (mg.kg<sup>-1</sup> sorbent) was calculated as follows (Anhalt *et al.*, 2008);

$$S = V(C_i - C_e)/m$$

where,  $V$  is the volume of aqueous solution (l),  $C_i$  and  $C_e$  are the spinosad initial and equilibrium concentrations (mg l<sup>-1</sup>), respectively, and  $m$  is the mass of sorbent (kg).

Adsorption isotherms of spinosad on the three tested sorbents were plotted for further data analysis.

### 6- Spinosad desorption experiment:

The spinosad desorption experiment was conducted instantly after the adsorption experiment. After completing the adsorption process, the entire supernatant was decanted and replaced with 10 ml 0.01 M CaCl<sub>2</sub> solution. Suspensions were shaken at 200 rpm for 24 h at room temperature (25±1°C) to establish a new desorption equilibrium conditions followed by centrifugation to separate the liquid phase containing desorbed spinosad for analysis. These steps were repeated two times consecutively. The amount of desorbed spinosad was calculated from its concentration in the supernatant and volume of aliquots. The amount of spinosad remaining adsorbed was calculated as the difference between its initial adsorbed and the desorbed amounts. Desorption isotherms of spinosad for the three tested sorbents were also plotted for further data analysis.

### 7- Data Analysis:

Data analysis was performed according to El-Aswad and Hedia (2002); Singh and Cameotra (2013).

Adsorption and desorption experimental data were fitted to the Freundlich model:

$$S = K_{ads} C_e^{1/n_{ads}}$$

where  $S$  is the amount of pesticides sorbed per mass of soil (mg kg<sup>-1</sup> soil),  $C_e$  is the equilibrium concentration of spinosad in the liquid phase (mg l<sup>-1</sup>),  $K_{ads}$  is the Freundlich adsorption coefficient (l kg<sup>-1</sup>), and  $n_{ads}$  is a dimensionless parameter. Adsorption coefficients  $K_{ads}$  and  $1/n_{ads}$  values were determined from the regression lines of the logarithmic form of Freundlich equation:

$$\log S = \log K_{ads} + 1/n_{ads} \log C_e$$

The same calculations were carried out on the data of desorption experiment to calculate the intercept  $K_{des}$  and the slope  $1/n_{des}$  of the logarithmic form of Freundlich equation.

The distribution coefficient ( $K_d$ ) was also calculated as the ratio between spinosad concentration on the soil surfaces ( $C_s$ ) and in the aqueous solution at equilibrium ( $C_e$ ).  $K_d$  was then normalized to the organic carbon (OC, %) content of the soil using the following equations;

$$K_{OC} = 100 \times K_{ads} / \%OC$$

The larger the  $K_{oc}$ , the stronger pesticides are held to soil organic matter and the less likely it will be leached. The  $K_{oc}$  value provides a single representation of a particular pesticide for all soils (USUCE, 2004).

The hysteresis coefficient,  $H$ , was calculated as  $H = (1/n_{des}) / (1/n_{ads})$  according to Kumar and Singh (2013).

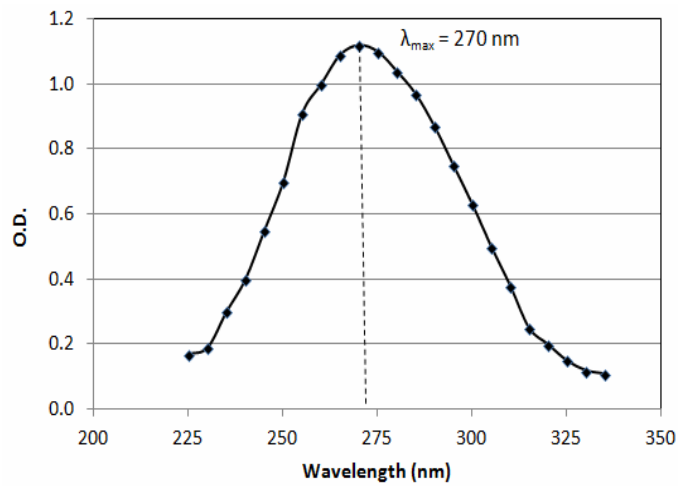
## RESULTS AND DISCUSSIONS

### Quantification of spinosad:

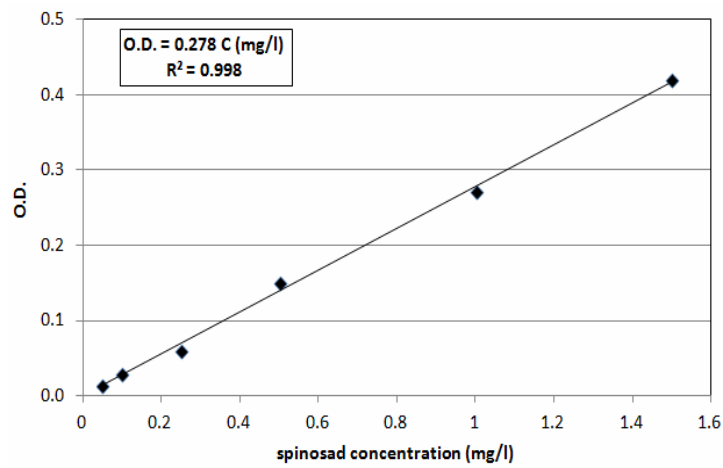
Data on the measured optical density versus wavelength for 10 mg l<sup>-1</sup> spinosad aqueous solution are presented in Fig. (2). The optimum wavelength at which quantification of spinosad can be properly conducted was found at 270 nm, where the maximum O.D. was obtained. The calibration curve was then carried out at this wavelength (Fig. 3). The regression line equation obtained for the calibration curve recorded a slope 0.28 with a very high determination coefficient ( $r^2 = 0.99$ ). This finding is consistent with previous studies on HPLC quantification of spinosad (Hui-jun *et al.*, 2013).

### Equilibrium time for spinosad adsorption:

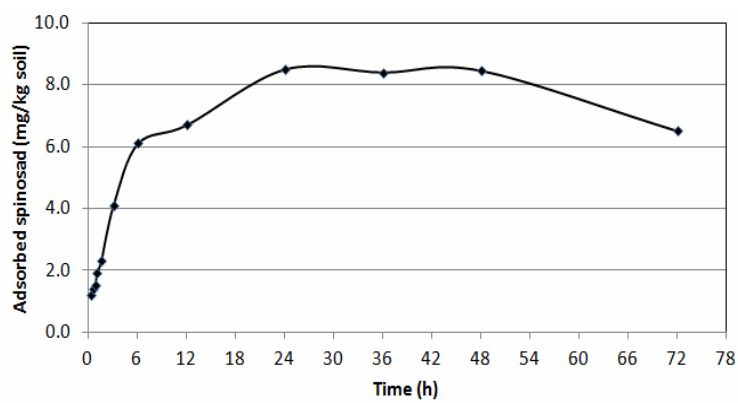
The study of adsorption kinetics is necessary to know the time required to reach equilibrium. Data of the equilibrium state of spinosad adsorption on the tested soil (Fig. 4) show that the amount of spinosad adsorbed to the soil increases with time to a maximum of 8.5 mg kg<sup>-1</sup> soil after 24 h. No further significant changes were observed in spinosad adsorbed till 48 h of adsorption.



**Fig. 2.**The S-D curve of spinosad



**Fig. 3.**The C-D curve of spinosad



**Fig. 4.** Kinetics of spinosad adsorption on Abis lacustrine soil

However, a slight decline in spinosad adsorbed was detected after 72 h. The time needed to reach equilibrium state in soil was 24 h. Consequently, 24 h was set as the equilibrium time for the subsequent spinosad adsorption and desorption experiments. This finding is consistent with Hui-jun *et al.* (2013) on of spinosad. On the other hand, Bajeer *et al.* (2012) reported that the equilibrium time for imidacloprid obtained in alluvial soil was reached after 6 h. It was found that the time required for a pesticide-soil system to reach adsorption equilibrium depends on the type of pesticide and soil characteristics (Nkedi-kizza and Brown, 1998).

#### Spinosad adsorption isotherms:

Isotherms spinosad adsorption on Abis soil, clay and HA fractions and the fitted Freundlich model with its parameters are presented in Fig. (5) and Table (3). Isotherms show that spinosad adsorption on the three sorbent increases with increasing the initial concentration within the tested range. The adsorption patterns represent the S-type where adsorption becomes easier as the concentration in the liquid phase increases (Calvet, 1989; Delle, 2001). Clay fraction shows more affinity to adsorb spinosad than HA fraction. However, Abis soil shows the least ability to adsorb spinosad. This might be attributed to a strong intermolecular attraction within the layers of clay minerals and exposed functional groups of humic acid rather than the complex matrix of soil.

**Table 3. Physiochemical parameters of adsorption and desorption of spinosad from data curve fitting to Freundlich equation**

Parameters	Sorbents		
	Soil	HA	Clay
Adsorption parameters			
$K_{ads}$	2.09	5.02	9.21
$1/n_{ads}$	1.11	1.54	1.49
$r^2$	0.98***	0.95***	0.96***
SE	0.38	0.46	0.43
Desorption parameters			
$K_{des}$	1.13	0.80	0.55
$1/n_{des}$	0.76	1.29	1.26
$r^2$	0.88**	0.78*	0.82**
SE	0.68	0.92	1.01

\*, \*\*, \*\*\* are significant at 0.05, 0.01 and 0.001 probability levels, respectively.

SE: Standard error of estimation.

Similar behavior of spinosad was observed by Hui-jun *et al.* (2013) on three different soils where spinosad increased with increasing soil clay content and the adsorption isotherms followed the S-type. SCBP (2010)

reported that spinosad adsorption showed a strong correlation with soil clay content for five different soils from France. El-Aswad and Hedia (2002) found that isotherms of Aldicarb adsorption coefficient on the soil organic matter and clay fractions of Abis soil were S-type.

At the initial spinosad concentration 10 ppm, the amount of adsorbed spinosad is 16.96, 39.68 and 55.82 mg/kg for Abis soil, HA and clay fractions, respectively. This can be also confirmed by the parameters of the data fitting to Freundlich model (Table 3). The calculated values of  $1/n_{ads}$  were 1.11, 1.54 and 1.49 for Abis soil, HA and clay, respectively. Since the  $1/n_{ads}$  value represents the slope of the regression line of the linearized form of Freundlich equation, the adsorption affinity of the sorbent surfaces to spinosad is proportional to the value of this parameter. Moreover, the intercept of the linearized Freundlich equation,  $K_{ads}$  describes the strength of initial adsorption of spinosad on the tested sorbents. From Table (3),  $K_{ads}$  values are 2.09, 5.02 and 9.21 for Abis soil, HA and clay fractions, respectively. The obtained determination coefficients of the linear Freundlich regressions are 0.98, 0.95 and 0.96 for Abis soil, HA and clay fractions, respectively which indicate the good fitness of the Freundlich model to describe the behavior of spinosad adsorption on the tested sorbents. The calculated distribution coefficient values,  $K_d$  were 5.67, 36.02 and 51.31 l kg<sup>-1</sup> for soil, HA and clay, respectively at 50 mg l<sup>-1</sup> initial spinosad concentration. The calculated  $K_{OC}$  values from  $K_d$  and % OC of the soil was 1050 l kg<sup>-1</sup>. Hui-jun *et al.* (2013) found that spinosad  $K_d$  values from 13 to 20 l kg<sup>-1</sup> for three soil samples of fine texture and varying organic matter content. They reported that the  $K_d$  values increased with the increase in soil clay and organic matter contents. DPR (1995) reported a  $K_{OC}$  value of 1425 for a sandy loam soil with pH= 7.5 and CEC= 12 cmol<sub>(+)</sub> Kg<sup>-1</sup>.

#### Spinosad desorption isotherms:

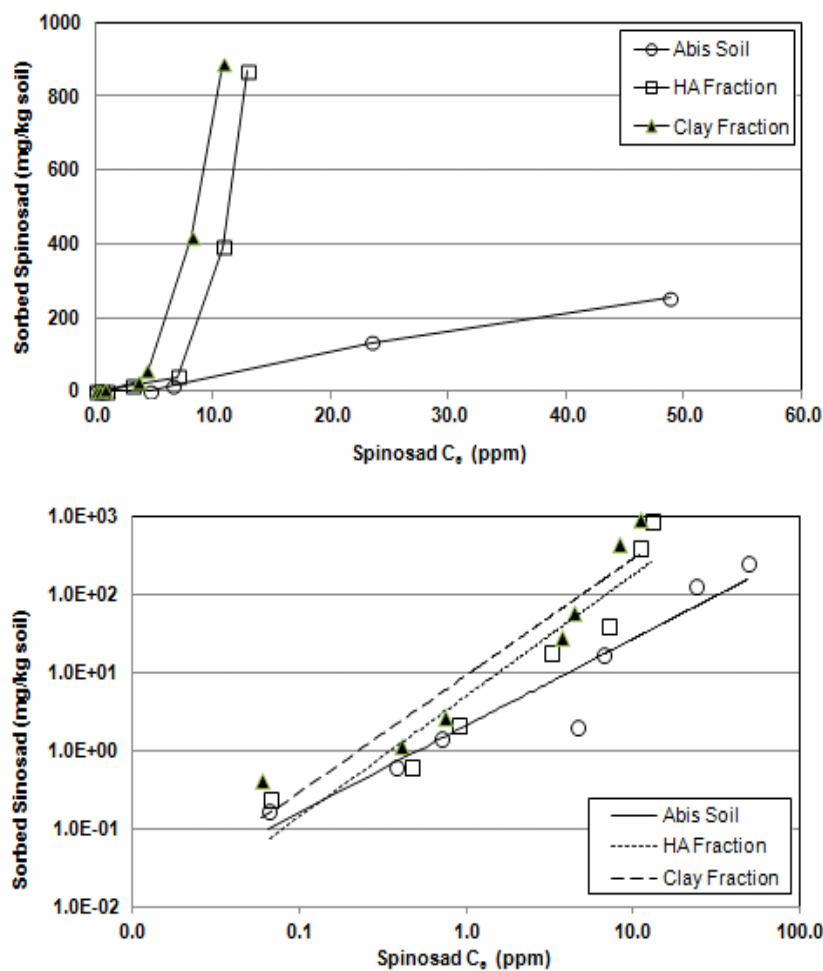
Data of spinosad desorption from the sorbents tested are presented in Fig. (6) and the calculated parameters of fitting Freundlich equation to these data are listed in Table (3). After two consecutive desorption steps, the equilibrium spinosad concentrations were generally lower than those for adsorption experiment (Fig. 6). Having the lowest spinosad adsorption capacity, Abis soil released the lowest amount of spinosad compared with HA and clay soil constituents. Although clay fraction had higher affinity to adsorb spinosad than HA fraction (Fig. 5), desorption from this fraction is relatively higher than HA fraction (Fig. 6).

The calculated Values of  $1/n_{des}$  (Table 3) are 0.76, 1.29 and 1.26 for Abis soil, HA and clay, respectively. Since the  $1/n_{des}$  value represents the desorption rate of spinosad, HA and clay surfaces have higher slopes than Abis soil reflecting the higher amounts of spinosad adsorbed on their surfaces before desorption. Moreover, the intercept of the linearized Freundlich equation,  $K_{des}$  describes the strength of initial desorption of spinosad from the tested sorbents.  $K_{des}$  values are 1.13, 0.80 and 0.55 for Abis soil, HA and clay fractions, respectively. This means that Abis soil tends to release more spinosad in the beginning of the desorption course than HA and clay fractions. Relatively lower and less significant determination coefficients (0.78 - 0.88) of the linear Freundlich regressions of desorption indicate a satisfactory fitness of the Freundlich model to describe the behavior of spinosad desorption from the tested sorbents.

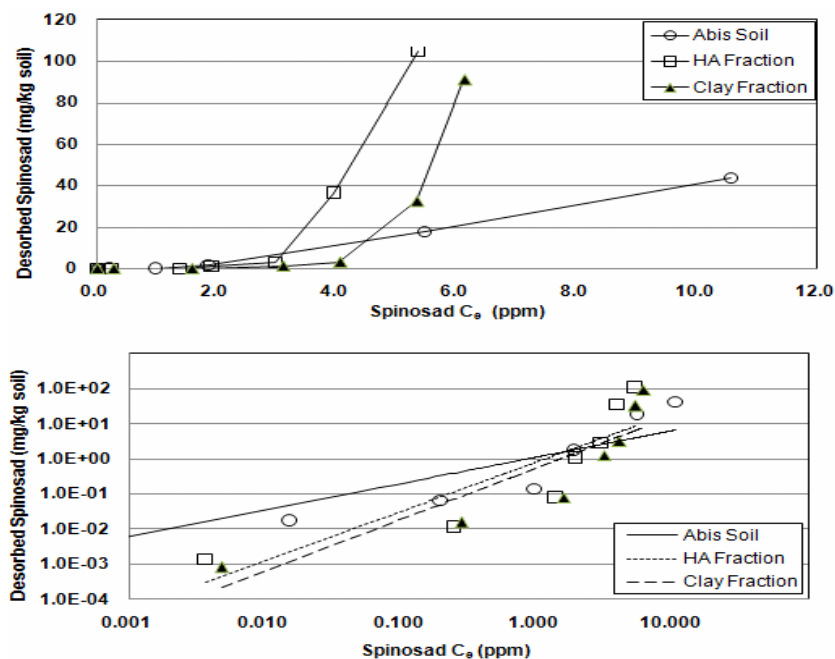
The hysteresis coefficient ( $H$ ) compares the strength of desorption and adsorption processes (Kumar and Singh, 2013). Calculated  $H$  values were 0.68, 0.90, and 0.85 for Abis soil, HA and clay fractions, respectively. This may indicate that not all the spinosad adsorbed to the surfaces of these sorbents can be released to soil aqueous phase and will be retained against biodegradation or leaching.

**Leaching potential of spinosad:**

Half-life is the period of time it takes for one-half of the amount of pesticide in the soil to degrade (Seiber, 2002). Variations in half-life depend on soil microbial populations and activity, soil moisture content, soil temperature, and other factors. Pesticides that have  $t_{1/2} \leq 30$  days are nonpersistent, moderately persistent pesticides have  $t_{1/2}$  of 31 to 99 days, and persistent pesticides have  $t_{1/2} \geq 100$  days.



**Fig. 5. Adsorption isotherms (upper) and fitted Freundlich linearized equation (lower) of spinosad on Abis soil, clay and HA fractions**



**Fig. 6. Desorption isotherms (upper) and fitted Freundlich linearized equation (lower) of spinosad from Abis soil, clay and HA fractions**

To evaluate the leaching potential of spinosad, data on the degradation rate and half-life time ( $t_{1/2}$ ) reported by DPR (1995) and Hale and Portwood (1996) were used. In alkaline soils, spinosad had a  $t_{1/2}$  range from 9 to 17 days and from 161 to 250 days under aerobic and anaerobic soil conditions, respectively. Thus, spinosad is considered nonresistant under aerobic conditions but it is resistant under anaerobic conditions.

**Table 4. GUS index calculated for spinosad in Abis soil under aerobic and anaerobic conditions**

Limits	Soil conditions	
	Aerobic	Anaerobic
	Half life time, days	
Minimum	9	161
Maximum	17	250
	GUS Index	
Minimum	0.93	2.16
Maximum	1.20	2.35

The calculation of GUS index of spinosad in Abis soil under aerobic and anaerobic conditions was done (Table 4) using the estimated  $K_{oc}$  ( $1050 \text{ l kg}^{-1}$ ) in this study and the reported  $t_{1/2}$  values by DPR (1995) and Hale and Portwood (1996). GUS index of spinosad under aerobic conditions ranges from 0.93 to 1.20 corresponding to a relative ranking of very low to low leaching potential (Table 1). Under anaerobic conditions and due to the higher  $t_{1/2}$  values, the GUS

index ranges from 2.16 to 2.35 revealing a moderate leaching potential of spinosad in Abis soil. Pfeiffer (2010) obtained values of GUS index of spinosad from - 0.035 to 0.9 for a wide variety of soils under aerobic conditions which indicate extremely low to low leaching potential.

**CONCLUSION**

This study investigated the adsorption and desorption behavior of spinosad insecticide on Abis soil. Clay and humic acid soil constituents were responsible for spinosad adsorption. Adsorbed spinosad was not completely released from the adsorption sites and showed considerable hysteresis. The Freundlich equation was suitable to represent the adsorption and desorption data of spinosad on the sorbents tested. The calculated groundwater ubiquity score revealed that spinosad may have very low to low or moderate under aerobic and anaerobic soil conditions. More extensive studies are needed for field fate and transport of spinosad in this soil to help in designing an effective management strategy in the study area.

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$$1/n_{ads} = 1.106, 1.543 \text{ and } 1.487$$

$$K_{ads} = 2.091, 5.022 \text{ and } 9.210$$

spinosad

sandy clay loam

batch experiments

10 mg l<sup>-1</sup>

hysteresis

0.01M

$$K_{OC} = 1050 \text{ l kg}^{-1}$$

Groundwater

(0.1, 0.5, 1, 5, 10, 50, and 100mg l<sup>-1</sup>)

(Ubiquity Score, (GUS  
 leaching potential

GUS

0.01 M

0.93 – 1.20

very low to low

2.16 - 2.35

moderate

Freundlich