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Effect of Soil Amendments on Leaching of Thiamethoxam in Alluvial and Calcareous Soil

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Abstract: In this study, peat, compost and charcoal were added to reduce groundwater pollution with thiamethoxam by soil columns. Iodide has been used as a water tracer at a rate of 10 mL (0.1 M) for each soil column and that leached fast in all soil columns. The breakthrough curve of thiamethoxam was appeared from leachates of calcareous soil column and alluvial soil column with iodide. Accordingly it is considered thiamethoxam is highly mobile compound in tested soils. The addition of soil amendments reduced downward movement and significantly increased cumulative percentage of thiamethoxam from soil columns. After application; 85.21, 93.23, 98.12 and 97.84 % of applied thiamethoxam were recovered in leachates of alluvial soil, 5% peat-soil, 5% compost-soil and 5% charcoal-soil. While; 91.50, 99.30, 94.09 and 86.89 % from calcareous soil, 5% peat-soil, 5% compost-soil and 5% charcoal-soil columns. This is first study to assess, leaching of thiamethoxam and effect of soil amendments on leaching by soil columns. This information can be used to understand how alterations in agricultural practices and potential effects to groundwater.

Keywords: Charcoal, Compost, Leaching, Peat, Soil, Thiamethoxam.

Introduction

Leaching process occurs when water seeps through the soil, carrying water-soluble chemicals with it. The higher water solubility of a particular chemical, the greater the potential for leaching (Al-Farttoosy & Al Sadoon, 2022). Many chemicals do not leach because they are adsorbed, or tightly held, by soil particles. The longer the compound persists in the soil, the longer it is available to leach into groundwater. Understanding the variables influencing pesticide behaviour in the environment is crucial to lowering the danger of contaminating groundwater (Peres *et al.,* 2022). Leaching of pesticides into soil is dependent of sorptive properties of substance and soil. Spraying pesticides on soil as well as reaching groundwater is a considerable problem in the environment. Therefore, the contamination of surface water and groundwater with pesticides has been a source of concern for the past several years (El-Aswad *et al.,* 2022; Fouad, 2023b; Shamsan *et al.,* 2023). The risk of water pollution by pesticides and/or their derivatives is frequently estimated using adsorption coefficient, bio-degradability indicts and leaching tests through columns in the laboratory (Elhady *et al.,* 2022). The adsorption and desorption reactions are of essential for evaluation of leaching of pesticides in agriculture environment (El-Aswad *et al.,* 2019; Nasidi *et al.,* 2021). The behaviour and fate to pesticide into soil depend on different factors including soil type and organic matter (OM) content. Clay soils retain pesticides more than sandy soils, and there is also a positive relationship between adsorption, OM content, and clay content (El-Aswad *et al.,* 2019; Fouad *et al.,* 2023).

Changes in pore size distribution, greater porosity, improved water retention, and decreased bulk density are just a few of the features of soil that can be affected by soil amendments (Si *et al.,* 2006; Saleem *et al.,* 2022). The sorption and transport of pesticides in soils can be impacted by organic amendments used to enhance soils with low OM concentrations (Cox *et al.,* 1997; Fouad, 2022a). Applying organic amendments to soils improved their physical characteristics and raised their OM content, according to several studies. A significant part in managing pesticide runoff and leaching losses can be played by soil amendments (Fouad, 2023b). Any modification to soil alters its physico-chemical characteristics, which then has an impact on the adsorption-desorption, degradation, and leaching of pesticides applied on soil (Majumdar & Singh, 2007). In soils treated with these kinds of organic materials, pesticide sorption is boosted due to the efficient sorption of pesticides by charcoal and other charcoal-like materials (Salisu *et al.,* 2021a, b; Fouad, 2023b).

More than 130 nations use thiamethoxam insecticide in agrochemical formulations, including the two largest grain-producing nations in the world, the Brazil and United States. Additionally, it is widely used for seed treatment (Hilton *et al.,* 2016; Peres *et al.,* 2022). Thiamethoxam has a low vapour pressure, which reduces losses from volatilization, and is very soluble and has a low K_{ow}, which results in little adsorption in organic matrix and a lot of permanence in soil solution. Any thiamethoxam molecule that is not intercepted by crop after spray treatments will therefore virtually probably target soil (Peres *et al.,* 2022). Thiamethoxam has a significant leaching potential because of its physical-chemical properties, especially into sandy soils where its sorption is quite constrained by its polarity (Morrissey *et al.,* 2015; Peres *et al.,* 2022). Therefore, after application, thiamethoxam primarily finds its way to the soil. Due to thiamethoxam's high toxicity, and bioaccumulative nature, its potential for leaching and pollution of subsurface waters must be clarified (Peres *et al.,* 2022). The study aimed to understand the leaching and the transport of thiamethoxam in alluvial soil, and calcareous soil and the effect of soil amendments (peat, compost and charcoal) on leaching by soil columns under laboratory conditions.

Materials & Methods

Thiamethoxam

Pesticide source; Egyptchem International, Second Industrial zone, An Nubariyah, Beheira Governorate, Egypt. Manufacturer; Nanjing Zhongken Intelligent Technology Co., Ltd. Commercial formulation type; suspension concentrate (SC), capsule suspensions (CS), water dispersible granules (WG), flowable concentrate for seed treatment (FS), and water-dispersible powders for slurry seed (WS).

Chemicals

Calcium chloride ($CaCl_2$), potassium iodide (KI), sodium thiosulphate ($Na_2S_2O_3$), sulphuric acid (H_2SO_4), hydrogen peroxide (H_2O_2), and starch indicator.

Devices

UV-Vis Spectrophotometer, Centrifuge (Model 90-1 UK), Water distillatory (DESA

0035, Eu), pH meter (Milwaukee, MARTN, Italy).

Tested soils

The alluvial soil and calcareous soil were collected from the Alexandria Governorate, Egypt. The physicochemical properties were presented in tables (1 and 2).

Table (1): Physical characteristics of soils

Properties	Particle size (%)			Texture type	Water holding capacity (%)
	Sand	Silt	Clay		
Alluvial soil	39	18	43	Clay	47
Calcareous soil	66	15	19	Sandy clay loam	39

Table (2): Chemical characteristics of soils

Characteristics	Alluvial soil	Calcareous soil
EC (ds m^{-1})	1.4	5.1
pH	8.3	8.2
OM (%)	3.4	1.6
Total carbonate (%)	7.9	44.7
Soluble cations concentration (ppm)		
Ca^{++}	76	374
Mg^{++}	60	106
Na^{+}	216	518
K^{+}	20	12
Soluble anions concentration (ppm):		
CO_3^{--}	96	48
HCO_3^{-}	159	281
Cl^{-}	302	746
SO_4^{--}	29	1148

Leaching study

The bench-scale soil columns were used to estimate the mobility potential of thiamethoxam in soil and amended soil. The tested soil and amended soil with 5% of different amendments; peat, compost, and charcoal (Badawy *et al.,* 2017) was loaded into columns (about 40 cm high and 10 cm diameter PVC pipes). Each column was uniformly packed to a known bulk density by 3 kg soil. The bottom end cap supported a porous stainless steel plate. The columns were preconditioned before applying the pesticide and KI by saturation with 0.01 M $CaCl_2$. Each column received 10 mL KI (0.2 M) solution as a water tracer. The quantity of each tested pesticide dissolved in a solvent was applied drop wise on the soil surface of each column, consistent with 20 µg g^{-1} soil. Next, the $CaCl_2$ solution was applied and the leachates (10 mL leachate). The KI was determined in all leachate samples depending on the Iodimetric method according to (Mendham *et al.,* 2000). Also, all leachates were analyzed to determine the tested pesticide at 256 nm (Al-Farttoosy & Al Sadoon, 2022; Fouad, 2022b).

Analysis of data

The statistical analysis was carried out with the help of the Minitab 19 Statistical Software, and experimental data are shown as mean ± standard deviation. One-way analysis of variance was used to investigate possible correlations between thiamethoxam mobility and soil amendments.

Results & Discussion

The most definitive tests of organic chemicals mobility have occurred by adding a non-adsorbing tracer such as chloride or bromide. In similar, iodide has been used as a water tracer at a rate of 10 mL KI 0.1 M for each soil column. The results show that the water tracer I^- leached fast in soil columns. The highest concentration of iodide could be detected in first 600 to 1800 ml of leachates from alluvial soil columns. The breakthrough curve (BTC) of thiamethoxam was appeared from leachates of the alluvial soil column with of iodide, indicating that thiamethoxam is highly mobile compound in alluvial soil. The maximum concentration of thiamethoxam in the alluvial soil column leachates was obtained after percolating 900 mL. Addition of 5% peat, 5% compost, or 5% charcoal to alluvial soil reduced downward movement of thiamethoxam into columns and affected the maximum concentration of thiamethoxam in leachates. Maximum concentration of iodide into the alluvial soil columns did not affected by peat, compost, and charcoal. While maximum concentration of thiamethoxam was obtained after 1000-2800 mL of 5% soil amendments columns of leachates cumulative volume. The amendment of alluvial soil column with peat, compost, and charcoal decreased the bread of thiamethoxam BTCS compared to that of unamended soil (Fig. 1).

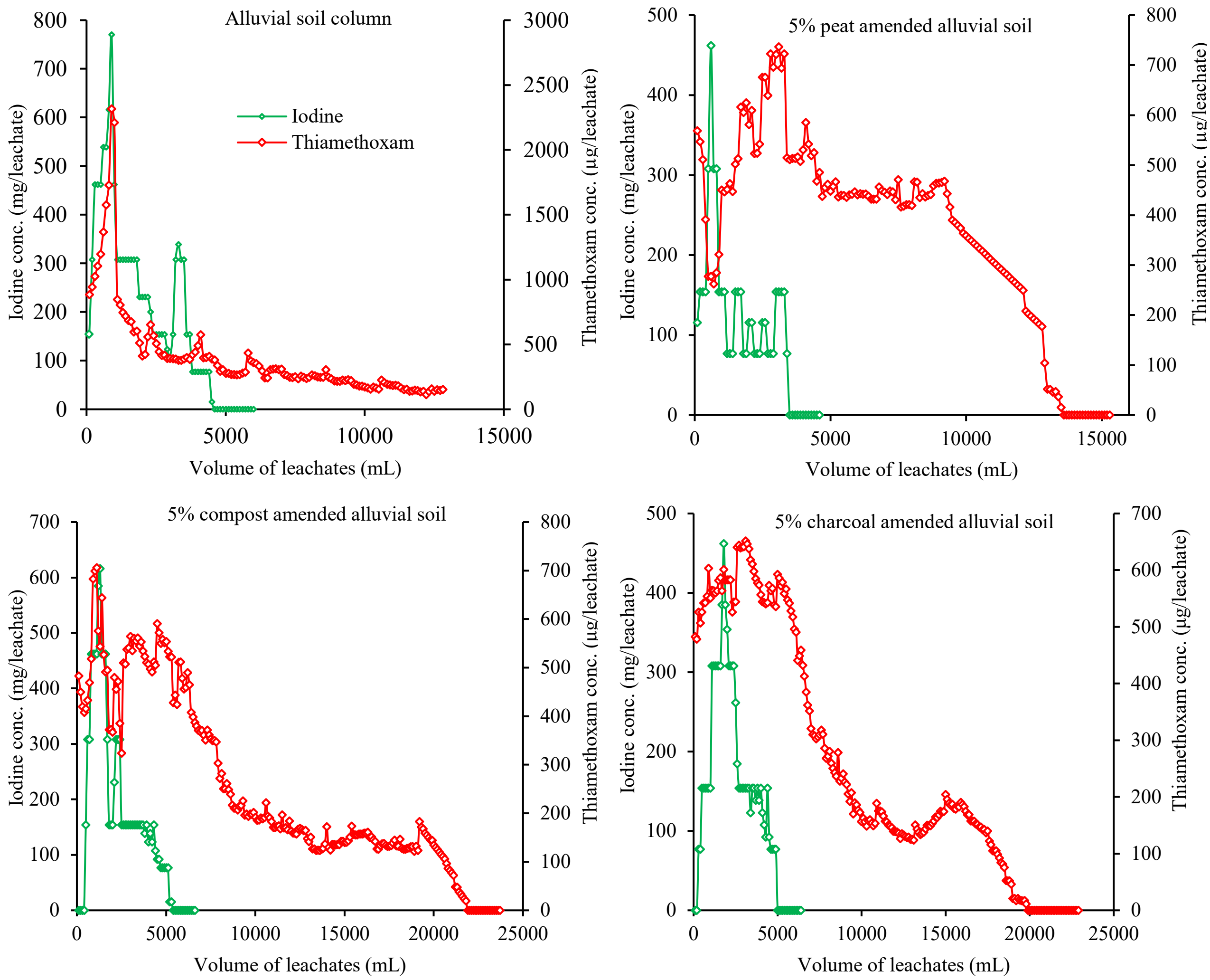

Fig. (1): Breakthrough curves of thiamethoxam and water tracer I^- in unamended and amended alluvial soil columns. (LSD = 55.72, There are significant differences between the treatments)

Fig. (2) and table (3) shows the percentage of cumulative leachates and volume of cumulative percolates of thiamethoxam collected in the leachates unamended and amended alluvial soil columns. Peat, compost, and charcoal significantly increased the cumulative percentage of thiamethoxam throughout the percolation compared to that unamended alluvial soil. After application; 85 to 98 %, of applied thiamethoxam were recovered in leachates of bulk alluvial soil and modified soil.

Fig. (3) represents the BTC curves of thiamethoxam compared to iodide as water tracer in un-amended and amended calcareous soil. The top of BTC corresponding to maximum concentration of thiamethoxam was obtained after percolating 0.4-3.6 L of leachates. The amendment of calcareous soil columns with peat, compost and charcoal decreased leaching of thiamethoxam, consequently increased the break through time. The maximum concentration of iodide in calcareous soil columns did not affected by the soil amendments. In addition, 87-99% of applied thiamethoxam in un-amended and amended calcareous soil were recovered in the leachate after percolating about 20 L of $CaCl_2$ solution (Table 3 and Fig. 4).

Table (3): Percentage of cumulative leachates and volume of cumulative percolates from soil columns

Columns	Cumulative leachates (%)	Cumulative percolates (L)
Alluvial soil	85.21[a]	12.8[a]
5% peat amended alluvial soil	93.23[c]	13.5[ab]
5% compost amended alluvial soil	98.12[d]	21.8[d]
5% charcoal amended alluvial soil	97.84[d]	19.8[c]
Calcareous soil	91.5[b]	20.5[c]
5% peat amended calcareous soil	99.30[d]	21.6[d]
5% compost amended calcareous soil	94.09[c]	18.8[b]
5% charcoal amended calcareous soil	86.89[ab]	12.6[a]

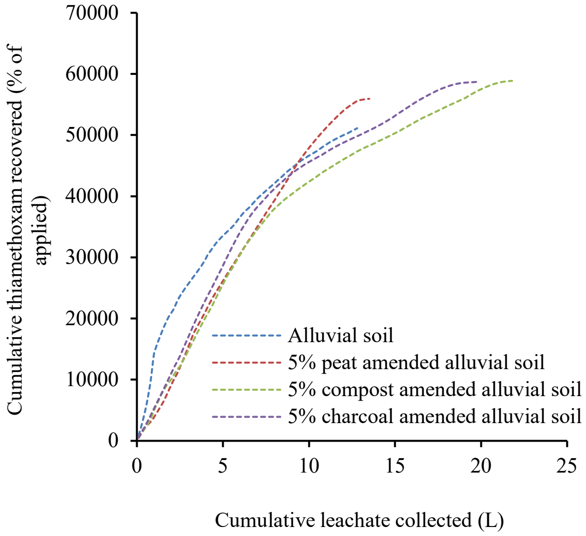

Fig. (2): Cumulative leachate curves of thiamethoxam in unamended and amended alluvial soil columns. (LSD = 3674.28, There are significant differences)

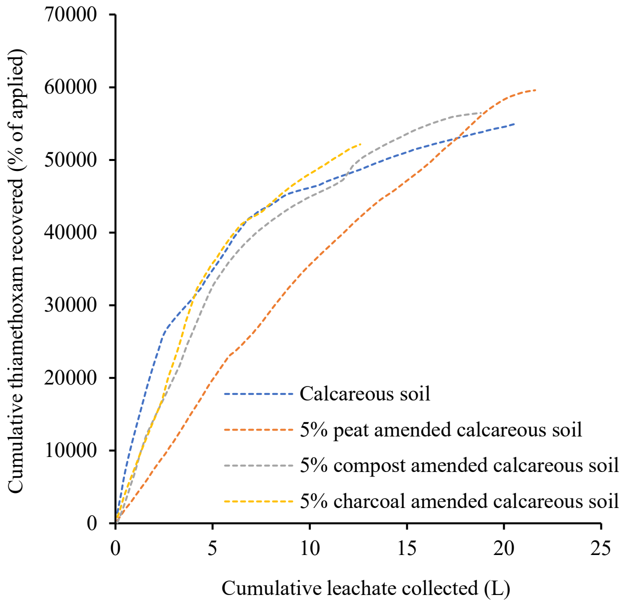

Fig. (4): Cumulative leachate curves of thiamethoxam in unamended and amended

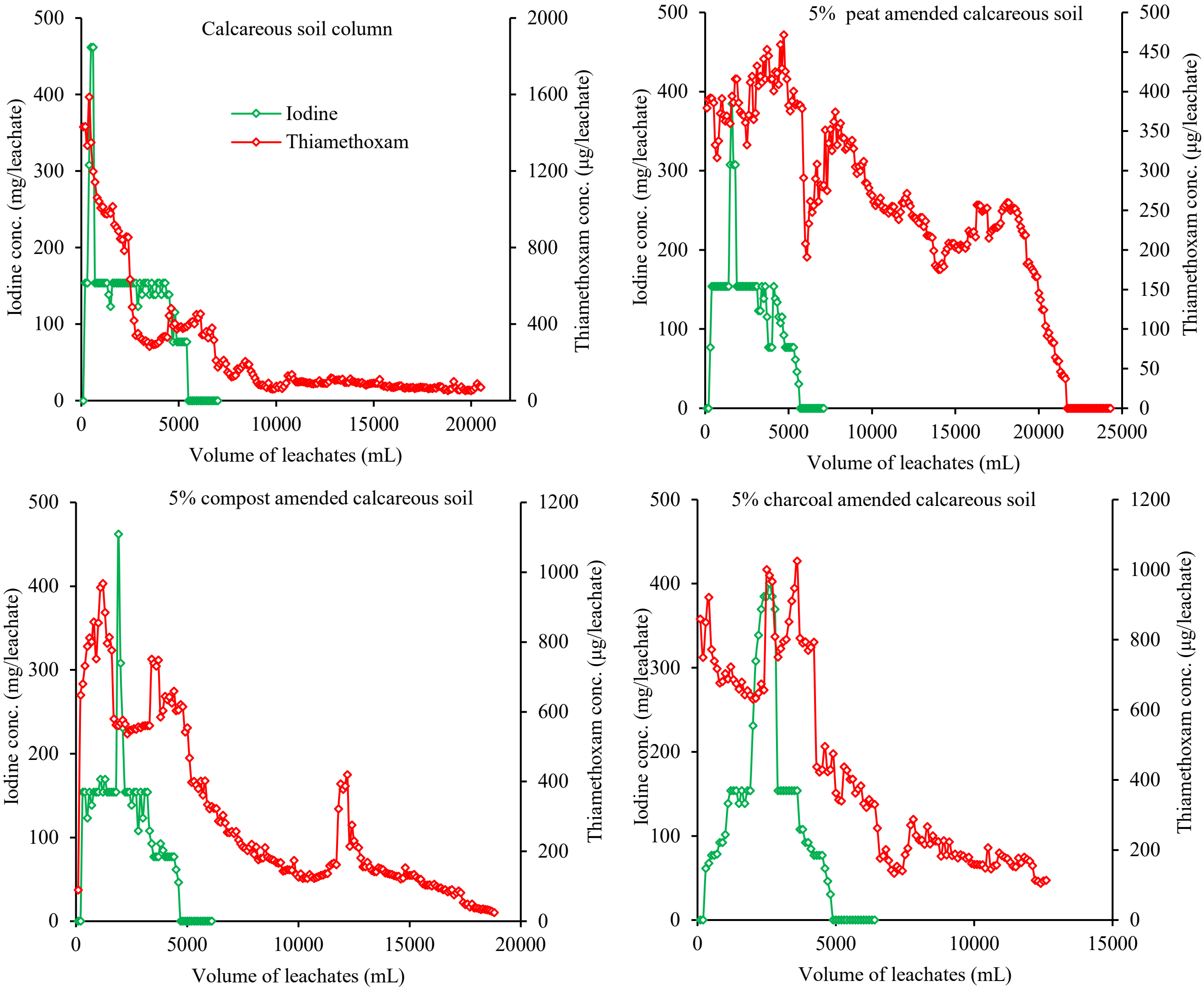

Fig. (3): Breakthrough curves of thiamethoxam and water tracer I^- in unamended and amended calcareous soil columns. (LDS = 63.11, There are significant differences between the treatments)

calcareous soil columns. (LSD = 3358.38, There is a significant difference).

The results showed that iodide is a nonreactive water tracer. The water tracer I^- was leached fast and the BTCs in the unamended soils and peat and compost and charcoal amended soil columns are symmetrical (Fouad, 2023b). Also, Gaber *et al,* (1992) obtained a symmetrical BTC for water tracer bromide. The rapid release of thiamethoxam as well as I^- from the calcareous soil columns compared to the alluvial soil columns may be due to the soil type. The sandy soil containing more sand is more susceptible to the agricultural chemicals leaching (Perry *et al.,* 1988; El-Aswad *et al.,* 2022). The top of BTC, corresponding to maximum concentration of thiamethoxam was delayed in amended alluvial soil. Whereas, this observation did not recorded in the case of calcareous soil. It is probably because the calcareous soil has macro and micro pores which influences the movement of chemicals (Aly *et al.,* 2021). The specific form of BTC curve dependents on physic-chemical characteristics of chemical and soil solids, and structure of soil through which chemical moves (Shipitalo *et al.,* 1990). The amendment of soil columns with 5% peat or compost or charcoal decreased the thiamethoxam leachability. Many previous studies recorded that the organic amendments reduce the chemical leaching in the soil columns (Cox *et al.,* 1997; Majumdar & Singh, 2007; Jones *et al.,* 2011; Fouad *et al.,* 2023). In general, leaching data are useful for predicting and understanding the behaviour of pesticides in different soil types (Fouad, 2023a). The groundwater pollution does not only affects health of humans being as it is being used for drinking purpose, but also can act as a source of contamination for the food chain, when used for irrigation (Navarro *et al.,* 2007). According to research of Si *et al.,* (2006) organic amendments may be a useful management strategy for reducing pesticide leaching. The risk of groundwater contamination by pesticides especially in the alluvial and calcareous soils can be progressively reduced as soil becomes incorporated with organic amendments (Cox *et al.,* 1997; Tatarková *et al.,* 2013).

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Conflicts of interest

As for the requirements of the publishing policy, there is no potential conflict of interest for the author.

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تأثير أضافة محسنات التربة على غسيل مبيد الثيامثوكسام فى التربة الطينية والتربة الجيرية

محمد رياض فؤاد

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المستخلص: تم استخدام اليوديد كمتتبع للمياه بمعدل 10 مل (0,1 مولر) لكل عمود تربة والذي تم غسيله بسرعة في جميع أعمدة التربة. ظهر منحنى غسيل مبيد الثيامثوكسام من عمود التربة الجيرية وعمود التربة الطينية مع اليوديد ، مما يشير إلى أن مبيد الثيامثوكسام مركب عالي الحركة في الأراضى المختبرة. أدت إضافة 5٪ من البيتموس ، و 5٪ من الكمبوست ، و 5٪ من الفحم الحيوى إلى التربة الطينية والجيرية إلى تقليل الحركة الهبوطية للثيامثوكسام في الأعمدة وزيادة كبيرة في النسبة المئوية التراكمية للثيامثوكسام خلال الترشيح مقارنةً بالتربة غير المعدلة. بعد تطبيق محلول الغسيل تم استرداد 85,21 و 93,23 و 98,12 و 97,84 و 91,50 و 99.30 و 94,09 و 86,89٪ من الثيامثوكسام المطبق من عمود التربة الطينية وعمود التربة الطينية المعدلة بنسبة 5٪ بيتموس وعمود التربة الطينية المعدلة بنسبة 5٪ كمبوست وعمود التربة الطينية المعدلة بنسبة 5٪ فحم حيوى وعمود التربة الجيرية وعمود التربة الجيرية المعدلة بنسبة 5٪ بيتموس وعمود التربة الجيرية المعدلة بنسبة 5٪ كمبوست وعمود التربة الجيرية المعدلة بنسبة 5٪ فحم حيوى على التوالى. هذه هي الدراسة الأولى في ظل الظروف المعملية عن غسيل ونقل مبيد الثيامثوكسام في التربة الطينية والتربة الجيرية وتأثير تعديلات التربة (البتموس والكمبوست والفحم الحيوى) على الغسيل بواسطة أعمدة التربة. يمكن استخدام هذه المعلومات لفهم كيفية الأستخدام في الممارسات الزراعية والتأثيرات المحتملة على المياه الجوفية.

الكلمات المفتاحية: الفحم الحيوى، الكمبوست، الغسيل، البتموس، التربة، مبيد الثيامثوكسام.