**Non-competitive and competitive sorption of imidacloprid and $KNO_3$ onto soils and their effects on the germination of wheat plants (*Triticum aestivum L.*)**

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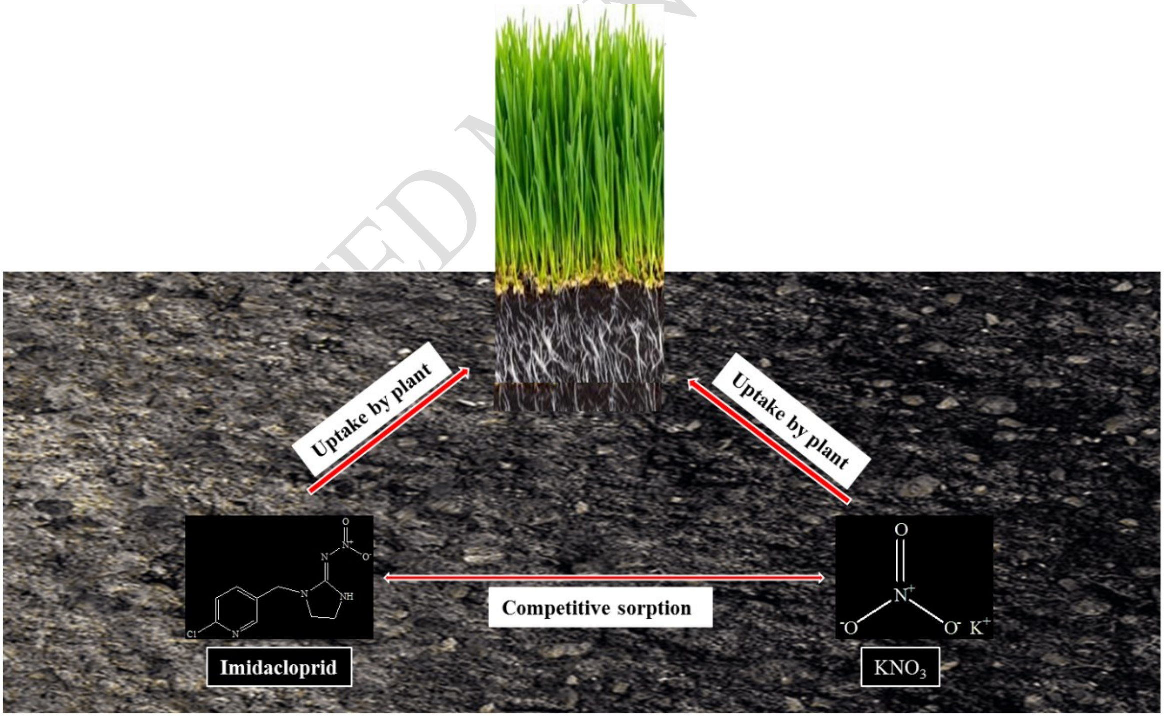
**Graphical abstract**




## Abstract

The non-competitive and competitive adsorption/desorption of agrochemicals into soil play an important role in the fate and behaviour of contaminants in the environment. Non-competitive and competitive adsorption/desorption experiments of imidacloprid

and $KNO_3$ into alluvial soil and sandy soil were performed via batch experiments. Non-competitive and competitive experiments showed that imidacloprid was strongly more adsorbed and desorbed than $KNO_3$ in both tested soils. The adsorption of imidacloprid and $KNO_3$ was greater in the non-competitive experiments than in the competitive experiments, as their presence together reduced the chances of association with the adsorption sites onto soil for each of them individually. The adsorption and desorption of imidacloprid were greater than those of $KNO_3$ in the two soil types. Imidacloprid adsorption was greater in the sandy soil than alluvial soil, while $KNO_3$ was greater in the alluvial soil than sandy soil. The best fits were obtained with the Langmuir model in both soils for competitive and non-competitive adsorption, and competitive and non-competitive desorption. The data showed a reduction in the relative root and shoot elongation percentage for wheat plants when imidacloprid was combined with $KNO_3$ or with imidacloprid alone. On the other hand, the use of $KNO_3$ fertilizer alone resulted in a significant increase in root and shoot length.
**Keywords:** Sorption, imidacloprid, $KNO_3$, soil, germination, wheat plant

## 1. Introduction

Wheat is the most significant grain crop, providing 40% of the world's energy calories and 20% of the protein supply (Hussain *et al.,* 2022). It is a key staple crop because it feeds 35% of the world's population (Ahmed *et al.,* 2013; Hussain *et al.,* 2022). Many insect pests associated with wheat crops, such as aphids, wheat midges, termites, and soil pests, infest and cause damage, resulting in significant output losses (Zhang *et al.,* 2016; Fouad, 2023a; Zhang *et al.,* 2016). Termite infestation in wheat crops begins with sowing and continues until harvest, and poor germination may occur as a result of termite damage. Imidacloprid pesticide is used to combat these pests, and to treat seeds before planting to prevent soil insects from damaging seeds (Ko *et al.,* 2014). The availability of nutrients in soil can be enhanced by using fertilizers such as $KNO_3$, resulting in maximum wheat yield (Hussain *et al.,* 2022).

Indeed, agricultural sustainability has long been associated with the use of a wide variety of pesticides that control disease-causing pests and crop-destroying insects (Tariq *et al.,* 2016) and the use of fertilizers to increase vegetative growth. As an outcome, large amount of agrochemicals, such as imidacloprid and $KNO_3$, enter soils via soil treatments, seed treatments, spray drifts, or wash-off from treated foliage (Tariq *et al.,* 2016). These agrochemical residues may be evaporated directly with evaporating soil moisture and/or leached into groundwater and surface waters by leaching or run-off from the soil (Fouad, 2023b). Soil is the primary reservoir of agrochemicals in terrestrial systems. Increased agrochemical concentrations in soil can have unfavourable impacts, such as phytotoxicity, decreased agricultural production, and bioaccumulation (Soria *et al.,* 2020).

Agrochemicals, which include pesticides and fertilizers, are the most dangerous agricultural soil contaminants (Tariq *et al.,* 2016; El-Aswad *et al.,* 2023a). The problem is compounded if the soil has a mixture of pesticides and fertilizers, as this makes the remediation procedure more complex. The degradation of agrochemicals is an essential process that contributes to the removal of contaminated soils and bodies of water (Fouad *et al.,* 2023a, b). Pesticide-fertilizer complexation interactions may lower the rate of pesticide degradation into soil (Tariq *et al.,* 2016; El-Aswad *et al.,* 2024a, b), and increase adsorption onto soil components. Understanding the behaviour of agrochemicals in soils is aided by a number of characteristics, such as the organic matter content, moisture content, pH, soil texture, and soil mineral content (Tariq *et al.,* 2016). The ionic composition of a natural field's soil solution is a mixture of cations and diverse anions. As a result, an evaluation of agrochemical sorption is required to apply laboratory results to field circumstances (Kamewada, 1996).

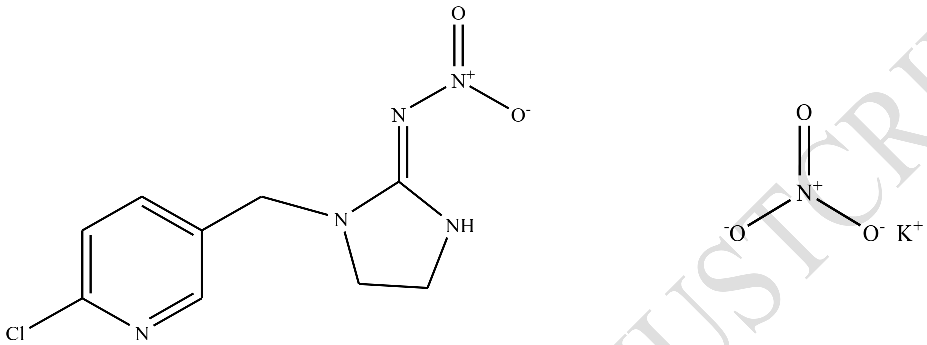
Sorption/desorption is one of the most important processes influencing the fate and distribution of agrochemicals in the soil/water ecosystem. It is usually used to describe the process of pesticide partitioning between a water solution and soil (Fouad *et al.,* 2024a, b). Sorption also impacts agrochemical availability in soil solutions, which governs the amount of imidacloprid and $KNO_3$ accessible for uptake by wheat plants. The features of the soil, as well as its competitive behavior for adsorption sites, influence agrochemical adsorption (Soria *et al.,* 2020). It is still unclear what factors influence the binding affinity and interactions of imidacloprid and $KNO_3$ in the complex soil environments. Therefore, this research aimed to study the interaction between imidacloprid and $KNO_3$ fertilizer in two different soils and to understand the mechanism of their absorption and desorption, as well as their impact on the germination rate of wheat seeds.

## 2. Materials and methods

### *2.1. Agrochemicals*

Imidacloprid (N-1-6-chloro-3-pyridyl-methyl-4,5-dihydroimidazol-2-yl-nitramide), CAS-number (138261-41-3), technical grade (97%), chemical structure (Figure 1), and appearance (colourless crystals); was obtained from KZ Pesticides and Chemicals Company, Egypt.

$KNO_3$ (potassium nitrate), CAS-Number (7757-79-1), technical grade (99%), chemical structure (Figure 1), and appearance (white solid); was obtained from the El-Gomhouria Chemical Company, Egypt.




Imidacloprid KNO3

**Figure 1.** Chemical structures of imidacloprid and $KNO_3$.

*2.2. Soil and site characteristics*

Soil samples were analysed for various physiochemical characteristics that are considered important for the adsorption and desorption of agrochemicals. The site and characteristics of the tested soils are presented in Table (1). Particle size analysis, pH, EC, organic matter (OM), total carbonate content, water holding capacity (WHC), and cation and anion contents are among these factors (Day and Black, 1965; Abdel-Raheem *et al.,* 2023).

**Table 1.** Physicochemical properties of the tested soils

| Characteristics | Alluvial soil | Sandy soil |
|---|---|---|
| Coordinates (N/E) | 304835/31151472 | 173085/3367732 |
| Texture | Clay | Sand |
| pH | 8.22 | 7.40 |
| EC (ds/m) | 2.06 | 9.50 |
| WHC (%) | 40 | 35 |
| OM (%) | 1.26 | 0.16 |
| Total carbonate (%) | 15.97 | 3.76 |
| Cations (meq/L) | | |
| $Ca^{++}$ | 4.01 | 32.00 |
| $Mg^{++}$ | 3.20 | 15.00 |
| $Na^{+}$ | 18.10 | 64.90 |
| $K^{+}$ | 0.41 | 2.25 |

| | | |
|---|---|---|
| Anions (meq/L) | | |
| $CO_3^{--}$ | 0.41 | 0.00 |
| $H\ CO_3^{-}$ | 1.50 | 4.50 |
| $Cl^{-}$ | 16.92 | 100.00 |

*2.3. Adsorption isotherm*

The non-competitive and competitive adsorption/desorption of imidacloprid and $KNO_3$ at room temperature was studied in a batch equilibrium system according to El-Aswad *et al* (2023b). Initially, agrochemical solutions with concentrations in the 0-20 µg/mL range were prepared in ethanol and then mixed with a $CaCl_2$ (0.01 Molar) solution. Soil samples (1g) were weighed into glass tubes containing imidacloprid and $KNO_3$ and adjusted with $CaCl_2$ solution to reach the appropriate ratio (1:5). The agrochemicals were added to reach imidacloprid and $KNO_3$ concentrations equivalent to 0, 6.25, 12.5, 25, 50, 75, and 100 µg/g soil. The samples were shaken for 24 hours (140 revolutions/minute) before being centrifuged for 7 minutes (5000 rpm). The concentration of imidacloprid in the supernatant was then determined using a UV spectrophotometer (Fouad, 2022), and the concentration of $KNO_3$ was determined using a flame photometer (Heidari *et al.,* 2014). The amount of imidacloprid and $KNO_3$ retained by the adsorbent was determined based on the difference in agrochemical concentration between the initial and final equilibrium solutions. For the binary mixture adsorption isotherms, each individual concentration of imidacloprid and $KNO_3$ described above was collected and blended together to determine the concentration of the mixture of imidacloprid + $KNO_3$. The concentrations were then blended with soil for a competitive adsorption test.

*2.4. Desorption isotherm*

Desorption studies were carried out immediately following adsorption experiments using a parallel setup for all concentrations. Following the adsorption isotherm experiment, 5 mL of $CaCl_2$ (0.01 Molar) solution was added to each tube for the desorption isotherm equilibrium stage using a decant refill procedure. For 24 hours, the tubes were mechanically shaken at 140 rpm to establish a fresh desorption equilibrium. The liquid phase containing the desorbed agrochemicals was analysed after centrifugation. The amount of agrochemicals desorbed in the centrifuge sediment was compensated for the amount in the solution left with the soil by taking the final concentration of the solution and the weight of the retained solution into account (Fouad *et al.,* 2024c, d).

*2.5. Langmuir isotherm model*

The Langmuir model assumes homogeneous adsorption energies on the surface and no adsorbate transmigration in the plane of the adsorbent surface. The Langmuir equation can be written as follows:

$$\frac{1}{q_e} = \frac{1}{bq_m}\frac{1}{C_e} + \frac{1}{q_m}$$

where $q_e$ is the amount of solute adsorbed per unit weight of adsorbent (µg/g), $C_e$ is the solute's equilibrium concentration in the bulk solution (mg/L), $q_m$ is the maximum adsorption capacity (µg/g) and b is a constant related to the free energy for adsorption (L/mg) (El-Aswad *et al.,* 2023a).

*3.6. Seed germination assay*

We used; a Phytotoxkit germination assay to estimate the phytotoxic effects of imidacloprid and potassium nitrate (Phytotoxkit, 2004), either/individually or in combination, at different concentrations of 0, 6.25, 12.5, 25, 50, 75, and 100 µg/g soil. Two types of soil clay and sandy soil were used. Flat, transparent test plates; were filled with equal weights of moist clay and/or sandy soil (saturated soil with WHC). Ten wheat seeds (*Triticum aestivum L.*) were placed at equal distances near the middle edge of the test plate on filter paper placed over moist alluvial or sandy soil. The test plates were closed with transparent covers, placed vertically in a rack and incubated in an incubator for 6 days in the dark at 25±2 °C. Following the incubation, the root and shoot length, germination percentage, relative elongation (%), relative germination rate, and germination index were calculated according to AOSA (1978); as follows:

$$\text{Relative germination rate} = \frac{(\text{Seeds germinated in test sample} \times 100)}{\text{Seeds germinated in control}}$$

$$\text{Relative root elongation} = \frac{(\text{Mean root length in test sample} \times 100)}{\text{Mean root length in control}}$$

$$\text{Germination Index} = \frac{(\text{Relative germination rate} \times \text{Relative root elongation})}{100}$$

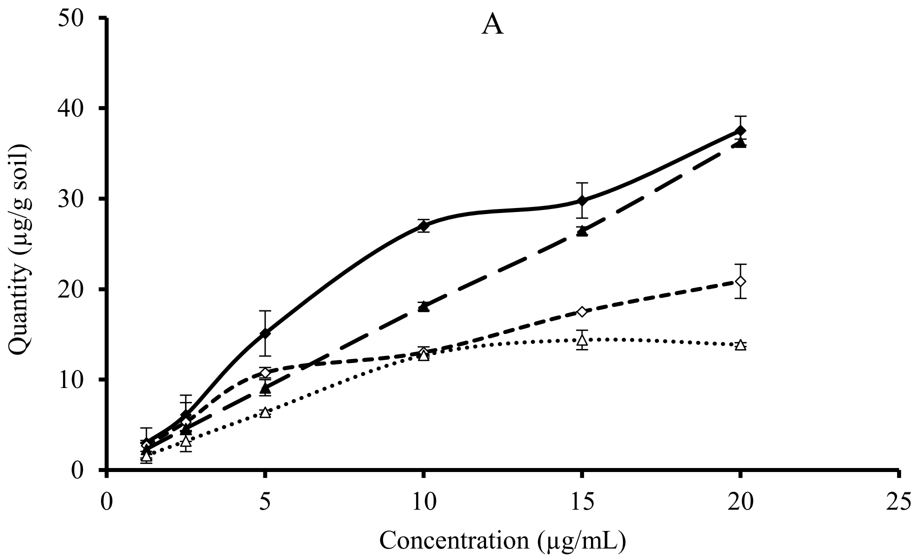
*3.7. Statistical analysis*

The results of adsorption/desorption were analysed to obtain standard errors and R-squared values using Microsoft Excel 2019, while the germination data were statistically analysed using a one-way ANOVA with SPSS software (Fouad, 2023c).

## 4. Results

*4.1. Non-competitive sorption of the tested agrochemicals*

The non-competitive adsorption/desorption of imidacloprid and $KNO_3$ into alluvial soil and sandy soil were studied at initial concentrations ranging from 1.25 to 20 μg/mL (Figure 2A and Figure 3A). Non-competitive adsorption was greater than Non-competitive desorption in both alluvial and sandy soils, especially at high concentrations. Similarly, the adsorption and desorption of the pesticide imidacloprid were greater than those of $KNO_3$ in the two soils tested, except at a concentration of 20 μg/mL in sandy soil. The percentages of non-competitive adsorption were 44 and 36% in the alluvial soil and 47 and 35% in the sandy soil, while the percentages of non-competitive desorption were 26 and 19% in the alluvial soil and 27 and 21% in the sandy soil for the imidacloprid pesticide and $KNO_3$ fertilizer, respectively. It is clear from this that imidacloprid adsorption was greater on sandy soil than on alluvial soil, while the opposite was true for $KNO_3$.



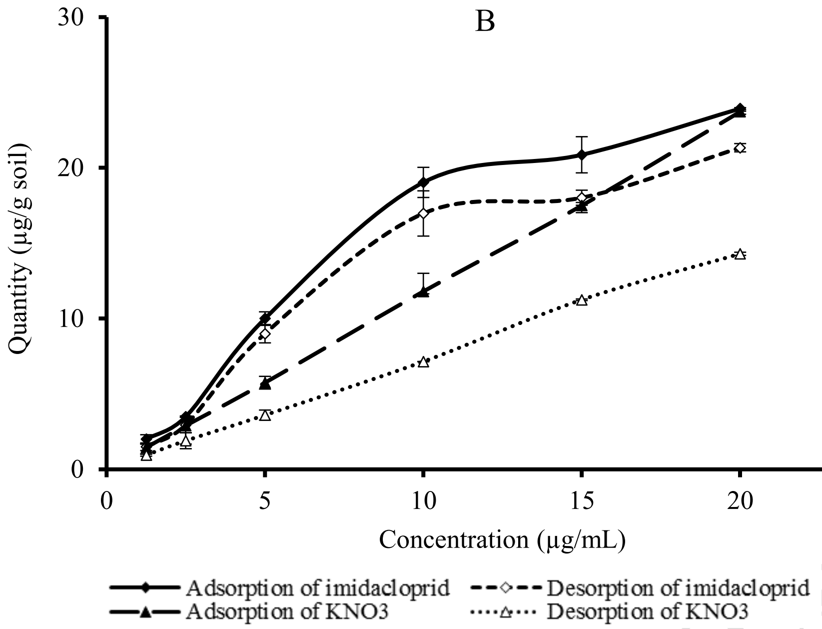



**Figure 2.** Non-competitive sorption isotherm (A) and competitive sorption isotherm (B) of imidacloprid and $KNO_3$ in alluvial soil.

*4.2. Competitive sorption of the tested agrochemicals*

The results for competitive adsorption and competitive desorption of the imidacloprid pesticide and $KNO_3$ fertilizer are presented in Figure 2B and Figure 3B. It was found that the forms of competitive adsorption and competitive desorption of the tested agrichemicals take the same forms as non-competitive sorption, with the differences in the amount of adsorption and desorption. The presence of both imidacloprid pesticide and $KNO_3$ fertilizer had a clear effect on the adsorption and desorption processes. The presence of $KNO_3$ led to a reduction in the amount of imidacloprid from 44.1 and 47.1% to 29.5 and 27.6% for adsorption and from 26.1 and 27.5% to 26.0 and 19.6% for desorption in alluvial and sandy soils, respectively. The presence of imidacloprid also led to a decrease in $KNO_3$ from 36.0 and 34.7% to 23.5 and 21.3% for adsorption and from 19.4 and 21.2% to 14.6 and 15.2% for desorption in alluvial soil and sandy soil, respectively.

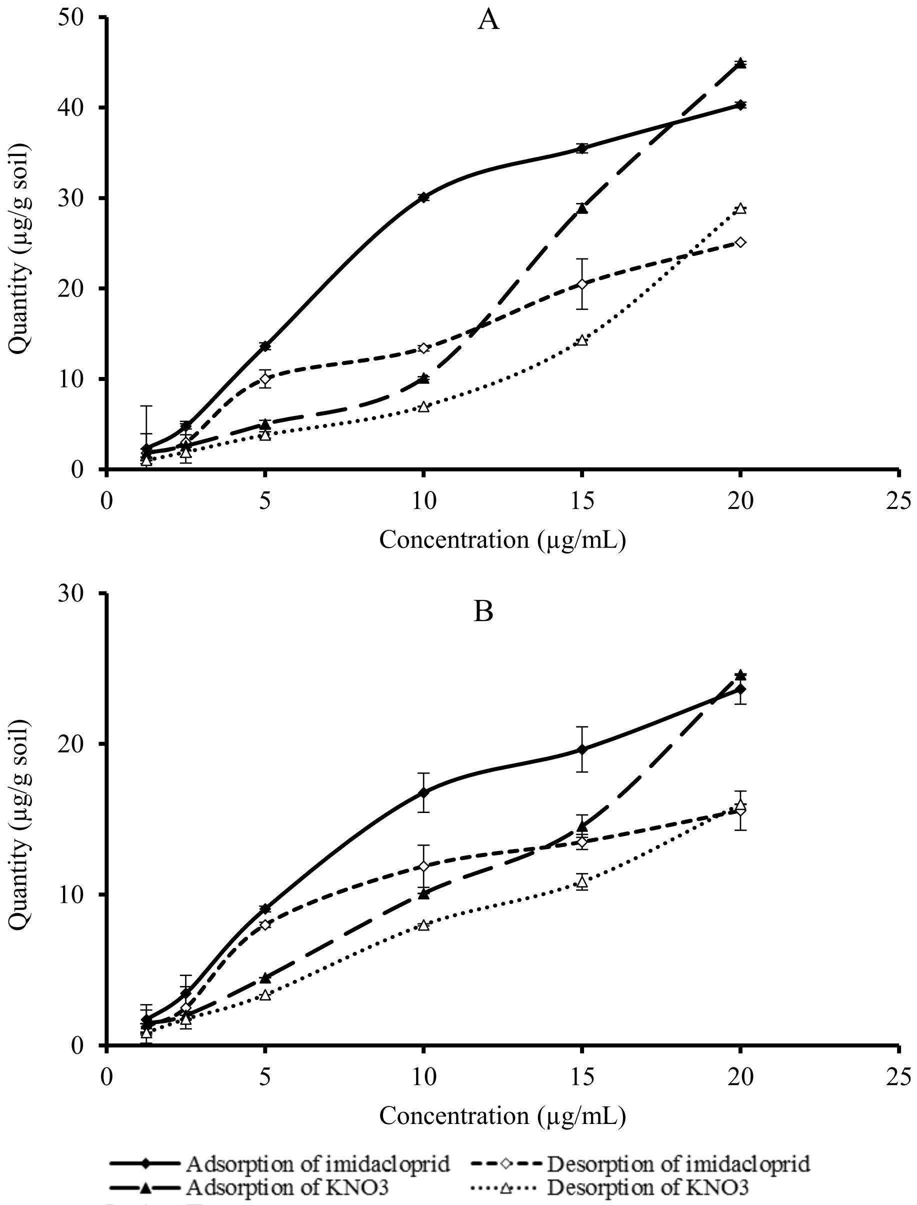



**Figure 3.** Non-competitive sorption isotherm (A) and competitive sorption isotherm (B) of imidacloprid and $KNO_3$ in sandy soil.

*4.3. Langmuir model*

Regression analysis was used to fit the linearized expression of the Langmuir isotherm model to the adsorption and desorption data for imidacloprid and $KNO_3$ in alluvial soil and sandy soil. The values of the Langmuir constant and some parameter isotherms are presented in Table 2. The values of parameters derived from the tested agrochemicals in alluvial and sandy soils were found to be different. Langmuir expression produced higher of correlation coefficients for all the adsorption and desorption of the tested agrochemicals into soils except for the non-competitive desorption of $KNO_3$ in sandy soil ($R^2$ = 0.706). The Langmuir model agreed with the experimental data for imidacloprid and $KNO_3$ for non-competitive sorption and competitive sorption into the tested soils, as indicated by the higher values of the determination coefficient and lower values of the standard error. These Kd values and soil property values are contained in many agrichemical databases and are used to predict agrichemical behaviour. Kd is defined as the ratio of the agrichemical concentration in the soil to that in the equilibrium solution at a certain equilibrium concentration, and was computed as the average of Kd values corresponding to different concentrations. The Kd values were 0.270 to 0.889 for adsorption and 1.166 to 7.307 for desorption into the tested soils.

**Table 2.** Parameters of the Langmuir model and some parameter isotherms

| Parameters | Alluvial soil | | | | Sandy soil | | | |
|---|---|---|---|---|---|---|---|---|
| | Non-competitive | | Competitive | | Non-competitive | | Competitive | |
| | Imidacloprid | $KNO_3$ | Imidacloprid | $KNO_3$ | Imidacloprid | $KNO_3$ | Imidacloprid | $KNO_3$ |
| | Adsorption isotherm | | | | | | | |
| Average (%) | 44.102 | 36.022 | 29.520 | 23.488 | 47.062 | 34.732 | 27.623 | 21.278 |
| Kd | 0.789 | 0.563 | 0.419 | 0.307 | 0.889 | 0.532 | 0.382 | 0.270 |
| $q_m$ | -204.082 | 588.235 | -1428.571 | -1666.667 | -27.473 | 34.364 | -204.082 | 588.235 |
| b | -0.005 | 0.003 | -0.002 | -0.002 | -0.067 | 0.074 | -0.005 | 0.003 |
| $R^2$ | 0.974 | 1.000 | 0.973 | 1.000 | 0.966 | 0.917 | 0.974 | 1.000 |
| SE | 1.493 | 0.570 | 0.509 | 0.384 | 0.577 | 0.480 | 1.031 | 0.134 |
| | Desorption isotherm | | | | | | | |
| Average (%) | 26.092 | 19.395 | 25.966 | 14.568 | 27.446 | 21.152 | 19.614 | 15.186 |
| Kd | 1.449 | 1.166 | 7.307 | 1.633 | 1.399 | 1.558 | 2.449 | 2.493 |
| $q_m$ | 16.750 | 40.650 | -10.352 | 50.251 | 16.556 | -454.545 | 16.750 | 40.650 |
| b | 0.006 | 0.010 | -0.030 | 0.010 | 0.015 | -0.001 | 0.006 | 0.010 |
| $R^2$ | 0.990 | 0.992 | 0.838 | 0.999 | 0.907 | 0.706 | 0.990 | 0.992 |
| SE | 1.197 | 0.539 | 0.609 | 0.184 | 1.935 | 0.185 | 0.978 | 0.115 |

*4.4. Effect of the interaction between imidacloprid and $KNO_3$ on wheat germination*

The data in Table (3) show a reduction in the relative root, and shoot elongation percentage when the pesticide imidacloprid was combined with $KNO_3$ at different concentrations (1.25 to 20 µg/mL), and the root length decreased to 6.54, 6.39, 5.46, 4.55, 4.45, and 3.79 cm, respectively compared with that of the control (6.62 cm) under the experimental conditions of the wheat seeds in alluvial soil. Additionally, the shoot length significantly decreased to 4.24, 4.92, 4.67, 4.39, 4.31, and 3.75 cm, compared with that of the control (4.99 cm). When we used imidacloprid individual at the same concentrations, the experiment revealed a significant decreases in root length of 6.58, 6.08, 4.38, 4.26, 3.27, and 2.45 cm compared with that of the control (6.25 cm); and a significant decreases in shoot length of 4.84, 4.66, 3.53, 3.46, 3.29, and 3.02 cm compared with that of the control (4.99 cm). In contrast, the use of $KNO_3$ fertilizer resulted in a significant increase in root, and shoot length at concentrations ( of 1.25, 2.5, 5, 10, and 15 µg/mL ) when compared to those of the control, but the concentration of 20 µg/mL resulted in a decrease in root and shoot length when compared to those of the control. Furthermore, the data revealed a modest decrease in the germination index when $KNO_3$ was combined with imidacloprid compared to that of the control, but the decrease was greater when imidacloprid was used alone. When using $KNO_3$ alone, the germination index increased, reaching 104.3, 124.2, 107.81, and 107.68% compared to that of the control (100%) at concentrations of 1.25, 2.5, 5, and 10 ppm, respectively, but concentrations of 15 and 20 µg/mL caused a decrease in the germination index of 69.96 and 44.76%, respectively, when compared to that of the control (100%).

Table (4) shows a reduction in the relative root and shoot elongation percentages when imidacloprid and $KNO_3$ were combined in sandy soil. The root lengths decreased to 4.32, 3.82, 3.21, 2.57, 2.07, and 1.30 cm, respectively compared with those of the control (5.02 cm). Additionally, the shoot length significantly decreased to 4.43, 3.75, 3.53, 3.15, 3.03, and 1.40 cm, respectively compared with that of the control (4.72 cm) of the wheat seeds. However, when we used imidacloprid only at the same concentrations, a significant decrease in root length of 3.63, 2.88, 2.57, 2.42, 2.03, and 1.12 cm was detected compared with that of the control (5.02 cm), while shoot length significantly decreased to 3.75, 3.06, 2.70, 2.41, 2.20, and 1.66 cm, respectively compared with that of the control (4.72 cm). On the other hand, the use of $KNO_3$ at concentrations ( of 1.25, 2.5, 5, and 10 µg/mL ) led to significant increases in root and shoot length compared with those of the control, but at concentrations of 15 and 20 μg/mL, it induced a reduction in root and shoot length compared with those of the control. Additionally, the data showed that there was a slight decrease in the germination index when using $KNO_3$ with imidacloprid compared with the control, but the decrease was greater when using imidacloprid alone. When $KNO_3$ was used alone, the germination index increased to 118% compared with that of the control (80%) at a concentration of 5 μg/mL, but at 15 and 20 μg/mL, $KNO_3$ decreased the germination index to 69.96% and 44.76%, respectively compared with that of the control (80%).

**Table 3.** The non-competitive and competitive effects of imidacloprid and $KNO_3$ on wheat seed germination in alluvial soil

| Treatments | Root (cm) | Relative root elongation (%) | Shoots (cm) | Relative shoot elongation (%) | Relative Germination (%) | Germination index |
|---|---|---|---|---|---|---|
| Control | $6.62 \pm 0.18^{cd}$ | 100 | $4.99 \pm 0.08^{cde}$ | 100 | 100 | 100 |
| Concentrations (µg/mL) | | | Imidacloprid | | | |
| 1.25 | $6.58 \pm 0.14^{bc}$ | 99.40 | $4.84 \pm 0.12^{abcd}$ | 96.99 | 90 | 89.46 |
| 2.5 | $6.08 \pm 0.31^{cd}$ | 91.84 | $4.66 \pm 0.53^{bcde}$ | 93.39 | 80 | 73.47 |
| 5 | $4.38 \pm 0.31^{fgh}$ | 66.16 | $3.53 \pm 0.28^{e}$ | 70.74 | 70 | 46.31 |
| 10 | $4.26 \pm 0.34^{efgh}$ | 64.35 | $3.46 \pm 0.31^{de}$ | 69.34 | 60 | 38.61 |
| 15 | $3.27 \pm 0.13^{hi}$ | 49.40 | $3.29 \pm 0.22^{de}$ | 65.93 | 50 | 24.70 |
| 20 | $2.45 \pm 0.16^{i}$ | 37.01 | $3.02 \pm 0.33^{e}$ | 60.52 | 50 | 18.51 |
| Concentrations (µg/mL) | | | $KNO_3$ | | | |
| 1.25 | $6.91 \pm 0.18^{bc}$ | 104.38 | $4.94 \pm 0.18^{bcde}$ | 99.00 | 100 | 104.38 |
| 2.5 | $8.25 \pm 0.05^{a}$ | 124.62 | $6.01 \pm 0.12^{abc}$ | 120.44 | 100 | 124.62 |
| 5 | $7.93 \pm 0.18^{ab}$ | 119.79 | $6.40 \pm 0.17^{ab}$ | 128.26 | 90 | 107.81 |
| 10 | $7.92 \pm 0.11^{ab}$ | 119.64 | $6.63 \pm 0.04^{a}$ | 132.87 | 90 | 107.68 |
| 15 | $7.11 \pm 0.04^{abc}$ | 107.40 | $4.99 \pm 0.05^{bcde}$ | 100.00 | 80 | 85.92 |
| 20 | $5.53 \pm 0.39^{de}$ | 83.53 | $3.74 \pm 0.30^{de}$ | 74.95 | 70 | 58.47 |
| Concentrations (µg/mL) | | | Imidacloprid + $KNO_3$ | | | |
| 1.25 | $6.54 \pm 0.15^{cd}$ | 98,79 | $4.24 \pm 0.30^{de}$ | 84.97 | 80 | 79.03 |
| 2.5 | $6.39 \pm 0.16^{cd}$ | 96.55 | $4.92 \pm 0.12^{bcde}$ | 98.60 | 80 | 77.24 |
| 5 | $5.46 \pm 0.08^{def}$ | 82.48 | $4.67 \pm 0.13^{cde}$ | 93.59 | 80 | 65.98 |
| 10 | $4.55 \pm 0.02^{efgh}$ | 68.73 | $4.39 \pm 0.04^{cde}$ | 87.98 | 70 | 48.11 |
| 15 | $4.45 \pm 0.39^{efg}$ | 67.22 | $4.31 \pm 0.56^{de}$ | 86.37 | 70 | 47.05 |
| 20 | $3.79 \pm 0.34^{gh}$ | 57.25 | $3.75 \pm 0.48^{de}$ | 75.15 | 70 | 40.08 |
| LSD | 1.16 | | 1.40 | | | |

**Table 4.** The non-competitive and competitive effects of imidacloprid and $KNO_3$ on wheat seed germination in sandy soil

| Treatments | Root (cm) | Relative root elongation (%) | Shoots (cm) | Relative shoot elongation (%) | Relative Germination (%) | Germination index |
|---|---|---|---|---|---|---|
| Control | 5.02±0.04[abc] | 100 | 4.72±0.14[cd] | 100 | 80 | 80 |
| Concentrations (µg/mL) | | | Imidacloprid | | | |
| 1.25 | 3.63±0.19[de] | 72.31 | 3.75±0.18[ef] | 79.45 | 70 | 50.62 |
| 2.5 | 2.88±0.20[efg] | 57.37 | 3.06±0.02[fghi] | 64.83 | 70 | 40.16 |
| 5 | 2.57±0.20[fg] | 51.19 | 2.70±0.12[ghi] | 57.20 | 70 | 35.70 |
| 10 | 2.42±0.15[fg] | 48.21 | 2.41±0.12[hij] | 51.06 | 60 | 28.93 |
| 15 | 2.03±0.02[gh] | 40.44 | 2.20±0.02[ijk] | 46.61 | 50 | 20.22 |
| 20 | 1.12±0.04[h] | 22.31 | 1.66±0.11[jk] | 35.17 | 50 | 11.16 |
| Concentrations (µg/mL) | | | $KNO_3$ | | | |
| 1.25 | 5.31±0.01[ab] | 105.78 | 5.40±0.30[bc] | 114.41 | 90 | 94.5 |
| 2.5 | 5.60±0.04[a] | 111.55 | 6.16±0.13[ab] | 130.51 | 90 | 100.3 |
| 5 | 5.93±0.03[a] | 118.13 | 6.43±0.22[a] | 136.23 | 100 | 118.13 |
| 10 | 5.12±0.30[abc] | 101.99 | 4.88±0.19[cd] | 103.39 | 90 | 91.79 |
| 15 | 4.39±0.32[bcd] | 87.45 | 4.43±0.29[de] | 93.86 | 80 | 69.96 |
| 20 | 3.21±0.21[ef] | 63.94 | 3.31±0.18[fgh] | 70.13 | 70 | 44.76 |
| Concentrations (µg/mL) | | | Imidacloprid + $KNO_3$ | | | |
| 1.25 | 4.32±0.34[cd] | 86.06 | 4.43±0.14[de] | 93.96 | 80 | 68.85 |
| 2.5 | 3.83±0.18[de] | 76.29 | 3.75±0.20[ef] | 79.45 | 70 | 53.40 |
| 5 | 3.21±0.05[ef] | 63.94 | 3.53±0.13[efg] | 74.79 | 70 | 44.76 |
| 10 | 2.57±0.25[fg] | 51.20 | 3.15±0.15[fghi] | 66.74 | 60 | 30.72 |
| 15 | 2.07±0.07[gh] | 41.24 | 3.03±0.22[fghi] | 64.19 | 60 | 24.74 |
| 20 | 1.30±0.05[h] | 25.90 | 1.40±0.08[k] | 29.66 | 60 | 15.54 |
| LSD | 0.90 | | 0.89 | | | |

## 5. Discussion

The results obtained show that the presence of imidacloprid pesticide and $KNO_3$ fertilizer together affects the behavior of their adsorption and desorption into the tested soils. This finding is consistent with prior research findings (Schalscha *et al.,* 1974; Kamewada, 1996; Moreira and Alleoni, 2010; Pateiro-Moure *et al.,* 2010; Jin *et al.,* 2013; Wang *et al.,* 2020; Esfandiar *et al.,* 2022; Abd-Eldaim *et al.,* 2023). The presence of both atrazine and imidacloprid decreased the adsorption of carbendazim onto silty sand soil (Jin *et al.,* 2013). Pateiro-Moure *et al.* (2010) performed competitive and/or non-competitive sorption experiments on diquat, paraquat, and difenzoquat in eight types of soil and found paraquat to be the most powerful in terms of adsorption, followed by diquat, and difenzoquat in non-competitive experiments. However, there was a considerable effect between the divalent cationic herbicides paraquat and diquat, as well as between them and the monovalent herbicide difenzoquat, difenzoquat had little effect on paraquat and diquat in competitive experiments. The interaction between $KNO_3$ and $K_2SO_4$ adsorption on soil was evaluated by Kamewada (1996), who reported a decrease in the amount of $KNO_3$ adsorbed with increasing concentrations of $K_2SO_4$ or $KNO_3$. The competitive and non-competitive adsorption data were described by the Langmuir equation in previous studies by Moreira and Alleoni (2010).

Through our study on the effect of imidacloprid on the germination of wheat seeds in alluvial and sandy soils, it became clear that imidacloprid had a negative effect on both root and shoot length and on the germination index. These results were consistent with what has been studied in many studies. Murthy and Rajesh (2004) reported that the germination percentage, growth, plant weight, vigour index, and other parameters decreased when imidacloprid was applied to rice seeds that had not been dried before germination (Pulikkal *et al.,* 2015). Additionally, it was discovered that in these measures, damage increased with longer periods of exposure and greater imidacloprid concentrations. Pulikkal *et al.* (2015) investigated the effect of the insecticide imidacloprid on cucumber plants and discovered that the pesticide inhibited seed germination and vigor. Deformities such as swelling, chlorosis, cotyledon root formation, root tip burning, a decrease in root length, and hypocotyl deficiency were also detected with increasing imidacloprid concentrations. Shaker *et al.* (2016) evaluated the effect of the overuse of four common insecticides (lambda-cyhalothrin, imidacloprid, alpha-cypermethrin, and emamectin benzoate) on tomato plant germination, photosynthetic pigments, and seedling vigour. The results showed that using an amount exceeding the permissible dose of these pesticides led to a decrease in seed germination; while inhibiting tomato growth. Zhang *et al.* (2022) reported that, depending on growth factors and membrane lipid peroxidation results under various nitrogen supply conditions, imidacloprid limits maize growth. According to the results of our study, which are consistent with previous research, potassium nitrate helped reduce the negative impact of abiotic stress resulting from the use of the pesticide imidacloprid on wheat seeds and led to improvements in the root length, shoot length, and germination index of wheat seeds. Steiner *et al.* (2018) reported that $KNO_3$ improved wheat seedling germination, early growth, and the vigour index. $KNO_3$ can enhance seed germination by producing nitric oxide when plants are exposed to salt stress (Sanz *et al.,* 2015; Parankusam *et al.,* 2017). Additionally, using $KNO_3$ as a foliar treatment improves water availability, nutrient uptake, chlorophyll content, and photosynthesis (Marschner *et al.,* 1995; Egilla *et al.,* 2001). Tanin *et al* (2023) demonstrated that $KNO_3$ is important for postponing leaf senescence and enhancing resistance to abiotic and biotic stressors.

## 6. Conclusion

In general, the adsorption of the tested agrichemicals was greater than their desorption into both soils. The adsorption of the pesticide imidacloprid was greater than that of $KNO_3$ in both soils, and it was greater in sandy soils than in alluvial soils; and was greater in non-competitive adsorption than in competitive adsorption. While $KNO_3$ adsorption was lower than imidacloprid adsorption in the tested soils, greater in the alluvial soil than in the sandy soil, and greater in the non-competitive adsorption than in the competitive adsorption. The Langmuir equation was used and was compatible with the experimental results. The pesticide imidacloprid led to a reduction in wheat seed germination, which was more evident in sandy soil. This may be due to the lack of nutrients compared to those in alluvial soil, while when using imidacloprid with $KNO_3$, $KNO_3$ helped reduce the severity of the negative effect resulting from the pesticide. The use of $KNO_3$ alone also improved root and shoot length and the germination index, but at high concentrations, $KNO_3$ inhibited plant growth.

## References

Abd-Eldaim F.A., Farroh K.Y., Safina F.S., Fouad M.R., Darwish O.S., Emam S.S. and Abdel-Halim K.Y. (2023). Phytotoxic effects of ımidacloprid and its nano-form on the cucumber plants under greenhouse condition and their toxicity on HepG2 cell line. *Archives of Phytopathology and Plant Protection,* **56(19),** 1467-1486.

Abdel-Raheem S.A., Fouad M R., Gad M A., El-Dean A.M.K. and Tolba M.S. (2023). Environmentally green synthesis and characterization of some novel bioactive pyrimidines with excellent bioefficacy and safety profile towards soil organisms, *Journal of Environmental Chemical Engineering*, **11(5),** 110839.

Ahmed G., Hamrick D., Guinn A., Abdulsamad A. and Gereffi G. (2013). Wheat value chains and food security in the Middle East and North Africa region. *Center on Globalization, Governance & Competitiveness, Duke University: Durham, NC, USA*, 50.

Association of Official Seed Analysts. (1978). *Rules for testing seeds*. The Association.

Day P.R. and Black C.A. (1965). Methods of soil analysis. *Agronomy*, ***9*,** 545-567.

Egilla J.N., Davies,F.T. and Drew M.C. (2001). Effect of potassium on drought resistance of Hibiscus rosa-sinensis cv. Leprechaun: Plant growth, leaf macro-and micronutrient content and root longevity, *Plant and Soil,* **229,** 213-224.

El-Aswad A F., Fouad M.R., Badawy M.E. and Aly M.I. (2023b). Effect of calcium carbonate content on potential pesticide adsorption and desorption in calcareous soil, *Communications in Soil Science and Plant Analysis,* **54(10),** 1379-1387.

El-Aswad A.F., Fouad M.R. and Aly M.I. (2023a). Experimental and modeling study of the fate and behavior of thiobencarb in clay and sandy clay loam soils, *International Journal of Environmental Science and Technology*, **21(4),** 4405-4418.

El-Aswad A.F., Fouad M.R., Badawy M.E.I. and Aly M.I. (2024a). Modeling study of Adsorption Isotherms of Chlorantraniliprole and Dinotefuran on Soil, *Current Chemistry Letters,* **13(3)**. DOI: 10.5267/j.ccl.2024.008

El-Aswad A.F., Mohamed A.E. and Fouad M.R. (2024b). Investigation of dissipation kinetics and half-lives of fipronil and thiamethoxam in soil under various conditions using experimental modeling design by Minitab software, *Scientific Reports,* **14(1),** 5717.

Esfandiar N., Suri R. and McKenzie E.R. (2022). Competitive sorption of Cd, Cr, Cu, Ni, Pb and Zn from storm water runoff by five low-cost sorbents; Effects of co-contaminants, humic acid, salinity and pH, *Journal of Hazardous Materials,* **423,** 126938.

Fouad M.R. (2022). Spectrophotometric detection and quantification limits of fipronil and neonicotinoids in acetonitrile, *International Journal of Family Studies, Food Science and Nutrition Health,* **3(1),** 106-123.

Fouad M.R. (2023a). Effect of Temperature and Soil Type on the Adsorption and Desorption Isotherms of Thiamethoxam Using Freundlich Equation, *Egyptian Journal of Chemistry,* **66(7),** 197-207.

Fouad M.R. (2023b). Effect of peat, compost, and charcoal on transport of fipronil in clay loam soil and sandy clay loam soil, *Current Chemistry Letters*, **12(2),** 281-288.

Fouad M.R. (2023c). Effect of Soil Amendments on Leaching of Thiamethoxam in Alluvial and Calcareous Soil, *Basrah Journal of Agricultural Sciences,* **36(1),** 164-172.

Fouad M.R., Aly M.I., El-Aswad A.F. and Badawy M.E.I. (2024a). Effect of particles size on adsorption isotherm of chlorantraniliprole, dinotefuran, bispyribacsodium, and metribuzin into sandy loam soil, *Current Chemistry Letters,* **13(1),** 61-72.

Fouad M.R., Badawy M.E., El-Aswad A.F. and Aly M.I. (2023b). Experimental modeling design to study the effect of different soil treatments on the dissipation of metribuzin herbicide with effect on dehydrogenase activity, *Current Chemistry Letters,* **12(2),** 383-396.

Fouad M.R., El-Aswad A.F., Aly M.I. and Badawy M.E.I. (2023a). Sorption characteristics and thermodynamic parameters of bispyribac-sodium and metribuzin on alluvial soil with difference in particle size and pH value, *Current Chemistry Letters*, **12(3),** 545-556.

Fouad M.R., El-Aswad A.F., Badawy M.E.I. and Aly M.I. (2024b). Effect of pH variation and temperature on pesticides sorption characteristics in calcareous soil, *Current Chemistry Letters,***13(1),** 141-150.

Fouad M.R., El-Aswad A.F., Badawy M.E.I. and Aly M.I. (2024c). Effect of soil organic amendments on sorption behavior of two insecticides and two herbicides, *Current Chemistry Letters*,**13(2),** 377-390.

Fouad M.R., El-Aswad A.F., Badawy M.E.I. and Aly M.I. (2024d). Impact of organic amendments addition to sandy clay loam soil and sandy loam soil on leaching process of chlorantraniliprole insecticide and bispyribac-sodium herbicide, *Current Chemistry Letters*,**13(2),** 277-286.

Heidari S., Azizi M., Soltani F. and Hadian J. (2014). Foliar application of Ca (NO3) 2 and KNO3 affects growth, essential oil content, and oil composition of French tarragon, *Industrial Crops and Products,* **62,** 526-532.

Hussain D., Asrar M., Khalid B., Hafeez F., Saleem M., Akhter M. and Hanif K. (2022). Insect pests of economic importance attacking wheat crop (*Triticum aestivum L.*) in Punjab, Pakistan, *International Journal of Tropical Insect Science,* **42(1),** 9-20.

Jin X., Ren J., Wang B., Lu Q. and Yu Y. (2013). Impact of coexistence of carbendazim, atrazine, and imidacloprid on their adsorption, desorption, and mobility in soil, *Environmental Science and Pollution Research,* **20,** 6282-6289.

Kamewada K. (1996). Application of "Four-Plane Model" to the Adsorption of K+, NO3-, and $SO_4$ 2-from a Mixed Solution of $KNO_3$ and $K_2SO_4$ on Andisols, *Soil Science and Plant Nutrition,* **42(4),** 801-808.

Ko A.Y., Rahman M.M., Abd El-Aty A.M., Jang J., Park J.H., Cho S.K. and Shim J.H. (2014). Development of a simple extraction and oxidation procedure for the residue analysis of imidacloprid and its metabolites in lettuce using gas chromatography, *Food Chemistry,* **148,** 402-409.

Marschner H. (1995). Mineral nutrition of higher plants 2nd edn. Institute of Plant Nutrition University of Hohenheim, Germany.

Moreira C.S. and Alleoni L.R.F. (2010). Adsorption of Cd, Cu, Ni and Zn in tropical soils under competitive and non-competitive systems, *Scientia Agricola,* **67,** 301-307.

Murthy G.P. and Rajesh N. (2004). Individual and combined effects of Krilaxyl® and Gaucho® on chloroplast pigments, relative water content and early growth attributes in rice seedlings, during germination under wet treatment, *Journal of Phytological Research,* **17,** 7-11.

Parankusam S., Adimulam S.S., Bhatnagar-Mathur P. and Sharma K.K. (2017). Nitric oxide (NO) in plant heat stress tolerance: current knowledge and perspectives. *Frontiers in Plant Science,* **8,** 1582.

Pateiro-Moure M., Arias-Estévez M. and Simal-Gándara J. (2010). Competitive and non-competitive adsorption/desorption of paraquat, diquat and difenzoquat in vineyard-devoted soils. *Journal of Hazardous Materials,* **178(1-3),** 194-201.

Phytotoxkit F.T.M. (2004). Seed germination and early growth microbiotest with higher plants. *Standard operation procedure. MicroBioTests Inc., Nazareth*.

Pulikkal A., RafiqKhan M., Palancheeri A., Paulson M.M. and Parambil S.T. (2015). Imidacloprid effects on germination of seeds and associated physiological changes of cucumber (*Cucumis sativus L.*). *A National Science Journal,* **11(1),** 22-26.

Sanz L., Albertos P., Mateos I., Sánchez-Vicente I., Lechón T., Fernández-Marcos M. and Lorenzo O. (2015). Nitric oxide (NO) and phytohormones crosstalk during early plant development. *Journal of Experimental Botany,* **66(10),** 2857-2868.

Schalscha E.B., Pratt P.F. and Domecq T.C. (1974). Nitrate adsorption by some volcanic-ash soils of southern Chile, *Soil Science Society of America Journal*, **38(1),** 44-45.

Shakir S.K., Kanwal M., Murad W., ur Rehman Z., ur Rehman S., Daud M.K. and Azizullah A. (2016). Effect of some commonly used pesticides on seed germination, biomass production and photosynthetic pigments in tomato (Lycopersicon esculentum), *Ecotoxicology, **25,*** 329-341.

Soria R.I., Rolfe S.A., Betancourth M.P. and Thornton S.F. (2020). The relationship between properties of plant-based biochars and sorption of Cd (II), Pb (II) and Zn (II) in soil model systems, *Heliyon,* **6(11)**.

Steiner F., Zuffo A.M., da Silva Oliveira C.E., Honda G.B. and Machado J.S. (2018). Potassium nitrate priming mitigates salt stress on wheat seedlings, *Revista de Ciências Agrárias,* **41(4),** 989-1000.

Tanin M.J., Sharma A., Ram H., Singh S., Srivastava P., Mavi G.S. and Sohu V. S. (2023). Application of potassium nitrate and salicylic acid improves grain yield and related traits by delaying leaf senescence in Gpc-B1 carrying advanced wheat genotypes, *Frontiers in Plant Science,* 14.

Tariq S.R., Shafiq M. and Chotana G.A. (2016). Distribution of heavy metals in the soils associated with the commonly used pesticides in cotton fields, *Scientifica,* 2016.

Wang F., Cao D., Shi L., He S., Li X., Fang H. and Yu Y. (2020). Competitive adsorption and mobility of propiconazole and difenoconazole on five different soils, *Bulletin of Environmental Contamination and Toxicology,* **105,** 927-933.

Zhang P., Zhang X., Zhao Y., Wei Y., Mu W. and Liu F. (2016). Effects of imidacloprid and clothianidin seed treatments on wheat aphids and their natural enemies on winter wheat, *Pest Management Science,* **72(6),** 1141-1149.

Zhang X., Fu H., Wu Q., Chen L., Lu Y. and Gao S. (2022). Imidacloprid Disturbs the Nitrogen Metabolism and Triggers an Overall Stress Response in Maize Seedlings, *Agronomy,* **12(12),** 3161.

Zhang Z., Li Y., Li X., Zhu X. and Zhang Y. (2023). Efficacy of Imidacloprid Seed Treatments against Four Wheat Aphids under Laboratory and Field Conditions, *Plants,* **12(2),** 238.