PRIMARY RESEARCH

Removal rate of compacted clay soil in the batch and continuous reactors and its permeability

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Abstract— In Turkey, municipal solid wastes are primarily disposed in landfills. The infiltrated water in the landfill affects the chemical composition of leachate. The filtration, adsorption, dissolution, precipitation, ion exchange, and biochemical processes occur between the compacted clay soil and leachate. In this study, batch and continuous reactors are used to inveatigate permeability and adsorption of compacted clay soil. The clay soil, obtained from the Kemerburgaz-Odayeri landfill area on the European side of Istanbul, is put through standard and modified proctor compaction tests. The effects of Total Phosphorus (TP) and Total Kjeldahl Nitrogen (TKN) in the influent and effluent have been analyzed to determine the treatment capability for batch and continuous reactors of the compacted clay soil. The results of the permeability measurements using leachate show that the permeability in the compacted clay soil associated with the contamination is slightly increased. Removal efficiencies of TP in clay soil were obtained as 72% for standard compaction and 77% for modified compaction in continuous reactor. Also, TKN in clay soil was obtained as 60% for standard compaction and 81% for modified compaction in continuous reactor. Optimum adsorption time of TKN was 5 hours in batch reactor.

I. INTRODUCTION

In Municipal Solid Waste (MSW) management, a lot of policies, plans, strategies, and methods have been improved. Landfills, especially sanitary landfills, reflect an applicable and the most commonly used implementation for solid waste disposal all over the world because it may achieve the reclamation of vacant area. However, other impacts may reveal from gas and leachate occurrence if not controlled well [1].

Leachate occurs from MSW during the landfill process because of several effects, such as precipitation, rainfall, surface runoff, biological degradation in the waste, etc., [2, 3]. Landfill leachate possesses a dark color and a scent, which contains some organic and inorganic contaminants. Leachate has some pollutants in aqueous solution. Compacted clay soil has natural matters to minimize the perme-ability of soil liners in landfill areas [4]. Clay soil as natural, compacted, and consolidated various structures of clays and especially compacted clays due to their productiveness in relation to cost and large capacity of attenuation [5] could be used for leachate control in the landfills. In addition, the compacted clay soil has low permeability [4]. According to the design criteria of Turkish Solid Waste Management Legislation, the liner component is compacted to achieve hydraulic conductivity no greater than 10^{-8} m/s [6].

Compacted clay soil may be affected negatively because of the matters on leachate. The suspended solid matters, layer expansion, ion adsorption, and bacterial clogging in the leachate may be different reasons for filling the spaces between the clay particles and this causes a reduction in the permeability. On one hand in a past study, permeability of compacted clay soil was not affected by the permeation of

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compacted clay soil with diluted organic waste liquids while on the other hand, some other studies have also claimed that permeability of compacted clay soil was affected by pure organic waste liquids [7, 8, 9, 10].

The aim of this paper has been carried out in two stages. In the first stage, clays taken from Kemerburgaz-Odayeri landfill area on the European side of Istanbul have been compacted and the permeability of the leachate has been investigated. Clay soil was put to the standard and modified proctor compaction tests. In the second stage, TKN and TP have been performed for the purpose of determining the treatment capacity of the compacted clay soil for batch and continuous reactors. These analyses have been conducted on the samples taken from the influent and effluent of the reactors treating the leachate.

II. MATERIALS AND METHODS

A. Properties of the Clay Soil

The clay soil samples were taken from Kemerburgaz-Odayeri landfill area on the European side of Istanbul. The clay liner underlying domestic solid wastes stored in the Kemerburgaz-Odayeri solid waste landfill site is 60 cm thick with a permeability coefficient between $k = 7.27 \times 10^{-7}$ and 5.32×10^{-7} m/s.

The geomechanical properties of the clay soil from Kemerburgaz-Odayeri landfill area have been determined. Their color was brownish-gray. The kaolinite and illite have been considered to be true clay soil minerals. Soil samples contained: Natural Unit Weight (γ_n), 2.0 g/cm^3, Natural Water Content (W_n), 30%; Plastics Limit (W_P), 35%; and Liquids Limit (W_L), 60%; Plasticity Index (I_p), 40%, Unit Weight of Soil Solids (γ_s), 2.68 g/cm^3; and Dry Unit Weight (γ_k), 1.6 g/cm^3 [11, 12].

B. Properties of the Leachate

Leachate has dark brown color and very small granules, and also contains large amounts of organic and inorganic contaminants, and a high concentration of metals. The results of the characterization studies conducted on the leachate from the Kemerburgaz-Odayeri landfill area are presented in Table 1.

TABLE 1
PROPERTIES OF THE LEACHATE

	pH	COD (mg/L)	SS (mg/L)	TKN (mg/L)	NH_4-N (mg/L)	$Org-N$ (mg/L)	TP (mg/L)
Sample 1	7.9	18725	1878	2752	2310	325	18
Sample 2	7.6	17650	1427	2910	2543	203	22

C. Permeability Tests

Compaction is a laboratory or in-situ soil improvement method which rearranges and densifies soil particles through the application of mechanical energy and thereby increases its dry density where the air-voids are reduced for specific purposes, such as increasing bearing capacity, shear strength, and reducing permeability and settlement.

Standard (ASTM D698/AASHTO T99) and Modified Proctor (ASTM D1557/AASHTO T180) methods are commonly applied in the laboratory at different water contents in a mould (0.102m. ID X 0.117m. H) and vary only in the amount of applied energy to determine the maximum dry density-water content relationship. Standard Proctor involves 25 drops of a 24.5 kN hammer from a height of 0.305 meters and three soil layers. The Modified Proctor uses a 45 kN hammer, a fall of 0.45 meters on five layers of soil,
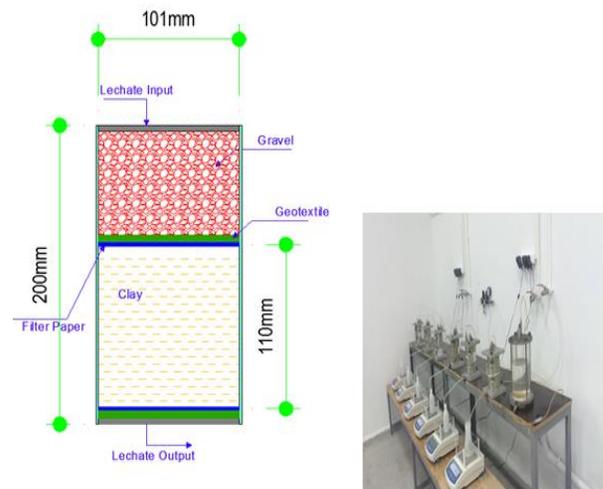

Fig. 1 . Graphics and photography of experimental setup

i.e., a higher compactive energy [13]. The reactor tests have been performed by flowing the liquid downwards through 100 mm diameter compacted specimens. The height of the compacted clay soil was 110 mm. The soil was constrained against swelling. The clay soil has been saturated under a 0.3-bar pressure [14, 15]. Experimental setup is given in Figure 1.

Constant Head Tests, using the following equation, have been performed to find the coefficient of permeability of the clay soil:

$$k = \frac{QL}{At(h_1 - h_2)} \tag{1}$$

where,

k: Coefficient of permeability, cm/s;
A: Surface area of the specimen, cm^2;
L: Distance between the manometers, cm;
$(h_1 - h_2)$: Differential head across the sample, cm;
Q: Total discharge, cm^3/s ;
t: elapsed time, s.

D. Adsorption Experiments

In this study, clay taken from Kemerburgaz-Odayeri landfill area of İstanbul changing color from yellow to brown was used as an adsorbent [16, 17, 18, 19]. Adsorption experiments were carried out via lab scale batch system. The shaking process was carried out at a 100 rpm spin rate using a Zhicheng ZHWY–211B model shaking incubator. 250 mL samples at pH 7.5 were shaken for 5 hours at 100 rpm. After 5 hours, samples were allowed to settle. The adsorption capacities of Kemerburgaz-Odayeri landfill area clay soil were determined for TKN by the batch system. During the period of study, the pH level of the leachate from the sanitary landfill was approximately 7.5 (between 7.6-7.9). Langmuir and Freundlich isotherm models were applied to establish the relationship between the amount of TKN adsorbed to clay soil and the amount of clay. For determining the adsorption isotherm, initial TKN concentrations were varied between 0.25, 0.5, 1, 2.5, 5, and 10 g/L. Afterwards, 250 mL of leachate and 2.5g/L adsorbent were placed in a flask. The leachate was diluted 50, 80, 90, 95, and 97.5% with distilled water prior to testing to obtain various data points for the adsorption isotherms. The pH of the solution was set to 7.5 and the flask was shaken with a thermostated shaker for different contact times. 5 hours was selected as the optimum retention time for this study.

E. Analysis

Aiming to obtain the removal capacity of the compacted clay soil, TKN and TP have been measured according to Standart APHA Methods both in the influent and effluent of the batch and continuous reactors [20].

III. RESULTS AND DISCUSSION

A. Results of the Compaction and Permeability Tests

Compaction tests were caried out to obtain maximum dry density and optimum water content, and average values were obtained from permeability tests. The average permeability has the lowest value when prepared with the optimum water content both for standard and modified Proctor compaction tests, which matches well with earlier studies.

The optimum water content of the standard Proctor compaction tests result was 25% and the optimum water content was 21% in the modifiying Proctor compaction test. The obtained permeability results are shown in Figure 2.
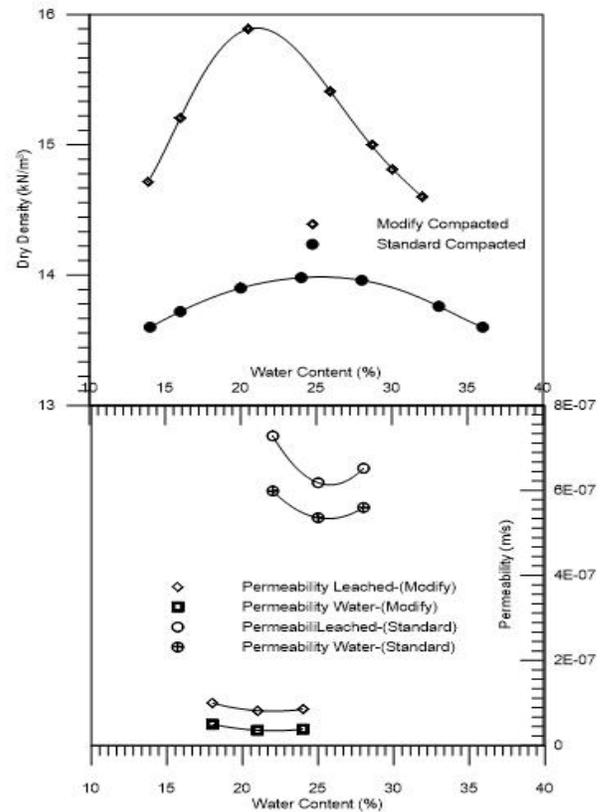

Fig. 2 . Results of standard and modified Proctor compaction and permeability tests

The permeability of the current clay soil in Kemerburgaz-Odayeri landfill area is measured between k = 7.27x10^{-7} and 5.32x10^{-7} m/s. The permeability is increased when clay soil samples are leached with TKN and TP, which clearly can be seen from Figure 2.

B. Removal Rate of TKN and TP

Laboratory experiments for investigating the influence of TKN and TP on permeability of compacted clay soil have been performed for 300 days. With the purpose of determining treatment capability of compacted clay soil, TKN and TP were measured in analytical tests performed on influent and effluent [20]. The results are given in Figures 3-6.

Influent TKN concentration of leachate was measured to be 2910 mg/L. After 20 days, permeant (water) was replaced by the leachate, and effluent TKN concentration and efficiency have been determined to be 1283 mg/L and 56% respectively (Figure 3). It is believed that the sharp decrease in the effluent concentration is caused by replacing water with leachate between the 20th and the 40th day of the experiment, leachate penetration took place in the compacted clay soil, and water completely left the system. Effluent TKN concentrations of leachate were measured to be 1163 mg/L and removal rate efficiencies 60% for sample prepared at optimum water contents of 25% have been obtained on the 40th day for samples compacted at standard Proctor energy (Figure 3).
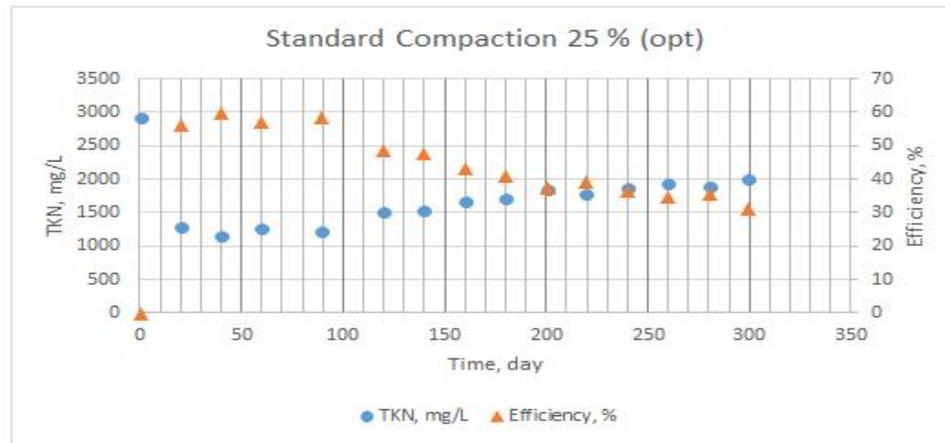

Fig. 3 . Removal rate of TKN in continuous reactors

The breakthrough time of the leachate through the clay soil is 40 days. Adsorption continues for 300 days. However, the efficiency of the removal rate decreases after the 40th day. Change in removal rate can be explained with the adsorption up to the 40th day and desorption afterwards.
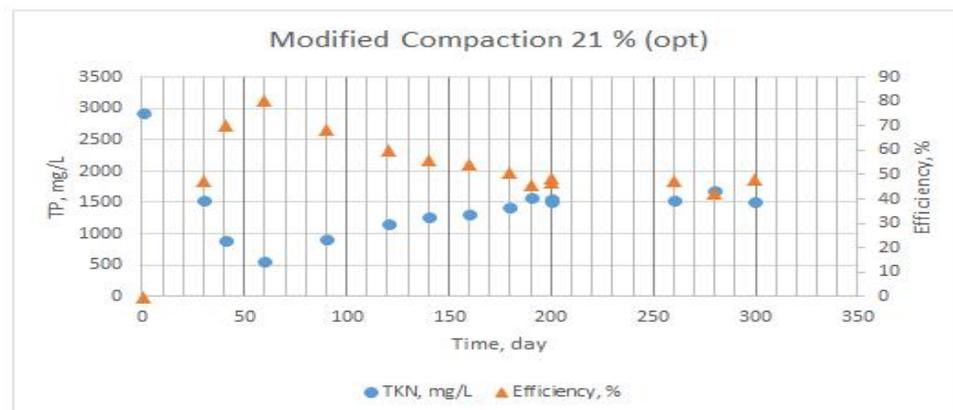

Fig. 4 . Removal rate of TKN in continuous reactors

The measured TKN concentration of the leachate is 2910 mg/L, which is permeated through the soil compacted at differing water contents utilizing the modified Proctor energy. The breakthrough time of the leachate through the clay soil is 60 days.

Removal rate of 81% was obtained for sample compacted at modified Proctor water contents of 21% on the 60th day, but decreased after the 60th day (Figure 4). Removal rate behavior can be explained with adsorption criteria up to the 60th day and desorption afterwards. TKN removal rate for samples prepared with modified Proctor compactive energy was found to be higher than the ones

prepared with standard Proctor method. Initial TP concentration of leachate was measured to be 22 mg/L. After 30 days, permeant (water) was replaced by the leachate.

Removal rate efficiency has been determined to be 72% at optimum water contents of 25% obtained on the 40th day for samples prepared with standard Proctor compaction effort (Figure 5). Adsorption continues up to the 300th day. However, in general, the efficiency of the removal rate decreases after the 40th day. Removal rate behavior can be explained with adsorption criteria up to the 40th day and desorption afterwards.
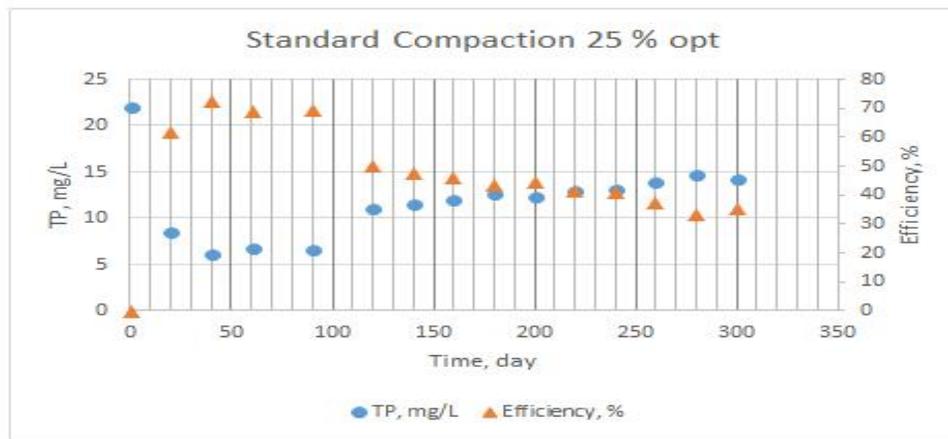

Fig. 5 . Removal rate of TP in continuous reactors

The measured TP input value of the leachate is 22 mg/L which is permeated through the soil compacted at differing water contents utilizing the Modified Proctor energy. The breakthrough time of the leachate through the clay soil is 60 days. Removal rate of 77% was obtained for sample compacted with the modified Proctor effort and water contents

of 21% on the 60th day, which decreased after the 60th day to approximately 39% on the 300th day (Figure 6). TP removal rates for sample prepared with the Modified Proctor compaction method were higher than those prepared with Standard Proctor Method. The TKN and TP removal rate efficiency of the clay soil is significantly high.
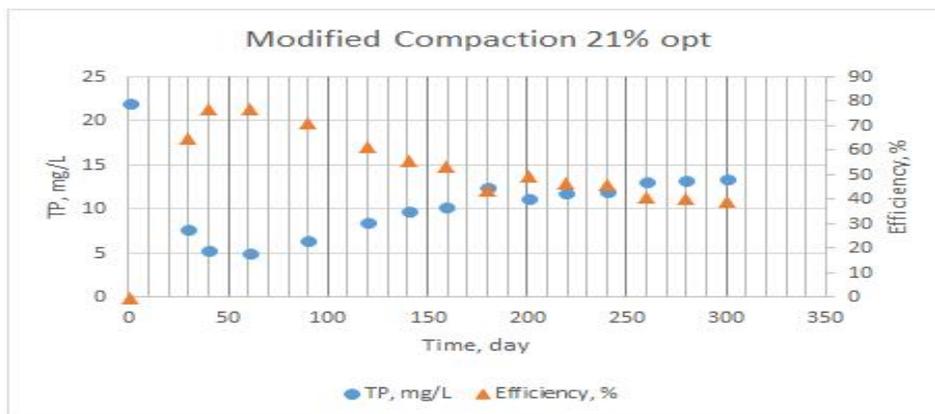

Fig. 6 . Removal rate of TP in continuous reactors

C. Adsorption Isotherm of TKN and TP in the Batch Reactors

To determine the different amount of TKN concentrations on adsorption, isotherm experiments were carried out. The data derived from the adsorption isotherm experiments were applied to the Freundlich and Langmuir isotherm models, which are given as follows:

$$log q_e = log K_f + \frac{1}{n} log c_e \qquad (2)$$

where,
q_e: Adsorbed TKN concentration, mg/g;
c_e: Concentration of TKN in the solution at equilibrium, mg/L;
K_f: Freundlich affinity coefficient, mg/g.

Depending on the linear form of the adsorption isotherm obtained from plots of log c_e versus log q_e, constants were calculated from the slope of the graph. The other equation conforming to the results of the adsorption isotherm is given as:

$$\frac{C_e}{q_e} = \frac{1}{q_m K} + \frac{c_e}{q_m} \qquad (3)$$

where,
q_e: Amount of adsorbed TKN concentration, mg/g;
c_e: Concentration of TKN in the solution at equilibrium, mg/L;
q_m: Capacity parameter, mg/g;
K: Langmuir constant, L/mg.

Depending on the linear form of the adsorption isotherm obtained from plots of C_e versus c_e/q_e, constants were calculated from the slope of the graph. These Freundlich and Langmuir isotherm models have been widely used by researchers to account for the dosage effects when observing the adsorption of organic matters [21, 22]. Figures 7-8 show Langmuir and Freundlich-type adsorption isotherms of clay taken from Kemerburgaz-Odayeri Area (TKN at pH 7.5, 5 hours' retention time, and 250 mL solution contacted with 2.5 g adsorbent). R^2, the correlation coefficient, of Freundlich is (0.9858) being higher than the Langmuir isotherm (0.808). This study, carried out with TKN based on the R^2 values, shows that the Freundlich isotherm fits the experimental data better than the Langmuir isotherm.
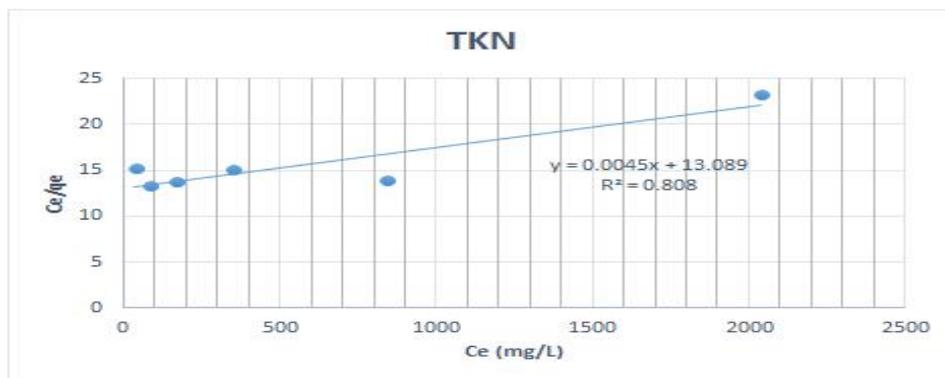

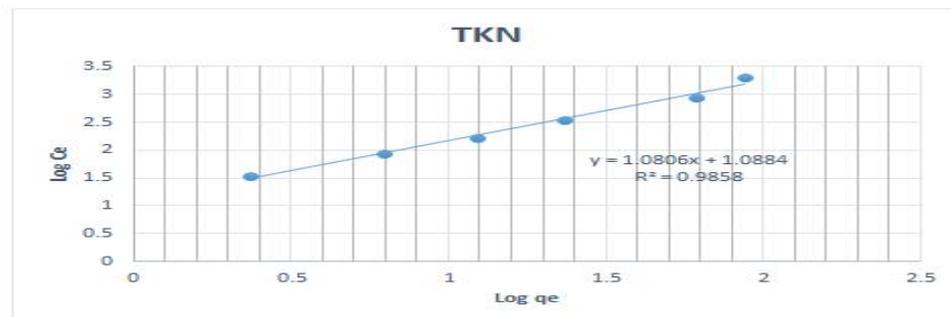Fig. 7 . Linearized Langmuir isotherm of Kemerburgaz-Odayeri clay soil for TKN

Fig. 8 . Linearized Freundlich isotherm of Kemerburgaz-Odayeri clay soil for TKN

TKN concentration is significantly higher than TP (TKN 2910 mg/L, TP 22 mg/L). For this reason, the same conditions can not be established and the isotherm cannot be applied because it is below measurable limits in batch experiments.

IV. CONCLUSION

In this study, it is found that the permeability is increased depending on deformation on clay soil caused by leachate.

The results came out from the continuous reactor showing that removal rates of TP in clay soil are 72% and 77% for standard compaction and modified compaction respectively. TKN in clay soil is around 60% and 81% for standard compaction and modified compaction respectively. TP and TKN removal efficiencies for standard compaction were higher than modified compaction. In adsorption experiments made with clay soil, the average yield of 40% is obtained. On a continuous basis/system, the average removal efficiency was around 70%. As can be understood from this, 40% of the adsorption mechanism is effective in nitrogen removal, while the remaining part is affected by mineralization, nitrification, ion exchange, complexation, biological use, and denitrification mechanisms. In batch reactor adsorption studies, maximum adsorption time for TKN was found to be 5 h. For longer shaking processes, efficiency of adsorption decreases, since not only desorption but also adsorption occurs. Adsorption results are consistent with Freundlich isotherm. The R^2 value indicated that TKN fits the experimental data better than Langmuir isotherm. Phosphorus can easily be removed from the soil by means of mainly adsorption and chemical precipitation. The adsorptive surfaces of the soil particles are regenerated by adsorption mechanism and the active zones of the soil particles are filled while the phosphine builds complexes with aluminum, calcium, and iron so they become insoluble. In this respect, phosphorus can be retained in the soil without leaking far away.

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