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Soil Chemical Properties and Performance of Groundnut (*Arachis hypogaea*) on Crude Oil Polluted Soil

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Abstract

The experiment was carried out in the Faculty of Agriculture Teaching and Research Farm, Ignatius Ajuru University of Education (IAUE) Ndele campus in Rivers State, Nigeria. The study investigated the soil chemical properties and performance of groundnut (*Arachis hypogaea*) on crude oil polluted soil. The experiment was laid out in a Randomized Complete Block Design and replicated 3 times. 10kg of sandy top soils (0-15cm depth) were collected from the research farm site into 48 polythene bags. The crude oil contamination was applied at the rate of 0ml (control), 10ml, 20ml, and 40ml per polythene bag before sowing the groundnut seed sourced from the local market. Data collected were subjected to the analysis of variance (ANOVA) using statistical software, SPSS version 20.1 and the significant treatment means were compared using the Duncan multiple range test (DMRT) at $P \leq 0.05$. Results showed that increasing the crude oil rate significantly ($P \leq 0.05$) decreased germination percentage, leaf area and groundnut yield. At 10ml and 20ml, number of leaves and plant height of the groundnut seedling increased but at the same rate it significantly ($P \leq 0.05$) decreased the number and weight of the groundnut seed and pod. At 40ml of crude oil contamination, the vegetative growth and yield of the groundnut plant reduced significantly ($P \leq 0.05$). It was observed that the pH decreased from 6.82 at planting to 6.69 at harvest for the control, and increased with increasing crude oil concentration at planting and harvest respectively. Nitrogen and organic matter were at least at 40ml but exceeded control at 10ml and 20ml application at planting. Also at planting, increasing crude oil rates significantly increased cation exchange capacity and percentage base saturation when compared to control and then significantly reduced electrical conductivity. Crude oil concentration did not significantly influence phosphorus and potassium at planting. At harvest, increasing crude oil rate increased pH, organic matter, and percentage base saturation but decreased phosphorus, potassium, cation exchange capacity and electrical conductivity. Crude oil reduced the performance of groundnut plants and influenced the chemical properties of the soil. It is recommended that further study be conducted to determine the chemical composition of the groundnut plant at harvest under similar conditions.

Keywords: Remediation, Soil contamination, Crude oil, Groundnut, Soil chemical properties

Introduction

The Nigerian economy, even in recent times has increasingly depended on crude oil export which has greatly increased crude oil exploration and production (Thisdaylive, 2022). Crude oil is a naturally occurring hydrocarbon compound used in several ways as fuel for automobiles, cooking gas and other fractions utilized in the manufacture of synthetic products (Edema et al., 2009). Crude oil becomes toxic to plants and their habitat when spilled on the soil (Adenipekun et al; 2006). Consequently, resulting in the pollution of the environment (Jessup and Leighton, 1996; Odularu, 2008).

Pollution caused by petroleum and its derivatives is the most prevalent problem in the environment. The release of crude oil into the environment by oil spills is receiving worldwide attention (Millioli, et al., 2009). Contamination of the soil with hydrocarbons can have a profound effect on soil fauna (Dendooven et al. 2011). Several authors reported the negative effect of polycyclic aromatic hydrocarbons (PAHs) on the survival and reproduction of earthworms (Brown et al. 2004; Contreras-Ramos et al. 2006). The results obtained confirmed the hypothesis that oil contamination with PAHs modified the physical properties of forest soils and oil had a negative impact on enzyme activity in soil. Enzyme activity in the studied soils was negatively correlated with PAHs (Anna K et al., 2015). The activity of soil enzymes is one of the approved parameters used for the evaluation of soil quality polluted with organic compounds, including PAHs (Lipińska et al., 2014). Oil pollution could affect soil's physical properties, pore spaces could be clogged, which could reduce soil aeration and water infiltration and increase bulk density, subsequently affecting plant growth. Oils which are denser than water could reduce and restrict soil permeability (Abosede 2013).

The effect of crude oil pollution on soil pH, temperature, number of plant species and vegetation productivity has been observed (Debojit, 2006). The significant ($p<0.05$) effects of various concentrations (20 – 80 ml) of crude oil on plant height, leaf length, area and number of leaves of soybean plants have been observed also (Ekpo et al., 2012). In another research conducted, the number of leaves and total seedling dry weight were noticeably reduced in 10, 15 and 20% oil-treated soil than garden soil treated as control. The tolerance in seedlings of *V. unguiculata* was also decreased with increasing concentration of oil pollution treatment. Principally, the highest concentration of crude oil-polluted soil exhibited a higher percentage of reduction in most of the growth parameters than control (Anila et al., 2018). Crude oil is reported to reduce available phosphorus and total nitrogen in the soil (Baker-Coke and Ekundayo, 1995). Nitrogen deficiency in soil hinders vegetative growth while phosphorus deficiency will affect nodulation and root development (Suleiman and Tran, 2015; Valentine et al., 2017).

However, even with the toxic effect of crude oil on plants, certain plants have been noted to survive, grow and reproduce even in crude oil-polluted soils at certain levels of concentration. Groundnut (*Arachis hypogaea* L.) for instance has been noted to have better tolerance in crude oil-contaminated soils than sorghum (*Sorghum bicolor*) (Iheme et al; 2017). It has been reported by researchers that plant growth and performance in crude oil polluted soil vary as some have recorded increased growth at a certain concentration as well as decreased growth or delayed germination within similar concentrations (Edema and Okoloko, 1997; Agbogidi and Bamidele et al., 2000; Achuba, 2006). Groundnut being a leguminous plant, possesses the characteristics of fixing atmospheric nitrogen to the soil through the nitrifying bacteria in the root nodes of the plant (Brady and Weil, 2017). This study was aimed to evaluate the soil chemical properties and performance of groundnuts as influenced by crude oil pollution.

Materials and Methods

Area of Study

The experiment was carried out in the Faculty of Agriculture Teaching and Research Farm, Ignatius Ajuru University of Education (IAUE) Ndele campus, Rivers State, Nigeria. The research farm lies at latitude 40 58' N and Longitude 60 48' E of the Niger Delta. The area is characterized by a rainfall range of 2000 mm – 3500 mm with high relative humidity and maximum annual temperature varying between 27.3°C and 35°C.

Samples Sources and pot preparation

The crude oil was obtained from the Nigeria Agip Oil Company OB/OB Gas Plant Obrikom Rivers State, Nigeria, West Africa. The groundnut seeds (*Arachis hypogaea*. L) were obtained from the local market. Twelve (12) polybags of width 45cm and height of 27cm were perforated with 10 small holes each to allow easy drainage, and were made available for the pot. Topsoil (sand) at 0-15cm were collected from the demonstration farm of weight 10kg and filled into the polybag up to the height of 25cm leaving a space from the top of about 2cm to allow for application of water. This was replicated into three.

Experimental treatment design and field layout

The crude oil was measured into the polybag at the rate of 0ml, 10ml, 20ml, and 40ml crude oil contamination. The 0ml pot serves as the control. On the same day that the polybags were prepared; crude oil treatment was applied and the groundnut seed was sown at 3 seeds per polybag at a depth of 3cm and the seedlings were thinned to one after 14 days from germination. The experiment was laid in a Randomized Complete Block Design replicated 3 times.

Collection of Data

Data on the plant were collected from the field weekly and from the date of planting. Data collected from the field include; Germination Percentage, Plant height, Number of leaves, Leaf area, Number of pods per plant, wet weight of pod per pot and the wet seed weight of the groundnut plant immediately after harvest. Soil samples were collected for laboratory analysis during planting (after application crude oil) and at harvest.

Statistical analysis

The data obtained was subjected to the analysis of variance (ANOVA) using a statistical software, SPSS 20.1 version. Significant treatment means were compared using the Duncan multiple range test at $P\leq0.05$ level of significance.

RESULTS

Germination was delayed with an increased crude oil rate. The 40ml concentration of crude oil polluted soil experienced germination and emergence from the soil in the second week while the others 0ml, 10ml and 20ml within the first week after planting. This gives a 100% germination at the first week for 0ml, 10ml and 20ml and so too for the 40ml rate crude oil treated soil (Table 1).

The plant height decreased with increasing crude oil contamination as seen in Table 2. At 40ml crude oil rate, plant growth was least for a consecutive 12 weeks after planting and highest for 20ml;33.68cm at 6WAP, 10ml;44.00cm at 9WAP, 20ml;79.43cm at 12WAP and 20ml;91.49cm at 15WAP when compared to control.

Table 1: Influence of crude oil rates on the percentage germination of groundnut

Crude oil polluted soil (ml)	Week 1	Week 2
0	100	-
10	100	-
20	100	-
40	0	100

Leaf area decreased significantly (P≤0.05) with increase in the crude oil rates as seen in Table 3. At the 8th week, it was observed that the result of mean separation of the number of leaves and leaf area was significant. The Control had leaf area of 9.605mm2 which is greater than those of 10ml;9.228mm2; 20ml;9.147mm2 and 40ml;8.172mm2.

As observed from Table 3, the number of leaves significantly increased from 164.250 at a 10ml crude oil rate to 182.500 at a 20ml crude oil rate which exceeded the control of 156.667cm. At the 40ml crude oil rate number of leaves decreased to the least of 92.833.

Table 2: Influence of crude oil rates on plant height (cm) of groundnut

Crude oil polluted soil(ml)	3WAP	6WAP	9WAP	12WAP	15WAP
0	17.61d	31.64b	43.77c	76.65c	86.68b
10	17.30c	33.25c	44.00d	71.36b	79.58a
20	16.26b	33.68d	43.26b	79.53c	91.49d
40	12.99a	27.13a	39.02a	66.53a	89.23c
SE	0.047	0.020	0.037	1.505	0.710

Mean with different alphabets in the same column are significantly different at P ≤ 0.05 using the Duncan multiple range test. WAP=Weeks after Planting. SE=Standard Error.

Groundnut yields significantly (P≤0.05) decreased with an increase in crude oil rates as observed in Table 4. The Control (0ml) resulted in the highest yields when compared to the crude oil polluted soils. The 10ml crude oil rate resulted in a higher number of pods (21.4) when compared to 20ml;17.5 and 40ml;20.00, and lowest pod weight (31.3g), when compared to 20ml;50.4g and 40ml;41.0g, then lowest number of seed (14.1) when compared to 20ml;19.9 and 40ml;15.4 and still lowest seed weight (14.6g) when compared to 20ml;20.6g and 40ml;16.3g.

Soil chemical properties of the soil were influenced by the crude oil contamination at planting and harvest. Table 5 shows that crude oil contamination of the soil increased the pH of the soil above the control from 6.82 at control (0ml) to 6.98 and 6.99 at 10ml and 20ml crude oil respectively. It was observed from Table 5 and 6 that the control for crude oil (0ml) reduced from 6.82 at planting to 6.69 at harvest. But crude oil polluted soil at harvest (Table 6) increased pH exceeding the control for 10ml and 20ml crude oil.

However, as observed at planting, the addition of crude oil had no significant mean increase of pH but at harvest there is a reduction from 7.08 at 10ml to 6.99 at 20ml. 20ml rate of contamination by crude oil at planting remained unchanged at harvest but 10ml crude oil increased the soil pH from 6.98 at planting to 7.08 at harvest.

Table 3: Influence of crude oil rates on the number of leaves and leaf area at 8WAP of groundnut

Crude oil (ml)	Number of leaves	Leaf area (mm^2)
0	156.67b	9.60d
10	164.25c	9.22c
20	182.50d	9.14b
40	92.83a	8.17a
SE	0.87	0.01

Mean with different alphabets in the same column are significantly different at P ≤ 0.05 using the Duncan multiple range test. WAP=Weeks after Planting. SE=Standard Error.

Table 4: Yield response of groundnut yield to crude oil polluted soil

Crude oil (ml)	Number of pods	Pod weight (g)	Number of seeds	Seed weight (g)
0	24.0d	67.3d	28.2d	29.0d
10	21.4c	31.3a	14.1a	14.6a
20	17.5a	50.4c	19.9c	20.6c
40	20.0b	41.0b	15.4b	16.3b
SE	0.32	0.28	0.33	0.34

Table 5: Influence of crude oil rates on the chemical properties of the soil at planting of groundnut

Crude oil (ml)	pH (H_2O) (1:2.5)	%N	%O.M	Available P	K (cmol/kg)	CEC (cmol/kg)	EC (μ/cm)	%B.S
0	6.82b	0.298b	3.355c	14.683b	0.026bc	6.833a	117.875d	96.644a
10	6.89c	0.204b	3.203b	13.148a	0.029c	7.561c	47.600a	98.017b
20	6.99c	0.195b	3.423d	15.141bc	0.025b	7.630d	50.000c	98.075b
40	6.61a	0.171a	2.914a	15.909c	0.023a	7.135b	58.992c	97.691b
SE	0.007	0.005	0.001	0.375	0.001	0.002	0.058	0.270

Mean with different alphabets in the same column are significantly different at P ≤ 0.5 using the Duncan multiple range test; WAP: Weeks after Planting. SE=Standard Error.

Table 6: Influence of crude oil rates on the chemical properties of the soil at harvesting of groundnut

Crude oil (ml)	pH (H_2O) (1:2.5)	%N	%O.M	Available P	K (cmol/kg)	CEC (cmol/kg)	EC (μ/cm)	%B.S
0	6.69b	0.248a	3.236a	13.639d	0.023d	7.078c	81.033d	97.032a
10	7.08d	0.216a	3.965d	12.158b	0.008a	5.657a	74.917c	97.001a
20	6.99c	0.219a	3.354b	10.453a	0.017c	6.071b	60.742b	97.163a
40	6.47a	0.212a	3.639c	13.044c	0.009b	6.068b	26.237a	97.698b
SE	0.007	0.005	0.001	0.375	0.001	0.002	0.058	0.270

Mean with different alphabets in the same column are significantly different at P ≤ 0.5 using the Duncan multiple range test; WAP: Weeks after Planting. SE=Standard Error.

At planting (Table 5), total Nitrogen decreased from 0.298% at control to 0.171% at 40ml crude oil contamination. Organic matter decreased from 3.355% at control to 3.203% and 2.914% at 10ml and 40ml crude oil rates respectively as observed in Table 5. However, Crude oil pollution at 20ml; 3.423% had increased organic matter above the control ; 3.355% but least at 40ml; 2.914. Available P was significantly highest at 20ml; 15.141ppm and least at 10ml; 13.148ppm when compared to control; 14.683ppm. Potassium decreased from 0.026 Cmol/kg at control to 0.023 Cmol/kg at 40ml crude oil pollution. CEC increased from 6.833 Cmol/kg at control to 7.630 Cmol/kg at 10ml crude oil concentration. and EC decreased from 117.875 μ/cm at control to 47.600 μ/cm. Percentage base saturation increased from 96.644% at control to 97.691%

At harvest, as seen in Table 6, effect of crude oil on the total nitrogen in the soil was not significant at control and polluted soil. Organic matter increased from 3.236% at control to 3.965% at 10ml crude oil pollution. Available P, Potassium, CEC and EC decreased from 13.639ppm, 0.023cmol/kg, 7.078 Cmol/kg, 81.033 μ/cm at control to 10.453ppm at 20ml, 0.08 Cmol/kg at 10ml, 5.657cmol/kg at 10ml and 26.237 μ/cm at 40ml crude oil pollution respectively. The percentage base saturation increased from 97.032% at control to 97.698 %.

Discussion

In this study, germination was delayed with an increased crude oil rate. This is similar to reports by Peretiemo-Clarke and Achuba (2007) in which the groundnut seed germination rate decreased with an increase in crude oil rate while studying the phytochemical effects of petroleum on peanut (*Arachis hypogea*) seedlings. The ability of the groundnut to germinate and emerge from the soil within the first week of planting at a lower concentration of crude oil and then the second week for a higher concentration (40ml) prove the tolerance of the groundnut as a legume to grow in crude oil polluted soils.

The height of the groundnut plant in this study significantly decreased at 40ml crude oil rate but increased at 10ml and 20ml rates when compared to the control. This is consistent with reports by other researchers like Achuba, (2006), Bamidele *et al.*, (2000), Edema and Okoloko (1997), that crude oil at lower concentrations can increase plant growth and also decrease plant growth at higher concentrations. Plant response to crude oil polluted soil depends on plant species, oil concentration, and time of exposure (Skrypnik *et al.*, 2021). However, Chaîneau *et al.* (1997) reported that crude oil contamination of soil had adverse effects on plant growth and development. Kayode *et al.* (2009) reported the inhibition of radical plumule growths as well as the reduction in the number of leaves in seedlings of *Vigna unguiculanta* and *Zea mays* in spent engine oil (a product of crude oil) polluted soil. Hence, the growth rate of the groundnut seedling decreases with increased concentration of crude oil pollution.

The decrease in leaf area with increasing crude oil rate as observed in this study is consistent with the report by Terek *et al;*(2015) that crude oil pollution in soil resulted in to decrease in dry matter production in leaves of plants and this could consequently reduce photosynthesis due to less area of leaves exposed to sunlight. In that study, Terek *et al.* (2015) reported that leguminous plant bean (*Faba bona*) significantly increased in height when compared to grass plants; *Carex hirta* L and *Trifolium pretense* L. Hence, *Arachis hypogaea* being a leguminous plant could have had an increase in growth rate (height) and number of leaves at a certain rate of crude oil pollution due to its characteristics to fix nitrogen in soil through the activities of nitrogen-fixing bacteria in roots of legumes. It is notable that nitrogen is an essential plant nutrient that enhances the foliage and vegetative growth of plants (Witcombe and Tiemann, 2022). Notably, there was an increase in height and number of leaves of the groundnut at 10ml and 20ml and a general decrease at 40ml crude oil rate when compared to control. Again, Crude oil could also supply nutrients to the soil given that it is composed of organic compounds, heteroatom compounds (S,N,O), hydrocarbons (C, H), metals and organic (Ni, V, Fe) and inorganic (Na^+, Ca^{++}, Cl^-) compounds (*Chemical Constitution of Crude Oil | FSC 432: Petroleum Refining*, 2017.).

In this study, Groundnut yields significantly ($P \leq 0.05$) decreased with an increase in crude oil rates. This is consistent with reports that crude oil is toxic to plants, especially at higher concentrations and this reduction in yield has been attributed to the consequent reduction in available phosphorus and nitrogen in the crude oil polluted soils (Benka-Coker and Ekundayo, 1995) when compared to the control, and the loss of nutrient, the interference with soil chemical and biological activities in the crude oil contaminated soil (Prado-Jatar *et al*; 1993, Amadi *et al*; 1993).

From the results, crude oil contamination of the soil decreased soil fertility from the period of planting to harvest. At planting, it is observed that increasing crude oil rate resulted in the decrease in organic matter, potassium, percentage nitrogen and electrical conductivity but resulted in the increase of available phosphorus, cation exchange capacity (CEC), and percentage base saturation of the soil when compared to control. At harvest, increasing crude oil rate resulted in a significant decrease in potassium, available phosphorus, cation exchange capacity and electrical conductivity, but a nonsignificant difference in the decrease of total nitrogen of the soil. Increasing crude oil rates also resulted in the increase of percentage base saturation and organic matter at harvest.

From this study, the pH of the control decreased from 6.82 at planting to 6.69 at harvest. The pH of contaminated soil increased to a peak of 6.99 (20ml) and 7.08 (10ml) at planting and harvest respectively. This is consistent with the report of Agbogidi *et al.* (2005) that crude oil contamination increased the pH of the soil. The recommended pH range for groundnut cultivation is between 5.5 and 7.0 (Jadhav, 2017). Hence, in this study, the crude oil pollution maintained the soil pH requirement for groundnut cultivation. Noted that at planting, the soil samples had no presence of the groundnut plant (*Arachis hypogaea* L.), hence the effect of the atmospheric nitrogen-fixing ability of the leguminous plant was not experienced resulting in a significant decrease of nitrogen in the soil with increasing crude oil rate which is consistent with the study by Agbogidi (2007) in which he evaluated crude oil contaminated soil on the mineral nutrient elements of maize (*Zea mays* L.) and reported decrease in total nitrogen in the contaminated soil. But at harvest, increased nitrogen in the soil was observed but not significantly different when compared to the Control. This indicates that the groundnut plant fixed atmospheric nitrogen in the soils from data taken at harvest.

The decrease in organic matter with increasing crude oil rate at planting could be attributed to possible clogging of soil pore spaces caused by the dense crude oil which resulted in the reduction of soil aeration and consequently affects the survival of aerobic bacteria and other relevant microorganisms for decomposition of organic matter as reported by Ewetola, (2013). At harvest, increasing organic matter with the increase in crude oil rate can be due to the leaching of crude oil in the soil over time and the decomposition of crude oil to organic carbons by the activities of microorganisms in the soil and given to the high carbon content of crude oil as reported by Agbogidi *et al*. (2005). Marinescu *et al*. (2011) reported similar values of potassium in crude oil polluted soil and unpolluted. However in this study observed a decrease in potassium at planting and harvest with increasing crude oil rate.

The decrease in electrical conductivity (EC) of the soil with increasing crude oil rate at planting and harvest in this study is not consistent with the report by Oyems *et al*. (2013) that EC is usually higher in crude oil concentrated soil due to high concentration of charge ions-cations and anions. However, Ekundayo (1997) reported that given the sandy soil type and heavy rainfall experienced in the Niger Delta which is capable of leaching salts from the topsoil and thus washing down the crude oil could contribute to the decrease in EC when compared to arid regions with limited rainfall. Agbogidi *et al.* (2005) reported a decrease of EC in crude oil polluted soil.

The increase of available phosphorus with increasing crude oil rate at planting could be due to the pH of the soil within the range of 6-7 which favours the availability of phosphorus Wang *et al;*(2010). But at harvest, available phosphorus decreased when compared to control due to the uptake of available phosphorus by groundnut plants during nodulation and production of groundnut pod and seed. Baughman *et al.* (2015) reported that groundnut plant requires an adequate level of phosphorus, potassium and other micronutrients and a pH of less than 7. Phosphorus is an essential nutrient used by groundnut plants, especially for the growth and development of roots and nodulation (Sulieman and Tran, 2015; Valentine *et al.,* 2017).

At planting cation exchange capacity (CEC) increased with increasing crude oil rate which contradicts reports by (Udoh and Chukwu, 2014) that crude oil contamination results in to decrease in the CEC of the soil. At harvest CEC decreased with increasing crude oil rate, which is consistent with the report by Udoh and Chukwu (2014). This study shows that over time CEC changed from increasing with increasing crude oil rate at planting to decreasing with increasing crude oil rate at harvest. This implies that the crude oil with time decreased the soil fertility. CEC is a very important parameter used to indicate soil fertility. It has an influence on soil structure and stability, nutrient availability, pH of the soil and the soil`s response to fertilizers and other nutrients (Hazleton and Murphy 2007). CEC is the total capacity of soil to hold exchangeable cations. Exchangeable cations like calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}) are generally referred to as base cations and are associated with CEC in soils (Rayment and Higginson, 1992). Clay soils usually have higher CEC when compared to sandy soils.

Percentage base saturation increased with increasing crude oil at planting and harvest. Crude oil increases the pH of the soil (Agbogidi *et al.,* 2005) as such increases exchangeable basic cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}). The increased percentage base saturation could have been responsible for the significant increase in the number of leaves and total leaf area as observed for 10ml and 20ml crude oil rates.

Conclusion

Groundnut (*Arachis hypogaea*) plants at lower concentrations of crude oil-polluted soil (10ml and 20ml crude oil per 10kg soil) increased in height, and the number of leaves but decreased in both parameters at higher crude oil concentrations of 40ml per 10kg of soil. Groundnut yield decreased at all crude oil concentrations when compared to the control. It was observed that the pH decreased from 6.82 at planting to 6.69 at harvest and increased with increasing crude oil concentration at planting and harvest respectively. Nitrogen and organic matter were least at 40ml but exceeded control at 10ml and 20ml application at planting. Also at planting, increasing crude oil rates significantly increased cation exchange capacity and percentage base saturation when compared to control and then significantly reduced electrical conductivity. Crude oil concentration did not significantly influence phosphorus and potassium at planting. At harvest, increasing crude oil rate increased the pH, organic matter, and percentage base saturation but decreased phosphorus, potassium, cation exchange capacity and electrical conductivity. In conclusion, crude oil significantly ($P \leq 0.05$) reduced the performance of groundnut plants and influenced the physicochemical properties of the soil.

It is recommended that further study be conducted to determine the chemical composition of the groundnut plant at harvest under similar conditions.

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