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SPATIAL VARIABILITY OF DIFFERENT MAGNESIUM FORMS IN LUVISOLS FORMED FROM GLACIAL TILL*

Mirosław Kobierski[1], Jacek Długosz[1], Anna Piotrowska[2]

[1]Chair of Soil Science and Soil Protection
[2]Department of Biochemistry
University of Technology and Life Sciences in Bydgoszcz

Abstract

Ions occurring in the soil solution as well as exchangeable ions related to exchangeable complex are a reservoir of magnesium for plants. The content of magnesium forms important for plants can reveal a very high spatial variability of this element on a field scale. Determination of such spatial variability of elements is extremely important for the so-called precision agriculture, in which application of a fertilizer dose is by principle related to the actual deficit of elements, even in a small area.

In order to evaluate parameters connected with the spatial variability of magnesium forms, the H_2O (water) soluble (Mg-H_2O), exchangeable (Mg-E) and available magnesium (Mg-A) forms were determined. The soil samples were taken in spring 2007 from the humic Luvisols horizon under winter wheat. Fifty soil samples were taken from the sites located in a square sampling grid (10 m x 10 m). The results were evaluated with the use of classical statistical methods as well as geostatistical calculations. The raster maps illustrating the spatial variance of determined nitrogen forms were drawn on the ground of semivariograms.

The concentration of magnesium forms in the surface horizon of the soil showed significant differentiation: Mg-H_2O ranged from 0.76 to 2.89 mmol(+) kg^{-1}; Mg-E 1.69-8.06 mmol(+) kg^{-1} and Mg-A 28.50-91.40 mg kg^{-1}. The data were analyzed statistically. Coefficients of variations equaled 31.6% for Mg-H_2O; 30.5% for Mg-E and 24.9% for Mg-A. Analysis of dispersion showed the highest similarity to the mean value, reaching 1.24 mmol kg^{-1} Mg-H_2O, which was confirmed by high kurtosis (8.73). The most flattened distribution was noted for Mg-E (– 0.39 kurtosis). Geostatistical calculations demonstrated that the analyzed magnesium forms did not occur in total dispersion in the soil mass, which was confirmed by high nugget variance values equal 0.423 (mmol $kg^{-1})^2$ for Mg-E, 0.031

dr inż. Mirosław Kobierski, Chair of Soil Science and Soil Protection, University of Technology and Life Sciences, Bernardyńska 6/8 St., 85-029 Bydgoszcz, Poland, e-mail: kobierski@utp.edu.pl

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(mmol kg^{-1})^2 for Mg-H_2O and 83.42 (mg kg^{-1}) for Mg-E. The highest participation of the nugget variance in sill variance (47.3%) was observed on the Mg-E semivariogram. The range of influence, defined as a maximum distance of correlations between point values, ranging 80.0-98.0 m, was higher than the real distance of soil sampling.

Key words: exchangeable magnesium, water soluble magnesium, available magnesium, spatial variability, Luvisols.

ZRÓŻNICOWANIE PRZESTRZENNE RÓŻNYCH FORM MAGNEZU W GLEBIE PŁOWEJ WYTWORZONEJ Z GLINY LODOWCOWEJ

Abstrakt

Rezerwuarem magnezu dla roślin jest gleba, głównie jony znajdujące się w roztworze wodnym, oraz jego kationy wymienne związane z kompleksem sorpcyjnym. Zawartość magnezu przyswajalnego – ważna ze względu na zabezpieczenie potrzeb pokarmowych roślin – może się charakteryzować bardzo dużym zróżnicowaniem przestrzennym w skali pola uprawnego. Określenie przestrzennego zróżnicowania tych składników jest niezmiernie istotne w rolnictwie precyzyjnym, uzależniającym dawkę nawożenia od rzeczywistego niedoboru pierwiastka, nawet na niewielkim areale pola uprawnego.

W celu oszacowania parametrów związanych z przestrzenną zmiennością form magnezu określono zawartość magnezu wodno-rozpuszczalnego (Mg-H_2O), wymiennego (Mg-W) i przyswajalnego dla roślin (Mg-P). Próbki z 50 punktów poziomu orno-próchnicznego gleby płowej pobrano wiosną 2007 r. w sieci kwadratów rozmieszczonych co 10 m. Zawartość poszczególnych form magnezu oznaczono tradycyjnymi metodami, a wyniki opracowano metodami statystycznymi i geostatystycznymi, które posłużyły do wykonania map określających ich przestrzenne zróżnicowanie.

Wykazano duże zróżnicowanie zawartości form magnezu (Mg-H_2O – 0,76-2,89 mmol(+) kg^{-1}; Mg-W – 1,69-8,06 mmol(+) kg^{-1}; Mg-P – 28,50-91,40 mg kg^{-1}) w poziomie orno-próchnicznym gleby płowej. Zróżnicowanie to potwierdzają wysokie wskaźniki zmienności, wynoszące odpowiednio: Mg-H_2O – 31,6%; Mg-W – 30,5%; Mg-P – 24,9%. Na podstawie analizy geostatystycznej wyników stwierdzono, że najbardziej skupione wokół średniej arytmetycznej, wynoszącej 1,24 mmol Mg kg^{-1}, były zawartości Mg-H_2O. Potwierdza to także obliczona dla tej formy magnezu wysoka wartość kurtozy (8,73). Najbardziej spłaszczony rozkład miały wyniki określające zawartość magnezu przyswajalnego dla roślin (kurtoza -0,39). Poszczególne formy magnezu w masie glebowej badanego pola charakteryzują się niewielkim wskaźnikiem rozproszenia, na co wskazuje wysoka wartość efektu samorodka, odpowiednio: 0,423 (mmol kg^{-1})^2 dla Mg-W; 0,031 (mmol kg^{-1})^2 dla Mg-H_2O oraz 83,42 (mg kg^{-1})^2 dla Mg-P. Największy udział efektu samorodka w wariancji progowej (47,3%) zaobserwowano na semiwariogramie określającym zawartość Mg-P. Obliczony zasięg oddziaływania, czyli korelacji między próbkami, wynosił 79,3-98,0 m i był większy niż rzeczywista odległość między poszczególnymi próbami pobranymi do badań.

Słowa kluczowe: magnez wymienny i wodno-rozpuszczalny, magnez przyswajalny dla roślin, zmienność przestrzenna, gleba płowa.

INTRODUCTION

Magnesium as a component of chlorophyll and the activator of enzymes involved in phosphorylation processes (phosphokinases, phosphotransferases) (MARSCHNER 1986, VOET, VOET 2004) participates in many important processes, which determine the quality and the quantity of crop yields. Magnesium ions occurring in the soil solution as well as exchangeable ions related to the exchangeable complex are a reservoir of magnesium for plants.

The concentration of magnesium in the soil solution depends on soil moisture, grain size distribution, organic matter content and soil microbiological activity, season of the year as well as mineral and organic fertilization (ŁABĘTOWICZ, RUTKOWSKA 2001, MARCHNER 1986). The content of magnesium forms important for plants can reveal a very high spatial variability of this element on a field scale. Determination of spatial variability of elements is extremely important for the so-called precision agriculture, in which application of a fertilizer dose as related to the actual deficit of elements, even in a small area.

The objective of this study has been to evaluate and compare the spatial variability of different magnesium forms: the H_2O (water) soluble (Mg-H_2O), exchangeable (Mg-E) and available magnesium (Mg-A) in the surface horizon of Luvisols from the Polish region called Kujawy and Pomorze.

MATERIAL AND METHODS

The area from which the soil samples were collected was localized on a 80-hectare field in the village of Orlinek near Mrocza in Kujawy and Pomorze. The area is partialy covered with typical Luvisols formed from till of the Vistulian glaciation.

Winter wheat after winter rape as the forecrop was cultivated on the selected field. The specimens were taken from the surface horizon (0-20 cm) of the soil profile at a stage of the wheat spreading (April 2007). In total, 50 soil samples were taken from points located in a square sampling grid (10 m x 10 m). Each soil sample accounted for a mean value of 10 individual samplings. The basic parameters of the investigated soils are shown in Table 1. The soil profile morphology and particle-size in respective (each) genetic horizons confirmed that the soil is Luvisols with an argic horizon, containing $CaCO_3$ in the parent material (Table 2). Soil analyses were performed on air dried and sieved (< 2 mm) soil samples according to the standard methods commonly used in soil science. Basic physicochemical parameters were determined: particle-size by Cassagrande'a method modified by Proszyński; fraction > 2 mm content by the sieving method; pH in 1 mol

Table 1

Ranges and means of basic soil physical and chemical parameters

Data	Organic carbon	Total nitrogen	pH		Fraction < 0.002 mm
	g kg^{-1}		H_2O	1M KCl	
Min – Max / Mean	5.5. – 9.0 / 7.3	0.68 – 0.99 / 0.80	4.66 –6.83 / 5.44*	4.11 – 5.77 / 4.70*	4.0 – 9.0 / 6.1

* geometric mean

Table 2

Selected properties of the Luvisols profile

Horizon	Depth	pH	$CaCO_3$	TOC	ρ_a	Particicle size (mm)		
						2-0.05	0.05-0.002	0.002
	(cm)	KCl	(%)	(g kg^{-1})	(Mg m^{-3})	(%)		
Ap	0-28	5.07	0	6.66	1.31	77	18	5
AE	28-42	4.70	0	5.24	1.55	82	14	4
Eet	42-68	5.09	0	1.05	1.59	83	13	4
EB	68-84	5.18	0	0.75	1.65	70	15	15
Bt	84-115	5.48	0	0.36	1.76	63	19	18
BC	115-135	6.32	1.81	0.22	1.78	64	20	16
C1cagg	135-150	6.92	3.18	0	1.87	69	22	9

TOC – total organic carbon; ρ_a – bulk density

KCl by the potentiometric method; organic carbon content by using a dry combustion CN analyser (Vario Max CN) and $CaCO_3$ by Scheibler procedure. The analysis of magnesium forms was completed by atomic absorption spectroscopy using the following extractants: water with 1÷5 soil: water suspension for Mg-H_2O; Schachtschabel's extractant (0.0125 mol dm^{-3} $CaCl_2 \cdot 6H_2O$) for Mg-A and $BaCl_2$ solution according to PN-ISO 13636 (2002) for Mg-E.

The results were evaluated with the use of classical statistical methods (Statistica v. 8.0 Software) by calculating arithmetic and geometric means, standard deviation, coefficients of variation as well as skewness and kurtosis. Geostatistical calculations included empirical semivariogram graphs and a theoretical mathematical model of variograms. On the basis of the models thus obtained, the following geostatistic parameters were read out: nugget, sill variance, range of influence and nugget effects ([Co/(Co+C)]·100 (NAMYSŁOWSKA-WILCZYŃSKA 2006). On the grounds of the semivariograms, raster maps illustrating the spatial variance of the determined magnesium forms were drawn. The method of point kriging was adapted to the date estimation (DAVIS 1986) and the calculations were done using SURFER 8.0 of Golden Software.

RESULTS AND DISCUSSION

Among many forms of magnesium, the most important in agricultural practice is the available one since it is the basis for optimization of magnesium fertilizer doses. The mean value of Mg-A in the surface horizon (Ap) of the investigated Luvisols was 60.5 mg kg^{-1}, being higher than the results obtained by CZEKAŁA et al. (2001). According to our results, the investigated soil could be classified as having a high Mg-A content (IV class abundance) i.e. soil not requiring magnesium fertilization (OBOJSKI, STRACZYNSKI 1995). Such soils account for 12% of the country's area (IGRAS, LIPIŃSKI 2006) and make up from 16% (GOSEK, KOPIŃSKI 2001) to about 25% of the soils in the Province of Kujawy and Pomorze (IGRAS, LIPIŃSKI 2006). The results on the available magnesium content in the surface horizon of the examined showed, however, demonstrated significant differentiation, as indicated by the range (28.5-91.4 mg kg^{-1}), standard deviation value (15.06) and variation coefficient obtained for this form (24.9%). The negative value of kurtosis (-0.39) further confirmed the wide dispersion of Mg-A and gave evidence of a flattened distribution, whereas the skewness analysis showed right-sided asymmetry (0.245), which indicated a higher number of soil samples with values lower than the mean for the whole investigated area. Moreover, this fact was evidenced by a lower median than the mean.

Geostatistical analysis showed some spatial variability of this Mg-A form in the surface horizon in the analyzed area. This was shown by a high sill variance value equal 259.32 (mg $kg^{-1})^2$. Our semivariogram model analyses showed the appearance of nugget variance, reaching 83.42 (mg $kg^{-1})^2$ – Table 3, Figure 1), which proved that the Mg-A distribution was influenced by structural factors, resulting in a short-range variability.

The influence of the above factors was significant, as demonstrated by the nugget effect at the level 32.2%.

Hovewer, the raster map of abundance classes drawn on the basis of the semivariogram (Figure 2) did not show high Mg-A changeability because most of the investigated area (70-75%) belonged to abundance class IV (soils with high abundance). It is in agreement with the abundance classification prepared for the studied area according to the mean values.

Soil available magnesium consists of ions occuring in the soil solution (Mg-H_2O) and Mg^{2+} cations bonded to the sorption complex (Mg-E), which showed differentiation in the surface horizon of the investigated Luvisols. This fact could be evidenced by the range of aforementioned magnesium

Table 3

Basic statistical and geostatistical parameters of analyzed properties

Parameter	Magnesium		
	exchangeable	water soluble	available
	mmol(+) kg^{-1}		mg kg^{-1}
η	50	50	50
Minimum	1.90	0.77	28.5
Maximum	8.06	2.90	91.4
Arithmetical mean	4.51	1.24	60.5
Geometric mean	4.31	1.17	58.6
SD***	1.378	0.392	15.06
Median	4.24	1.16	57.9
CV (%)****	30.5	31.6	24.9
Kurtosis	0.140	8.73	-0.39
Skewness	0.585	2.61	0.245
Variance	1.90	0.15	226.67
Model	spherical	spherical	spherical
Nugget (Co)	0.423*	0.031*	83.42**
Sill (Co+C)	2.083*	0.139*	259.32**
Nugget effect (%)	20.3	22.3	32.2
Range (m)	97.3	98.0	79.9

* (mmol(+) kg^{-1})^2, ** (mg kg^{-1})^2, ***SD – standard deviation, ****CV (%) – coefficient of variation

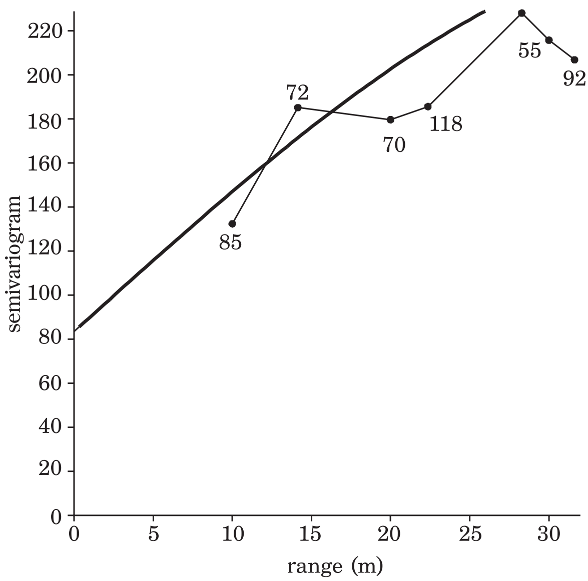

Fig. 1. Empirical semivariogram of the available magnesium content (Mg-A) obtained according to the estimated theoretical model

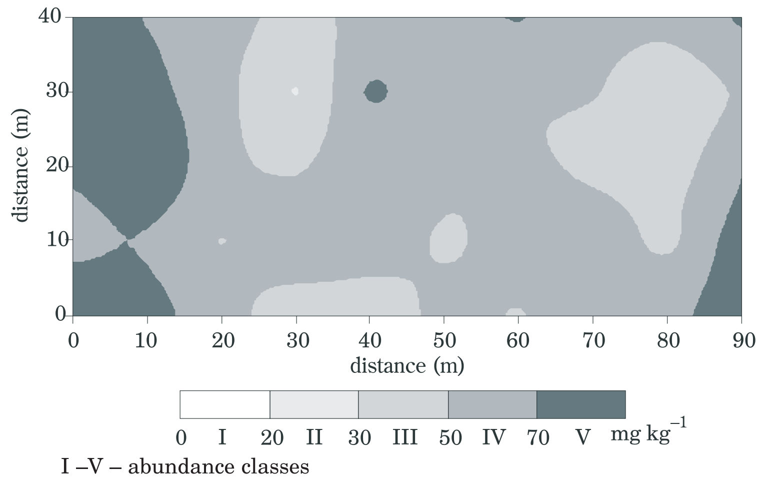

Fig. 2. Raster map of the available magnesium content (Mg-A)

forms, which varied between 1.90 and 8.06 mmol(+) kg^{-1} for Mg-E and 0.77-2.90 mmol(+) kg^{-1} for Mg-H_2O (Table 3). The differentiation was confirmed by high standard deviation values such as 1.378 mmol(+) kg^{-1} for Mg-E and 0.392 for Mg-H_2O calculated for the analyzed magnesium forms. However, the variation coefficients obtained for these Mg forms (30.5% for Mg-E and 31.6% for Mg-H_2O, respectively) pointed out that their differentiation was uniform over the investigated area. In turn, the results of dispersion analyses of Mg-H_2O were characterized by very high concentration around the mean value, which was confirmed by leptokurtic distribution (kurtosis 8.73), while the distribution of Mg-E values was similar to normal distribution (kurtosis -0.140). Although the concentration of both Mg forms displayed right-sided asymmetry, higher values were obtained for Mg-H_2O (Table 3). The right-sided Mg-H_2O distribution is further verified by the positive skewness value and lower median than mean values (Table 3).

Geostatistical analysis demonstrated spatial variability of both Mg-E and Mg-H_2O values. The distribution indicated that most of soils samples contained the Mg-H_2O concentration below the mean value. In the surface horizon of the analyzed soil, higher spatial variability was found for Mg-E than Mg-H_2O, which was indicated by the sill variance calculated for these parameters according to the experimental semivariograms and models derived from these semivariograms (Table 3, Figures 3 and 4). Additionally, they showed that the spatial variability of Mg-E and Mg-H_2O in the surface horizon of the investigated Luvisol was influenced by short-range variability, the fact that was proven by the nugget variance amounting to 0.423 $(mg\ kg^{-1})^2$ for Mg-E and 0.031 $(mg\ kg^{-1})^2$ for Mg-H_2O. The contribution of short-range variability to the total changeability of both magnesium forms (Mg-E and Mg-H_2O) was equal and reached approximately 20% (Table 3). The raster

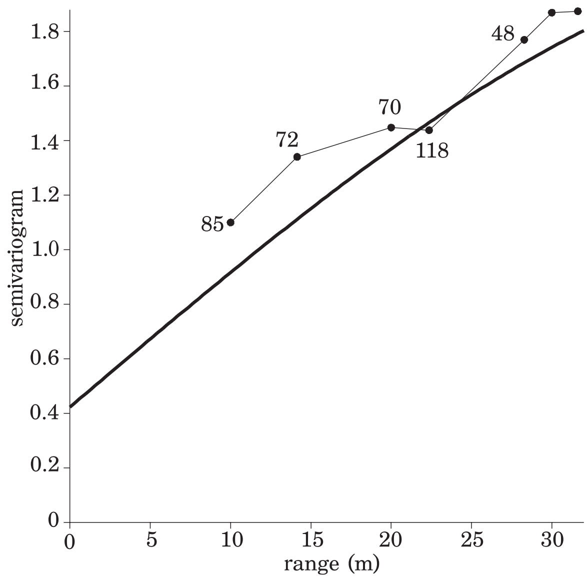

Fig. 3. Empirical semivariogram of the exchangeable magnesium content (Mg-E) obtained according to the estimated theoretical model

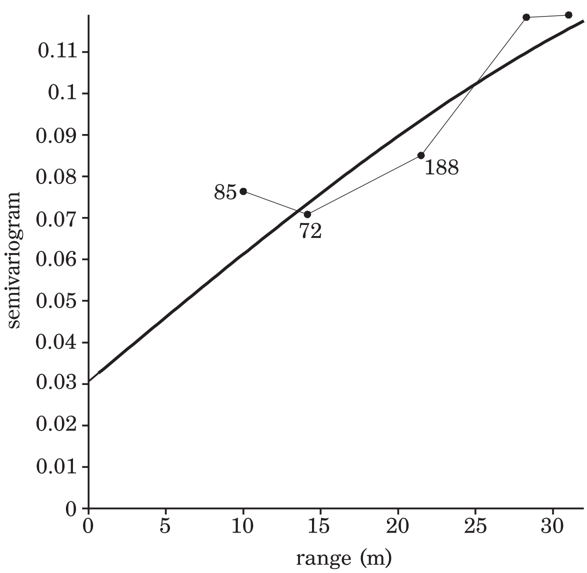

Fig. 4. Empirical semivariogram of the water-soluble magnesium content (Mg-H_2O) obtained according to the estimated theoretical model

maps displaying the spatial variability of Mg forms in the analyzed area showed higher differentiation of Mg-E than that of Mg-H_2O (Figures 5 and 6). The range of semivariograms (Table 3), showing the distance where point results could be auto-correlated, indicated that the range for each Mg forms was similar, i.e.: to 80 m for Mg-A and to 98 m for Mg-H_2O and 97.3 for Mg-E.

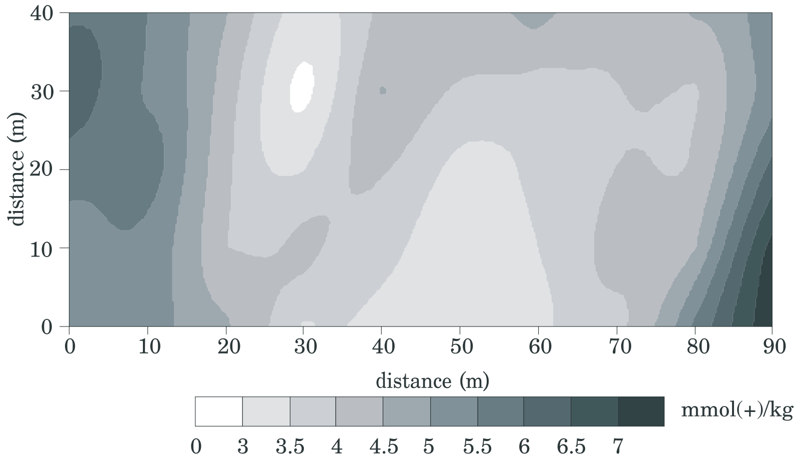

Fig. 5. Raster map of the exchangeable magnesium content (Mg-E)

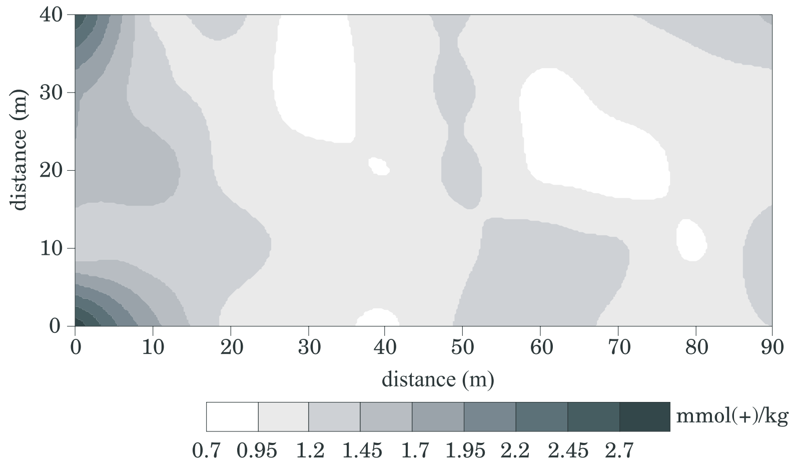

Fig. 6. Raster map of the water-soluble magnesium content (Mg-H_2O)

CONCLUSIONS

The investigation showed differentiation of the spatial variability of available magnesium as well as both water soluble and exchangeable magnesium forms in the Luvisols surface horizons on a scale of a microregion. The significant participation of short-range variability to the total changeability of all the investigated Mg forms was demonstrated and could show some irregular location Mg^{2+} cations in the soil mass, which was probably a consequence of soil heterogeneousness. The geostatistical analysis helped us to show that the maximal distance between sampling points for both Mg-H_2O and Mg-E spatial variability estimation should be about 100 m, while for the Mg-A abundance distance between estimation points should not exceed 80 m. A traditional criterion establishing abundance classes, when used for drawing maps of Mg-A variability, causes overgeneralization and homogenization of an analyzed, which could affect negatively the efficiency and accuracy of fertilization.

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