Originalarbeiten

(From the University of Agriculture in Vienna and the Suez Canal University in Ismaelia)

Potentiality for Soil Erosion Control and Improving Plant Production in Arid Zones*

1st Communication: Laboratory and Electron Microscopic Investigations of Soil Stabilizers and Evaporation Inhibitors

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(With 7 figures)

Research on this topic began in Austria in 1978, was extended to Egypt in 1984 and was assisted by cooperation with the universities of Ismaelia and Gießen. Due to the large quantity of results, it will be published by the following four communications:

1st Communication: Laboratory and electron microscopic investigations of soil stabilizers and evaporation inhibitors.
2nd Communication: Green-house and phytotron investigations of soil stabilizers and evaporation inhibitors.
3rd Communication: Application technique of soil stabilizers and evaporation inhibitors and investigations on the environmental behaviour of these substances.
4th Communication: Field trials and results.

1. Problems and Present Level of Knowledge

Soil erosion is a serious problem in many parts of the world. It is mainly caused by rain in humid areas and by wind in arid regions. Several possibilities to avoid soil erosion are considered, such as gentle soil management, minimum tillage (covering the soil for some time by crop residues), sowing plant covers and overwintering catch crops by which the soil will also be covered continously by plants.

Wind erosion is also tried to be reduced by wind shielding belts, whereas sometimes plant mulch or soil stabilizers are used against water erosion.

In this study, based on trials made during more than ten years, soil stabilizers and evaporation inhibitors were applied to the soil surface. They are applied in humid areas to decrease run-off and soil surface detachment as well as to control wind erosion and water evaporation in arid zones. Some of these soil conditioners are bitumen, polyurethans, polyvinylacetates, ureaformaldehyds and silox-

* This project has been financed by Shell International and CMB-Cairo (Chemicals for Modern Building). By these companies the Bituplant products will be commercialized.

anes (Stoye 1987). Bitumen emulsions are commonly used for slope stabilization, reducing run-off and preventing sand encroachment in desert areas.

Bitumen, a natural product obtained from petroleum industry, is also used for improving soil structure (Blümel 1982). A certain bitumen emulsion, called "Terrafix", sprayed at a rate of 1500 l/ha after having been warmed up, improved early plant growth and increased yield (Neururer 1982, 1984). Results obtained from field trials measuring the influence of bitumen film on the water storage capacity of a test site showed a 2 to 5 % higher water content than the non-treated soil (Gerard and Chambers 1967, Hartmann et al. 1976). Reduction of evaporation by a bitumen film was studied by Wang Jiu Zhi and Wu Dongtang (1986). They found that evaporation reduction ranged from 7.8 to 29.7 %, but any exact details of the trials were not mentioned. Collis-George et al. (1963) found from a green-house experiment that evaporation was reduced by 10 to 90 % after 0.02 to 1.8 l/m^2 bitumen application.

Sometimes, bitumen emulsions were incorporated into the top soil layers (de Boodt 1970, Tayel and Anter 1978, Tayel and El Hady 1981). In principle, soil stabilizers should have both hydrophilic and hydrophobic properties. They should not interfere with gaseous exchange, should be permeable to water and beneficial to the environment (Stoye 1987).

2. Material and Methods

2.1 Material

Several soil stabilizers, soil conditioners and evaporation inhibitors could be used, such as bitumen emulsions, talloil emulsions, styrol-butadien dispersions, urea-formaldehyd resins, polyacrylic resins, polyvenylester dispersions and polybutadien emulsions. Three groups of substances were chosen for further studies. They are:

A. Bitumen emulsion, represented by the first product called "Terrafix", and the newly developed one, called "Bituplant 22". Terrafix, developed by COLAS-Austria, must be warmed up before being sprayed, whereas Bituplant 22, developed by Shell International and CMB-Cairo, could be sprayed as a cold emulsion. Developed especially for agriculture, both products are anionic 50 % emulsions. The recommended rate of application for each of them is 1000 l/ha to 3000 l/ha.

B. Urea-poly-condensate, called Sarea Soil Stabilizer, developed in Austria by Sarea-Nestlé, should be applied at 100 kg/ha diluted with 1000 l of water. This product contains 20 to 22 % of nitrogen, 4 to 5 % of K_2O and 5 to 6 % of P_2O_5. It does not only act as a soil stabilizer but also as a fertilizer.

C. Polydimethylsiloxane, called "Sarea Evaporation Inhibitor", was developed by Sarea-Nestlé. It is a liquid product which is applied at a rate of 75 l/ha, diluted with 15 000 to 30 000 l of water.

2.2 Methods

It has become necessary to carry out several laboratory tests to investigate the quality of soil stabilizers and evaporation inhibitors sometime before conducting longterm field trials. The aims of the short-term tests are investigating the changes in soil physical properties, the efficacy against erosion, soil crusting and evaporation. These tests are:

2.2.1 Ability for being sprayed

Due to the fact that each product has to be suited for being sprayed, viscosity, fineness, emulsion stability, breaking time and spraying capability are important factors for the assessment of bitumen emulsions. Fineness is evaluated by the spreading test by which a drop of the bitumen emulsion is spread on a slide by means of a cover glass. So any inhomogeneity and the fineness of the emulsion will be immediately detected (fig. 1). Viscosity and emulsion stability are tested according to the method used by highway engineers. The application test is made by atomizing 5 ml of the product by a standard glass nozzle (flow passage according to TeeJet nozzle 11004) upon Petri dishes filled with sand. Any blockage of the nozzle will be recorded and film quality can be evaluated.

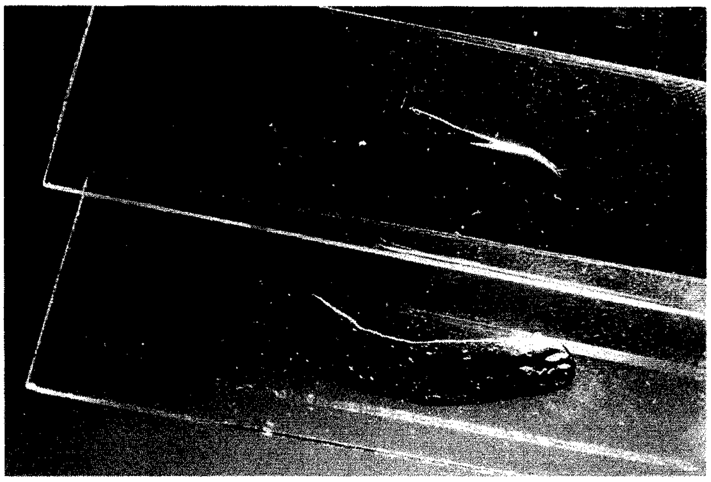

Fig. 1: Spreadproduct for investigating soil stabilizers and evaporation inhibitors concerning their spraying capability. Above: fine bituminous emulsion, easily sprayed. Down: granular emulsion, hardly sprayed

2.2.2 Film Quality

The product is sprayed at the required rate upon Petri dishes filled with air-dried sand. After the dessiccation of the film it is lifted and examined by electron microscopy.

2.2.3 Infiltration Depth

Treated sand aggregates are lifted off and the infiltration of the used conditioner is evaluated microscopically. Sodium fluorescin was added to the Sarea Soil Stabilizer. Ultra violet light was used to measure the infiltration depth.

2.2.4 Soil Structure Stability

It had been learned from preliminary tests dealing with the investigation of the influence of soil stabilizers on the stability of soil structure that convential methods (e. g. wet sieving) had not been satisfying. A rain simulator was used to introduce water droplets from a height of 8.5 m on aggregates located on a sieve (1 mm hole diameter). Its kinetic energy is $5.4 \cdot 10^{-4}$ J. Splashed and dispersed soil particles were collected separately and their quantities were determined gravimetrically. Investigations of soil structure stability were kindly done by Prof. Dr. H. G. Frede and Dipl.-Ing. D. Lütkemöller at the Justus-Liebig-University in Gießen.

2.2.5 Gaseous Exchange

Bituplant 22 was tested for gaseous diffusion using two compartments diffusion apparatus, described by FREDE (1986).

Cylinders were filled with loess or fine sand. They were saturated by capillarity, gradually adjusted to different tension values, namely 1.8, 2.5 and 3.0 pF values. The cylinders were placed in the upper compartment so that the upper sample surface was exposed to the atmosphere while its lower surface was exposed to the lower compartment which was filled with nitrogen. The increase of O_2 in the nitrogen filled compartment was continously measured by means of gaschromatography. Based upon the changes in O_2 concentrations, its diffusion ratio Ds/Do was calculated.

The investigations of gaseous exchange were kindly done by Prof. Dr. H. G. Frede and Dipl.-Ing. D. Lütkemöller at the Justus-Liebig-University in Gießen.

2.2.6 Stability against Wind Erosion

A tube (20 cm ∅, with a lattice for laminar flow) was mounted to adjustable blower. The air stream was directed to sand containers of 30 × 45 cm from a distance of 1 m a 30° angle. The containers were filled with sandy soil. One container was treated, while the other one remained untreated. Wind velocity increased until erosion began on the treated surface. Each test was repeated 5 times.

3. Results

3.1 Spraying Capability

Among several tested bitumen emulsions, number 22 proved very promising in regard to viscosity, stability, breaking time, fineness and spraying capability. This anionic 50 % emulsion, which can be sprayed under the prevailing temperature condition, is called Bituplant 22. Afterwards, it was used for field trials as a bitumen emulsion for plant production.

Concerning the Sarea Soil Stabilizer, some difficulties arose, when higher amounts of its powder were added into water at once because dissolving was impeded by a tacky external layer. These difficulties, however, did not occur if the powder was injected into the barrel (similarly to plant protection products by modern field sprayers).

Table 1

Spraying capabilities of soil conditioners

Product (Spraying concentration)	Spraying capability class*
Bituplant 22 (50 %)	4
Bituplant 22 (25 %)	3
Sarea Evaporation Inhibitor (10 %)	1
Sarea Soil Stabilizer (10 %)	1
Bituplant 22 (50 %) + Sarea Evap. Inhib. (2 %)	2
Bituplant 22 (50 %) + Sarea Evap. Inhib. (1 %)	2
Bituplant 22 (50 %) + Sarea Evap. Inhib. (0,5 %)	3—4
Bituplant 22 (25 %) + Sarea Evap. Inhib. (2 %)	1
Bituplant 22 (25 %) + Sarea Evap. Inhib. (1 %)	1
Bituplant 22 (25 %) + Sarea Evap. Inhib. (0,5 %)	2

* 1 = free from nozzle blocking
2 = slight nozzle blocking
3 = pre-sieving needed
4 = frequent nozzle blocking inspite of pre-sieving

The Sarea Evaporation Inhibitor, however, could be sprayed without any problem. If the two products were combined together in one mixture, Bituplant 22 could be sprayed more easily (table 1).

3.2 Film Quality

The appearance of the conditioner film was examined. From the numerous electron microscopic figures, the 500 to 700 magnifications offered the best details. In figure 2 a bituminous film structure is shown, which has a good bridge- and meniscus-formation and operates so far not only in stabilizing the soil, but reduces also the evaporation. A bitumen formulation with a brittle film structure is shown in figure 3. In cases where the viscosity of the emulsion is too high the product remains on the surface and forms a film, which is too tight and troubles

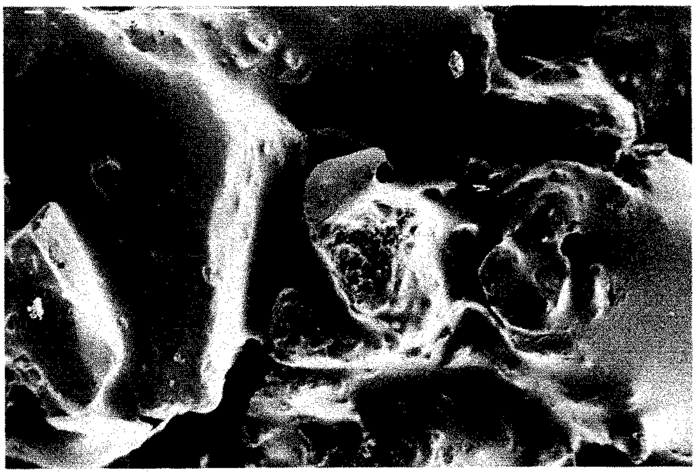

Fig. 2: Semipermeable film with good bridges and menisci, produced by Bituplant 22 (electron microscope, enlarged 500 times)

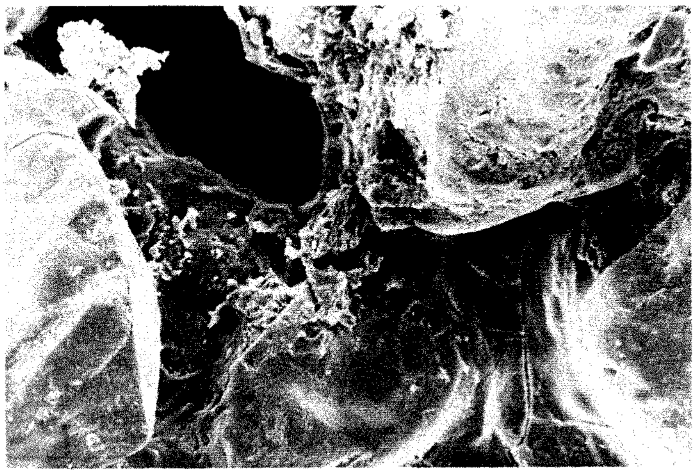

Fig. 3: Bituminous emulsion with cracked film. Very poor soil stabilization and reduction of evaporation (electron microscope, enlarged 500 times)

the water- and gas exchange (fig. 4). Also the Sarea Soil Stabilizer cohered the soil particles good, but forms a perforated film structure which does not hamper the evaporation (fig. 5).

Fig. 4: Bituminous emulsion of too high viscosity. Therefore, film too compact. Filtration, gaseous exchange and crop emergence impeded (electron microscope, enlarged 500 times)

Fig. 5: Sarea Soil Stabilizer causing surface compaction and inhibiting crustation (electron microscope, enlarged 500 times)

Bituplant 22 developed good bridges and menisci. Consequently, soil particles cohered. Both, hydrophobic and hydrophilic characters were observed. Therefore, Bituplant 22 may be used as a soil stabilizer and evaporation inhibitor. Three conclusions were confirmed by measuring evaporation in the phytotron and by field trials: Sarea Soil Stabilizer resulted in intimate cohesion of soil particles. However, there was a lack of film structure inhibiting evaporation. Therefore, its evaporation reduction is not expected to be high. Its soil stabilizing properties were confirmed by results obtained from wind tunnel tests.

Due to the high amount of water associated with Sarea Evaporation Inhibitor, it caused only a slightly crust of the soil surface. It is hardly resisting to wind erosion, and the hydrophobic layer is 10 to 15 mm. This soil conditioner is mainly suited for reducing evaporation. The formed hydrophobic layer can be destroyed by pelting rains or by sprinkler irrigation. It will regenerate itself, but can also be stabilized by mixing with Bituplant 22 or Sarea Soil Stabilizer.

3.3 Infiltration Depth

Table 2

Infiltration depth of the products (arithmetic mean and standard deviation, measuring repeated 4 times)

Product	Application rate/ha	Infiltration depth into sand in mm			
		dry sand		moist sand	
		$\bar{x}$	s	$\bar{x}$	s
Bituplant 22	1 500 l, 50 %	1.2	0.1	2.1	0.2
Bituplant 22	3 000 l, 25 %	2.1	0.2	3.2	0.2
Sarea Soil Stabilizer	100 kg/1 000 l water	1.7	0.1	3.5	0.2
Sarea Evaporation Inhibitor	75 l/15 000 l water	9.1	1.3	14.4	0.7

The application technique is also a decisive factor for film production and above all for infiltration depth. When Bituplant was atomized, a homogenous film was produced but its penetration was not very deep (fig. 6). However, if the product was sprayed, the relatively large droplets penetrated between the sand grains forming better menisci (fig. 7). Penetration also depends on the viscosity of the soil conditioner, the breaking time of a bitumen emulsion and its rate of application. As the viscosity increases, penetration depth proportionally decreases. Moreover, as soil moisture constantly increases, penetration depth also increases, probably due to the miscibility of the soil conditioner in soil water (table 2).

Fig. 6: Influence of application technique on film production. Bituplant was atomized, film is coating the surface of the sand grains and the material hardly penetrates the soil surface (electron microscope, enlarged 500 times)

Fig. 7: Influence of application technique on film quality. Having been sprayed, Bituplant penetrates more deeply and more unblocked pores are produced assisting infiltration and gaseous exchange (electron microscope, enlarged 750 times)

3.4 Soil Structure Stability

It is well known that soil erosion, particularly splash erosion, may occur if the kinetic energy of intercepted water drops is high.

Moreover, increased soil particles dispersion will result in increasing soil erosion. However, the use of soil conditioners is beneficial for improving soil aggregate stability. The data obtained for the reduction of soil erosion after the application of Bituplant 22 and of Sarea Soil Stabilizer are given in table 3. Apparently, bitumen reduced percent dispersed soil particles and splashed soil particles, consequently soil erosion by about 60 %. In the meantime, Sarea Soil Stabilizer appeared to be less effective than Bituplant 22 as it only reduced splashed soil particles by 20 %; but higher dosages proved more effective.

Table 3

Percent reduction of dispersed and splashed soil particles for loamy soil

Product	Dispersed soil particles (g)			Splash (g)		
	$\bar{x}$ (n=5)	s	LSD P 5 %	$\bar{x}$ (n=5)	s	LSD P 5 %
Bitumen	181.9*	12.29	104.6	18.79*	1.60	2.16
Control	528.0*	100.5		32.61*	1.35	
Reduction in %	65.6			64.2		
Sarea Soil Stabilizer	245.6	15.0	70.33	35.28	2.17	3.67
Control	307.4	66.4		34.65	2.81	
Reduction in %	20.1			0.0		

* Significance at ≦5 %

3.5 Gaseous Exchange

The data obtained for O_2 diffusion ratio, Ds/Do increased as pF values increased. It was also found that O_2 diffusion in the sandy soil is extremely higher than in the loamy soil. The application of Bituplant 22 definitely inhibited O_2 diffusion. This inhibition is evident at 1.8 pF value for both soils. Yet, O_2 diffusion ratio became almost constant for the sandy soil at pF values greater than 1.8. However, its values for the loamy soil were approximately equal to the control. Such behaviour is attributed to the presence of bitumen film partially blocking the interparticle spaces at the soil surface.

Table 4

The effect of bitumen on O_2 diffusion ratio, Ds/Do at various soil moisture tensions (measuring repeated 15 times)

pF	Sand Control $Ds/Do \cdot 10^{-2}$	Bituplant 22 $Ds/Do \cdot 10^{-2}$	 % of control
1.8	11.0	7.97*	72.5
2.5	13.5	9.22*	68.3
3.0	14.4	9.27*	64.4
pF	**Loess** Control $Ds/Do \cdot 10^{-2}$	Bituplant 22 $Ds/Do \cdot 10^{-2}$	 % of control
1.8	0.18	0.09*	50.0
2.5	0.70	0.63	90.0
3.0	1.38	1.41	102.2

* Significance at $P \leqq 5\,\%$

Assuming $Ds/Do = 0.02$ as a limiting value for the inhibition of the growth of plants and aerobic microorganisms, as known from literature, hence it will be expected that bitumen is harmless for the sandy or loamy soil at soil moistures near field capacity. Concerning loess, only in the range of high water contents (as field capacity and more) bitumen films may be considered inhibiting gaseous exchange by diffusion.

3.6 Stability against Wind Erosion

Table 5

Results of wind erosion tests in the laboratory (arithmetic mean and standard deviation, measuring repeated 4 times)

Product	Application rate	Erosion beginning at wind velocity, km/h $\bar{x}$	 s
untreated	—	46.0	1.3
Bituplant 22	1500 l/ha	98.5	2.1
Sarea Soil Stabilizer	100 kg/ha	90.0	2.0
Sarea Evaporation Inhibitor	75 l/ha	47.5	0.9

Data presented in table 5 indicate that sandy soil is susceptible to wind erosion at wind velocity greater than 12.8 m/s. After the application of Bituplant 22 or Sarea Soil Stabilizer, soil erosion will occur only if wind velocity is increased to approximately 25 m/s. On the other hand, Sarea Evaporation Inhibitor behaved similarly to the control. These results prove that not every soil conditioner can control wind erosion.

4. Discussion

Beside minimal tillage, sowing plant covers and covering the soil by organic material, also the use of soil stabilizers for soil protection has been investigated. In humid areas soil erosion and wind erosion should be reduced, whereas in arid zones wind erosion and also evaporation should be inhibited. These methods should be used for improving plant production in crop areas yet existing as well as for recultivating desert soils.

After various products had been tested in Austria and in Egypt during several years, the following strategy of product finding was developed:

1. Laboratory trials: the effective mechanisms and the properties of any product have to be investigated under defined environmental conditions, must then be described hypothetically and finally examined in regard to their reproducibility. Product finding could be done by electron microscopy, according to the objectives aimed at. Any test method developed in the laboratory, should also ensure quick control of a soil conditioner during production or at least, before delivery.

2. Green-house and phytotron tests: the second step in assessing the products were growth trials in the green-house and evaporation tests in the phytotron, where desert climate could be simulated.

3. Field trials: when the properties of the products will have been evaluated, specific field trials may be done. Any differences in the efficiency of the products will be evaluated more easily.

Among several bitumen emulsions tested, a new formula called "Bituplant 22", showed the best properties for being used in agriculture. This 50 % anionic emulsion can either be sprayed or atomized. It has soil stabilizing and soil warming capacities. Soil crusting and evaporation is reduced.

Among all non-bitumenous soil stabilizers, Sarea Soil Stabilizer proved very promising. By this colourless product soil particles are cohered, soil crusting is inhibited and, due to its content of 20 to 22 % of nitrogen, 4 to 5 % of K_2O and 5 to 6 % of P_2O_5 it is considered also a fertilizer.

The Sarea Evaporation Inhibitor is also colourless. By this product evaporation is reduced for a longer period in lightly textured soils. It is applied with high amounts of water (sprayed or irrigated), and a reversible hydrophobic layer will occur at a depth of 10 to 15 mm.

All these three products can be mixed and applied as a tank-mixture. If Sarea Soil Stabilizer or Sarea Evaporation Inhibitor will be added, Bituplant will be sprayed more easily.

Summary

The use of soil stabilizers and evaporation inhibitors was studied for more than ten years. Methods for assessing the products of being used for agriculture were developed. Three products have been found showing the following properties:

Bituplant 22, a 50 % anionic bitumen emulsion, applied at a rate of 1000 to 3000 l/ha, proved soil stabilizing, soil warming and reducing evaporation and soil crusting.

Sarea Soil Stabilizer, a powder, forms a colourless film and has to be applied at a rate of 100 kg/ha, diluted with 1000 l of water. Soil stabilization, reduction of evaporation and a fertilizing effect can be observed. Sarea Evaporation Inhibitor, a liquid product, applied at a rate of 75 l/ha with appropriate water amounts, forms a hydrophobic reversible layer at a depth of 10 to 15 mm. All the three products may also be applied as a mixture, if necessary.

Möglichkeiten zur Verhinderung der Bodenerosion und Verbesserung der Pflanzenproduktion in ariden Klimagebieten

1. Mitteilung: Grundlegende Untersuchungen über bodenfixierende und verdunstungshemmende Substanzen im Labor und mittels Elektronenmikroskopie

Zusammenfassung

In mehr als zehnjähriger Forschungsarbeit wurde die Verwendung von bodenstabilisierenden und verdunstungshemmenden Substanzen studiert. Es wurden Verfahren entwickelt, die eine Beurteilung derartiger Produkte für ihre Eignung in der Landwirtschaft gestatten.

Es konnten drei Produkte mit folgenden Eigenschaften gefunden werden:

Bituplant 22, eine 50 %ige anionische Bitumenemulsion, die in Aufwandmengen von 1000 bis 3000 l/ha bodenstabilisierend und bodenerwärmend sowie vedunstungs- und verkrustungshemmend wirkt.

Sarea-Bodenfestiger, ein pulverförmiges Produkt, das in Aufwandmengen von 100 kg/ha, gelöst in 1000 l Wasser, einen farblosen Film bildet. Das Produkt hat eine bodenfixierende und verkrustungshemmende Wirkung und enthält Pflanzennährstoffe.

Sarea-Verdunstungshemmer ist ein Flüssigprodukt, das in Aufwandmengen von 75 l/ha mit entsprechend hohen Wassermengen ausgebracht wird und eine hydrophobe, reversible Schicht in 10 bis 15 mm Tiefe bildet.

Alle drei Produkte können entsprechend den Erfordernissen auch in Form von Tankmischungen ausgebracht werden.

Acknowledgement

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