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THE CONTENT OF TOPSOIL NUTRIENTS, pH AND ORGANIC CARBON AS AFFECTED BY LONG-TERM APPLICATION OF MINERAL AND ORGANIC FERTILISERS

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Soil is the fundamental element in agriculture and is affected in a variety of ways. Besides other things, the long-term application of mineral and organic fertilisers can significantly influence the topsoil pool of nutrients, organic carbon content and pH. Within the scope of long-term field experiments in Praha-Ruzyně, we evaluated the effect of six fertiliser treatments – unfertilised Control, farmyard manure (FYM), cattle slurry (CAT), cattle slurry amended with straw from previous cereals (CAT+STR), mineral fertiliser (NPK) and NPK amended with FYM (NPK+FYM) on a topsoil pool of nutrient content, organic carbon content (Cox) and pH between the years 2001 and 2012. In the selected period, the fertiliser treatment did not influence the N and Cox content (ranging from 0.126% to 0.143%). Phosphorus and potassium were significantly higher in the NPK+FYM treatment (109.82 and 279.27 mg/kg, respectively), while calcium and magnesium were significantly lower in the NPK treatment (2,973 and 134.95 mg/kg, respectively). Application of mineral fertilisers significantly decreased the value of pH, influencing the Ca and Mg topsoil concentrations. Organic fertilisers cannot provide a sustainable amount of nutrients to generate high yields in a short time, but release their nutrients slowly and the range of nutrients is wider. Mineral fertilisers, if not amended with organic fertilisers, can provide huge doses of nutrients, which can be quickly reused for high yields, but negatively influence the pH value, resulting in a decrease in the pool of Ca and Mg.

Key words: soil, nutrient pool, cattle slurry, farmyard manure, NPK

Application of mineral and organic fertilisers on arable soil is accompanied by many pros and cons. Due to fertilisers, farmers can increase the potential yields and quality of arable crops and provide sustainable production of raw materials to fulfil the increasing demands from the food-processing industry. Furthermore, organic and mineral fertilisers can have a beneficial effect on soil characteristics and fertility by increasing soil organic carbon in topsoils (Hati *et al*. 2006; Sradnick *et al*. 2014), water holding capacity, saturated hydraulic conductivity (Zhang *et al*. 2014), microbial biomass (Geisseler & Scow 2014) and decreasing bulk density (Bandyopadhyay *et al*. 2010; Zhang *et al*. 2014). Application of cattle manure can increase the total N concentration in the upper soil layers (Zhengchao *et al*. 2013). Application of N can significantly increase the content of Fe and Mn, and application of FYM can significantly increase Cu and Zn in topsoils (Zhang *et al*. 2014).

On the other hand, over-fertilisation of arable soils (especially the use of nitrogen) can cause serious harm to the environment via ground and surface water pollution and also significant financial losses (Raun & Johnson 1999). The combination of mineral and organic fertilisers can cause environmental damages as many farmers do not consider organic fertilisers, pig slurry specifically, as fertiliser, but as

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a waste product. As a consequence, farmers do not reduce the total amount of mineral nutrients, harming the environment (Berenguer *et al*. 2008).

Within the framework of a long-term crop rotation experiment in Prague-Ruzyně, established in 1954, we evaluated the effect of six fertiliser treatments on the topsoil (0–20 cm) content of nutrients (N, P, K, Ca, Mg), organic carbon content (Cox) and pH between the years 2001 and 2012.

MATERIAL AND METHODS

Site description

The Ruzyně Fertiliser Experiment (RFE) was established on a permanent arable field in 1954, on the western edge of Prague. At the study site, the longtime mean annual temperature is 8.8 ± 7.5°C and the mean annual precipitation is 519.7 ± 23 mm (Prague-Ruzyně Meteorological Station 1953–2013). During the time of our experiment (2001–2012), the mean annual temperature and precipitation were higher, as the temperature increased to 9.5 ± 7.5°C and precipitation to 552.4 ± 26.5 mm (Figure 1). According to World Reference Base for Soil Resources (2nd ed., revised, 2007), the soil type was classified as Luvisol (LV). The parent material is loess mixed with highly weathered chalk. The ground water level is 20 m below the field surface. The upper 30 cm (arable layer) contains 27% clay, increasing to 40% in the subsoil (soil layer 30–40 cm) and 49% at 40–50 cm depth.

Experimental design

The RFE consists of four strips (I, II, III and IV). Each strip is divided into 96 experimental plots, where a total of 24 variants of fertiliser treatments in four replications are running (24 × 4 = 96). The size of the individual plot is 12 × 12 m. To eliminate the edge effect, only the central 5 × 5 m area is used for sample collection. A more detailed description of RFE is available in Hejcman *et al*. (2012). Data, evaluated in this paper are from the strip IV. Out of 24 fertiliser treatments, only 6 variants were evaluated in this paper. These are: Control (non-fertilised from 1954), FYM, CAT, CAT+STR, mineral fer-

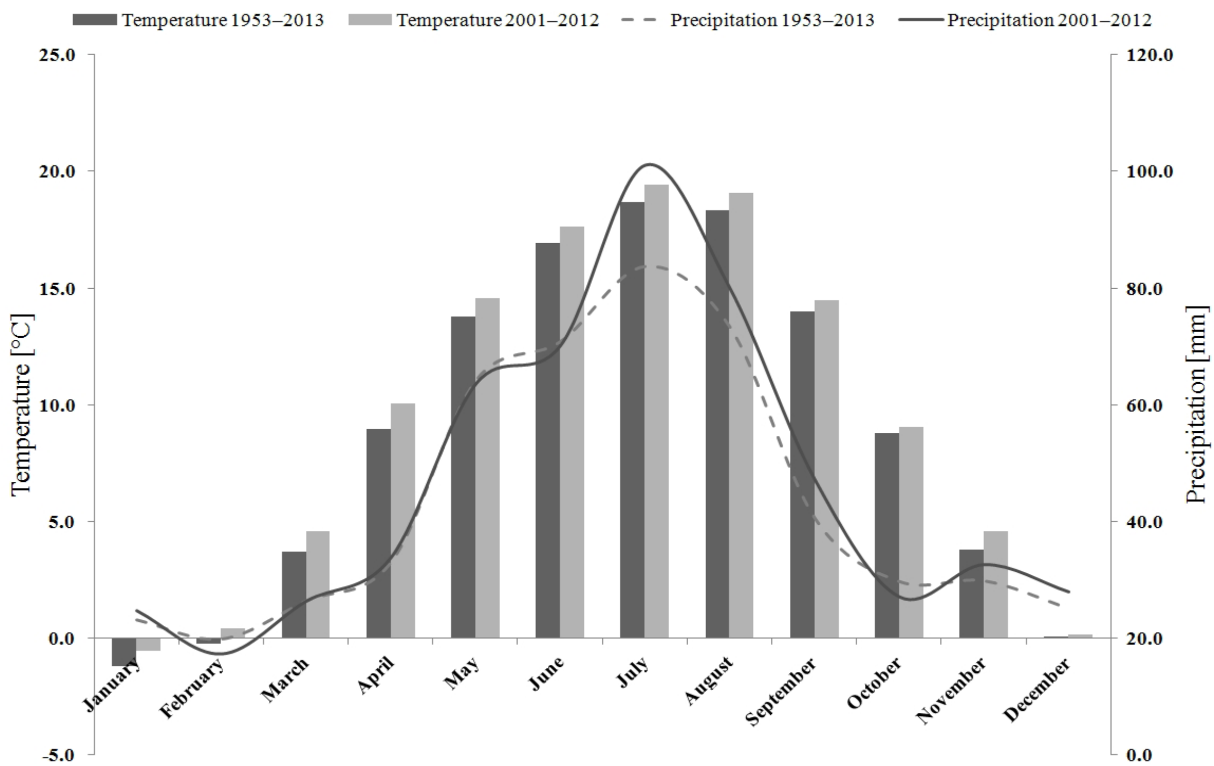

Figure 1. Comparison of the mean monthly temperature [°C] and precipitation [mm] between 1953 and 2013 (longtime means) and 2001 and 2012 (means during the experiment)

tilisers (NPK) and NPK+FYM. The FYM and CAT were applied in the autumn and only to root crops in the crop rotation. STR was ploughed back into the land only after cereals. Nitrogen, phosphorus and potassium were applied as ammonium nitrate with lime, 27% N, triple superphosphate, 19.4% P and potassium chloride, 49.8% K. Nitrogen was applied in the spring, and phosphorus and potassium were applied in the autumn before sowing. The crop rotation is composed of 45% of cereals, 33% of roots and 22% of fodder. The specific crop rotation with exact rates of applied organic and mineral fertilisers is shown in Table 1. Photography of the experimental site is shown in Figure 2.

Soil analysis

Soil samples [depth of 0–0.2 m] were recovered every autumn before fertilisers were applied. To analyse the content of nitrogen [%], soil samples were decomposed with concentrated sulphuric acid in a heating block (Tecator, Sweden), followed by the Kjeldahl method analysis. Phosphorus, potassium, calcium and magnesium [mg/kg] were analysed through Mehlich 3 (Mehlich 1984) and then by ICP OES (Integra XL, GBC Scientific Equipment, Australia). The pH value was analysed through ionometric measurement in KCl. Cox [%] was analysed by oxidation in a dichromate digestion solution (Zbíral *et al*. 1997).

Statistical analysis

All statistical analyses were performed using STATISTICA 12.0 software (www.StatSoft.com). The effect of the treatment was analysed by one-way analysis of variance (ANOVA). After obtaining significant ANOVA results, a Tukey HSD post hoc

Figure 2. Aerial photograph of Ruzyně Fertiliser Experiment (RFE) strips I–IV

Table 1

The crop rotation and doses of organic [Mg/ha] and mineral [kg/ha] fertilisers on strip IV between 2000 and 2012

Year	Crop rotation	FYM [Mg/ha]	CAT [Mg/ha]	CAT+STR [Mg/ha]	N, P, K [kg/ha]	NPK+FYM [kg/ha; Mg/ha]
2000	*Solanum tuberosum* L.	15	32	32	110, 70, 224	110, 70, 224+15
2001	*Triticum aestivum* L.	–	–	–	95, 60, 120	95, 60, 120
2002	*Beta vulgaris* L.	21	45	45	200, 80, 200	200, 80, 200+21
2003	*Hordeum vulgare* L.	–	–	–	70, 60, 100	70, 60, 100
2004	*Medicago sativa* L.	–	–	–	0, 70, 220	0, 70, 220
2005	*Medicago sativa* L.	–	–	–	0, 100, 300	0, 100, 300
2006	*Triticum aestivum* L.	–	–	–	75, 60, 120	75, 60, 120
2007	*Beta vulgaris* L.	21	45	45	200, 80, 200	200, 80, 200+21
2008	*Hordeum vulgare* L.				70, 60, 100	70, 60, 100
2009	*Solanum tuberosum* L.	15	32	32	110, 70, 224	110, 70, 224+15
2010	*Triticum aestivum* L.	–	–	–	95, 60, 120	95, 60, 120
2011	*Beta vulgaris* L.	21	45	45	200, 80, 200	200, 80, 200+21
2012	*Hordeum vulgare* L.	–	–	–	70, 60, 100	70, 60, 100

test was applied to determine significant differences among individual treatments.

RESULTS AND DISCUSSION

Application of mineral and organic fertilisers did not significantly influence the total soil N content between the years 2001 and 2012 (d.f. = 5, F = 0.354, p = 0.878). The highest N content in topsoil was recorded in the NPK+FYM treatment (0.143%), while the lowest was in the Control treatment (0.126%) (Figure 3a). No statistical differences between Control (without any fertiliser inputs from 1954) and NPK+FYM treatments can be probably explained by several factors. The first factor is a strict compliance with crop rotation, which includes 22% of legumes. Legumes can be a sustainable source of nitrogen in agricultural systems (Peoples *et al*. 1995). According to Yang *et al*. (2010), the adjusted average N_2 fixation rate of alfalfa is 218 kg N/ha, ranging from 141 to 300 kg N/ha. The second factor is the loss of nitrogen to the atmosphere and due to drainage. Jenkinson (1991) concluded that approximately 30% of the total nitrogen entering the plant/soil system of the Broadbalk Wheat Experiment at Rothamsted each year is lost. The leached N comes from mineralisation of soil organic matter and not unused fertiliser residues. With a higher content of soil organic matter, the loss increases and the differences between treatments are not retained. Finally, nitrogen is the most limiting element for yields. The NPK+FYM is the treatment providing one of the highest yields in the RFE (Hlisnikovský & Kunzová 2014), which is associated with a high N demand and its use.

T a b l e 2

The evaluation of P, K and Mg soil content [mg/kg] (Mehlich 3) according to Budňáková *et al*. (2004)

Element/Range	P	K	Mg
Low	<50	<105	<105
Suitable	51–80	106–170	106–160
Good	81–115	171–310	161–265
High	116–185	311–420	266–330
Very high	>185	>420	>330

Phosphorus and potassium soil content exhibited a reciprocal relation. Both elements were significantly influenced by fertiliser treatment (P: d.f. = 5, F = 52.52, p = 0.01; K: d.f. = 5, F = 26.18, p = 0.001), both elements have had the highest concentrations in NPK+FYM treatment (109.82 and 279.27 mg/kg respectively) and the lowest in the Control treatment (25.00 and 139.45 mg/kg respectively; see Figure 3b, 3c). According to Budňáková *et al*. (2004), the concentration of P in the NPK+FYM treatment is classified as ‘good’, while in the NPK treatment, it is just ‘suitable’ and ‘low’ in all other treatments (Table 2). It means that application of organic fertilisers, without mineral fertiliser amendment, cannot provide a sufficient amount of nutrients to create high yields and increase the soil nutrient pool for the next arable crops.

Calcium and magnesium content also showed a similar pattern. The contents of both elements were significantly influenced by fertiliser treatment (Ca: d.f. = 5, F = 16.64, p = 0.001; Mg: d.f. = 5, F = 14.59, p = 0.001). The highest concentrations of Ca (3,680 mg/kg) and Mg (196.45 mg/kg) were recorded in the CAT+STR treatment in both cases, with the lowest (2,973 mg/kg and 134.95 mg/kg, respectively) in the NPK treatment (Figure 3d, 3e). The higher concentrations of Ca and Mg in organic treatments can be explained by two factors. First, organic fertilisers contain a big scale of nutrients in smaller rates. Thus, they provide a regular supply of not only N, P and K, but also Ca, Mg and others. Second, concentrations of Ca and Mg were strongly associated with the pH value. The highest mean pH value was recorded in the CAT treatment (6.61), while the lowest was in the NPK treatment (5.66; see Figure 3g). The correlation relationship was strongly positive between Ca and pH (r = 0.9) and medium positive between Mg and pH (r = 0.55). Application of mineral fertilisers significantly decreased the pH value in our experiment and strongly influenced the Ca and Mg topsoil content. This is in agreement with Barak *et al*. (1997), who also recorded a negative change in pH, Ca and Mg concentrations accompanied by increasing N rates, or with Wang *et al*. (2003). Amendment of FYM to NPK can particularly smooth down the negative effect of NPK as the pH and concentrations of Ca and Mg were slightly higher, when compared to NPK.

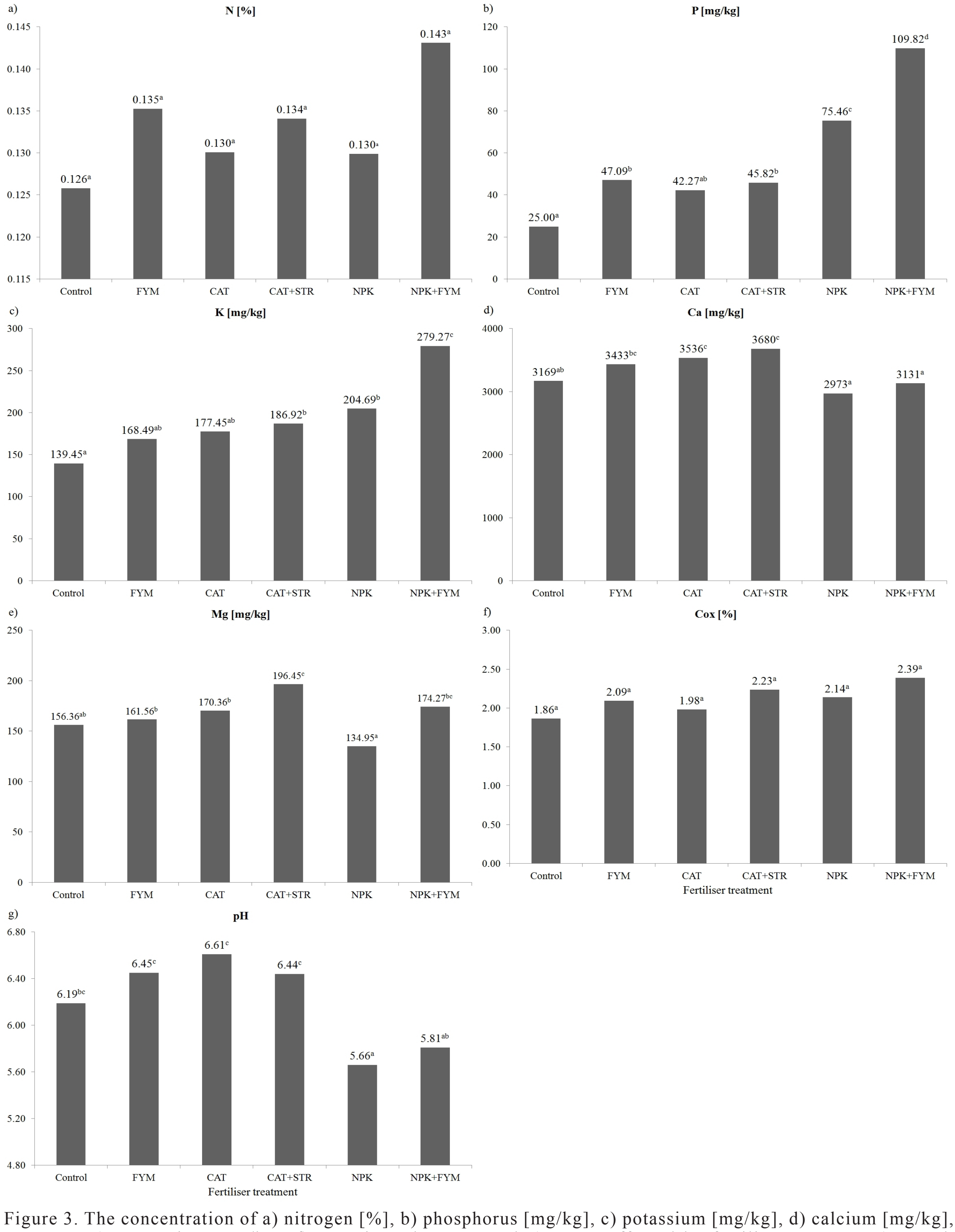

Figure 3. The concentration of a) nitrogen [%], b) phosphorus [mg/kg], c) potassium [mg/kg], d) calcium [mg/kg], e) magnesium [mg/kg], f) organic carbon [%] and g) pH as affected by fertiliser treatment (Control, FYM, CAT, CAT+STR, NPK, NPK+FYM) between 2001 and 2012. Different letters indicate significant differences ($p < 0.05$) between treatments.

No significant differences between fertiliser treatments were observed in the case of Cox (d.f. = 5, F = 0.384, p = 0.858). The highest Cox was recorded in the NPK+FYM treatment (2.39%) and the lowest in the Control treatment (1.86%) (Figure 3f). This is contrary to the results of Zhengchao *et al*. (2013), who recorded a significant increase in soil organic carbon concentration between different mineral fertilisation treatments in the 26-year experiment. There are a few ways in which fertilisers enrich the soil N and Cox content. First, organic fertilisers provide a medium amount of carbon and other nutrients. However, those nutrients are slowly degraded and it takes time to integrate them back to the soil–plant system. According to Pratt *et al*. (1973), 35% of the total N in manure was available to crops during the first year and only 10% and 5% in the second and the third year after application. According to Klausner *et al*. (1994), only 9% of the total N applied by manure was released in the second year and 3% in the third year after manure application. On the other hand, mineral fertilisers provide a huge amount of nutrients, which can be relatively quickly absorbed by plants, leading to the development of a rich root system and thus higher yields (Hejcman *et al*. 2012) under good weather conditions. The ratio of fertiliser mineralisation decreases during dry seasons and increases during wet seasons, when the soil moisture is near the field capacity (Cassman & Munns 1980). Under unsuitable weather conditions, even high doses of mineral fertilisers cannot provide sufficient yields (Hlisnikovský *et al*. 2014). If the aboveground parts of the arable crops are not returned back to the soil by ploughing or tillage, as in our case (except for the CAT+STR treatment), the biggest source of Cox and N remains in decaying roots. Those factors can explain the differences between the Cox topsoil content of specific fertiliser treatments.

CONCLUSION

Between 2001 and 2012, application of organic and mineral fertilisers did not significantly influence the N and Cox topsoil content. The N content increased in the order: Control < CAT, NPK < CAT+STR < FYM < NPK+FYM; Cox showed a similar pattern. As the aboveground parts of the plants are not returned back to the soil in our experiment (except in one treatment), the higher N and Cox contents in well-fertilised treatments are caused due to a richer root system, the only source of organic material. Phosphorus and potassium concentrations did not differ significantly between organic treatments; the content was equal, but was significantly higher in NPK and NPK+FYM treatments. Calcium and magnesium concentrations behaved oppositely. While regular application of high doses of mineral nutrients can provide high yields and leave a relatively good pool of nutrients in the soil, organic fertilisers release more nutrients (N, P, K, Ca, Mg and others) in smaller doses and in a longer period. If the application of mineral fertilisers is not amended with regular application of Ca, the soil pool of those nutrients can decrease significantly and negatively influence the pH value. Thus, the combined application of mineral NPK and FYM provides a wide range of nutrients, which are released in both, short and long periods, and reduce the negative effect of NPK on topsoil pH.

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