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Effects of organic and mineral fertilizer inputs on maize yield and soil chemical properties in a maize cropping system in Meru South District, Kenya

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Abstract Soil nutrient depletion as a result of continuous cultivation of soils without adequate addition of external inputs is a major challenge in the highlands of Kenya. An experiment was set up in Meru South District, Kenya in 2000 to investigate the effects of different soil-incorporated organic (manure, *Tithonia diversifolia*, *Calliandra calothyrsus*, *Leucaena leucocephala*) and mineral fertilizer inputs on maize yield, and soil chemical properties over seven seasons. On average, tithonia treatments (with or without half recommended rate of mineral fertilizer) gave the highest grain yield (5.5 and 5.4 Mg ha^{-1} respectively) while the control treatment gave the lowest yield (1.5 Mg ha^{-1}). After 2 years of trial implementation, total soil carbon and nitrogen contents were improved with the application of organic residues, and manure in particular improved soil calcium content. Results of the economic analysis indicated that on average across the seven seasons, tithonia with half recommended rate of mineral fertilizer treatment recorded the highest net benefit (USD 787 ha^{-1}) while the control recorded the lowest (USD 272 ha^{-1}). However, returns to labor or benefit-cost ratios were in most cases not significantly improved when organic materials were used.

Keywords Biomass transfer · Economic returns · Combination · Soil fertility · Tithonia

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Introduction

Many interrelated factors, both natural and managerial, cause soil fertility decline. This decline may occur through leaching, soil erosion, and crop harvesting (Donovan and Casey 1998). Unless the nutrients are replenished through the use of organic or mineral fertilizers, or partially returned through crop residues, or rebuilt more comprehensively through traditional fallow systems that allow restoration of nutrients and reconstruction of soil organic matter, soil nutrient levels decline continuously.

The soils in the central highlands of Kenya are Humic Nitisols with moderate to high inherent fertility (Jaetzold and Schmidt 1983), however, their fertility has declined over time, with an annual net nutrient depletion exceeding 30 kg N

(Smaling 1993) as a result of continuous cropping with insufficient external nutrient replenishment. For instance, a long term trial in Kabete, Kenya, indicated that a fertile red soil lost about 1 Mg ha^{-1} of soil organic N and 100 kg P ha^{-1} of soil organic P during 18 years of continuous maize-common bean rotation in the absence of nutrient inputs (Sanchez et al. 1997). During this period maize yields without N and P fertilizer inputs decreased from 3 to 1 Mg ha^{-1} (Bekunda et al. 1997; Sanchez et al. 1997). In most smallholder farms, these deficiencies could be replenished through the use of mineral fertilizers and cattle manure. The situation is however, further aggravated by the fact that even the farmers using mineral fertilizers hardly use the recommended rates (60 kg N ha^{-1}) in the area, with most of them applying less than 20 kg N ha^{-1} (Adiel 2004). As a result, soil fertility has continued to decline as has the productivity of the land (Kapkiyai et al. 1998; Adiel 2004).

Locally available organics could be used to curb this problem. For instance, Mugendi et al. (1999) reported that soil-incorporation of calliandra and leucaena green biomass with or without fertilizer increased total soil nitrogen by 1–8% over a period of 4 years. During the same period, total soil nitrogen declined by 2–4% when biomass was not applied. Mutuo et al. (2000) reported that treatments that had received tithonia biomass had a high residual effect of 50% yield increase above the control in western Kenya.

Technologies that combine mineral fertilizers with organic nutrient sources can be considered as better options in increasing fertilizer use efficiency, and providing a more balanced supply of nutrients (Donovan and Casey 1998). Combination of organic and mineral fertilizer nutrient sources has been shown to result in synergistic effects and improved synchronization of nutrient release and uptake by crop (Palm et al. 1997) leading to higher yields; especially when the levels of mineral fertilizers used are relatively low as is the case in most smallholder farms of central Kenya (Kapkiyai et al. 1998). Maize yields were increased with increasing rates of farmyard manure application, however, maize grain yields above 3.5 Mg ha^{-1} were only obtained when both farmyard manure and NP fertilizers were applied (Kihanda 1996). Leucaena biomass combined with mineral fertilizer gave higher crop yields as compared to sole use of mineral fertilizer or sole leucaena biomass (Mugendi et al. 1999). The practice may hold the key to effective soil fertility management in Meru South District of Kenya.

A trial using organic and mineral inputs was established in the main maize growing areas of the central highlands of Kenya in 2000 with the main objective of addressing the decline in soil fertility. The study aimed to determine the effects of different organic sources and combinations with mineral fertilizers inputs on maize yield, and soil chemical properties and also to determine the economic returns of the different inputs.

Materials and methods

Experimental site

The study was conducted in Chuka Location (0°20′07″S; 37°37′14″E), Meru South District, Kenya. According to Jaetzold and Schmidt (1983), the area is in upper midlands 2 and 3 (UM2–UM3) with an altitude of approximately 1,500 m above sea level, annual mean temperature of about 20°C and annual rainfall varying from 1,200 to 1,400 mm. The rainfall is bimodal, falling in two seasons, the long rains (LR) lasting from March through June and short rains (SR) from October through December (Fig. 1). The soils are Humic Nitisols (Jaetzold and Schmidt 1983), which are deep, well weathered with moderate to high inherent fertility (Table 1).

Experimental layout and management

The experiment was established in March 2000 and laid out as a randomized complete block design (RCBD) with the plot sizes measuring 6 m × 4.5 m replicated thrice. A maize variety H513 commonly grown by farmers in the area was planted at a spacing of 0.75 and 0.5 m inter- and intra-row, respectively and two (2) maize plants planted per hill. Nine external soil fertility amendment inputs ((1) manure, (2) manure + 30 kg N ha^{-1}, (3) tithonia, (4) calliandra, (5) leucaena, (6) tithonia + 30 kg N ha^{-1}, (7)

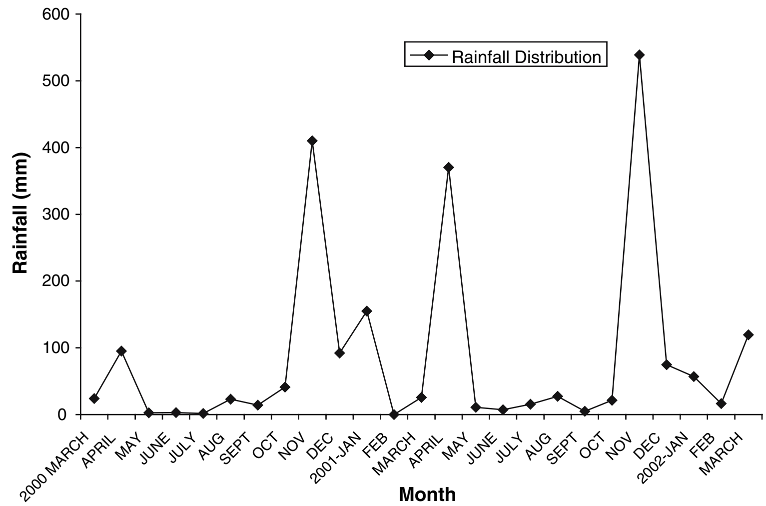

Fig. 1 Rainfall distribution from 2000 to 2003 in Chuka, Meru South District, Kenya

Table 1 Background soil physical and chemical characteristics (0–15 cm) in Chuka, Meru South District, Kenya

Soil parameters	
pH in water	5.2
Total N	2.1 g kg^{-1}
Total P	0.8 g kg^{-1}
Total soil organic carbon	18 g kg^{-1}
Exchangeable P	7.1 cmol kg^{-1}
Exchangeable K	0.3 cmol kg^{-1}
Exchangeable Ca	3.4 cmol kg^{-1}
Exchangeable Mg	1.2 cmol kg^{-1}
Clay	33.5%
Sand	38.5%
Silt	28%

calliandra + 30 kg N ha^{-1}, (8) leucaena + 30 kg N ha^{-1}, and (9) 60 kg N ha^{-1}) were applied every season to give an equivalent of 60 kg N ha^{-1}—this is the recommended rate of N to meet maize nutrient requirement for an optimum crop production in the area (FURP 1987). The tenth treatment was an absolute control where no external inputs were applied.

The organic materials were harvested, from nearby plots established for that purpose. A sample of each organic input was taken and N content determined, then the amount of organic to be applied, equivalent to 30 or 60 kg N, was determined. The average nutrient composition of the organic inputs that were incorporated in the seven seasons is shown in Table 2. The organic materials were then weighed, chopped and incorporated into the soil to a depth of 15 cm during land preparation in all the seasons. Fertilizer N was applied in split applications with 33.3% being top-dressed 4 weeks after planting and the rest (66.6%) 4 weeks later. A uniform P application was done in all the plots at the recommended rate (60 kg P ha^{-1}) as triple super phosphate (TSP). Other agronomic procedures for maize production were appropriately followed after planting.

Sampling and analyses

Sub-samples of the organic materials were collected randomly at the beginning of each season and analyzed for N, P, K, Ca and Mg to determine their quality (Table 2). Soil was sampled at 0–15 cm depth at the beginning of the 2000 LR season (1st season) and at the end of the 2001 SR season (4th season). Soil samples were taken at eight different spots per plot and then bulked to one sample and were then analyzed for pH, Ca, Mg, K, C, and N using the ICRAF Laboratory Methods of Soil and Plant Analysis (1995). At maturity, maize was harvested and the fresh weight of both grain and stover taken. The maize grain was then air-dried and the dry weight taken and expressed on a 12.5% water content basis. Biophysical data was subjected to analysis of variance using Genstat programme and the

Table 2 Average nutrient composition (%) of organic materials applied in the soil from 2000 to 2003 at Chuka, Meru South District, Kenya

Treatment	N (%)	P (%)	Ca (%)	Mg (%)	K (%)	Ash (%)
Cattle manure	1.4 d	0.2 a	1.0 c	0.4 b	1.8 b	46.1 a
Tithonia	3.0 c	0.2 a	2.2 a	0.6 a	2.9 a	13.2 b
Calliandra	3.3 b	0.2 a	0.9 d	0.4 b	1.1 c	5.8 d
Leucaena	3.8 a	0.2 a	1.4 b	0.4 b	1.8 b	8.7 c

Means with same letter in each column, are not statistically different at $P < 0.05$

means separated using *t*-test and Tukeys test at $P < 0.05$.

Economic analysis

The information used for cost-benefit analysis in this study was collected at the specific time of each activity in the course of each season. The data was mainly from farmers and agro-input retailers. The cost-benefit analysis was done using the farm gate prices of the various inputs, however, all the organic amendments (except manure) did not have market prices in the area and hence they were costed in terms of the labor involved in harvesting and incorporation (Table 3) (CIMMYT 1988).

Since the organic resources were collected near the experimental plots, only the labor for collection, transport and application was taken into account and it was estimated to be 2.9 USD 100 kg^{-1} on dry matter basis (Nziguheba et al. 2002). The labor was valued at the local wage of 0.13 USD h^{-1}. The application of the fertilizer was estimated to take an extra 7% of the total labor cost required for maize planting (Jama et al. 1997). Harvested yields in each treatment were reduced by 10% to adjust to realistic values if the experiment had been managed by a farmer (CIMMYT 1988). Maize stover was used as cattle feed in the area (with a market value of 12 USD ton^{-1}) and was thus accounted for as a benefit in addition to the maize grain.

Table 3 Parameters used to calculate the economic returns for the different nutrient replenishment technologies

Parameter	Actual values
Price of NPK (23:23:0)	1.38 USD kg^{-1} N
Labor cost	0.13 USD h^{-1}
Labor cost for planting maize	10.5 USD ha^{-1}
Labor for applying fertilizer	0.74 USD ha^{-1}
Labor for application of organic inputs	2.9 USD 100 kg^{-1} DM
Price of maize	0.146 USD kg^{-1}
Price of stover	0.012 USD kg^{-1}

DM = dry matter basis. Exchange rate 76 Ksh = 1 USD (February 2004)

Results

Soil properties

After 2 years of continuous cultivation and application of organic and mineral fertilizer inputs, the general soil fertility parameters changed in the different treatments (Tables 4 and 5).

For instance, soil carbon had increased significantly ($P < 0.05$) by the end of the 2001 SR season in treatments that received organic or inorganic inputs with treatments of manure, calliandra and calliandra with half recommended rate of mineral fertilizer having the highest soil carbon content. Potassium increased significantly in the manure, tithonia and tithonia with half recommended rate of mineral fertilizer treatments. Calcium increased most significantly in the sole manure treatment. Soil pH decreased significantly in sole tithonia, calliandra with half recommended rate of mineral fertilizer, leucaena with half recommended rate of mineral fertilizer and recommended rate of mineral fertilizer treatments in comparison with other organic treatments. However, only pH of soil under calliandra with half recommended rate of mineral fertilizer and the sole recommended rate of mineral fertilizer treatments were lower than that of the control by the end of 2001 SR season.

Table 4 Soil chemical properties (0–15 cm) at the beginning of the 2000 long rains season at the experimental site, Chuka, Meru South District, Kenya

Treatment	pH	Ca	Mg	K	C	Total N
		Exchangeable (cmol/kg)			g/kg	
Manure	5.2 cde	3.1 cd	1.1 d	0.3 bc	16.8 c	2.4 b
Manure + 30 kg N ha^{-1}	5.4 bc	4.0 b	1.5 ab	0.3 bc	16.5 c	2.3 c
Tithonia	5.2 cde	3.1 cd	1.4 bc	0.2 c	18.9 ab	2.5 a
Calliandra	5.1 de	2.4 e	0.9 e	0.3 bc	16.9 c	2.5 a
Leucaena	5.6 ab	5.1 a	1.6 a	0.5 a	18.2 ab	2.4 b
Tithonia + 30 kg N ha^{-1}	5.8 a	5.6 a	1.5 ab	0.4 ab	17.1 bc	2.4 b
Calliandra + 30 kg N ha^{-1}	5.0 e	2.6 de	1.0 de	0.3 bc	19.2 a	2.5 a
Leucaena + 30 kg N ha^{-1}	5.2 cde	3.4 bc	1.4 bc	0.3 bc	16.7 c	2.3 c
60 kg N ha^{-1}	5.3 cd	3.4 bc	1.3 c	0.4 ab	18.7 ab	2.5 a
Control	5.2 cde	2.8 cde	1.1 d	0.4 ab	16.6 c	2.3 c

Means with same letter in each column, are not statistically different at $P < 0.05$

Table 5 Soil chemical properties (0–15 cm) at the end of the 2001 short rains season at the experimental site, Chuka, Meru South District, Kenya

Treatment	pH	Ca	Mg	K	C	Total N
		Exchangeable (cmol/kg)		g/kg		
Manure	5.5 a	6.3 a	2.3 a	0.9 a	21.5 bc	2.5 a
Manure + 30 kg N ha^{-1}	5.3 b	5.5 b	2.2 a	0.7 b	18.7 e	2.4 a
Tithonia	4.8 cd	3.9 d	1.6 c	0.5 c	20.8 c	2.4 a
Calliandra	4.9 c	4.6 c	1.6 c	0.3 d	22.5 ab	2.4 a
Leucaena	5.3 b	5.9 ab	1.7 c	0.6 bc	20.8 c	2.1 b
Tithonia + 30 kg N ha^{-1}	5.3 b	5.7 b	1.9 b	0.6 bc	20.3 cd	2.4 a
Calliandra + 30 kg N ha^{-1}	4.5 f	2.9 e	1.0 f	0.3 d	22.8 a	2.4 a
Leucaena + 30 kg N ha^{-1}	4.7 de	3.8 d	1.4 d	0.3 d	19.5 de	2.2 b
60 kg N ha^{-1}	4.6 ef	3.5 d	1.2 e	0.3 d	19.3 de	2.1 b
Control	4.7 de	3.6 d	1.1 ef	0.3 d	16.5 f	1.9 c

Means with same letter in each column, are not statistically different at $P < 0.05$

Maize grain yield

The maize grain yields were significantly different ($P < 0.05$) between treatments in the seven seasons (Table 6).

On average tithonia treatments, sole or in combination with half recommended rate of mineral fertilizer, gave the highest yields (5.5 and 5.4 Mg ha^{-1} respectively). The control gave consistently the lowest yield (average 1.5 Mg ha^{-1}) across all seasons. On average, tithonia, leucaena, and calliandra with mineral N fertilizer resulted in improved maize grain yields as compared to the sole mineral N fertilizer treatment. Sole calliandra and manure treatments were among the lowest yielding organic based treatments. However, combining calliandra with mineral N fertilizer improved maize yields towards the end of the experiment.

Economic analysis

The results of the economic analysis indicated that on average across the seven seasons tithonia with half recommended rate of mineral fertilizer recorded the highest net benefit of USD 787 ha^{-1} while the control recorded the lowest (USD 272 ha^{-1}) (Table 7). Leucaena recorded the highest benefit cost ratio (BCR) (USD 7.0 ha^{-1}) while manure with half recommended rate of mineral fertilizer and tithonia with half recommended rate of mineral fertilizer recorded the lowest BCR (3.5 ha^{-1}) together with mineral fertilizer treatment (USD 3.6 ha^{-1}). On the other hand,

Table 6 Maize yields under different technologies from 2000 to 2003 in Chuka, Meru South District, Kenya

Treatment	Seasons							
	2000 LR Grain weight (Mg ha^{-1})	2000 SR	2001 LR	2001 SR	2002 LR	2002 SR	2003 LR	Mean
Manure	1.2 abc	6.7 ab	3.7 d	4.6 d	4.2 f	6.1 cd	5.0 c	4.5 c
Manure + 30 kg N ha^{-1}	1.2 abc	6.5 bc	4.9 b	2.9 e	5.9 a	5.0 e	6.5 b	4.7 bc
Tithonia	1.2 abc	6.6 ab	4.3 c	6.5 a	5.4 b	7.0 b	7.4 a	5.5 a
Calliandra	0.7 d	4.6 f	2.8 e	4.5 d	4.5 ef	7.6 a	6.5 b	4.5 c
Leucaena	1.0 c	6.1 d	4.0 cd	5.8 b	4.7 de	6.3 c	6.4 b	4.9 b
Tithonia + 30 kg N ha^{-1}	1.3 ab	6.8 a	5.4 a	5.6 b	5.4 b	6.2 cd	7.2 a	5.4 a
Calliandra + 30 kg N ha^{-1}	1.1 bc	5.8 e	4.3 c	5.1 c	4.3 f	7.2 ab	6.2 b	4.9 b
Leucaena + 30 kg N ha^{-1}	1.3 ab	6.1 d	3.7 d	4.4 d	5.0 cd	7.2 ab	6.2 b	4.8 b
60 kg N ha^{-1}	1.4 a	6.3 cd	5.0 ab	3.2 e	4.3 f	5.8 d	5.5 c	4.5 c
Control	0.6 d	2.6 g	1.2 f	1.5 f	1.2 g	1.6 f	2.0 d	1.5 d

Means with same letter in each column, are not statistically different at $P < 0.05$. LR and SR denotes long rains and short rains respectively

recommended rate of mineral fertilizer gave the highest (USD 12.5 ha^{-1}) return to labor while sole tithonia gave the lowest (USD 4.0 ha^{-1}).

On average across the seven seasons, treatments with sole application of organics recorded a higher BCR compared to treatments with combined organic and mineral fertilizers. On the other hand, treatments with sole organics recorded lower return to labor compared to the treatments with combined organic and mineral inputs, apart from leucaena.

Discussion and conclusions

After 2 years of continuously growing maize, soil pH declined in the calliandra or leucaena with half recommended rate of mineral fertilizer, and the recommended rate of mineral fertilizer treatments. These results corroborates with Kang (1993) and Mugendi et al. (1999) who reported a general reduction in pH after application of mineral fertilizer, and leucaena and calliandra biomass. There was also an increase in organic carbon, exchangeable Ca, and K, after application of manure and this is consistent with the work of Gao and Chang (1996). Changes in soil properties under organically and conventionally managed farming systems have been found to be more variable, perhaps due to differences in climate, crop rotation, soil type, or length of time a soil has been under a particular management (Werner 1997).

The lower pH in the combination of organics and mineral fertilizers compared to the sole application of organic inputs in the calliandra and leucaena treatments could be as a result of the H^+ ions, which are added on the cation

Table 7 Net benefit, benefit-cost ratio (BCR) and return to labor from 2000 to 2003 in Chuka, Meru South District, Kenya

Treatment	USD ha^{-1}		
	Net benefit	BCR	Return to labor
Cattle manure	645 b	5.0 bc	5.0 cb
Cattle manure + 30 kg N ha^{-1}	616 b	3.5 c	6.8 bc
Tithonia	784 a	4.0 bc	4.0 d
Calliandra	653 b	5.8 ab	5.9 cd
Leucaena	780 a	7.0 a	7.0 bc
Tithonia + 30 kg N ha^{-1}	787 a	3.5 c	6.3 cd
Calliandra + 30 kg N ha^{-1}	747 a	4.4 bc	9.0 b
Leucaena + 30 kg N ha^{-1}	572 b	4.3 bc	6.9 bc
60 kg N ha^{-1}	666 b	3.6 c	12.5 a
Control	272 c	5.2 abc	5.2 cd

Means with same letter in each column, are not statistically different at $P < 0.05$

exchange complex of soils from the mineral fertilizer (Tisdale et al. 1993). The pH increase with manure treatment corresponds with the findings by Eghball (2002) and could be attributed to the reduction of exchangeable aluminum in these acidic soils (pH 4.5–5.5) (Hue and Amien 1989). This reduction is considered to occur through aluminum precipitation or chelation on organic colloids or by complexation of soluble aluminum by organic molecules, especially organic acids (Hue and Amien 1989). Indeed, the manure treatment was the only treatment that consistently showed an increase in all the other soil nutrients by the end of 2001 SR, corroborating results reported by Schlegel (1992) and Eghball and Power (1999), who observed an increment of nutrients after manure application over time. Manures have the advantage of supplying essential plant nutrients either directly or indirectly by alleviating aluminum toxicity or by producing organic acids which complex with aluminum, thereby increasing nutrient availability (Nziguheba et al. 1998).

The sole organic materials had a positive contribution to soil carbon in comparison to the mineral fertilizer and the control. This agrees with Eghball (2002), who observed an increase in soil organic carbon after 4 years of manure application where about 25% C was retained in the soil carbon pool. He also observed no significant difference in soil carbon with the mineral fertilizer application only. This was because the organic materials had a major impact on mineralization rates by increasing soil C directly, whereas the effect of mineral fertilizer N was less pronounced since it increased C inputs only indirectly by improving plant growth (Antil et al. 2001).

The relatively low maize grain yield in the 2000 and 2001 LR seasons could be associated with the low and unevenly distributed precipitation that was received in the two seasons respectively. The precipitation received during the 2000 LR season (March–June) totaled to 126 mm and most of it was recorded within the first 3 weeks of the season (Fig. 1). During the 2001 LR season a total of 431 mm was recorded with 86% of the rains being received within the first 2 weeks of the season (Fig. 1).

During the initial seasons, calliandra treatment had low maize grain yields (Table 6) and this could have been attributed to the lower rate of decomposition and mineralization of calliandra biomass that was brought about by its high polyphenol content that is known to bind with N lowering the decomposition rate and N release (Chesson 1997). Indeed, Lehmann et al. (1995) reported that only 52% of calliandra N is released by the time of maximum N demand by maize. However, in the later seasons maize grain yields in the calliandra treatment improved as a result of residual effects from the previous seasons. Calliandra being of relatively low quality usually builds soil organic matter which mineralizes slowly to release N (Niang et al. 1996; Palm et al. 2001).

The often higher return to labor in the treatments with combined organic and inorganic fertilizers could be due to the lower labor required compared to the treatments with sole application of organic inputs. Despite the fact that tithonia had the lowest return to labor in the demonstration site (Table 7), most farmers in the study area were willing to try tithonia biomass transfer in their farms. This could be most probably be due to the low opportunity cost of their time as also observed by Mutuo et al. (2000) with some farmers in their study in Western Kenya. Some of the organic materials like calliandra and leucaena could be more economically attractive when used as a protein supplement for dairy cattle (ICRAF 1993; Jama et al. 1997) and the manure returned back to the fields.

The application of organic and mineral fertilizer inputs increased maize yields across the seven seasons. On average, tithonia treatments, sole or with half recommended rate of mineral fertilizer recorded the highest maize yield. Since the organic materials may often not be available in large amounts that are required for sole application, farmers are encouraged to adopt the combination of organic and mineral fertilizers as they resulted in high maize grain yields, higher net benefits and higher returns to labor.

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