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Soil Properties as Influenced by Soil Fertility Management in Small Scale Maize Farms in Njoro, Kenya

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Abstract: Most farmers are aware of soil fertility gradients within their farms which influence their management decisions and further accentuate these variations. The purpose of this study was to assess the effect of soil amendments on soil properties under farmers management. Soil sampling was done in 37 small scale maize farms in Njoro Division of Nakuru District at 0-20 cm depth. Results of a structured questionnaire showed that 65% of the farmers used inorganic fertilizers predominately diammonium phosphate (DAP), 15% used only farmyard manure, 15% used both organic and inorganic fertilizer, while 6% did not use any soil amendments. Most of the farms had a pH ($CaCl_2$) of less than 5.2, 27% of the farms had a pH lower than 4.0. Organic carbon (C) ranged from 1.6 to 5.8%, with a median value of 2.6%. Most of the farms were phosphorus (P) deficient with an Olsen-P of less than 10 mg kg^{-1}. All farms had sufficient amounts of extractable potassium (K). Total nitrogen (N) ranged from 0.12 to 0.33% with 97% of the farms with N content (>0.12%). Farms amended with farmyard manure had higher organic C and total N levels in Kikapu with correspondingly lower C: N ratios. Soil pH and total N were higher for farms with gentle and undulating slopes. Overall most of the farms were acidic and of moderate fertility. Liming increased maize biomass production in Njoro. This study underscores the need for organic inputs and regular soil testing for small scale farmers.

Key words: Organic fertilizer, diammonium phosphate, nutrient levels, digital elevation model slopes

INTRODUCTION

The Ministry of Agriculture in Kenya in its 2003 strategy for revitalizing agriculture policy paper underscores the need to intensify agricultural production for food security and poverty reduction in rural Kenya. Rural communities are predominantly composed of small scale farmers who have access to various organic inputs but often in insufficient quantities to provide the necessary soil nutrients required for improved production. On the other hand, many small scale farmers apply inorganic fertilizer at low doses, primarily for lack of capital and information on appropriate recommendation rates. The farmers are therefore in a vicious cycle of under-production which results in low capital resulting in less soil inputs. Additionally, poor fertilizer: output ratios for food crops further exacerbate the problem (Mose, 1998). Some of the ways to address these problems include supplying fertilizer in small packages to encourage none-users to start using fertilizers, information on the need to apply appropriate quantities based on the yield goals and integrated use of organic and inorganic nutrient sources.

Use of soil amendments is mainly intended to improve crop yields. Improved yields results from improved nutrient status in soil and other soil properties such as soil organic matter. Long term (20 year) use of manure was shown to significantly reduce bulk density and increase SOC concentration under an intensive rice cropping system (Zhangliu *et al*., 2009). In the same study, combined application of crop residue and mineral fertilizer also improved soil physical properties, but the improvement by mineral fertilizer alone was limited. Ayoola and Makinde (2009) reported that after two years of application and cropping, enriched poultry manure increases soil N, P and K contents by 42, 2 and 21%, respectively. While, fortified cow dung increases the nutrients by 25, 0.3 and 3%, respectively in the

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degraded tropical rain forest zone in Nigeria. Similarly, Mucheru-Muna *et al.* (2007) reported improved total soil carbon and nitrogen contents with the application of organic residues (*Tithonia diversifolia*, *Calliandra calothyrsus*, *Leucaena leucocephala*) and manure in particular improved soil calcium content after 2 years in Eastern Kenya. Use of gliricidia prunings for 11 years resulted in a 24% increase in organic C in surface soils (0-20 cm) but no change in Olsen-P (Makumba *et al.*, 2006). Research about the effects of specific soil amendment practices on soil properties has mostly been done on research plots or, when done on farmers fields, under researcher controlled conditions.

Spatial information about fields or farms are displayed, stored and analyzed more effectively with a Geographic Information System (GIS). A GIS allows users to create Digital Elevation Models (DEM) for fields of interest that enables users to calculate topographic derivatives such as slope and aspect. The relationship of DEM-derived attributes with crop yields and soil properties has been investigated by Kravchenko and Bullock (2000) and Moore *et al.* (1993). For example Moore *et al.* (1993); reported that DEM-derived slope was negatively correlated to extractable P and organic matter. Established correlations with easily generated parameters such as DEM-derived factors can be cost effective especially for landscape analysis. Study about the effects of specific soil amendment practices on soil properties has mostly been done on research plots or, when done on farmers fields, under researcher controlled conditions. The purpose of this study was to assess the effect of different soil amendments on soil properties under farmers' management, to evaluate the relationship between Digital Elevation Model (DEM)-derived slopes and soil properties and to e valuate the effect of liming on maize and bean yields.

MATERIALS AND METHODS

Site selection: Two locations in Njoro Division of Nakuru District (Kenya) were selected; Kikapu and Kerma sub-divisions. The average farm size is 3 ha. The two locations selected for this study were part of the Ministry of Agriculture-Food and Agriculture Organization (FAO) farmer field schools experimenting on conservation agriculture. The soils in both areas are predominantly Andisols. Soils samples were taken at 0-20 cm depth in farms under continuous maize intercropped with beans, the dominant cropping system in Njoro for small scale farmers. All the farms had been under cultivation for more than 20 years. Sampling was limited to the surface 20 cm because the soil surface is the most sensitive to change as a result of soil management. In each field, 7 cores of 5 cm diameter were taken to make one composite sample. In addition, a semi-quantitative description of past and current soil management was obtained from interviews with the farmers. Soil fertility amendments were grouped into inorganic fertilizer, manure, inorganic fertilizer+ manure and none. Farmers used 5-368 kg ha^{-1} of DAP (mean 94 kg) and 47-2940 kg ha^{-1} of animal manure (mean 781 kg) for inorganic fertilizer and manure categories, respectively (Omamo *et al.*, 2002). Most of the farms had used the same input for at least three years. Soil sampling was done in March 2006 just before the planting season that usually begins in April.

Soil analysis: Soil samples were divided into two sub-samples, one was air dried and the other kept field moist under refrigeration. The air dried sample was sieved through a 2 mm sieve to homogenize the sample. Samples were extracted with 0.5 M $NaHCO_3$+0.01 M EDTA (pH 8.5, modified Olsen) using a 1:10 soil/solution ratio and analyzed by flame photometer for exchangeable K and calorimetrically (molybdenum blue) for extractable P. Organic C (SOC) was determined calorimetrically after H_2SO_4-potassium dichromate oxidation at 150°C for 30 min. Total N was determined by Kjeldahl digestion (Okalebo *et al.*, 2002) with sulphuric acid and selenium as a catalyst. Soil pH (1:1) in water and $CaCl_2$ was also determined. Soil bulk density was determined for the top 5 cm depth using a sampler of 5 cm in diameter and 5 cm height.

Potential mineralizable N was determined from the difference in NH_4^+ concentration between 0 and 7 days of anaerobic incubation of field moist samples. Inorganic N was determined from the filtered extract of an 8 g sub-sample of field moist soil shaken with 40 mL of 2 M KC1 for 1 h by salicylate-nitroprusside and Cd-reduction autoanalyzer techniques (Mulvaney, 1996).

On-farm trial: Following soil analysis, it was clear that most of the farms had acidic soils. We set a field trial to test the effect of liming on maize and bean grain yields and above ground biomass. The experimental field was divided into two equal sections each of 47.9 m by 10 m. The equivalent of 3000 kg ha^{-1} of agricultural lime was applied in May 2006 to one block. In each section the following treatments were established in a RCBD and three replications; maize (H6213) intercropped with either beans (*Phaseolus vulgaris*), dolichos (*Dolichos lablab*), or crotalaria (*Crotalaria ochroleuca*) without fertilizer, maize + beans treated with 125 kg ha^{-1} of Diammonium phosphate, or triple super phosphate or Mavuno (a compound fertilizer of 10- 26-10, S-4, Ca-10, Mg-4 and micronutrients-5). Maize plants were spaced 75 cm between and 30 cm within rows. The legumes were planted in the middle of the maize rows, with beans and crotalaria spaced at 20 cm within rows and dolichos at 50 cm. Maize planting in Njoro is usually in April/May (during the long rains) and harvesting is in November/December. The year 2006, was a drought year, resulting in very little harvestable grain for both maize and beans. Dolichos and crotalaria were used as green manures. The experiment was repeated in 2007 with no additional lime and the legumes were incorporated in March 2007 prior to planting maize and beans in April.

Statistical analysis: The mean, median, standard deviation, skewness, kurtosis and coefficient of variation for each soil attribute were calculated using Proc UNIVARIATE in SAS (2001). The distribution was evaluated at $\alpha = 0.05$ probability level. The distributions of the data were tested for normality using the Shapiro-Wilk test in SAS (2001). This test is more reliable when N<50. Analysis of variance was done using Proc GLM and means separated by Tukey's test (SAS, 2001). The sampling area was classified in terms of percentage slope as per FAO terrain-slope suitability rating for rain-fed crops based on digital elevation map of Njoro and GPS coordinates for each field. There are seven slope classifications which include: 0-2% flat, 2-5% gently sloping, 5-8% undulating, 8-16% rolling, 16-30% hilly, 30-45% steep and >45% very steep. Analysis of variance was performed for maize and bean yield parameters using proc GLM (SAS, 2001).

RESULTS

Total N, pH (water), pH ($CaCl_2$), organic C, carbon to nitrogen ratio, NH_4-N and NO_3-N were normally distributed for Kikapu soils. In Kikapu, total N ($p = 0.01$) and organic carbon ($p = 0.06$) were higher in soils amended with organic manure, while C: N ratio ($p = 0.02$) was lowest in the same soils. All other nutrients were comparable across soil amendments (Table 1). None of the soil parameters were normally distributed for Kerma soils or when data was combined for the two sites. Kurtosis ranged from 0.72 (% N) to 10.99 (C: N ratio), while skewness ranged from 0.95 (pH) to 3.50 (extractable P). Normally distributed parameters would have a kurtosis of 3 and skewness of zero. When the data was transformed by natural log, extractable P, total N and organic C were normally distributed for Kerma. However, no differences were observed between different soil amendments for this location.

Table 1: Ranges of soil properties under different soil fertility management in Kikapu

Variables	Inorganic fertilizer	Organic fertilizer	Inorganic+ organic	Tukey's test
Extractable P (mg kg^{-1})	4.80±3.0[a]	11.40±17.6	7.20±5.2	NS
Extractable K (mg kg^{-1})	589.00±81	702.00±208	642.00±111	NS
Total N (%)	0.18±0.04	0.26±0.04	0.18±0.02	*
Organic C (%)	2.60±0.5	3.40±0.5	2.80±0.2	*b
C: N ratio	14.90±0.9	12.80±1.4	15.60±1.3	*
NH_4 (mg kg^{-1})	24.20±3.7	24.30±4.6	24.80±3.1	NS
NO_3 (mg kg^{-1})	23.10±14.0	31.90±11.4	18.10±4.1	NS
PMN[c] (mg kg^{-1})	34.80±44.4	39.30±35.4	18.60±21.5	NS
pH ($CaCl_2$)	4.68±0.26	4.63±0.45	4.40±0.4	NS
Bulk density (Mg m^{-3})	0.93±0.09	0.90±0.06	0.99±0.05	NS

[a]Values plus or minus one standard deviation; *Indicate significant difference at $p<0.05$; [b]Significant differences at $p = 0.06$; [c]PMN is potentially mineralizable N

Table 2: Delineations of soil nutrient ranges for different availabilities

Variables	Very low	Low	Moderate	High
Organic C (%)	<0.50	0.50-1.50	1.50-3.00	>3.00
Total N (%)	<0.05	0.05-0.12	0.12-0.25	>0.25
Extr. P (mg kg^{-1})†	<5.00	5-10	10-15	>15.00
Exch. K (mg kg^{-1})	<50.00	50-100	100-175	>175.00

Okalebo *et al.* (2002); †After Landon (1991)

Table 3: Percentage of farms within different plant nutrient sufficiency levels

Variables	Very low	Low	Moderate	High
Organic C	None	None	72	28
Total N	None	3	89	8
Extr. P	47	36	3	14
Exch. K	None	None	None	100

Soil properties differed among sites with Kikapu generally having higher median values for total N (0.20 vs. 0.15%), organic C (2.8 vs. 2.6%), extractable K (616 vs. 562 mg kg^{-1}) and pH (4.5 vs. 4.0). Conversely, the median for C: N (14.2 vs. 18.8) ratio and extractable P (4.4 vs. 7.2 mg kg^{-1}) was lower for Kikapu (Fig. 1, 2). Most of the farmers in Kerma (94%) use inorganic fertilizer with the rest using both inorganic and organic fertilizer. In contrast, 35 and 53% of farmers in Kikapu use inorganic fertilizer and both inorganic and organic fertilizer, respectively.

All farms had moderate to high amounts (as defined in Table 2) of organic C ranging from 1.6 to 5.8 and 97% of the farms had total N >0.12%. Potassium content was high >100 mg kg^{-1} in all the farms. Phosphorus was the most deficient nutrient with 83% of the farms having <10 mg kg^{-1} $NaHCO_3$-extractable P (Table 3). Most of the soils in this region are Andisols which generally have higher organic C and high P fixing capacity. Organic C was positively correlated to extractable P ($r = 0.51$, $p = 0.016$), total N ($r = 0.43$, $p = 0.008$) and pH ($r = 0.43$, $p = 0.0097$).

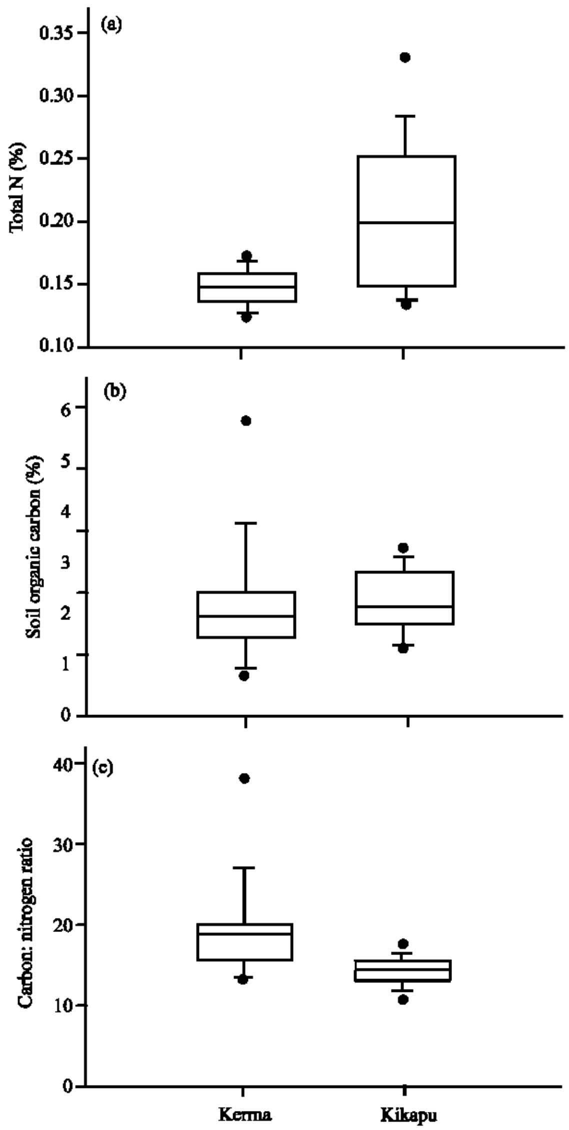

Fig. 1: (a) Soil total N, (b) Organic C and (c) Carbon: N ratio showing inherent variation for two sites in Njoro, Kerma and Kikapu. The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles. The round symbols show outlying points

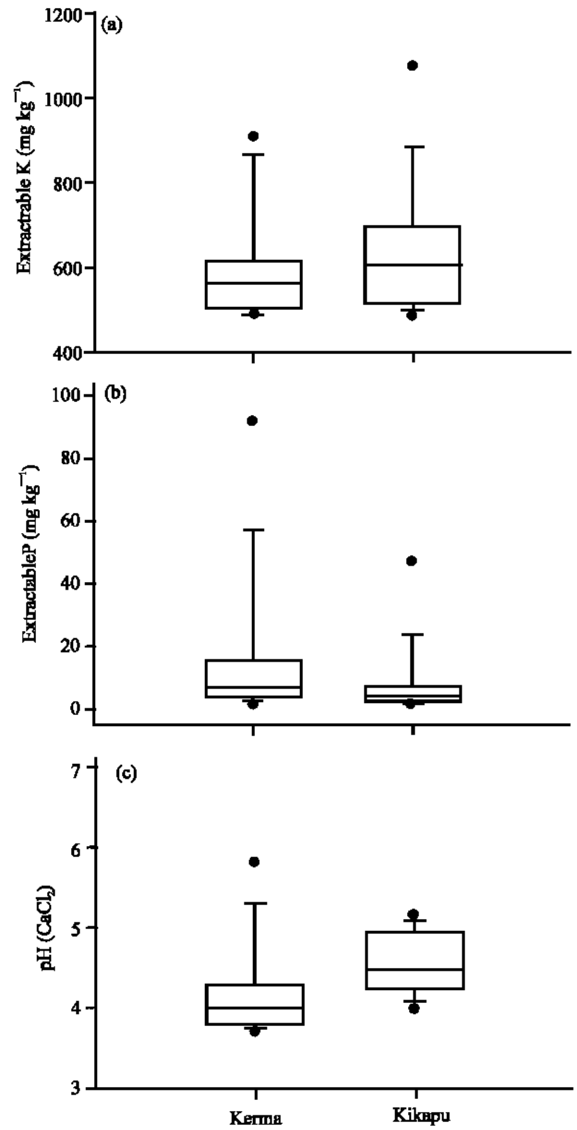

Fig. 2: (a) Exchangeable K, (b) Extractable P and (c) pH showing inherent variation for two sites in Njoro, Kerma and Kikapu. The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles. The round symbols show outlying points

Based on the slope classification of the area as generated from GPS coordinates and available Digital Elevation Map (DEM) for Njoro, 42% of the sampled farms were flat with slopes less than 2% and 39% had gentle slopes (2-5%) and the remaining 19% were under undulating slopes (5-8%). Total N was higher for lands with slopes greater than 2%, while pH was highest for undulating slopes. No differences were observed among slope classes for all other soil parameters (Table 4).

Results of on farm trials to assess the effect of liming on maize and bean biomass and grain yields are shown in Table 5. Maize aboveground biomass was higher in limed

Table 4: Nutrient ranges of farms in different slope classifications

Variables	Flat (0-2%)	Gently sloping (2-5%)	Undulating 5-8%	Tukey's test
Extractable P(mg kg^{-1})	14.60±23.7[a]	5.30±3.6	14.70±18.1	NS
Extractable K(mg kg^{-1})	595.00±122	611.00±81	721.00±199	NS
Total N (%)	0.16±0.3	0.19±0.06	0.20±0.05	*
Organic C (%)	2.90±0.9	2.70±0.6	2.70±0.8	NS
C: N ratio	18.40±6.1	14.40±2.9	13.70±1.5	NS
pH ($CaCl_2$)	4.20±0.6	4.30±0.3	4.80±0.3	*
pH (water)	4.70±0.6	4.80±0.2	5.40±0.3	*

[a]Values plus or minus one standard deviation; *Indicate significant difference at p<0.05

Table 5: Maize and bean grain and aboveground biomass in limed and unlimed fields in Njoro, Kenya

	Maize		Bean	
	Biomass	Grain yield	Biomass	Grain yield
Treatments	(kg ha^{-1})			
Limed	10671[a]	3281[a]	315[b]	188[b]
Unlimed	6915[b]	2291[a]	654[a]	386[a]
LSD[a]	2383	NS	132	78

[a]LSD is least significant difference at p = 0.05. Same letter(s) within a column indicate no differences at p = 0.05

fields while no differences were observed in maize grain yield. The contrast was true for beans, where bean biomass and grain yields were lower in limed than in unlimed plots (Table 5).

DISCUSSION

The probability distributions exhibited by many soil properties are often non-normal (Brejda *et al*., 2000). Most parametric statistical analysis require the data to be normally distributed and have equal variances. Violation of these assumptions may lead to incorrect conclusions. Natural log transformation can result in normal distribution although some soil properties (e.g., exchangeable K, Na and potentially mineralizable N) remain non-normally distributed (Brejda *et al*., 2000). For such soil properties other distributions may be present. However, it may be possible to detect changes of greater magnitude in soil properties using non-transformed data (Brejda *et al*., 2000).

Differences in soil properties due to management in our research were more pronounced in Kikapu where the number of farmers using different amendments was comparable (organic 29%, inorganic 35% and inorganic+ organic 24%). The higher fertility associated with Kikapu soils can be explained by differences in management, since, a higher number of farmers (53%) used organic inputs compared to only 6% who used organic inputs at Kerma. Extensive use of inorganic fertilizer (especially N based) may increase soil organic C through increased crop residues (Vanden Bygaart and Angers, 2006). However, a majority of small scale farmers who use fertilizer, apply ~22.5 kg N ha^{-1} (equivalent to 125 kg ha^{-1} DAP) and remove most of the crop residues as animal feed leading to depletion in soil fertility. The higher extractable P in Kerma is attributable to the use of inorganic fertilizer. Use of inorganic fertilizer increased Olsen P but not soil organic C in Embu, while 5 t of goat manure caused an increase in SOC but not P (Kihanda *et al*., 2005). Use of organic inputs has been shown to increase SOC in short term (Mucheru-Muna *et al*., 2007) and in long term trials (Zhanguli *et al*., 2009). Effect of organic inputs on other soil nutrients like P, Ca and Mg depends on type (Ayoola and Makinde, 2009), amount and duration of use of the organic input. Other factors such as soil type and climate will also influence the role of management on soil properties.

Tittonell *et al*. (2008) reported that areas with high extractable P were also high in soil C content in Western Kenya as reported in this study. Development of databases that show covariation of different soil properties is important in the effort of using soil testing for fertilizer recommendations because less parameters can be analyzed and an amendment decision made without having to analyze the sample for many soil properties which is costly. There is also need to understand the underlying mechanisms of soil properties correlations and the factors that affect such relationships to ensure consistent deductions.

Reports on the influence of topographic position and slope on soil properties have been inconsistent. DEM-derived slope was negatively correlated with extractable P and organic matter (Moore *et al*., 1993). In contrast soil P and K, pH and organic matter were similar for different topographic positions (Harmoney *et al*., 2001). Present results indicated that pH and total N were higher for gentle and undulating slopes when samples from farms using different soil amendments were combined. However, the samples analyzed were not sufficient to separate the management factor.

Application of lime affected maize and bean yields differently. Maize yields were not affected, but stover yields were higher and bean yields lower in limed plots. In Kenya, the dominant types of *Phaseolus*-nodulating rhizobia differ between an acidic soil and a high-pH soil, with *Rhizobium tropici* dominating in the acidic soil (Anyango *et al*., 1995). The pH changed from 5.4 to 7.9 one year after application of lime. It is possible that the change in pH reduced the effectiveness of the native rhizobia species that was more adapted to acidic conditions resulting in less N fixation and subsequently lower bean biomass and grain yields in limed field.

CONCLUSION

Total N and organic C were higher for farms that used organic manure compared to those that used DAP under farmers' management. Differences in sites were attributable to soil management, where Kikapu had higher overall fertility than Kerma. Kerma farmers predominantly used DAP as the main soil amendment, while 53% of the farmers in Kikapu used organic manures at various intensities. Most of the farms had acidic soils in the two locations and the continued use of DAP may exacerbate the problem. Liming may improve maize production in Njoro. The study to establish liming quantities and economic returns based on available lime sources should be carried out to improve crop productivity in Njoro.

Present results confirm that even under small scale farmers management, use of organic inputs can lead to increased soil organic carbon. This is particularly important given that most small-scale farms are assumed to deplete soil organic matter. However, most of the farms that used organic inputs had lower nutrient levels, particularly P, showing the need for integrated approach that incorporates both organic and inorganic inputs. Relationship between Digital Elevation Model (DEM)-derived slopes and soil properties was not clearly established probably because of the confounding effect of management on soil properties in different slope classes. Future research will assess DEM-derived slopes along different management classes.

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