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Research Paper

Effect of sulphur on growth, productivity, and economics of wheat (*Triticum aestivum*) and residual soil fertility under aerobic rice (*Oryza sativa*)–wheat cropping system in Inceptisols

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ABSTRACT

A field experiment was conducted during the winter (*rabi*) seasons of 2010–11 and 2011–12 at New Delhi, to study the direct and residual effect of sulphur (S) application on growth, productivity and economics of wheat (*Triticum aestivum* L.) grown under aerobic rice (*Oryza sativa* L.)-wheat cropping sequence. The experiment was laid out in a randomized block design for first aerobic rice and split-plot design for succeeding wheat and second cycle of aerobic rice–wheat system. Five treatments comprising combinations of 2 S sources i.e. gypsum and phosphogypsum and 3 S levels, i.e. 0, 30 and 60 kg S/ha, were taken in aerobic rice. And in succeeding wheat, each main plot was split into 3 sub plots for application of elemental sulphur at 3 levels, i.e. 0, 15, and 30 kg S/ha and replicated thrice. Application of sulphur resulted in increase of growth parameters i.e. plant height, dry matter accumulation, leaf-area index (LAI), chlorophyll content and crop growth rate (CGR) over the control. The yield attributes, *viz.* effective tillers/m^2, spike weight (g) and filled grains/spike were observed highest with 30 kg S/ha, followed by 15 kg S/ha. Averaged across two years, application of 15 and 30 kg S/ha increased the grain yield of wheat by 8.4 and 11.6%, respectively, over no sulphur treatment. Corresponding values for straw yields were 8.9 and 11.4%, respectively. Though highest yields (grain, straw and biological) were obtained with 30 kg S/ha, but significant response was observed only up to 15 kg S/ha. The highest net return was fetched with 30 kg S/ha, but significant response was found only up to 15 kg S/ha. Application of 60 kg S/ha through either of the sources to preceding rice had a significant residual effect on yields and economics of succeeding wheat. Highest status of available N, P and K after wheat harvest was recorded in no sulphur treatment and, in contrast availability of sulphur in soil increased with increasing level of sulphur up to 30 kg/ha.

Key words : Chlorophyll content index, Crop growth rate, Dry-matter accumulation, Elemental sulphur, Leaf-area index, Net returns, Yield

Wheat is the most important food crop of world and is grown under different soil and agro-climatic conditions. In India, it is the second most important food crop after rice and occupied approximately 31.46 million hectare area with a production of 86.52 million tonnes during 2014–15 (DAC & FW, 2016-17). The improvement in its productivity has played a key role in making the country self-sufficient in food grain. However, in the past decade a general slowdown in increase in the productivity of wheat has been noticed (Nagarajan, 2005). By 2020, India will have a population of about 1.3 billion and there will be a substantial pressure on land to produce more food, specially wheat and rice. Stagnation in wheat production, lower productivity and inferior quality of produce is due to various constraints including inadequate and imbalanced nutrition (Prasad, 2012). Wheat generally follows rainy season crops, viz. paddy, maize, sorghum and pearlmillet, which are highly nutrient exhaustive (Usadadiya and Patel, 2013). Amongst cereal-cereal cropping systems, rice-wheat cropping system (RWCS) is predominant system in Indo-Gangetic Plain (IGP) of India. Surveys conducted in the rice-wheat growing areas indicate that farmers' fertilizer management practices are skewed towards N and P, and S and micronutrients application is almost neglected (Singh and Gangwar, 2011).

Sulphur is the fourth essential nutrient for plants after the N, P and K. It was rarely deficient for agricultural

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crops until about two decades ago, and has become one of the most limiting nutrients for agricultural production today (Loudet, 2008; Reinbold *et al.,* 2008 and Kumar *et al*., 2012). In India, about 40% of total cultivated area (57 million ha) is suffering from various degree of sulphur deficiency (Singh *et al*., 2013). In 1991, only 70 districts were reported sulphur deficient but in year 2011 number of sulphur deficient district increased up to 300 (Tandon, 2011). The fast decline in available soil S is chiefly due to higher crop removal by high yielding genotypes; intensive cropping; poor replenishment in soil due to use of sulphur-free fertilizers *viz.* urea, DAP etc. Without adequate sulphur, crops cannot reach their full potential in terms of growth, yield and quality; nor can they make efficient use of other nutrients (Sahota, 2006). For wheat crop, S nutrition exerts a large inuence on crop growth, grain yield and quality (Ercoli *et al*., 2011). It is reported that wheat grain below 1.2 mg/g S and above 17: 1 N: S ratio is S deficient and both yield and quality are affected (Prasad and Shivay, 2017). Reproductive growth of wheat is more sensitive to sulphur deficiency than the vegetative growth, which decreases grain size (Jarvan *et al.,* 2008).

The experimental information about the agronomic effectiveness of elemental S (ES) on wheat is very meagre. And during last years, there was an important progress in ES product development in different countries. Taking into account that ES consumption has shown a sharp increase as S source for crops; it is necessary to increase the knowledge about the behaviour of reactive elemental S in soils. Therefore, a field experiment was conducted with the aim to study the direct and residual effect of sulphur application on growth, productivity, residual soil fertility and economics of wheat grown under aerobic rice-wheat cropping sequence.

MATERIALS AND METHODS

A field experiment on wheat was carried out during the winter (*rabi*) seasons of 2010–11 and 2011–12 at the Research Farm of ICAR-Indian Agricultural Research Institute, New Delhi (28°38' N, 77°09' E and 228.6 m above mean sea level). The mean annual rainfall of New Delhi is 650 mm and more than 80% generally occurs during the SW-monsoon season (July-September) with mean annual evaporation of 850 mm. Soil (*Typic Ustochrept*) of the experimental field had sandy clay loam texture, 176 kg/ha alkaline permanganate oxidizable N, 14.6 kg/ha available P, 275 kg 1 *N* ammonium acetate exchangeable K, 16.5 kg available S and 0.54% organic carbon at the start of study. The pH of soil was 7.5 (1:2.5 soil and water ratio).

The experiment was laid out in a randomized block design for the first season aerobic rice and split-plot design for succeeding wheat and second cycle of aerobic rice–wheat system. Five sulphur treatments comprising two sulphur sources [Gypsum (G) & phosphogypsum (PG)] with 2 levels, i.e. 30 and 60 kg S/ha, and control (no S was applied) were applied to *kharif* rice and replicated thrice. In the subsequent wheat (*rabi* season), each main plot was split and 0, 15 and 30 kg S/ha was applied in sub-plots through elemental sulphur. Recommended doses of NPK (120, 26.2, 33.2 kg/ha) along with sulphur treatments were applied every year to wheat crop. All the treatments were applied in the field at sowing. All P, K and 1/3rd N were broadcast at the time of sowing and rest N was top dressed at 25 days after sowing (DAS) and 45 DAS in 2 equal splits. Wheat (variety 'DBW 17') was grown (sowing time 24th November, 2010–11 and 15th November, 2011–12) as per recommended practices and harvested in mid April in 2011 and 2012. Wheat was sown at a row to row spacing of 22.5 cm with a seed rate of 100 kg/ha.

Growth parameters, viz. plant height, number of tillers/m^2, dry-matter accumulation were measured by using standard procedures. The area of fresh green leaves for each treatment was measured by using leaf-area meter (Model LICOR 3000, USA). Leaf-area index (LAI) was computed as per the procedure described by Evans (1972). The leaf-chlorophyll value was monitored with the chlorophyll meter (SPAD-502, Soil-Plant Analysis Development Section, Minolta Camera Co.) at the mid point of the second fully expanded leaf (Lin *et al*., 2010). For growth analysis, crop growth rate (CGR), relative growth rate (RGR), and net assimilation Rate (NAR) were computed according to formula given by Watson *et al.* (1952) and Watson (1958). Before harvesting of wheat crop, all the yield attributing characters were recorded and after harvesting, threshing, cleaning and drying, the grain yield was recorded at 14% moisture. Financial analysis was done based upon cost of cultivation, grain and straw yield and their prevailing market prices of wheat during the respective crop seasons.

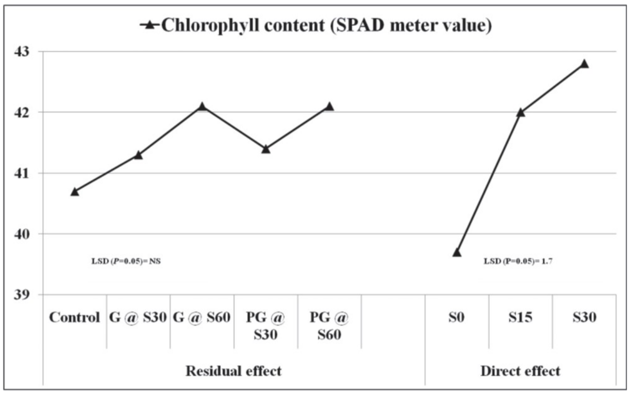
Soil samples were analyzed for organic carbon (Walkley and Black, 1934), available N (Subbiah and Asija, 1956), available P (Olsen *et al*., 1954), available K and available S (Williams and Steinberg, 1959) to see the residual soil fertility status. Analysis of variance (ANOVA) was performed with the PROC MIXED procedure of the SAS/STAT software (SAS Institute, 1999) to determine the effects of sulphur on growth, productivity, residual soil fertility and economics of wheat. Critical difference (CD) at 5% level of probability and P values were used to examine differences among treatment means.

RESULTS AND DISCUSSION

Growth parameters

Application of sulphur in wheat increased the plant height significantly over the control; however both the doses of sulphur remained statistically at par. Averaged over two years, sulphur application @ 15 and 30 kg/ha increased the dry-matter accumulation at 60 DAS by 24.8 and 34.7% in 2010–11 and 2011–12, respectively over the control. The corresponding values for dry-matter accumulation at harvest were 8.5 and 12.1%, respectively (Table 1). The significant response of sulphur in increasing dry-matter accumulation was observed up to 30 kg/ha. It is quite obvious that the continued and balanced supply of nutrients right from early stage of growth resulted in vigorous plant growth (Hussain and Leitch, 2007). Increase in plant height might be due to the positive role of S in plant metabolic activity, which may have led to the increase in photosynthesis and thereby increase in plant height (Lunde *et al.,* 2008).

Irrespective of the levels, application of sulphur had a significant effect on leaf-area index. The values of LAI increased substantially with the advancement of crop age and significant response in increasing LAI with S application was observed up to 30 kg/ha. Significant residual effects of sulphur applied @ 60 kg/ha to preceding rice were observed on LAI of succeeding wheat. Though highest chlorophyll content (42.8 SPAD meter value) at 90 DAS was observed with 30 kg S/ha (Fig. 1), but significant response was observed only up to 15 kg S/ha (42.0). The residual effects of different sources of sulphur applied to preceding rice were observed non-significant on chlorophyll content in succeeding wheat. Increase in chlorophyll



DAS, Days after sowing; G, gypsum; PG, phosphogypsum; NS, non-significant; $S_{0,\ 15,\ 30,\ 60}$; sulphur @ 0, 15, 30 and 60 kg/ha

Fig. 1. Direct and residual effect of sulphur on chlorophyll content (SPAD meter value) in wheat

content with increasing sulphur shows the strong relationship between chlorophyll meter reading and S status of the plant. Sulphur is a key component for various enzymes and essential for chlorophyll formation (Zhao *et al*., 1996).

Increase in dry-matter accumulation, plant height and LAI with sulphur application resulted in overall improved growth of the wheat crop. During 61–90 DAS, both the levels of sulphur increased the crop growth rate (CGR) significantly over the control. Sulphur applied to preceding rice at 60 kg/ha showed significant residual effects on crop growth rate (CGR) of succeeding wheat. During 61–

Table 1. Effect of sources and levels of sulphur on growth, chlorophyll content and growth analysis of wheat grown under aerobic rice-wheat cropping system (pooled data of 2 years)

Treatment	Plant height (cm)	Dry-matter accumulation (g/m^2)		LAI	Crop growth rate (CGR, g/m^2/day)	Relative growth rate (RGR, mg/g dry-matter/day)	Net assimilation rate (NAR, g/m^2 leaf area/day)
	Harvest	60 DAS	Harvest	90 DAS	61-90 DAS	61-90 DAS	61-90 DAS
Residual effect							
Control	85.4	92.0	1327.0	4.17	19.0	66.0	6.88
G @ S_{30}	86.9	97.5	1366.0	4.28	19.8	65.5	6.88
G @ S_{60}	88.3	101.0	1381.5	4.45	20.4	65.2	6.82
PG @ S_{30}	86.7	95.5	1354.5	4.24	19.5	65.8	6.91
PG @ S_{60}	87.4	99.5	1379.5	4.41	20.2	65.5	6.84
SEm±	0.8	2.5	10.0	0.05	0.3	0.9	0.13
CD (P=0.05)	NS	NS	33.5	0.16	NS	NS	NS
Direct effect							
S_0	84.3	81.5	1274.0	3.81	17.4	66.9	6.97
S_{15}	87.4	101.0	1382.0	4.45	20.5	65.4	6.86
S_{30}	89.1	109.0	1428.5	4.67	21.5	64.5	6.78
SEm±	0.8	2.0	12.0	0.06	0.3	0.7	0.09
CD (P=0.05)	2.3	6.5	34.6	0.17	0.6	NS	NS

DAS, Days after sowing; G, gypsum; PG, phosphogypsum; NS, non-significant; $S_{0,\ 15,\ 30,\ 60}$; sulphur @ 0, 15, 30 and 60 kg/ha

90 DAS, significantly higher relative growth rate (RGR; 66.9 mg/g dry weight/d) and net assimilation rate (NAR; 6.97 g/m^2 leaf area/d) was observed in control as compared to sulphur treatments. No significant residual effects of sulphur applied to preceding rice was observed in RGR and NAR of the succeeding wheat.

Yield attributes and yields

Averaged over 2 years, application of sulphur @ 15 and 30 kg S/ha increased the number of effective tillers/m^2 of wheat by 3.1 and 5.7 %, respectively over control. However, significant response of sulphur on effective tillers was observed only upto 15 kg/ha. Spike weight (g) of wheat increased from 1.76 g/spike (control) to 1.84 g/spike with application of 30 kg S/ha (Table 2). The number of filled grains/spike increased significantly with application of sulphur at either levels. Pooled across two years, application of sulphur @ 15 and 30 kg S/ha increased the number of grains/spike of wheat by 3.0 and 5.4% respectively over control. However, both the levels of S remained at par with each other. The residual effects of various sulphur sources and levels applied to preceding rice were observed non-significant on all the yield attributes of succeeding wheat during the study. The increase in yield attributes with S application might be due to a continued and balanced supply of other nutrients. Several greenhouse and field studies have shown a significant effect of S on the number of grains/spike (Zhao *et al*., 1999 and Monaghan *et al.,* 1997) and other yield attributes (Singh and Pathak, 2003 and Palsaniya and Ahlawat, 2009).

The grain yield of wheat was increased by 8.4 and 11.6% with 15 and 30 kg S/ha, respectively, over control. The corresponding increases for straw yield were 8.89 and 11.45%, respectively (Table 2). Application of S to soil increases the availability of SO_4-S in soil (Gupta and Jain, 2008), which may have helped the crop to achieve better growth. Grain yield of wheat is a product of three yield components, viz. the number of effective tillers/m^2, the number of grains/spike and individual grain weight (Bavec *et al*., 2002), which were increased with the application of sulphur.

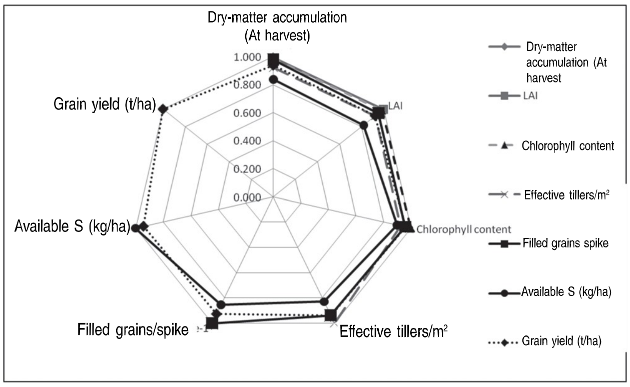
Ontogenetically, number of effective tillers per unit area is the first yield component to be fixed, and, thus, assumes particular importance. The number of effective tillers was positively correlated (R^2=0.86) with grain yield. Besides, number of effective tillers, other yield attributes and yields also positively correlated (>0.80) with each other and with available sulphur (Fig. 2). Various other investigations on sulphur nutrition have shown that the yield of wheat and some of the yield components significantly responded to the application of sulphur fertilizers (Girma *et al.,* 2005 and Bavec *et al.,* 2002). Another reason of higher grain yield might be due to higher nutrient uptake by wheat crop because sulphur improves the physical and chemical characteristics of soil. Results are in close conformity with the findings of Togay *et al.* (2008) and Al-Karaki and Al-Omoush (2002).

In case of residual effects, irrespective of the sources, S application @ 60 kg/ha to preceding rice had a significant residual effect on grain yield of wheat. Averaged across two years, residual effects of sulphur applied to rice through gypsum @ 30 and 60 kg S/ha and

Table 2. Effect of sources and levels of sulphur on yield attributes of wheat grown under aerobic rice-wheat cropping system (pooled data of 2 years)

Treatment	Effective tillers/m^2	Spike weight (g)	Filled grains/spike (Nos.)	Grain yield (t/ha)	Straw yield (t/ha)	Cost of cultivation (×10^3₹/ha)	Gross returns (×10^3₹/ha)	Net returns (×10^3₹/ha)	Benefit: cost ratio
Residual effect									
Control	363	1.77	45.3	4.67	6.97	24.9	66.6	41.7	1.68
G @ S_{30}	368	1.79	46.0	4.92	7.31	24.9	70.1	45.2	1.82
G @ S_{60}	377	1.83	46.3	5.12	7.64	24.9	73.1	48.2	1.93
PG @ S_{30}	366	1.79	46.0	4.89	7.38	24.9	69.9	45.0	1.81
PG @ S_{60}	369	1.81	46.1	5.06	7.57	24.9	72.2	47.3	1.90
SEm±	5.0	0.02	0.5	0.06	0.10	-	0.9	0.9	0.04
CD (*P*=0.05)	NS	NS	NS	0.20	0.30	-	2.8	2.8	0.11
Direct effect									
S_0	358	1.76	44.7	4.62	6.91	22.9	65.9	43.1	1.88
S_{15}	369	1.79	46.0	5.01	7.52	25.0	71.6	46.7	1.86
S_{30}	379	1.84	47.1	5.16	7.70	26.9	73.6	46.7	1.74
SEm±	5.0	0.02	0.5	0.06	0.11	-	0.8	0.8	0.03
CD (*P*=0.05)	13.7	0.05	1.2	0.16	0.30	-	2.3	2.3	0.09

G, Gypsum; PG, phosphogypsum; NS, non-significant; $S_{0, 15, 30, 60}$; sulphur @ 0, 15, 30 and 60 kg/ha



DAS, Days after sowing; G, gypsum; PG, phosphogypsum; NS, non-significant; $S_{0, 15, 30, 60}$; sulphur @ 0, 15, 30 and 60 kg/ha

Fig. 2. Correlation matrix between growth, yield attributes, yield and available sulphur

phosphogypsum @ 30 and 60 kg S/ha increased the grain yield of succeeding wheat by 5.2, 9.6, 4.6 and 8.4%, respectively, over control. Similar trend was observed in straw yield. The marked improvement in productivity of wheat with residual S could be ascribed to the enhancement of SO_4^{-2} S content of the soil as sulphur applied to aerobic rice was not fully utilized by the crop leading to its residual effect. Furthermore, this might have modified soil physico-chemical environment conducive for the growth and development of crop (Palsaniya and Ahlawat, 2009).

Economics

Sulphur application to wheat crop changed its economics significantly over the control (Table 2). Both the levels of sulphur produced significantly higher gross and net returns over control. Though highest gross returns (₹73,600) was observed with 30 kg S/ha, but it remained at par with 15 kg S/ha. Averaged across two years, application of sulphur @ 15 kg S/ha and @ 30 kg S/ha increased the gross return of wheat by 8.6 and 11.7% respectively, over control. Corresponding increases for net returns were 8.2 and 8.4% higher over control, respectively. However, significant response of S application on net return was found only up to 15 kg S/ha. All the S combinations applied to preceding rice had significant residual effect on gross and net returns of succeeding wheat. Among the sulphur levels, highest net benefit:cost ratio (1.86) was observed with 15 kg S/ha. This might be due to the high cost of elemental sulphur and less increment in yield with 30 kg S/ha as compared to 15 kg S/ha.

Residual soil fertility

Sulphur application to rice-wheat cropping system could not enhance the carbon content in soil. However, the available N (184 and 191 kg/ha), available P (14.5 and 14.9 kg/ha) and available K (275 and 279 kg/ha) were observed highest in control (Table 3). This might be due to lesser removal of N, P and K from soil because control received equal amount of N, P and K as sulphur treatments, but gave less yield, eventually lesser uptake of nutrients from the soil as compared to sulphur treatments. So, availability of N, P and K remained high in control plot. The residual effects of sulphur sources and levels applied to preceding aerobic rice were non-significant on available N, P and K after harvest of wheat during both the years of experimentation, except in available N during 2010–11.

Unlike N, P and K, application of sulphur significantly

Table 3. Effect of sources and levels of sulphur on organic carbon and available nutrients (N, P, K and S) in soil after harvest of wheat

Treatment	Soil organic carbon (%)		Available N (kg/ha)		Available P (kg/ha)		Available K (kg/ha)		Available S (kg/ha)	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Residual effect										
Control	0.54	0.53	187	189	14.5	15.0	276	280	15.2	15.3
G @ S_{30}	0.54	0.52	181	188	13.7	14.4	270	276	16.4	16.8
G @ S_{60}	0.53	0.51	178	184	13.6	13.8	269	261	17.9	18.6
PG @ S_{30}	0.54	0.52	181	189	13.8	14.1	272	275	17.4	17.8
PG @ S_{60}	0.53	0.52	180	185	13.7	14.0	268	273	18.1	18.9
SEm±	0.003	0.01	1.0	1.0	0.2	0.3	2.0	4.0	0.1	0.3
CD (*P*=0.05)	NS	NS	4.0	NS	NS	NS	NS	NS	0.3	1.0
Direct effect										
S_0	0.54	0.53	184	191	14.5	14.9	275	279	15.5	15.8
S_{15}	0.53	0.52	181	187	13.7	14.1	271	275	17.3	17.8
S_{30}	0.53	0.51	179	183	13.3	13.8	267	265	18.2	18.8
SEm±	0.004	0.00	1.0	1.0	0.3	0.3	2.0	4.0	0.2	0.3
CD (*P*=0.05)	NS	NS	3.0	4.0	0.8	NS	6.0	12.0	0.6	0.8

G, Gypsum; PG, phosphogypsum; NS, non-significant; $S_{0, 15, 30, 60}$; sulphur @ 0, 15, 30 and 60 kg/ha increased available S (Table 3). Averaged across 2 years, application of sulphur @ 15 and 30 kg S/ha increased the availability of S in soil by 12.1 and 18.2%, respectively, over control. Significant response of sulphur on its availability in soil was observed upto 30 kg S/ha. All the combinations of S sources and levels applied to preceding rice had significant residual effects on S availability after harvest of succeeding wheat. Amongst all S treatments applied to preceding rice, 60 kg S/ha applied through phosphogypsum showed highest residual effects, followed by 60 kg S/ha applied through gypsum. This might be attributed to the fact that only a small fraction of applied S was utilized by the crop and thus, the unutilized fertilizer S in soil led to the increase in S availability in soil (Palsaniya and Ahlawat, 2009).

On the basis of 2 year study, it may be concluded that irrespective of levels (15 or 30 kg/ha), S application improved the growth parameters, viz. plant height, number of tillers, dry-matter accumulation, LAI and CGR of wheat. Among the S levels, 30 kg/ha gave better results with respect to growth parameters as compared to 15 kg/ha, but both the levels remained at par. The values of yield attributes increased significantly by application of 30 kg S/ha over the control. The application of sulphur, on an average, increased the wheat grain yield by 10%. Economically, application of 15 kg elemental sulphur/ha to wheat in rice–wheat cropping system was found beneficial when sulphur was applied to preceding crop (rice) @ 60 kg S/ha through either gypsum or phosphogypsum. Availability of S increased in soil with increased dose of sulphur.

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