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P Leela Janaki
College of Horticulture,
Dr. YSR Horticultural University,
Venkataramannagudem,
West Godavari, Andhra Pradesh,
India

Dr. G Ramanandam
Principal Scientist & Head,
Horticultural Research Station,
Kovvur, Andhra Pradesh, India

Dr. B Prasanna Kumar and
Associate Dean, College of Horticulture, Dr. YSRHU,
Parvathipuram, Andhra Pradesh, India

Dr. K Sasikala
Associate Professor, College of Horticulture, Dr. Ysrhu,
Tadepalligudem, Andhra Pradesh, India

Corresponding Author:
P Leela Janaki
College of Horticulture,
Dr. YSR Horticultural University,
Venkataramannagudem,
West Godavari, Andhra Pradesh,
India

Effect of integrated nutrient management on growth and yield characters of cocoa (*Theobroma cacao* L.) Grown in coastal Andhra Pradesh

P Leela Janaki, Dr. G Ramanandam, Dr. B Prasanna Kumar and Dr. K Sasikala

Abstract
A field experiment was carried out to study the impact of integrated nutrient management on growth and yield characters of cocoa at existing coconut gardens, Horticultural Research Station, Ambajipeta during 2016 and 2017. The experiment was laid out in randomized block design replicated thrice with ten treatments of different combinations of organic, inorganic and biofertilizers. The growth parameters like tree height, girth, height at first branching (HAFB), canopy spread (North-South and East-West) and canopy volume were recorded before fertilizer application and eight months after fertilizer application. The results with respect to growth parameters, the tree height increment (1.16 m) and tree girth increment (1.01 cm) were recorded highest with the application of 75% RDF + 25% RDN through composted coir pith + 50 g *Azospirillum* + 50 g PSB. Other growth parameters like canopy spread (EW) (5.32 m), canopy spread (NS) (4.73 m) and canopy volume (30.02 m^2) were also recorded highest in the same treatment. The result with respect to yield characters like number of healthy pods (55.84), weight of the pod (485.26 g), husk weight (349.68 g), wet bean weight per pod (135.58 g), dry bean weight per pod (66.60 g), single bean weight (1.57 g) and total dry bean yield per tree (3.57 kg) were recorded highest in 75% RDF + 25% RDN through composted coir pith + 50 g *Azospirillum* + 50 g PSB treated trees. The above results indicated that application of 75% RDF + 25% RDN through composted coir pith + 50 g *Azospirillum* + 50 g PSB in black alluvial soils of Andhra Pradesh had promoted both growth and yield characters of cocoa.

Keywords: Cocoa, growth, yield, pod, dry bean, INM treatments

Introduction
The tropical tree crop cocoa (*Theobroma cacao* L.) popularly known as 'Food of God' originated from Amazon basin belong to the family Malvaceae. One of the most important plantation crops consumed worldwide and in India, it is cultivated as component crop in arecanut, coconut and oilpalm plantations and accounts to an area of 1,03,376 ha with a production of 27, 072 MT of dry beans and with average productivity of 669 kg/ha (DCCD, 2021) [5]. It is mainly cultivated in four southern states *viz.*, Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. Andhra Pradesh ranks first in area of 39, 714 ha and production of 10, 903 MT with average productivity of 950 Kg ha^{-1} of 40% share of country production (DCCD, 2021) [5]. Though cocoa has been known as the beverage crop even before tea and coffee, it is relatively a new crop to India. Cultivation of cocoa is done primarily for the production of chocolate and various byproducts used in cosmetics, confectioneries, perfumeries and pharmaceuticals. Considering the high yield potential in cocoa, nutrient application with due consideration on various crop growth stages *viz*., vegetative, flowering, pod set, pod development and maturity will help in realizing the potential yield (Krishnamoorthy and Rajamani, 2013) [8]. Balanced nutrition ensures efficient use of all nutrients by the plant. Imbalanced nutrition results in low yield, low fertilizer- use efficiency and low farmer profit, besides depletion of the deficient nutrients of the soil. There is a need for reduced consumptions of chemical fertilizers and increased use of organic manures and biofertilizer for sustainability. The growth and pod formation of a plant depends on nutrient status of the leaf. Hence, keeping all these point in view, the attempts were made to find out suitable combination of organic, inorganic manures and biofertilizers to increase growth and yield characters of cocoa.

Materials and Methods

The experiment site was located at Horticultural Research Station, Ambajipeta, East Godavari District, Andhra Pradesh. Fourteen years old cocoa trees were selected for the study. In coconut plantation of thirty year old with spacing of 8 × 8 m, the cocoa plants are intercropped with a spacing of 2.7 m × 2.7 m. The study was laid out in randomized block design with ten treatments. The treatment details were 75% RDF + 25% RDN through composted coir pith (T_1), 75% RDF + 25% RDN through composted coir pith + 50 g *Azospirillum* + 50 g PSB (T_2), 50% RDF + 50% RDN through composted coir pith (T_3), 50% RDF + 50% RDN through composted coir pith + 50 g *Azospirillum* + 50 g PSB (T_4), 75% RDF + 25% RDN through FYM (T_5), 75% RDF + 25% RDN through FYM + 50 g *Azospirillum* + 50 g PSB (T_6), 50% RDF + 50% RDN through FYM (T_7), 50% RDF + 50% RDN through FYM + 50 g *Azospirillum* + 50 g PSB (T_8), 100% RDF (T_9) and Control (T_{10}). The recommended dosage of N, P and K for cocoa is 100:40:140 g/tree/year. In inorganic fertilizer treatments (50%, 75% and 100% recommended dose of fertilizers) nitrogen, phosphorus and potassium nutrients were applied in the form of urea, single super phosphate and muriate of potash respectively. Nitrogen, Phosphorus and Potash was applied in two equal split doses i.e., first split during August and second split in November. Farm yard manure, composted coir pith and biofertilizers *viz*., *Azospirillum* and Phosphate solubilizing bacteria (PSB) @ 50 g/tree was inoculated with the respective organic manures thoroughly and incorporated in the soil after one month of first split of inorganic fertilizer application. Regular irrigations and other agronomic practices were adapted to all the treatments as per the recommendations of cocoa cultivation. The observations on growth and yield parameters of cocoa were recorded as per standard procedures laid out by Elain Aphsara *et al*., (2008) [4] and analysis carried out as per Panse and Sukhatme (1978) [11]. The height of the plant was measured from the ground level up to the tip of the canopy using a scale and expressed in meter (m).The tree girth was measured at 15 cm above the ground level at bimonthly intervals from the date of first spilt of fertilizer application and expressed in centimetre (cm). Height of the first jorquette was measured as the vertical distance from ground level up to the first jorquetting point using a measuring tape and expressed in meter (m). The canopy area was calculated by the height of tree and average of spread in both the direction by using the formula πrl and expressed in m^2, whereas, r= EW+NS/ 4, l= $\sqrt{r^2 + h^2}$, h= canopy height (obtained by plant height- HAFB), HAFB= Height at first branching (Elain Apshara *et al*., 2008) [4]. The total number of healthy pods and damaged pods were harvested in each treatment and numbered in the field itself. The pod weight, husk weight and wet bean weight per pod were measured randomly from six selected trees of each treatment and expressed in gram (g). The dry bean weight of a pod was measured by weighing dried beans after fermentation. The average single bean weight was worked out and expressed in grams (g). The average yield of dry beans from tree was calculated from the mean dry weight of the beans per pod and the total number of pods in each treatment.

Results and Discussion

The non-significant differences among the treatments with respect to tree height, girth and Height at first branching were observed after pruning and 8 months after fertilizer application. However, the highest mean incremental tree height (1.16 m) was recorded with T_2 and lowest (0.70 m) with T_3 respectively (Table 1). However, T_2 had recorded highest incremental tree girth value of 1.01 cm after pruning and the lowest value of 0.39 cm with T_{10} (Table 1). The highest HAFB (1.32 m) was recorded with T_6 and in T_{10}, while the lowest HAFB of 1.08 m with T_8 (Table 1). The non-significant differences with respect to canopy spread (EW) & (NS) after fertilizer application were recorded. The maximum canopy spread (EW) (5.32 m) and the maximum canopy spread (NS) (4.73 m) were recorded with 75% RDF + 25% RDN through CCP + 50 g *Azospirillum* +50 g PSB) (T_2) after 8 MAF. After 8 MAF, the maximum canopy volume (30.02 m^3) was recorded with 75% RDF + 25% RDN through CCP+ 50 g *Azospirillum* + 50 g PSB) (T_2) and the minimum canopy volume of 23.03 m^3 in control (T_{10}) (Table 2).

On an average, the highest healthy pods (55.84) and lowest damaged pods (0.37) were recorded in T_2 (75% RDF + 25% RDN through CCP + 50 g *Azospirillum* + 50 g PSB). The highest pod weight (485.26 g) and the highest wet bean weight (135.58 g) were recorded with T_2 (75% RDF + 25% RDN through CCP + 50 g *Azospirillum* + 50 g PSB) and lowest pod weight (329.50 g) in T_{10} (control). The highest dry bean weight (66.60 g) (Plate 1) was recorded with T_2 (75% RDF + 25% RDN through CCP + 50 g *Azospirillum* +50 g PSB) and lowest dry bean weight (58.20 g) in T_{10} (control) (Table 3 & Fig 2). On an average, the highest single dry bean weight (1.57 g) was recorded with T_2 (75% RDF + 25% RDN through CCP+ 50 g *Azospirillum* +50 g PSB) and lowest single dry bean weight (1.21 g) in T_{10} (control) (Fig 1). The total dry bean yield per tree varied significantly among different treatments. The highest dry bean yield per tree of 3.57 kg was recorded in T_2 (75% RDF + 25% RDN through CCP + 50 g *Azospirillum* +50 g PSB) and the lowest dry bean yield per tree (0.97 kg) was recorded in T_{10} (control).

Increase in growth characters were attributed by the association of nitrogen in the synthesis of protoplasm, phosphorus is known to play an important role in photosynthesis and application of potassium also had significant effect on the morphological parameters by accelerating the movement of assimilates. Inoculation with *Azospirillium* secrete growth promoting substances like gibberlic acid, IAA and cytokinins which might have lead to better root development, better transport and uptake of nutrients which resulted in increasing growth parameters. Solubilizaton of P improved by the secretion of organic acids and enzymes from applied PSB biofertilizer, which facilitates the crop to assimilate phosphorus easily. These results are in accordance with the findings of Ram *et al.* (2007) [10], Singh *et al.* (2008) [13] and Dutta *et al.* (2009) [3] in guava. The stem girth was not significantly affected by INM treatments across the period of study, because the trees which are selected for study were of similar age of over 14 years as such the influence of fertilizer may not be easily apparent which was also reported by Ibiremo *et al.* (2014) [6] and Alfred *et al.* (2016) [1]. The height at first branching did not differ considerably irrespective of treatment, as the pruning and training measures taken up during early stages of growth might have contributed to the uniform architecture. Similar results were reported in cocoa by Elain Apshara *et al*. (2008) [4]. Canopy spread is one of the deciding factor in cocoa for fruiting area which directly influences the vigour of the plant

and in higher yield. The use of bio fertilizers attributed to improve nutrient use efficiency under balance use of organic and inorganic sources of nutrient explained by Kumar *et al*. (2008). In cocoa, yield is determined by yield contributing characters such as number of pods per tree, dry bean yield per tree and pod value (Thondaiman *et al*. 2013) [12]. These characters are influenced both by genetic as well as environmental factors which includes soil moisture and nutrient status. Improvement in plant growth and yield attributes is due to composted coir pith application might have been attributed to the translocation of nutrients from soil to the plants and enhanced supply of macro & micro-nutrients during entire growing season. Baviskar *et al*. (2011) [2] in sapota also reported similar results. The increase in dry bean yield per tree is due to increased rate of photosynthesis which could have further led to the better partitioning of assimilates, higher fertilizer use efficiency and higher uptake of macro and micronutrients. These findings are in agreement with that of Kaur *et al*. (2007) [7] and Kundu *et al*. (2011) [9].

Table 1: Effect of different INM treatments on growth characters of cocoa (*Theobroma cocoa* L.)

Treatments	Tree height(m)		Girth of the tree (cm)		Height at first branching (HAFB) (m)	
	Initial tree height	8 MAF	Initial girth	8 MAF	Initial HAFB	8 MAF
T_1	2.79	3.72 (0.93)	45.96	46.89 (0.93)	1.20	1.21 (0.01)
T_2	2.81	3.97 (1.16)	46.46	47.47 (1.01)	1.17	1.17 (0.00)
T_3	2.93	3.63 (0.70)	45.88	46.88 (1.00)	1.09	1.09 (0.00)
T_4	3.13	3.96 (0.83)	46.92	47.88 (0.96)	1.14	1.14 (0.00)
T_5	2.88	3.71 (0.83)	46.80	47.56 (0.76)	1.25	1.27 (0.02)
T_6	2.93	3.89 (0.96)	47.12	47.96 (0.84)	1.31	1.32 (0.01)
T_7	3.01	4.00 (0.99)	44.48	45.23 (0.75)	1.25	1.26 (0.01)
T_8	2.95	3.82 (0.87)	44.64	45.33 (0.69)	1.06	1.08 (0.02)
T_9	3.00	3.88 (0.88)	46.46	47.06 (0.60)	1.29	1.31 (0.02)
T_{10}	2.83	3.75 (0.92)	45.08	45.47 (0.39)	1.31	1.32 (0.01)
SE m ±	0.15	0.25	1.63	1.70	0.09	0.09
CD (P=0.05)	NS	NS	NS	NS	NS	NS
CV (%)	9.33	11.45	6.15	6.31	13.96	13.78

T_1: 75% RDF + 25% RDN through composted coir pith T_2: 75% RDF + 25% RDN through composted coir pith+ 50 g *Azospirillum* + 50 g PSB
T_3: 50% RDF + 50% RDN through composted coir pith T_4: 50% RDF + 50% RDN through composted coir pith+ 50 g *Azospirillum* + 50 g PSB
T_5: 75% RDF + 25% RDN through FYM T_6: 75% RDF + 25% RDN through FYM+ 50 g *Azospirillum* + 50 g PSB
T_7: 50% RDF + 50% RDN through FYM T_8: 50% RDF + 50% RDN through FYM+ 50 g *Azospirillum* + 50 g PSB
T_9: 100% RDF T_{10}: Control
RDF- Recommended dose of fertilizers RDN-Recommended dose of nutrients CCP- Composted coir pith
FYM- Farm yard manure PSB-Phosphate solubilizing bacteria MAF-Months after fertilizer application
Figures in parenthesis indicate tree height, girth and HAFB values

Table 2: Effect of different INM treatments on growth characters of cocoa (*Theobroma cocoa* L.)

Treatments	Spread of canopy (EW) (m)		Spread of canopy (NS) (m)		Canopy volume (m^2)	
	After Pruning	8 MAF	After Pruning	8 MAF	After Pruning	8 MAF
T_1	3.68	4.97 (1.29)	3.19	4.50 (1.31)	12.68	25.80 (13.12)
T_2	3.63	5.32 (1.69)	3.58	4.73 (1.15)	13.88	30.02 (16.14)
T_3	3.54	4.78 (1.24)	3.22	4.35 (1.13)	13.28	24.55 (11.27)
T_4	3.42	4.55 (1.13)	3.17	4.16 (0.99)	13.56	24.50 (10.94)
T_5	3.29	4.79 (1.52)	3.13	4.46 (1.30)	12.67	24.69 (12.02)
T_6	3.31	4.47 (1.16)	3.16	4.24 (1.08)	11.79	23.18 (11.39)
T_7	3.48	4.65 (1.17)	3.08	4.37 (1.29)	12.81	25.54 (12.73)
T_8	3.54	4.66 (1.12)	3.12	4.21 (1.09)	13.50	24.76 (11.26)
T_9	3.74	5.26 (1.52)	3.32	4.50 (1.18)	13.78	27.19 (13.41)
T_{10}	3.18	4.44 (1.26)	2.98	4.28 (1.30)	10.51	23.03 (12.52)
SE m ±	0.13	0.27	0.17	0.22	1.28	2.91
CD (P=0.05)	NS	NS	NS	NS	NS	NS
CV (%)	6.77	9.80	9.19	8.85	17.31	19.94

T_1: 75% RDF + 25% RDN through composted coir pith T_2: 75% RDF + 25% RDN through composted coir pith + 50 g *Azospirillum* + 50 g PSB
T_3: 50% RDF + 50% RDN through composted coir pith T_4: 50% RDF + 50% RDN through composted coir pith + 50 g *Azospirillum* + 50 g PSB
T_5: 75% RDF + 25% RDN through FYM T_6: 75% RDF + 25% RDN through FYM + 50 g *Azospirillum* + 50 g PSB
T_7: 50% RDF + 50% RDN through FYM T_8: 50% RDF + 50% RDN through FYM + 50 g *Azospirillum* + 50 g PSB
T_9: 100% RDF T_{10}: Control
RDF- Recommended dose of fertilizers RDN-Recommended dose of nutrients CCP- Composted coir pith
FYM- Farm yard manure PSB-Phosphate solubilizing bacteria MAF-Months after fertilizer application
Figures in parenthesis indicate incremental canopy spread and canopy volume values

Table 3: Effect of different INM treatments on yield characters of cocoa (*Theobroma cocoa* L.)

Treatments	Healthy pods	Damaged pods	Weight of the pod (g)	Husk weight (g)	Wet bean weight (g)	Dry bean weight/ pod (g)	Single bean dry weight (g)	Total dry bean yield/tree (kg)
T_1	51.43	0.78	448.91	322.00	126.91	63.28	1.49	3.03
T_2	55.84	0.37	485.26	349.68	135.58	66.60	1.57	3.57
T_3	43.33	0.97	438.03	330.20	107.83	62.05	1.48	2.48
T_4	44.54	0.59	398.90	293.35	105.55	52.39	1.41	2.13
T_5	43.59	0.44	398.49	304.72	93.77	56.83	1.39	2.26
T_6	45.58	0.49	410.00	306.03	103.96	54.18	1.45	2.34
T_7	44.49	0.44	401.91	303.89	98.02	60.56	1.44	2.48
T_8	43.17	0.93	410.36	308.77	101.59	55.88	1.42	2.25
T_9	40.65	0.74	390.56	289.57	100.99	61.07	1.45	2.26
T_{10}	26.03	1.21	329.50	271.30	58.20	44.09	1.21	0.97
SE m ±	1.06	0.05	21.52	22.32	12.10	1.79	0.04	0.11
CD(P=0.05)	3.17	0.15	64.44	N.S	36.23	5.38	0.13	0.34
CV (%)	4.18	12.61	9.06	12.55	20.30	5.39	5.52	8.26

T_1: 75% RDF + 25% RDN through composted coir pith T_2: 75% RDF + 25% RDN through composted coir pith+ 50 g *Azospirillum* + 50 g PSB
T_3: 50% RDF + 50% RDN through composted coir pith T_4: 50% RDF + 50% RDN through composted coir pith+ 50 g *Azospirillum* + 50 g PSB
T_5: 75% RDF + 25% RDN through FYM T_6: 75% RDF + 25% RDN through FYM+ 50 g *Azospirillum* + 50 g PSB
T_7: 50% RDF + 50% RDN through FYM T_8: 50% RDF + 50% RDN through FYM+ 50 g *Azospirillum* + 50 g PSB
T_9: 100% RDF T_{10}: Control
RDF- Recommended dose of fertilizers RDN-Recommended dose of nutrients CCP- Composted coir pith
FYM- Farm yard manure PSB-Phosphate solubilizing bacteria MAF-Months after fertilizer application

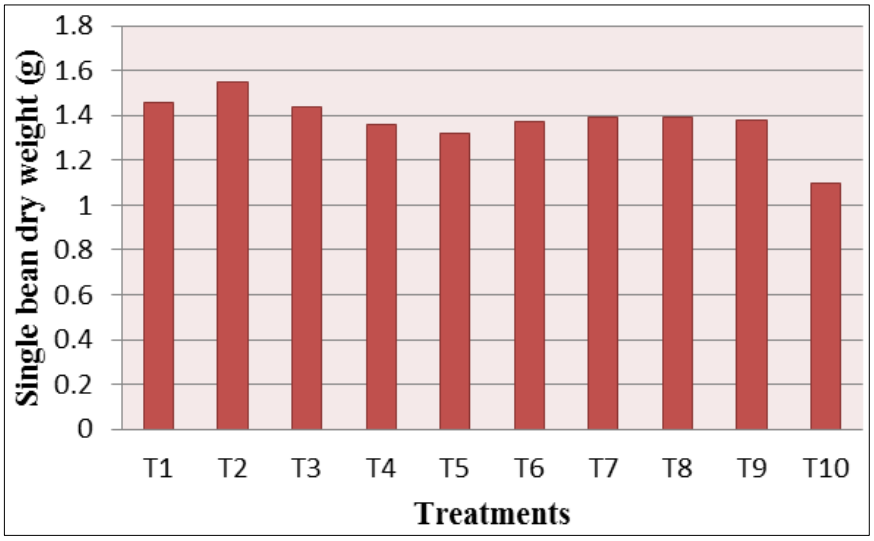

Fig 1: Effect of INM treatments on single bean dry weight of cocoa

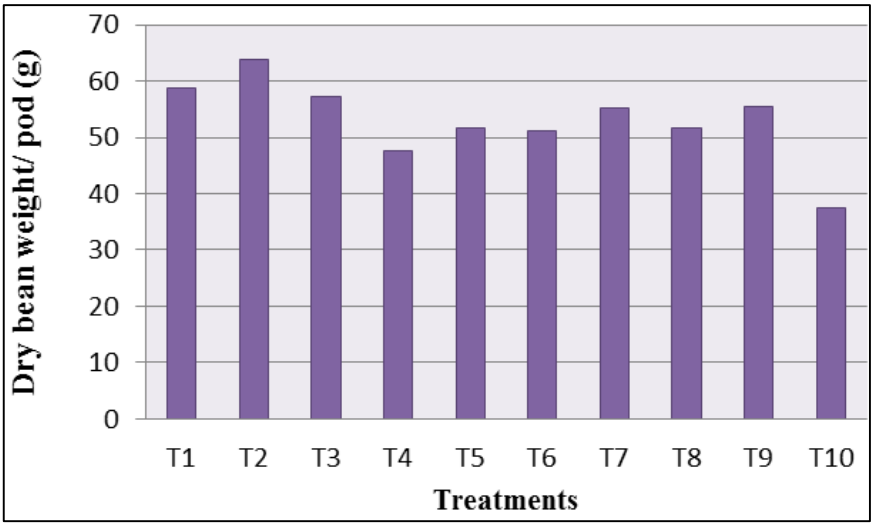

Fig 2: Effect of INM treatments on dry bean weight per pod of cocoa

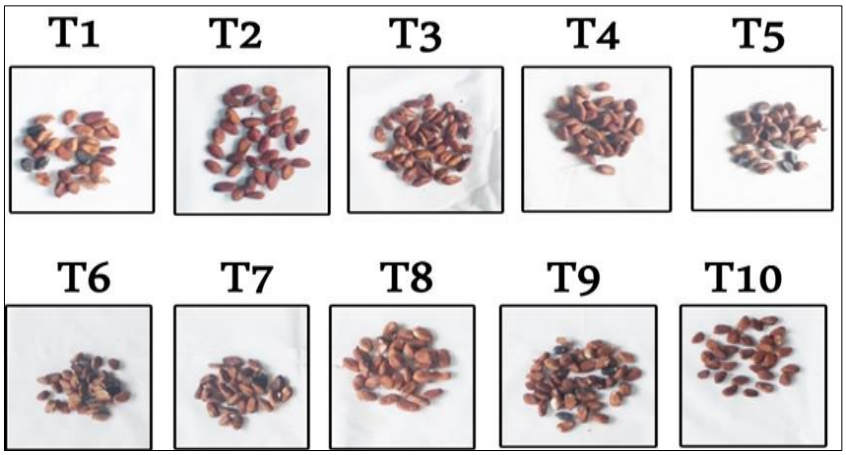

Plate 1: Effect of INM treatments on dry bean weight per pod of cococa

Conclusions

The present study represents the positive response of organic, inorganic and bio-fertilizers application to increase the growth and yield of cocoa. The combined use of organic manures, biofertilizers and chemical fertilizers has been found not only in maintaining higher productivity but also in providing stable crop yields for sustainable crop production through integrated nutrient use. The above results indicated that there is ample scope for substitution of inorganic fertilizers with INM treatments, by keeping the higher production and productivity in view, application of 75% RDF + 25% RDN through composted coir pith+ 50 g *Azospirillum* + 50 g PSB were recommended in black alluvial soils of Andhra Pradesh for higher returns.

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