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Effects of Site Burning on Multiple Leader Formation and Growth Performance of Selected *Acacia* Genotypes

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Abstract

Loss of apical dominance, resulting in seedlings with more than one leader, generally referred to as multiple leaders (ML), has been a major problem in forest tree plantation in the tropics. A study to examine the effects of site preparation by burning on growth performance and multiple leaders (ML) formation, and its variation in eight-genotypes of *Acacia mangium* and *Acacia auriculiformis* was conducted. The design used for this field trial is a randomized complete block design with four replications at two sites (burnt and unburned) and eight genotypes (four from each species), and the effects were monitored for 24 months. There were significant differences at $P < 0.05$ between sites and genotypes for the number of ML trees/plot, basal diameter and survival. Differences among the genotypes, in terms of height, were also significant, but not between sites. The site × genotype interaction was significant only for ML trees per plot. Generally, the number and the size of ML trees per plot in the burnt site were higher and bigger than those in the unburned site. The number of ML trees per plot formed increased exponentially with time, reaching a peak in about four months after their first occurrence and then leveled off to an almost steady state thereafter at both sites. The average number of multiples (leaders) per tree ranged from 2 to 5 at the burnt site whilst at the unburned site, all the ML trees were of two leaders. *A. mangium* provenances were more responsive to burning than *A. auriculiformis*, whereas at the unburned site, the variation between them was not significant. Based on the above variation, it can be concluded that burning causes ML formation and can affect the growth of these selected *Acacia* genotypes.

Keywords

***Acacias*, Genotype, Multiple Leaders, Growth Performance, Site Preparation**

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1. Introduction

Forest tree plantations in the tropics consist of exotic species mainly of tropical pines and acacias. Even though species trial results provide useful information on performance, adaptability and species-site interaction, extensive research is required to understand the physiology and the genetics of the introduced materials. Recently there has been upsurge of research on acacias throughout the tropics. *Acacia mangium* and *Acacia auriculiformis* are two of the fast growing tropical acacias, which have received the highest priority for genetic assessment and improvement other than *Acacia aulococarpa* and *Acacia crassicarpa*. Review of Turnbull [1] indicates the extent of *Acacia* plantations in Asia. In addition, many national and international provenance trials of *A. mangium* and *A. auriculiformis* have been reported from different regions and localities such as from China [2], Indonesia [3] [4], Malaysia [5] [6], Thailand [7] [8], Zaire [9] and Vietnam [10] [11]. Reports from Malaysia and Thailand, in particular, indicated that despite their successful introduction and adaptability, both *A. mangium* and *A. auriculiformis* provenances grown in plantation and trial sites have shown problems in tree form, growth habit and develop multiple leaders (ML) right from the base of the trunk and in some cases heavy epicormic branching with excessive low forking branch.

Multiple leaders (ML) seedlings referred to seedlings with terminal shoots greater in length than 20% of the dominant or main leader [12]. It is recognized that damage to terminal meristems will generally result in the loss of apical dominance, and severity of ML formation totally depends on the intensity of the damage. Terminal damage to the apical meristem normally can be associated with several biotic and abiotic factors. Studies on fertilization burn, herbicide soil residues, soil toxins and mycoplasmas led to the identification and recognition of some potential causal factors responsible for the repeated and consistency of ML formation in some temperate species [13]-[15]. In some cases, abnormal bud development and root:shoot ratios due to application of herbicide have been identified to increase the terminal shoot damage and eventually lead ML formation. Terminal damage also has been associated with frost and believed to increase the ML incidence in most of the temperate region. However results indicate that it may be reduced by altered nursery cultural practices such as employing early cut-off dates for supplemental nitrogen fertilization and herbicide application [12].

The actual factors that cause the formation of multiple leaders in these species are limited. Although *A. mangium* shows strong apical dominance, on some sites trees still show a strong tendency to develop multiple leaders from the base. Srivastava [16] related the causes to genetics and site environmental conditions. Others related it to site environmental factors including cultural practices, genetic variations within genotypes and families as well as growth regulators. The standard silvicultural practice to deal with the problem of multiple leader formation is singling, which involves the retaining of one shoot per tree and cutting-off the rest. It is done four to six months after out planting before the formation of heartwood. However, if singling is not done timely, there is always the danger of rot fungus entering through wound and eventually leading to heart rot disease [17] [18].

In forestry practice, the multiple leader development may be denied or favored depending on management objectives and end-use products. Trees, which invariably have a shrub-like growth habit, would not be preferred when clear bole of higher quality is required for sawn timber production. Currently, multiple leader formation is posing a serious problem to *A. mangium* plantation industry in Peninsular Malaysia in terms of wood quality and added cost by the introduction of singling. Branch-related defects can significantly decrease the quality of plantation grown for solid-wood products. Studies on ML were initiated because the occurrence of ML trees in acacia plantation at some trial plots was becoming unacceptably high. Thus, field trial to examine the effects of site preparation by burning on growth performance and multiple leaders (ML) formation and its variation in eight genotypes of *A. mangium* and *A. auriculiformis* was conducted.

2. Materials and Methods

Seeds of eight genotypes, four each of *A. mangium* and *A. auriculiformis* from a seed consignment obtained from the Australian Tree Seed Center, CSIRO Forestry and Forest Products were used. Three of the *A. mangium* provenances were from Queensland (QLD) and one was from Papua New Guinea (PNG) while two of the *A. auriculiformis* were from Northern Territory (NT) one was from Papua New Guinea (PNG) and one was from Queensland (QLD). The seeds were treated prior germination, following the guidelines provided by CSIRO. They were then transplanted to polyethylene bags (12 cm × 18 cm), filled with a potting medium of 5:3:2 top soil, sand and tropical peat, respectively, two weeks after sowing. Seedlings were then raised in nursery and were given necessary care.

2.1. Field Outplanting

The trial was established at the Dunbar Estate of the How Swee Sdn. Bhd. Aur Gading near Kuala Lipis in Pahang, Peninsular Malaysia in August 2010. It is located 4˚20.5′N latitude and 101˚55.5′E longitude, at an altitude of 91.5 m above sea level. The soil of the trial site were described as deep, brownish yellow to yellowish brown fine sandy loam, weak to moderate medium to fine sub angular blocky structure, friable, well drained with sporadic water logging in some part. The terrain was undulating and the parent material was either Shale or Riverine. The soil types are Bungor and Gong Yong series (Malaysian soil classification system). Two sites, burnt and unburned, were selected within the Estate, based on the recent history of land preparation for planting. Site preparation was carried out in some selected compartments, which were either mechanically cleared or mechanically cleaned and followed by broadcast burning of the old rubber trees (*Hevea brasilensis*). The sturdiest of the seedlings from the nursery production run were selected, conditioned and hardened-off at the nursery. They were then dispatched and transported to the field trial site a week prior to out planting for the purpose of further hardening-off at the planting site. Seedlings of similar size and vigor were selected for the purpose of field establishment. The experimental design used was a randomized complete block (RCBD) with four replications per site. Within each replication, eight genotypes were assigned randomly to eight single line plots of sixteen trees, planted at a spacing of 3 m × 3 m.

2.2. Data Collection and Analysis

Six periodic measurements of the ML formation, survival percentage, total tree height and basal diameter were measured for 24 months. Because of the ML formation an adjusted basal diameter was calculated using the geometric mean procedure for all ML trees. The data of the two sites combined and of each individual site were analyzed separately using SAS, version 6.2, for variance to detect the significance of variation of the sources and their interaction.

3. Results

3.1. Multiple Leader Formation

The result showed significant differences between site preparation methods for survival and basal diameter, ML, $p < 0.05$, but not for height. There were also significant differences between genotypes for ML, survival, height and basal diameter, and site × genotype interaction for ML, $p < 0.05$, but not for survival, height and basal diameter (**Table 1**).

There was also significant difference between the burnt and unburned sites in terms of ML trees/plot. The number of ML trees/plot at the burnt site was higher than the unburned site (**Table 2**).

Table 1. ANOVA summary on 24-month growth characteristics of *A. mangium* and *A. auriculiformis*.

Source of variation	df	ML	Survival (%)	Height	Basal diameter
Site	1	805.14*	11956.05*	0.04 ns	453.10*
Genotype	7	67.27*	443.47*	3.42*	2848.36*
Blocks	3	2.02 ns	422.72 ns	1.61*	524.24*
Site × Genotype	7	71.39*	87.81 ns	0.38 ns	113.24 ns

*Significant different at $p < 0.05$; ns: not significant different at $p < 0.05$.

Table 2. Effect of site preparation methods on mean growth characteristics of *A. mangium* and *A. auriculiformis* genotypes.

Site	ML trees/plot (No)	Survival (%)	Height (m)	Diameter (cm)
Burnt	7.56^a	95.11^a	5.63^a	93.78^a
Unburned	0.47^b	67.77^b	5.58^a	88.46^b

Means followed by the same letter in a column are not significantly different at $p < 0.05$ by Duncan's New Multiple Range Test.

The genotypes showed significant differences in terms of ML tree/plot formation at the burned site. It ranged from 1 (*A. auriculiformis*, Wenlock River) to 14.75 (*A. mangium*, Tully Mission Beach). Here, *A. mangium* showed significant differences between its provenances but *A. auriculiformis* did not. The genotypes also showed significant differences in terms of ML tree/plot formation at the unburned site. It ranged between nil (*A. auriculiformis*, Elizabeth River) to 1 (*A. auriculiformis*, May River). At this site *A. auriculiformis* showed significant differences between its provenances but not for *A. mangium*. The mean ML trees/plots of both sites combined also showed significant difference between the genotypes. It ranged from 0.75 (*A. auriculiformis*, Wenlock River) to 7.5 (*A. mangium*, Tully Mission Beach). *A. mangium* showed significant difference between its provenances. It ranged from 5.5 (SE Daintree) to 7.5 (Tully Mission Beach). But *A. auriculiformis* did not show any significant difference (**Table 3**).

Generally, *A. mangium* produced remarkably higher percentage of ML trees/ plot in the burnt site compared to *A. auriculiformis*. The value ranged from 66.67% (SE of Daintree) to 93.66% (Tully Mission Beach) for *A. mangium* provenances while it ranged from 6.25% (Wenlock River) to 20.66% (Mary River) for *A. auriculiformis*. However, the variation between the species was not pronounced in the unburned site. It ranged from 1.82% (Tully Mission Beach) to 5.13% (SSO Kuranda) for *A. mangium* while it ranged from nil (Elizabeth River) to 8.88% (Mary River) for *A. auriculiformis* (**Table 4**).

Table 3. Mean of ML trees per plot, height, basal diameter, and survival percentage for the burnt and unburned sites at 24 months.

	Burnt site				Unburned site				
Genotype	ML (no)	Ht (m)	Diameter (mm)	Survival (%)	ML (tree/plot)	Ht (m)	Diameter (mm)	Survival (%)	ML (tree/plot)
A. mangium									
Kuraida, FN-QLD	13.25^{ab}	6.5^{a}	110.05^{a}	89.06^{ab}	0.50^{ab}	6.8^{a}	114.93^{a}	60.94^{b}	6.88^{a}
Oriomo Province WP	13.00^{ab}	6.4^{a}	114.88^{a}	93.69^{ab}	0.50^{ab}	5.1^{ab}	1O3.13^{b}	64.06^{ab}	6.75^{ab}
Tully-Mission Beach	14.75^{a}	6.4^{a}	120.06^{a}	98.44^{a}	0.25^{ab}	5.7^{b}	1O5.12^{b}	85.94^{a}	7.50^{a}
SE of Daintree	10.75^{b}	5.83^{ab}	96.97^{b}	84.38^{b}	0.25^{ab}	5.5^{b}	92.76^{c}	51.56^{b}	5.50^{b}
A. auriculiformis									
SSO Fiji	2.00^{c}	5.4^{b}	87.24^{bc}	100.00^{a}	0.75^{ab}	5.6^{b}	85.05^{c}	65.63^{ab}	1.38^{c}
Elizabeth River	2.50^{c}	5.2^{bc}	80.34^{cd}	96.88^{a}	0.00^{b}	4.1^{b}	67.45^{ed}	70.31^{ab}	1.25^{c}
Wenlock River	1.00^{c}	4.1^{be}	70.91^{d}	100.00^{a}	0.50^{ab}	5.3^{b}	75.19^{d}	73.44^{ab}	0.75^{c}
Mary River	3.25^{c}	4.4^{c}	69.80^{d}	98.44^{a}	1.00^{a}	4.9^{b}	63.88^{e}	70.31^{ab}	2.13^{c}
Overall Site Mean	7.56	5.6	93.78	95.11	0.47	5.6	88.46	67.77	4.02
SD	5.88	0.77	19.9	5.7	0.31	0.54	18.71	10.02	1.29

Means followed by the same letter in a column are not significantly different at $p < 0.05$ by Duncan' New Multiple Range Test.

Table 4. Comparison of ML% occurrence between the burnt and unburned sites by genotype.

Genotype	ML (trees/plot)		ML (%)	
	Burnt	Unburned	Burnt	Unburned
A. mangium Tully Mission Beach	12	0.5	93.66	1.82
A. mangium SSO Kuranda	9.5	0.75	92.98	5.13
A. mangium Oriomo Province WP	11.25	0.75	83.87	4.88
A. mangium SE Daintree	9.5	0.25	66.67	4
A. auriculiformis Mary River	3.25	1.25	20.63	8.88
A. auriculiformis Elizabeth River	4.5	0.25	16.13	0
A. auriculiformis SSO Fiji	3.5	0.75	12.5	7.14
A. auriculiformis Wenlock River	1.5	0.5	6.25	4.26

3.2. Temporal Development of ML Trees

It took about 7 to 8 months for the planted trees to fully develop and obviously display the ML growth habit. **Table 5** illustrates the trend of ML development for *A. mangium* and *A. auriculiformis* genotypes through time and also compares the variation between the individual genotypes at the burnt and unburned sites. Generally the number of ML trees/plot formed increased exponentially with time, reached a peak in about four months after their first occurrence and then leveled off to an almost steady state thereafter at both sites (**Figure 1**). The average number of multiples trunks per tree ranged from 2 to 5 at the burnt site whilst at the unburned site all the ML trees was of the two-stem category. At the burnt site 78.30% of the total number of ML trees was of the two-stem category, 19.15% of the three-stem category, 2.13% of the four-stem category and only 0.43% was of the five-stem category. **Figure 2** shows the number of ML trees by genotypes in each of the four-number category (2 ML to 5 ML). *A. auriculiformis* SSO Fiji (PNG) and Wenlock River (QLD) had all their multiples in the two-stem category while the remainder had mixed proportion of the stem categories.

4. Discussion

Trees that develop multiple leader growth habit ultimately lose their timber value. The intensive investigation reports made by Hofstra *et al.* [19], Holopainen [20] and Birk [21] regarding multiple leader formation on temperate forest trees, both at the nursery and field level, indicate that multiple leader's growth habits are threats to

Table 5. Temporal development of growth characteristic of *A. mangium* and *A. auriculiformis* genotypes by site preparation method.

Age (month)	Height (m)		Diameter (mm)		ML (tree/plot)		Survival (%)	
	Burnt	Unburned	Burnt	Unburned	Burnt	Unburned	Burnt	Unburned
4	0.927 ± 0.20	0.976 ± 0.23	10.462 ± 1.58	8.725 ± 1.76	0.00 ± 0.00	0.00 ± 0.00	96.68 ± 6.35	83.38 ± 14.7
7	1.573 ± 0.29	1.555 ± 0.37	22.108 ± 4.14	15.597 ± 3.56	0.00 ± 0.00	0.00 ± 0.00	96.48 ± 6.34	76.75 ± 17.1
9	2.276 ± 0.35	2.181 ± 0.40	36.54 ± 11.98	25.124 ± 6.56	5.187 ± 3.45	0.43 ± 0.67	96.26 ± 6.53	75.77 ± 17.8
13	3.594 ± 0.50	3.168 ± 0.54	52.476 ± 11.70	39.196 ± 9.70	6.438 ± 4.38	0.531 ± 0.72	96.09 ± 6.69	72.85 ± 17.8
16	4.583 ± 0.70	3.964 ± 0.62	67.499 ± 14.50	56.499 ± 13.58	6.531 ± 4.31	0.625 ± 0.79	95.89 ± 6.66	68.53 ± 19.3
23	5.632 ± 0.89	5.582 ± 0.96	93.78 ± 20.52	88.459 ± 19.66	6.781 ± 4.54	0.625 ± 0.79	95.10 ± 8.06	67.77 ± 18.5

Note: Mean ± Standard Deviation.

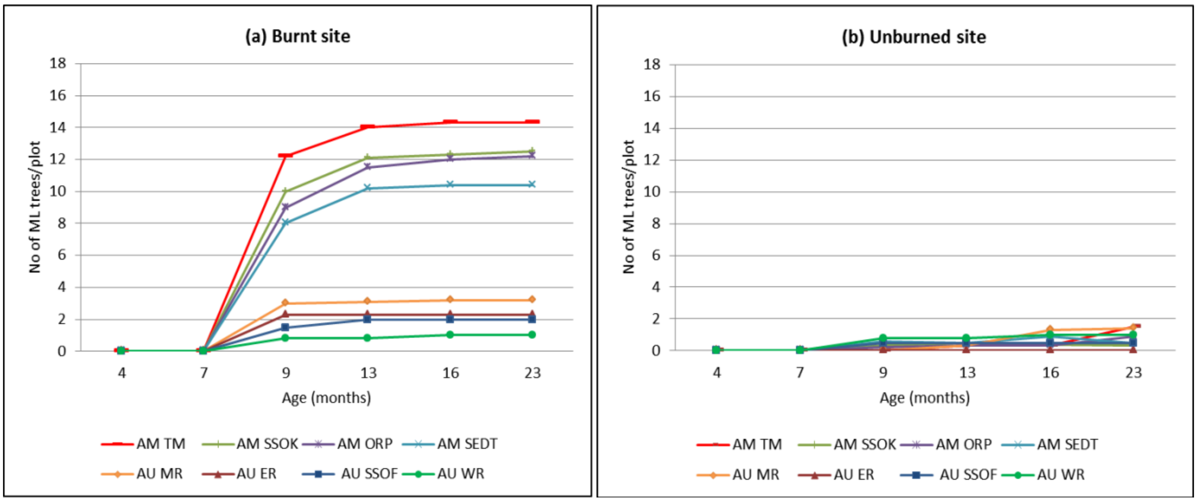

Figure 1. The trend and variation of ML development with time of *A. mangium* and *A. auriculiformis* genotypes at (a) burnt and (b) unburned sites. Key: abbreviations of the genotypes; AM TM = *A. mangium* Tully Mission Beach; AM SSOK = *A. mangium* SSO Kuranda; AM ORP = *A. mangium* Oriomo Province WP; AM SEDT = *A. mangium* SE Daintree; AU MR = *A. auriculiformis* Mary River; AU ER = *A. auriculiformis* Elizabeth River; AU SSOF = *A. auriculiformis* SSO Fiji; AU WR = *A. auriculiformis* Wenlock River.

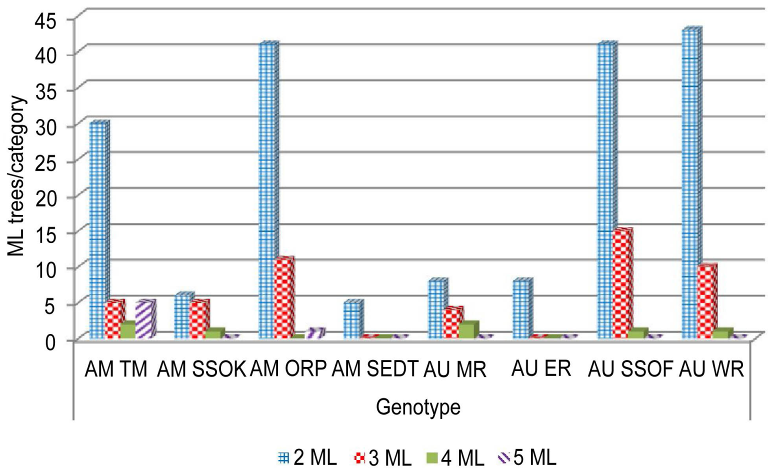

Figure 2. The proportion of ML trees in the four stem-categories by genotype. Note: abbreviations are the same as in **Figure 1**.

timber trees development. The result of the present study in agreement with the suggestion that environment has much influence on form and growth habit. In this context, about half (49.09%) of total number of planted trees at burnt site had multiple trunks as compared to only 4.25% at the unburned site. The result of the present study also revealed that the problem of ML growth habit in relation to site preparation method might be a potential problem for *A. mangium*, in particular. All four *A. mangium* provenances at the burnt site had significantly higher number of ML trees per plot compared to all four *A. auriculiformis* provenances (**Table 3**) while at the unburned site this was not the case. The genotypes varied a great deal in their response to site preparation by burning. At the burnt site 85% of the total number of the ML trees was from the provenances of *A. mangium* while only 15% were from *A. auriculiformis*. At the unburned site, however, *A. auriculiformis* contributed 60% of the total ML trees and *A. mangium* 40%. Taking into consideration the highly significant difference between the burnt and unburned sites, *A. mangium* provenances were more responsive to burning than *A. auriculiformis*, as land preparation method. However, this conclusion is not in full agreement with the findings by Khasa *et al.* [9] from a trial in Zaire, where *A. auriculiformis* had multiple stem of an average of three stems per tree while *A. mangium* had only single stem at four sites, in which site prepared by burning of the vegetation after mechanical clearing. However, the details of the provenance used were not reported. This was reflected by the fact that *A. auriculiformis* genotypes had no considerable variation in ML/plot across the two sites while *A. mangium* genotypes had highly significant differences in ML/per plot across the two treatments. The effect of ML leaders to the quality of timber should also not to be overlooked. If the aim of a plantation is to produce quality timber trees, then ML trees need to be rejected on the ground of ML formation. Otherwise, additional cost for silvicul-tural practices such as singling would be compulsory. Singling, on the other hand, if not done on time, will also has its own disadvantages as trees that have developed heartwood, if singled will be affected by rot fungus [17] [18]. However, ML formation are accepted or even desirable if the objective of the plantation is to produce fuel wood, poles, and pulp and paper production.

Regarding the survival rate, the result of the trial indicated that all the genotypes survived well at the burned site with a site mean of 95.11%, ranging between 84% - 100%, while the survival at the unburned site was comparatively low, with an overall site mean of 66.67%, ranging from 54.56% to 73.44%. However the mean of both sites combined ranged from 67.90% to 92.13%. *A. mangium* from the SE of Daintree showed the lowest survival rate. Generally, the results of the survival rate obtained in this study were comparable with the trends experienced in many of the *A. mangium* and *A. auriculiformis* provenances trials in the humid tropics [5] [6] [22]-[25]. The reasons for the low survival rate at the unburned site may be attributed to weed competition, animal trampling and shade.

The result of the 24 months observation, however, showed that there was no significant difference in terms of height between the provenances of each of the two *Acacia* species but only between the genotypes (**Table 1**). These results were in accordance with the reports of Peterson and Havmoller [26] for *A. mangium*, at the age of six months, in Philippines, but not with the result obtained by Atipanumpai [22] for *A. mangium*, at the age of 30 months, in Thailand where the species differed significantly in height. Sim and Gan [27] also found substantial differences in height between *Acacia* species but less between *A. mangium* and *A. auriculiformis* provenances. In general, *A. mangium* out performed *A. auriculiformis* provenances in terms of height growth. Basal diameter growth also showed significant differences in both sites, among genotypes at each site and at both sites combined. The trends of diameter growth were reported by Kamis *et al.* [5]; Nor Aini *et al.* [6]; Khasa *et al.* [9]; Atipanumpai [22] and Gwaze [24].

5. Conclusion

The results of the study are in agreement with the suggestion that environment has much influence on form and growth habit of *Acacia* genotypes. The use of fire to clear land for *A. mangium* and *A. auriculiformis* genotypes induces ML formation. It was also observed that *A. mangium* provenances were more responsive to ML formation than *A. auriculiformis* provenances. The number ML/tree ranged from two to five at the burnt site compared with only two at the unburned site for both species. The problem of ML growth habit of *Acacia* provenances in relation to site preparation method might be a potential problem for establishment of commercial plantation area, if the high quality grade timber was the target of a plantation. If fuel wood or small construction poles or even pulp and paper production is the objective, then the ML formation would be accepted and not greatly affect the end product, and in fact, it may be desirable in some cases. However, this could be utilized for better planning, and management of plantation area with option of other suitable methods depends on the objective of the end product, site condition and environment factors.

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