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Application stages and nitrogen sources in topdressing of super-early bean crop irrigated

Estádios de aplicação e fontes de nitrogênio em cobertura na cultura do feijoeiro superprecoce irrigado

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Abstract

Producing food in a sustainable manner, exploiting the genetic potential of crops and optimizing cultivation time to ensure increased production are the biggest challenges for agriculture. The cultivation of super-early common bean lineages with high productive capacity leads to minor water consumption in crops under irrigation and vacate the area in less time. The objective of this work was to evaluate the yield components of super-early cycle common bean cultivars, under irrigated system in function of sources of nitrogen (N) as well as to assess different application stages. The experiment was conducted in randomized block design in a factorial scheme 4x3 + 1, corresponding of four sources of N in coverage (urea, urea + ammonium sulfate, urea + ammonium sulfate + elemental sulfur and urea + elemental sulfur), three application stages (V3, V4 and R5) and a control treatment. The N incorporation did not influence on the grain yield of the super-early cycle common bean regardless of the source and season, whereas significant results were merely found when compared to the control. The number of pods was affected when the application was carried out at the R5 stage, with a significant reduction in this yield component. The relative chlorophyll index was lower when nitrogen coverage was performed at the R5 stage.

Additional keywords: BRS FC 104; nitrogen fertilization; *Phaseolus vulgaris* L.; relative chlorophyll index.

Resumo

Produzir alimentos de forma sustentável explorando o potencial genético das culturas e otimizando o tempo de cultivo para assegurar o aumento da produção são os maiores desafios para agricultura. O cultivo de linhagens de feijão comum superprecoce com alta capacidade produtiva pode proporcionar menor consumo de água nos cultivos sob irrigação e desocupação da área em menor tempo. Objetivou-se, neste trabalho, avaliar os componentes de produtividade em cultivar de feijoeiro-comum de ciclo superprecoce, sob sistema irrigado, em função de fontes de nitrogênio (N) e estádios de aplicação. O experimento foi conduzido em delineamento de blocos ao acaso, em esquema fatorial 4x3 + 1, correspondentes à quatro fontes de N (ureia, ureia + sulfato de amônio, ureia + sulfato de amônio + enxofre elementar e ureia + enxofre elementar), três estádios de aplicação (V3, V4 e R5) e um tratamento testemunha. A aplicação do N independente da fonte e época não influenciou a produtividade de grãos do feijoeiro-comum de ciclo superprecoce, havendo resultado significativo apenas quando comparado a testemunha. O número de vagens foi afetado quando a aplicação foi realizada no estádio R5, com redução significativa desse componente de produtividade. O índice relativo de clorofila foi menor quando a cobertura de nitrogênio foi realizada no estádio R5.

Palavras-chave adicionais: adubação nitrogenada; BRS FC 104; índice relativo de clorofila. índice relativo de clorofila; *Phaseolus vulgaris* L.

Introduction

Brazil is the largest producer and consumer of common beans (*Phaseolus vulgaris* L.) in the world, which are grown practically all over the country standing out as a basic protein source of the Brazilian diet (Ribeiro et al., 2014).

This common bean is sown in three seasons. The first between October and December and the second season, from January to March. Sowing is performed from March onwards during the third period within the end of the rainy season, mainly in the Cerrado region. Thus, irrigation techniques are needed for the production of this legume. Soil humidity controlled via irrigation and mild temperatures are factors that result in preeminent yields that can often exceed 3000 kg ha^{-1} (Portes, 2012).

The common bean is a legume that performs symbiotic nitrogen fixation with help of soil bacteria, but not sufficient to satisfy the plants' demand. Nitrogen management is considered difficult, since the nutrient, despite being the most required in quantity by the plant, has a complex dynamic in the soil. This element can be easily lost by leaching or volatilization, which compromises the environment and reduces managing efficiency (Cunha et al., 2014).

Cultivation aiming at elevated productivity purposes of common beans requires knowledge and technical skills, since this crop has noticeable nutritional requirements, sensitivity to climatic adversities, high susceptibility to pest attack and, generally, fast physiological cycle.

Super-early common bean cultivars with a 65–70-day cycle developed by the genetic improvement program at *Embrapa Arroz e Feijão* accentuate the challenge of managing this crop, bringing to light the urge to understand the production technology for these crops' management.

The use of super-early cycle common bean cultivars diminishes water consumption in crops under irrigation, whilst enabling harvest planning for drier seasons and area vacancy in less time for crops' succession (Ribeiro et al., 2014). However, studies on nitrogen management in crop coverage and application stages are still scarce, mainly in the Cerrado region. In this sense, the objective of this work was to quantify the effects of nitrogen sources applied in cover and in different application stages on both agronomic characteristics and yield of a super-early cycle common bean cultivar.

Material and methods

The experiment was conducted in the municipality of Rio Verde, Goiás State, at the *Fontes do Saber* farm at the University of Rio Verde. It was implanted under a central pivot irrigation system, at the geographical coordinates 17°48'S and 50º55'W, with an average altitude of 770 meters, within a flat relief (average slope less than 3%). The experiment was conducted from 05/24/2017 to 08/11/2017.

Prior to the experiment installation, soybeans were grown in the 2015/2016 summer harvest, followed by second season crop of corn. In the following harvest (2016/2017), soybeans were cultivated in the summer harvest, and then the beans were sown for experiment conduction under a central pivot irrigation system. Irrigation was performed when the average of the soil water potential evaluated by tensiometer installed in the area at 0.15 m deep was in the range between -30 kPa and -40 kPa.

According to the Köppen classification, the local climate is Aw, characteristic of tropical climates, with a dry season in winter and a humid summer, with rainfall concentrated in this season and a well-defined dry period during the winter season. The annual average precipitation is 1,500 mm and the annual average temperature is 23 ºC. The maximum and minimum temperatures and precipitation in the area during the period in which the experiment was performed are shown in Figure 1. The meteorological data were made available by the National Meteorological Institute (INMET) of the Rio Verde Automatic Meteorological Station, located at the University of Rio Verde.

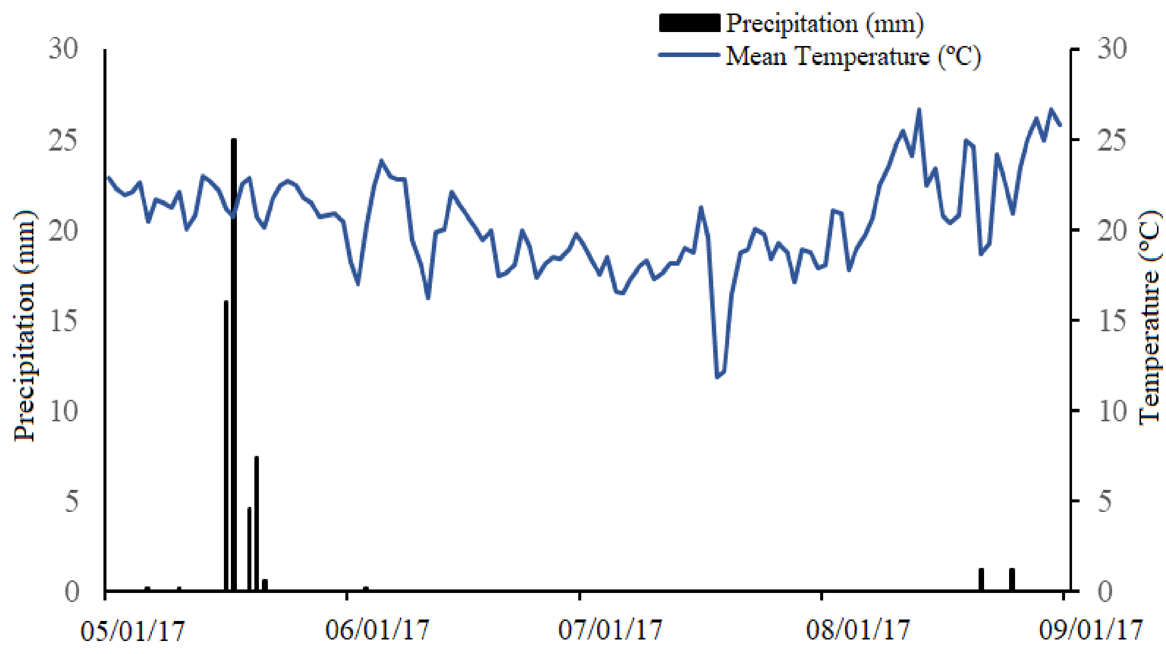

Figure 1 - Precipitation and mean daily temperature during the experiment. Data from the UniRV – University of Rio Verde weather station, 2017.

This study was carried out in a Dystrophic Red Latosol (Santos et al., 2018). Before the experiment installation, soil analysis was performed for physicochemical characterization (Table 1). The chemical composition of the 0 - 0.2 m layer, denoted that the soil chemical composition was in a range considered adequate for beans cultivation (Donagema et al., 2011).

Table 1 - Physicochemical characteristics of the soil in which the experiment was conducted at a depth of 0–0.2 m.

pH	Ca^{2+}	Mg^{2+}	K^{+}	Al^{3+}	$Al^{3+} + H^{+}$	P (Mehlich)	O.M.	Clay	Silt	Sand
($CaCl_2$)	---------------- ($cmol_c$ dm^{-3}) ----------------					($mg\ dm^{-3}$)	---------------- ($g\ kg^{-1}$) ----------------			
4.98	2.05	0.84	0.22	0.14	5.04	24.25	23.33	49.5	7.5	43.0

pH in $CaCl_2$ – potential measurement of ionic hydrogen by calcium chloride; Ca^{2+}, Mg^{2+} - extracted in 1 mol.L^{-1} KCl and determined by atomic absorption spectroscopy; Al^{3+} - extracted in 1 mol.L^{-1} KCl solution and determined by titration; $Al^{3+} + H^{+}$ extracted in 0.5 mol L^{-1} calcium acetate and acquired by titration; P, K, Cu, Zn, Fe, Mn - extracted in Mehlich-1 solution and determined by atomic absorption spectroscopy; O.M. - oxidation by sulfochromic solution, followed by spectrophotometry determination (EMBRAPA, 2011).

The experiment was installed in a randomized block design using a factorial scheme 4x3 + 1, with five replications. Factor A being composed of four nitrogen (N) sources: traditional urea (45% N); urea + ammonium sulfate + elemental sulfur (40.3% N); urea + ammonium sulfate (38.8% N) and urea + elemental sulfur (42.9% N). Factor B consisted of three N application times: in the vegetative stage V3 (when 50% of the plants presented the first fully expanded trifoliolate leaf), in vegetative stage V4 (when 50% of the plants presented the third fully expanded trifoliolate leaf) and during reproductive stage R5 (pre-flowering) (Didonet & Cavalho, 2014). An additional treatment without N application was done, hereafter called control.

The cultivar used was the super-early common bean BRS FC 104 from the “Carioca” commercial group, with maturation and harvest occurring between 60 and 70 days after emergence (DAE). Plots consisted of four rows of 5.0 meters in length, 0.5 m apart, totaling 10 m^2. The useful area encompassed the two central rows totaling 4 m^2 since 0.5 m were discarded at both ends of each row.

Intending to proceed with N fertilization, 80 kg ha^{-1} of each N source was used at the respective stages of development. The fertilizers were manually applied by haul without positioned incorporation between the rows of the plants in each plot. After fertilization, the plots were irrigated to enhance fertilizers’ incorporation. Prior to sowing, the area was desiccated by applying paraquat dichloride herbicides (2.0 L p.c. ha^{-1}) on the 05/20/2017.

Sowing was carried out on the 05/24/2017 by a seeder / fertilizer spreader, in a direct seeding system, with 13 bean seeds being distributed per meter. Seed treatment was achieved with thiamethoxan and fludioxonil + Metalaxil-M, respectively, at the doses recommended by the manufacturer. Base fertilization in the sowing furrow was performed with formulated 07-34-06 at a dose of 300 kg ha^{-1}.

Weeding was necessary for weed management as the invasive plants appeared. During crop development, four sprayings were carried out for insects and disease management, the first application occurring at 11 DAE and the second application at 20 DAE, both using Chloranthraniliprole + Lambda-cyhalothrin and Acephate (100 + 50 + 750 g L^{-1} , respectively) at doses of 0.2 L ha^{-1} and 1.0 kg ha^{-1}, correspondingly. The third and fourth application occurred at 31 and 44 DAE, respectively, in which Azoxystrobin 200 g L^{-1} + Diphenoconazole 125 g L^{-1} + + Thiamethoxam 141 g L^{-1} + Lambda-cyhalothrin 106 g L^{-1} + Abamectin 18 g L^{-1} were used, in the following doses: 0.4 L ha^{-1} + 0.3 L ha^{-1} and 1.0 L ha^{-1}. Harvest was manually performed in the useful area of each plot when the plants reached their physiological maturity.

During crop development, the relative chlorophyll index (RCI) was evaluated using the Minolta SPAD-502 model equipment, which contains diodes that emit light in the range of 650 to 940 nm through the leaf. The 650 nm wavelength is similar to two primary wavelengths associated with chlorophyll activity (645 and 663 nm). The 940 nm wavelength serves as an internal reference to compensate differences in leaf thickness and water content (Yadawa, 1986; Silveira et al., 2003). Random evaluations at 32 DAE were acquired in each experimental unit, selecting the first completely expanded trifoliate, avoiding the central vein and leaf margins, with three readings per trifoliate in ten plants in each plot, totaling thirty readings per plot.

Ten plants of each plot useful area were used to evaluate the following agronomic characteristics: plant height (PH), distance from the plant's neck to the apex; first pod insertion height (FPIH), distance from the neck of the plant to the first pod insertion point and the number of pods per plant (NPP).

In addition, at the time of beans harvesting, each plot had the mass of 100 grains (M100) weighed on a precision scale and had their humidity corrected to 13%. On August 11, 2017, manual harvesting of all plants presented in the useful area of each experimental plot was carried out to determine grain yield. Those plants were subsequently tracked, packaged, identified, weighed and the moisture of the grains corrected to 13%.

Statistical analysis was performed on ASSISTAT software. The data was submitted to analysis of variance by the F test and comparative test of means using Tukey's test ($p < 0.05$), whilst the control was compared with the other treatments by the Dunnett test ($p < 0.05$).

Results and discussion

Table 2 presents the summary of the analysis of variance for the characteristics evaluated according to the utilized N sources, different stages of application, and control for the super-early bean cultivar BRS FC 104. PH, FPIH and M100 presented none significant differences.

RCI, NPP and yield portrayed a significant effect between treatments and control. In addition, for the RCI and NPP variables, there was an isolated effect of the application stage. However, when assessing the sources of N fertilization exclusively, no significant effect was observed for the evaluated characteristics. This fact may be related to adequate soil fertility present in the area during experiment installation (Table 1). In addition, the predecessor crop was soybeans which is also a legume, contributing to a greater availability of N from their remaining residues on the surface, as attested by Barbosa Filho et al. (2005). In contrast, Binotti et al. (2009) observed greater fertility whilst using ammonium sulfate treatment when compared to the urea treatment justifying this difference with greater urea loss due to volatilization. In the present study, the use of irrigation immediately after fertilizing the haul with urea may have contributed to the rapid incorporation of the fertilizer into the soil, which may have minimized N loss through volatilization and, consequently, no differences were observed among the sources.

RCI is an index used to estimate the chlorophyll index present in plants and it is highly correlated with the N content in the leaves (Taiz & Zeiger, 2017). The control exhibited a significant difference compared to the treatments (Table 3). According to Barbosa Filho et al. (2008), RCI values below the critical content of 43 noticed before 28 DAE in common bean, indicate a high probability of response to N application in coverage, i.e. the plant is expressing N deficiency highlighting the need for application in immediate coverage.

Table 2 - Summary of the analysis of variance (calculated F values) of agronomic characteristics, yield and yield components of common bean grains under different nitrogen sources and application stages.

Variation Source	DF	F value					
		RCI	PH	FPIH	NPP	M100	Yield
Nitrogen source (N)	3	0.09^{ns}	1.07^{ns}	0.33^{ns}	0.71^{ns}	0.21^{ns}	2.48^{ns}
Stage (S)	2	68.14^{**}	2.33^{ns}	1.20^{ns}	3.22^{*}	0.13^{ns}	0.30^{ns}
N vs S	4	0.74^{ns}	2.01^{ns}	0.56^{ns}	0.67^{ns}	1.55^{ns}	1.38^{ns}
Factorial vs control	1	43.54^{**}	2.10^{ns}	2.00^{ns}	9.95^{**}	2.22^{ns}	8.30^{**}
Error	48	-	-	-	-	-	-
Mean		44.48	34.07	6.51	20.63	21.57	2925.87
CV (%)		2.38	4.03	4.32	15.40	2.77	7.81

RCI – relative chlorophyll index; PH – plant height; FPIH – first pod insertion height; NPP – number of pods per plant; M100 – mass of 100 grains. ** ($p < 0.01$); * ($0.01 \leq p \leq 0.05$); ^{ns} ($p > 0.05$).

It is noteworthy that the RCI values decreased for all sources used according to the progress of the development stages, reaching values close to critical in the R5 stage. In other words, the later the N application, the lower the RCI value, which can directly affect the applied N efficiency. Thus, to obtain elevated yield with the BRS FC 104 cultivar, performing N coverage before flowering is needed, so the relative chlorophyll index is maintained at satisfactory levels. A similar result was found by Braz et al. (2018) whilst also studying the super-early bean cultivar, they underlined V4 as the best N application stage.

Assessing the growth and behavior of super-early common bean plants by observing plant height is important for understanding the behavior of plants when subjected to different N sources and cover at different stages, since it collaborates in anticipating how insect and disease management may be adopted and intensified according to their growth potential. Nevertheless, a lack of significant difference was found for plant height and first pod insertion height depending on the sources and stages of application (Table 1). Guimarães et al. (2017) and Braz et al. (2018) also found no differences in these variables while using the same super-early bean cultivar.

Mechanized harvesting practice is only feasible when the pods at the base of the plant are at a minimum height of 15 cm above the soil surface. In addition to the benefit of mechanized harvesting, this ideal height avoids a direct contact between pods and soil, preventing their rotting by excess moisture, thus promoting better seeds' phytosanitary status (Salgado et al., 2012).

Table 3 - Relative chlorophyll index (RCI) at 32 days after emergence (DAE) in accordance with the nitrogen source and application stage.

N Source	Stage			Mean
	V3	V4	R5	
		RCI 32 DAE		
Urea	47.09 *a	44.71 *a	42.42b	44.78 ns
Urea + AS + S	46.42 *a	45.08 *a	42.70a	44.73 ns
Urea +AS	46.03 *a	45.39 *a	43.01a	44.81 ns
Urea + S	46.50 *a	45.03 *a	42.31b	44.61 ns
Mean	46.51 A	45.05 B	42.63 C	
Control		41.47		

* ($p < 0.05$) and ns: not significant ($p > 0.05$) in relation to control. Means followed by the same letter, uppercase on the line and lowercase on the column did not differ by Tukey's test ($p > 0.05$). AS: ammonium sulfate; S: elemental sulfur.

Despite this, mechanized bean harvesting evolves in an advanced manner allowing pods to be harvested efficiently and without significant yield losses even when inserted below 15 cm. It is worth mentioning that the BRS FC 104 cultivar, even with low values of pod insertion (average 6.5 cm) has excellent production potential with a considerably short cycle, therefore, using modern harvesters can foment excellent yields.

The NPP is considered an important production component, as it represents the direct expression of the bean plant regarding the management response adopted to conduct its development and, consequently, its productive potential expression (Fageria et al., 2014). A significant effect was observed for the NPP variable, contrast between factors and the control when the application stages were analyzed (Table 4). The control had significantly lower NPP values when compared to the treatments containing urea associated with ammonium sulfate in the application stage V3. Similarly, lower NPP values were found in the reference than treatments with urea linked to ammonium sulfate plus the addition of elemental sulfur when the application was carried out in the vegetative stage V4.

Table 4 - Number of pods per bean plant, depending on the nitrogen source and application stage.

N Source	Stage			Mean
	V3	V4	R5	
		Number of pods per plant		
Urea	22.04a	20.88 a	17.32 b	20.08 ns
Urea + AS + S	20.88a	22.14 *a	19.16 a	20.81 ns
Urea +AS	22.64 *a	21.28 a	20.92 a	21.61 ns
Urea + S	21.00a	22.68 *a	20.64 a	21.44 ns
Mean	21.64 ns A	21.81 ns A	19.51 ns A	
Control		16.32		

* ($p < 0.05$) and ns: not significant ($p > 0.05$) in relation to control. Means followed by the same capital letter on the line did not differ by Tukey's test ($p > 0.05$). AS: ammonium sulfate; S: elemental sulfur.

The yield of common bean culture is a function of production components: NPP and the M100 (Araujo et al., 1996). Thus, the reduction in the NPP explains the yield decrease in treatments with no N application. Even though there was no significant difference, this behavior is highlighted in this study when the control outcomes are compared with other variables where different sources of N were utilized at different application stages.

Arf et al. (2011) observed that the average number of both pods and grains per plant, showed no difference between the N sources, in the two cultivation years. However, for the application periods, the control denoted the lowest values for the two productive components in the first year of cultivation, thus contributing to the result obtained in the present work.

The variable M100 is an important component of variation in the yield of common beans and can directly influence yield. For this component, no significant effect was observed between the control and the treatments (Table 1). Crusciol et al. (2007) explained that because it is a varietal characteristic of each cultivar, the M100, in general, is a variable little influenced by management.

The results observed for the M100 in the present study agree with Soratto et al. (2001) and Binotti et al. (2014) who also did not observe significant effects on the characteristic M100 with the application of N at different stages. According to Gonzaga (2017), the BRS FC104 cultivar did not show any significant variation in the M100 when submitted to treatments with an inoculant, application stages nor doses of N in coverage.

For grain yield, there was a significant difference between the control and the treatment with urea linked to the application of elemental sulfur, used in coverage in stages V3 and R5, however, no significant effect was obtained between the variables evaluated and the control (Table 5).

The sowing of super-early common beans BRS FC 104 occurred after soybean cultivation and the control yield of 2,643.04 kg ha^{-1}, even without receiving N fertilization in coverage, can be considered a preeminent performance in terms of yield. This result can be explained by the conditions of management and implantation of common bean after soybean. The residual effect of N on the cultural remains of the predecessor crop may present a condition that enables partial or total replacement of N fertilization in the next crop, guaranteeing the optimization of yield and partial reduction of production costs (Mascarenhas et al., 2011).

The results for productivity obtained in this study agree with those discussed in Gonzaga (2017), who worked with the BRS FC104 cultivar and observed a lack of response to seed inoculation and N doses applied in cover. Nascente et al. (2017) also did not notice a response in grain productivity when the N dose of 90 kg ha^{-1} was applied at sowing and 90 kg ha^{-1} of N in cover, attributing this result to the N availability and the organic matter presented in the soil.

Table 5 - Bean grain yield according to nitrogen source and application stage.

N Source	Stage			Mean
	V3	V4	R5	
	Yield (kg ha^{-1})			
Urea	2976.93	2939.71	3047.11	2897.92 ^{ns}
Urea + AS + S	2968.90	2764.06	2867.44	2886.80 ^{ns}
Urea +AS	2704.49	3038.32	2897.85	2880.22 ^{ns}
Urea + S	3091.54 *	2982.17	3114.69 *	3062.80 ^{ns}
Mean	2935.46 ^{ns} A	2931.07 ^{ns} A	2981.77 ^{ns} A	
Control	2643.03			

* (p < 0.05) and ns: not significant (p > 0.05) in relation to control. Means followed by the same capital letter on the line did not differ by Tukey's test (p > 0.05). AS: ammonium sulfate; S: elemental sulfur.

Similarly to the application stages, no differences in yield were observed. The absence of differences in the super-early common bean yield between stages of N application is related to the shorter cycle of the genotypes used (Nascente et al., 2017), differently from what occurs with traditional cultivars.

Despite the absence of differences between nitrogen sources used in all evaluated, it was observed that the use of urea associated with elemental sulfur in vegetative stage V3 and in reproductive stage R5 portrayed higher yield than the control emphasizing a potential usage in the bean culture.

Conclusions

The variables plant height, first pod insertion height and mass of 100 grains were not influenced by the different stages of application and sources of nitrogen fertilization in topdressing for the BRS FC104 super-early cycle cultivar.

Moreover, the relative chlorophyll index accomplished better values in the application stages V3 and V4, a significant result when compared to the control, highlighting certain efficiency of fertilization on these stages.

Urea associated with elemental sulfur in both vegetative V3 stage and the reproductive R5 triggered higher productivity than the control and should be considered in the fertilization of the super-early common bean.

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