Ciencia e Investigación AGRARIA

Cien. Inv. Agr. 39(3):435-443. 2012
www.rcia.uc.cl

CROP PRODUCTION

RESEARCH PAPER

Inclusion of various controlled release fertilizers in moss substrates (*Sphagnum magellanicum*)

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Abstract

C. Oberpaur, C. Fernández, G. Délano, and M.E. Arévalo. 2012. Inclusion of various controlled release fertilizers in moss substrates (*Sphagnum magellanicum*). Cien. Inv. Agr. 39(3): 435-443. The most frequently used substrate for the production of covered root seedlings is peat, the extraction of which is under scrutiny due to its negative environmental impact; however, the use of *Sphagnum* moss in adequate mixtures constitutes a possible alternative. Lettuce seeds (*Lactuca sativa* L.) were sown in Polystyrene trays (240 alveoli, 24 cm^3) to test four substrates, 50% *Sphagnum* moss mixed with 50% humus or compost and 60% *Sphagnum* moss with 40% humus or compost, and commercial peat was used as a control. A dose (2.5 or 3.5 $g \cdot L^{-1}$) of controlled-release fertilizer (CRF) was added to all substrates except for the control mix, and the substrates were subsequently irrigated with or without a fertilizer solution. The study was conducted under shaded conditions between January and February 2008. A completely randomized statistical design with 16 treatments in a factorial structure (4 mixtures x 2 levels of controlled-release fertilizer x 2 with or without fertigation) was applied in addition to a common control with five repetitions, and the plant height, number of leaves and total dry weight were measured. In all cases, the results were unfavorable for the peat control and were significantly different from the treatments prepared with *Sphagnum* moss. The addition of the highest dose of CRF to the substrates renders the application of additional fertigation unnecessary; however, fertilizing irrigation is necessary with the lowest CRF dose. According to the physical and chemical analyses, the most suitable growth mixtures for lettuce seedlings were those composed of 50% *Sphagnum* moss and 50% humus or compost.

Key words: Compost, humus, lettuce, slow release fertilizer, *Sphagnum* moss.

Introduction

Peat is the most commonly used substrate for the production of vegetable seedlings and has excellent quality characteristics (Schmilewski, 2008). It is a fossil material that accumulates in peatlands and is considered a carbon reservoir; however, after a short period of use as a substrate, it becomes a major carbon emitter (Gaudig, 2008). The use of peat as a substrate is therefore under scrutiny, which has necessitated the search for other possible alternative substrates, especially in nurseries (Rivière and

Received April 7, 2011. Accepted October 18, 2012.
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Caron, 2001; Carlile, 2008). The fresh biomass of *Sphagnum* moss presents the same chemical and physical properties of peat (Emmel, 2008). *Sphagnum* moss is the young residue or live portion of the plant *Sphagnum magellanicum* (Robbins and Evans, 2011) and is commonly used in the cultivation of orchids. Chile exports the fiber of this moss with a minimum length for use on orchids; the remaining waste material that does not meet that standard could be used as an alternative to peat.

From a horticultural point of view, the purpose of plant growth media is to produce the best quality seedling in the shortest time and at the lowest possible production cost (Robbins and Evans, 2011). The culture media are designed to store a greater amount of water and nutrients and to absorb excesses of those elements that could cause damage (Alvarado and Rojas, 1996). Several tests have been performed previously on moss-based substrates. Hernández and Oberpaur (2007) tested different combinations of moss (70 or 60% v/v) mixed with perlite (30 or 40%) and stabilized the pH of the resulting mixtures at 5.5 and 6.5 by adding dolomite lime. Their work compared the establishment of lettuce and sweet pepper seedlings in these mixtures with that from a commercial peat control and daily fertigation. The growth of plants in the commercial peat control was always greater in terms of shoot and root dry weight compared with that of the other tested substrates. Later, Oberpaur *et al.* (2010) mixed moss (40, 50, 60% v/v) with varying proportions (60, 50, 40% v/v) of vermicompost, compost or composted pine bark. According to the chemical properties of these substrates, the most promising materials were selected and tested under nursery conditions in peppers and lettuce. The moss substrates with vermicompost added at various amounts (60 - 40% v/v) resulted in feasible growth media that can be used in container planting due to good physicochemical properties and low cost. However, the authors also indicated the need for improvement to achieve results equivalent to that of commercial peat.

The inclusion of controlled-release fertilizers (CRFs) in a substrate can deliver nutrients at a rate that matches the demand of the plant and thus avoids losses. This cultivation maximizes the efficiency, optimizes the quality of the plant and reduces the frequency of fertilization and losses due to leaching (Rose *et al*., 2004). Proper use of irrigation and fertilization together produces healthy and well-formed seedlings that recover quickly after transplantation. If the seed is planted in a substrate mixture that contains initial fertilizers, fertigation should be delayed by one to two weeks; otherwise, fertigation should begin during the developmental state of the first true leaf (Wayne, 2005).

The objectives of this study were to improve moss substrates (*S. magellanicum*) by including a controlled-release fertilizer in the formulation (with and without fertigation) and to test the substrate characteristics in lettuce as an indicator crop.

Materials and methods

The experiments were conducted under shaded conditions between January and February 2008 at the Catemito Experimental Campus of the Universidad Santo Tomás, located at 33º36′35s, 70º44′15w in the Metropolitan Region of Chile. Iceberg lettuce (*Lactuca sativa* var. capitata) seeds (250 g) were used for the test plants. The substrate materials tested included waste from *S. magellanicum* (S) (Natural Products Souther, Ancud, Chile), compost (C), humus (H) (both from Lombricultura Pachamama, Quillota, Chile) and commercial peat (Sunshine 3, Sun Gro Horticulture, Canada). The multipurpose Ultrasol commercial mixture containing NPK 1:1:1, 50% N-oxide and 50% N-ammonia, B, Mo, Fe, Zn, Cu, and Mn was applied for fertigation. The pH (solution of 1 g L^{-1} at 20 ºC) was maintained at 5.2, and the electrical conductivity was held at 1.18 $dS{\cdot}m^{-1}$ (Román, 2001). The controlled-release fertilizer (CRF) included in the substrate mixtures was Basacote Mini Prill, characterized by a small granule size between 1.5 and 2.8 mm and containing 13% of total nitrogen, 6% P_2O_5, and 16% K_2O, in addition to the microelements Fe, Cu, Mn, Zn, B, and Mo (Compo Expert, 2011). Forty-five trays of expanded polystyrene and 240 alveoli (24 cm^3 each) were used for growing plants. The equipment and instruments used in this study included a Hl9321 Hanna pH meter (range 0.0 to 14.0; precision ± 0.2), a HI9033 conductivity meter (range 0.00 to 19.99 dS m^{-1}, precision ± 0.19), a Denver analytical balance AA-250 (range 0.0 to 250 g, precision ± 0.0001) and a Binder drying oven (range 0 to 300 ºC).

The composition of the substrate mixtures together with the commercial peat control are summarized in Table 1. The selected substrate mixtures were those suggested by Oberpaur *et al*. (2010) because they showed promising results without fertilizer application. The treatments were arranged as a completely randomized factorial (4x2x2) design (substrate mixtures x with and without fertigation x CRF) and a common commercial peat control (one control with and one control without fertigation) with five replicates. The four substrate mixtures were S50C50 (50% *Sphagnum* moss + 50% compost), S50H50 (50% *Sphagnum* moss + 50% humus), S60C40 (60% *Sphagnum* moss + 40% compost), and S60H40 (60% *Sphagnum* moss + 40% humus). The experimental unit contained 120 alveoli with one seed per alveolus. An analysis of variance (ANOVA) was performed to determine the significant differences among the treatments, and the means were separated according to the multiple comparison test of Tukey ($P \leq 0.05$). Dunnett's test was performed to test significant differences between the respective control and treatments ($P \leq 0.05$).

Study management

Prior to the test, the moss was prepared from 6-kg pressed bales by sieving to 0.8 cm to eliminate various types of impurities and homogenize the material. Next, the moss was moistened with tap water and placed in transparent plastic bags under solarization for a period of 6 weeks. Subsequently, the different mixtures were prepared by incorporating the appropriate dose of CRF. Manual seeding was performed on January 3, 2008, and planted seeds were covered with 2 mm of perlite. The nursery was maintained throughout the test period under shaded conditions using a high-

Table 1. Substrate mixtures composition used in this study, including *Sphagnum* moss.

Treatments	*Sphagnum* (%)	Substratum (%)	Fertigation	CRF (g L^{-1})
Commercial peat	0	Peat (100)	with (FR)	0.0
			without(SFR)	0.0
S50C50[1]	50	Compost (50)	with (FR)	3.5
			with (FR)	2.5
			without (SFR)	3.5
			without (SFR)	2.5
S50H50[1]	50	Vermicompost	with (FR)	3.5
		(50)	with (FR)	2.5
			without (SFR)	3.5
			without (SFR)	2.5
S60C40[1]	60	Compost (40)	with (FR)	3.5
			with (FR)	2.5
			without (SFR)	3.5
			without (SFR)	2.5
S60H40[1]	60	Vermicompost	with (FR)	3.5
		(40)	with (FR)	2.5
			without (SFR)	3.5
			without (SFR)	2.5

[1]S: *Sphagnum* moss containing either 50% (S50H50) or 60% (S60H40) *Sphagnum* moss; C: compost; H: vermicompost; CRF: controlled-release fertilizer.

Table 2. Results of physical and chemical analyses of substrate mixtures prepared with Sphagnum moss, vermicompost, and compost.

Treatments	pH	EC dS m^{-1}	OM %	Da kg m^{-1}	N %	P %	K %
S50C50	6.1	3.6	41	210	1.7	1.12	0.7
S50H50	6	3.3	37	230	1.77	1.26	0.71
S60C40	5.5	2.5	36	150	1.45	0.98	0.24
S60H40	5	2.5	38	170	1.42	1.01	0.23

S: *Sphagnum***;** C: compost; H: vermicompost; number indicates percentage v/v.
EC: electric conductivity; OM: organic matter; Da: apparent density.

density polyethylene white mesh rated at 30% shade. In parallel with the study, test samples of each mixture without CRF were sent to a commercial soil analysis laboratory for chemical and physical analyses (Agrolab, Santiago Chile). A sample of tap water was also sent for analysis (unpublished data). Irrigation was performed manually by spraying three times each week with tap water. Six days after emergence (DAE), the weekly fertigation commenced with multipurpose Ultrasol at doses of 0.25 g L^{-1} of water. At 13 DAE, the water dose was increased to 0.60 g L^{-1} and finally suspended over the last week before the end of the test to harden the seedling. The criterion used to conclude the study required that the roots occupy the entire volume of the alveoli and that the seedlings develop four true leaves.

Evaluations

The evaluations were conducted every seven days with a random selection of five plants per replicate. The height of each seedling plant was measured from the base of the neck, and the number of true leaves and total dry weight (only in the last two measurements) were determined.

Results

Physical and chemical analysis of moss mixtures

Table 2 shows the results of the physical and chemical analyses in which the highest pH, electrical conductivity (EC) and bulk density values were present in the S50C50 and S50H50 mixtures. The organic matter contents ranged from 36% to 41%. The substrates that displayed the highest concentration of nitrogen, phosphorus and potassium were the S50C50 and S50H50 mixtures, which showed levels greater than those of the commercial peat corresponding to 0.50% N, 0.25% P_2O_5 and 0.26% K_2O.

Interactions

Relative to the dry weight ratio, significant p-values for such individual factors as substrate ($P \leq 0.001$) and CRF ($P \leq 0.001$) were detected at 20 DAE. The fertigation showed an influence on the number of leaves ($P \leq 0.048$, $P \leq 0.03$) and plant height ($P \leq 0.001$, $P \leq 0.008$) at 20 and 28 days after emergence (DAE). Three-way interactions were not observed, but two-way interactions were observed for the substrate and CRF ($P \leq 0.001$) at 20 DAE in terms of dry weight, for substrate and fertigation at 13 and 20 DAE in terms of plant height ($P \leq 0.002$, $P \leq 0.011$), and for CRF and fertigation at 28 DAE in terms of dry weight ($P \leq 0.025$).

Effect of substrates on seedlings

Table 3 shows the results from the substrates with or without the application of fertigation. Regarding fertigation, there were significant differences in plant height between the substrates containing moss and the commercial peat control. At 6 DAE, the maximum plant height was obtained in the control with fertigation and no differences were observed among the moss substrates. At 13 DAE, the plants grown in substrates containing 50% moss combined with compost or humus and S60H40 presented the greatest height values through the end of the study. The growth of the plants in all treatments exceeded that of the plants in the control mixture at 20 DAE.

The average heights of the seedlings grown without fertigation were then analyzed. The substrates with moss and the control were equal at 6 DAE; however, the scenario shifted from 13 to 28 DAE when significant differences between the moss substrates and commercial peat were observed. At 13 DAE, the plants in the S60H40 substrate reached maximum height, and the control plants had the lowest average height. From 13 to 20 DAE, the height increased in all treatments by 4 cm, except for the control, which grew less than 1 cm. At 20 and 28 DAE, the plant heights in the commercial peat control were exceeded by the other treatments.

With respect to the number of leaves per plant (Table 3), significant differences were observed among the substrates with fertigation beginning

Table 3. Influence of the substrate mixture on height, leaf number, and dry weight of lettuce plantlets, with or without fertigation.

		With fertigation				Without fertigation			
		Days after emergence							
Parameter	Substratum	6	13	20	28	6	13	20	28
Plant heightura (cm)	Peat	2.3 a[1]	4.2 b	6.1 b	6.7 c	2.1 a	3.5 c	3.7 c	4.4 c
height (cm)	S50C50[2]	1.6 b	5.0 a	10.9 a	12.4 a	1.7 a	3.6 c	7.6 b	10.0 b
	S50H50	2.0 b	4.8 a	10.1 a	12.3 a	1.9 a	4.6 b	9.4 a	11.2 a
	S60C40	1.9 b	3.7 c	10.3 a	11.9 b	1.9 a	4.4 b	10.0 a	11.7 a
	S60H40	2.1b	4.9 a	10.0 a	12.1 b	1.9 a	5.1 a	9.3 a	11.0 a
Leaves (Nº)	Peat	1.2 a	2.8 a	3.0 b	3.8 b	1.2 a	2.6 a	3.0 b	3.6 b
	S50C50	0.9 a	3.0 a	3.8 a	4.9 a	1.0 a	2.5 a	3.4 a	4.3 a
	S50H50	1.1 a	2.8 a	3.8 a	4.9 a	1.0 a	2.7 a	3.5 a	4.9 a
	S60C40	1.1 a	2.6 a	3.7 a	4.9 a	1.1 a	2.6 a	3,6 a	4.7 a
	S60H40	1.2 a	2.9 a	3.7 a	4.8 a	1.2 a	2.9 a	3.6 a	4.8 a
Dry weight (mg plant^{-1})	Peat			180 a	190 b			80 c	90 b
	S50C50			210 a	270 a			260 a	270 a
	S50H50			190 a	290 a			160 b	230 a
	S60C40			220 a	230 a			230 a	270 a
	S60H40			170 a	250 a			140 b	270 a

[1]Means with same letters in columns for each parameter, with or without fertigation, and days after emergence indicate no significant differences between treatments according to the Dunnett test ($P \leq 0.05$).
S: *Sphagnum***;** C: compost; H: vermicompost; number indicates percentage v/v.

at 20 DAE, and the plants grown in peat had the lowest number. Both, at 20 and at 28 DAE, no differences were observed among substrates that included *Sphagnum*. The average number of leaves per lettuce plant for the different substrates without fertigation was significantly lower only in the peat control at 20 and 28 DAE. The weekly increase in leaves per plant with or without fertigation was constant at one leaf per week.

For the dry weight (Table 3) with fertigation, significant differences were detected between the moss substrates and the peat only at 28 DAE and presented significantly higher values in the mixtures that included *Sphagnum*. Without fertigation, significant differences in seedling dry weight were detected between plants grown in the substrates and those in peat at 20 and 28 DAE; plants with the highest dry weight were obtained in S50C50 and S60C40 at 20 DAE.

Comparing the fertigated and non-fertigated lettuce seedlings, similar results in dry weight were observed between treatments. Seedlings in the commercial peat without fertigation achieved a lower total dry weight than those that were fertigated.

The numbers of leaves on the lettuce seedlings with or without fertigation and with the inclusion of 3.5 or 2.5 g L^{-1} of controlled-release fertilizer were not significantly different (data not shown) on the evaluation dates between 6 and 28 DAE.

Dry weight

At 20 DAE (Table 4), no differences were detected among the moss substrates with fertigation and with the highest dose of CRF. Without fertigation, the dry weight was lower in the S60H40 and S50H50 plants than that obtained in the plants grown in the S50C50 mixture. The S50C50 substrate resulted in plants with a higher plant dry weight without fertigation. However, fertigation is recommended in the S60H40 substrate. No significant differences among substrates with or without fertigation were detected by applying a lower dose of CRF. Comparing substrates with or without fertigation and with a lower CRF dose, application of fertigation is only recommended in the S50C50, S50H50 and S60C40 substrates.

At 28 DAE, comparing factors with and without fertigation and a high dose of CRF, a significantly lower plant weight was registered in the S60C40 substrate with fertigation. The plants showed a greater total dry weight in the S50C50 substrate without fertigation. In the case of the S50C50 and

Table 4. Influence of two controlled-release fertilizer doses included in the substrate mixture with *Sphagnum* moss, on the lettuce plantlets dry weight (cm), with or without fertigation.

		CRF[2] 3.5 g L^{-1}		CRF 2.5 g L^{-1}	
Days after emergence	Substratum	FR[3]	SFR	FR	SFR
20	S50C50[1]	290 Cb	380 Aa	184 Ca	156 Cb
	S50H50	170 Ca	156 BCa	212 Ca	156 Cb
	S60C40	254 Ca	316 ABa	142 Cb	148 Cb
	S60H40	168 Ca	138 Cb	164 Ca	156 Cb
28	S50C50	296 Ab	354 Aa	252 Aa	190 Bb
	S50H50	302Aa	280 Bb	284 Aa	190 Bb
	S60C40	244 Bb	298 Ba	210 Ba	232 Ba
	S60H40	272 Aa	310 Aa	228 Bb	232 Bb

Means for each day with same capital letter within columns and same small letter in rows indicate no significant differences between treatments according to the Tukey test (P≤0.05).
[1]S: *Sphagnum*; C: compost; H: vermicompost; number indicates percentage v/v.
[2]CRF: controlled-release fertilizer.
[3]FR: with fertigation; SFR: without fertigation.

S60C40 substrates, these should be used with the CRF 3.5 g L^{-1} mixture, and without additional fertigation. Fertigation is recommended for the S50C50 and S50H50 substrates with the lower dose of CRF, which also produced the highest lettuce dry weight.

Effect of the two-way interactions among the substrates tested

Interactions between the substrates and the CRF doses were detected at 20 DAE; specifically, interactions were found for the S50C50 and S60C40 substrates and the high dose of CRF, resulting in weights of 340 mg·$plant^{-1}$ in the first case and 290 mg $plant^{-1}$ in the second case, compared with lower doses that produced plants with weights of 107 mg $plant^{-1}$ and 150 mg $plant^{-1}$, respectively. At 28 DAE, no significant differences were observed with the use of either a high or low dose of CFR and with or without fertigation. For the fertigation factor (FR; SFR), significant differences were observed for both doses of CFR. The highest values of dry weight were obtained with a 3.5 g L^{-1} of CRF: 280 mg $plant^{-1}$ with fertigation and 310 mg $plant^{-1}$ without fertigation.

Discussion

According to the obtained results, it is feasible to improve the performance of *Sphagnum* moss substrates by including a CRF in its formulation. Among the characteristics of the substrates tested, the pH range was considered appropriate by Ansorena (1994) and FAO (2002). Substrates with a pH between 5.5 and 6.8 are classified as weakly acidic, thus increasing the availability of nutrients (Hartmann and Kester, 2002). Munita (2001) indicated that the availability of primary (nitrogen, phosphorus and potassium) and secondary (sulfur, calcium and magnesium) nutrients for organic and mineral substrates is greater at a pH between 5.5 and 6.5. In contrast, secondary elements such as iron, manganese, chlorine and zinc are less available in this pH range. In this study, there was no evidence of chlorosis or visual symptoms attributable to nutrient deficiencies. According to Ansorena (1994), the appropriate values of electrical conductivity (EC) fall in the range from 0.75 to 2.0 dS m^{-1}, and therefore, the S50C50 and S50H50 mixtures would be inappropriate. However, the plants were not damaged by salinity, most likely due to the frequency of irrigation applied (3 times per week), which washes the substrates. The EC values obtained by Oberpaur *et al.* (2010) in the same mixtures were much smaller, ranging between 0.32 and 0.6 dS m^{-1}. Carlile (2008) indicated that, in general, composted materials are highly variable in their characteristics, which depend on the place of production and the time of year, and have high bulk density, pH and EC. All organic matter contents of the mixtures were under the ideal value of 80%. The highest bulk density values corresponded to the S50C50 and S50H50 mixtures, which were close to the value of 220 kg m^{-3} proposed by Ansorena (1994) and FAO (2002).

The values of the height and dry weight measurements obtained from the lettuce plants exceeded those of Oberpaur *et al.* (2010) in whose studies the commercial peat control values were always equal to or greater than that of the S60C40 and S60H40 substrate mixtures. In this study, however, it was possible to exceed the control values. Therefore, the addition of CRFs to the substrates had a great influence on the results, especially in the seedling weight gain. One of the main advantages of CRFs is that they increase the nutrient recovery and reduce the adverse environmental impacts associated with the nutrients (Shaviv, 2005). According to Trenkel (1997), CRFs have a fast availability of nutrients, contain a protective cover to control water penetration and ensure high levels of nutrient solution and delivery. Rose *et al.* (2004) suggested that CRFs do not release 100% of the available nutrients at the time of application; the goal is to deliver nutrients at a rate that matches the demand of the plant, thus reducing losses due to leaching.

With respect to the application of fertigation as typically used in commercial horticultural nurseries, according to the dry weight results at 20 DAE, if the CRF dose is 3.5 mg L^{-1} in mixtures of 50% *Sphagnum* moss and 50% compost or humus, it is not advisable to add additional nutritional solutions through irrigation. However, with the lower dose of 2.5 mg L^{-1}, fertigation is essential.

In summary, peat moss combined with compost or humus can successfully replace peat as a substrate for seedlings. Substrates composed of *Sphagnum* (50%) with humus or compost (50%) in conjunction with the application of a CRF are appropriate as growth media for lettuce seedlings. If the CRF dose is 3.5 mg L^{-1}, it not necessary to apply additional fertilizer through irrigation, but if the CRF dose is 2.5 mg L^{-1}, fertigation becomes essential.

Resumen

C. Oberpaur, C. Fernández, G. Délano, and M.E. Arévalo. 2012. Inclusión de fertilizantes de entrega controlada en sustratos elaborados con musgo (*Sphagnum magellanicum*). Cien. Inv. Agr. 39(3): 435-443. El sustrato más utilizado en la producción de almácigos hortícolas a raíz cubierta es la turba, cuya extracción es cuestionada dado que provoca un negativo impacto ambiental, por lo que el uso de musgo, en mezclas adecuadas, constituye una alternativa. El ensayo se realizó en Calera de Tango, Región Metropolitana, bajo sombreadero, entre enero y febrero de 2008. Semillas de lechuga fueron sembradas en bandejas de poliestireno (240 alvéolos, 24 cm^3), probando cuatro sustratos (50% v/v musgo mas 50% de humus o compost; 60% musgo mas 40% de humus o compost), y una mezcla control de turba comercial. A los sustratos se incluyó una dosis de fertilizante de entrega controlada (FEC) de 2,5 ó 3,5 g L^{-1}, y fueron posteriormente manejados con y sin aplicación de fertirriego. Se utilizó un diseño estadístico completamente al azar, con 16 tratamientos en estructura factorial (4 mezclas x 2 niveles de fertilizante de entrega controlada x 2 con y sin fertirriego), más un control común, con cinco repeticiones. Se midió altura y cantidad de hojas, y el peso seco total. En todos los casos, al finalizar la etapa de almácigo los tratamientos superaron al control, existiendo diferencias significativas entre los tratamientos a base de musgo. Al incluir la dosis mayor de FEC no se requiere de fertirrigación adicional, sin embargo con la dosis baja es necesaria. Los análisis físicos y químicos indican que los sustratos compuestos por un 50% v/v de musgo combinado con 50% de humus de lombriz o compost son adecuados para un almácigo de lechuga.

Palabras clave: Compost, fertilizante de entrega controlada, humus, lechuga.

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