

Yield performance of soybean and corn subjected to magnesium foliar spray

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Abstract – The objective of this work was to evaluate the effect of magnesium foliar spray on yield performance of soybean (*Glycine max*) and corn (*Zea mays*) cultivated in soil with adequate levels of base saturation and magnesium content in Brazil. The field trials were conducted on a Typic Hapludox cultivated with soybean and corn in the 2013/2014 and 2014/2015 crop seasons, respectively. Treatments consisted of Mg rates (50, 100, 250, 500, 1,000 and 1,500 g ha⁻¹ and a control without Mg) applied during the V4, R1, and R5.1 (soybean) or V4 and R2 (corn) phenological growth stages as magnesium sulfate heptahydrate (MgSO₄·7H₂O). The SPAD index, leaf Mg content, grain yield, and 100-grain weight were evaluated. The Mg foliar spray increased the SPAD index in soybean and the leaf Mg content in corn. The Mg rates of 540 and 890 g ha⁻¹ increased in 325 and 737 kg ha⁻¹ the yield performance of soybean and corn, respectively, regardless of the phenological growth stages. The Mg application during the reproductive stages increased in 2% the 100-grain weight for both crops. Foliar spraying of Mg improves the yield performance in soybean and corn crops.

Index terms: *Glycine max*, *Zea mays*, foliar fertilization, magnesium sulfate.

Desempenho produtivo de soja e milho submetidos   aplica o foliar de magn sio

Resumo – O objetivo deste trabalho foi avaliar o efeito da aplica o foliar de magn sio no desempenho produtivo de soja (*Glycine max*) e milho (*Zea mays*) em solo com n veis adequados de satura o por base e conte do de magn sio, no Brasil. Os experimentos foram desenvolvidos em Latossolo Vermelho-Amarelo distr fico cultivado com soja e milho nas safras 2013/14 e 2014/15, respectivamente. Os tratamentos consistiram de aplica o foliar de doses de Mg (50, 100, 250, 500, 1.000 e 1.500 g ha⁻¹ e controle sem Mg) nos est dios fenol gicos V4, R1 e R5.1 (soja) ou V4 e R2 (milho), na forma de sulfato de magn sio heptahidratado (MgSO₄·7H₂O). Avaliaram-se o  ndice SPAD, teor foliar de Mg, produtividade de gr os e massa de 100 gr os. A aplica o foliar de Mg aumentou o  ndice SPAD na cultura da soja e o teor foliar de Mg na cultura do milho. As doses de Mg de 540 e 890 g ha⁻¹ proporcionaram incrementos de 325 e 737 kg ha⁻¹ na produtividade da soja e do milho, respectivamente, independentemente do est dio fenol gico. A aplica o foliar de Mg no est dio reprodutivo aumentou em 2% a massa de 100 gr os de ambas culturas. A pulveriza o foliar de Mg melhora os par metros produtivos das culturas de soja e milho.

Termos para indexa o: *Glycine max*, *Zea mays*, aduba o foliar, sulfato de magn sio.

Introduction

Magnesium is an essential element to plants, being a constituent of the chlorophyll molecule and acting in phosphorylation, translocation of photoassimilates and in the activation of multiple enzymes, such as

glutathione synthetase and phosphoenolpyruvate (PEP) carboxylase. Crop growth and yield are highly affected by Mg deficiency in intensive agricultural production areas (R mheld & Kirby, 2007). It should be noted that Mg is mainly provided by liming, which may not

be supplying sufficient amounts of this element to the plants.

Several factors can cause Mg deficiency in plants, such as a low Mg concentration in soil-forming rocks, Mg losses in the soil (Maathuis, 2009; Gransee & Fühns, 2013), and the planting of successive crops with unbalanced Mg fertilization relative to the crop Mg uptake (Pol & Traore, 1993). Even in soils with adequate Mg levels, Mg deficiency may occur due to excessive acidity, high levels of aluminium or manganese, salinity, low water availability in the soil, and low plant transpiration (Mengel & Kirby, 2001; Lynch & St. Clair, 2004; Gransee & Fühns, 2013). Moreover, high levels of Mg in the soil can inhibit the absorption of zinc and Mn causing the deficiency of these elements (Moreira et al., 2003). Fertilization with high potassium levels can also result in Mg deficiency once K inhibits Mg absorption by plants (Guiet-Bara et al., 2007).

The foliar spraying of Mg provides a means of addressing the increasing occurrence of Mg deficiency in crops. Foliar nutrient application can be a good strategy to increase crop yield, help in soil supplementation, and generate response in a short period of time (Fageria et al., 2009). Jezek et al. (2015) observed an increased leaf Mg content, SPAD index, photosynthetic rate, and accumulation of shoot biomass in corn (*Zea mays*) subjected to a foliar spray of Mg under controlled conditions. Positive effects on crop yield from spraying foliage with Mg were observed in sugar beet (*Beta vulgaris* L.) (Barlog & Grzebisz, 2001), soybean (*Glycine max*) (Vrataric et al., 2006), and fava bean (*Vicia faba*) (Neuhaus et al., 2014).

Few studies have assessed the effects of foliar fertilization on crop quality and yield, especially in annual crops such as soybean and corn (Gerendás & Fühns, 2013). Considering the positive effect of Mg on the translocation of photoassimilates and carbohydrates in plants (Cakmak & Yazici, 2010), it is possible that the foliar spraying of Mg during the reproductive period would increase grain filling and yield in soybean and corn crops.

The objective of this work was to evaluate the effect of Mg foliar spray on yield performance of soybean and corn cultivated in soil with adequate levels of base saturation and magnesium content in Brazil.

Materials and Methods

The experiments were carried out in the municipality of Uberlândia (19°25'S, 47°59'W, at an altitude of 700 m), in the state of Minas Gerais, Brazil, in the 2013/2014 and 2014/2015 crop seasons with soybean and corn, respectively. The climate of the region is classified as Cwa, according to Köppen's classification, which is characterized as a wet tropical climate with a rainy season in the summer, dry season in the winter, and average monthly temperature between 18 and 22°C. The rainfall and mean monthly temperature data from September to May for the 2013/2014 and 2014/2015 crop seasons in the experimental areas are shown in Figure 1.

The experimental areas had been cultivated in a no-tillage system for 11 years, with corn or soybean as the first crop and wheat (*Triticum aestivum*), oat (*Avena strigosa*), or pearl millet (*Pennisetum glaucum*) in succession. The soil of the experimental areas is classified as Latossolo Vermelho-Amarelo distrófico (Typic Hapludox) according to Santos et al. (2006), and the soil chemical properties (Raij et al., 2001; Vitti, 1989) and textural attributes (Camargo et al., 1986) are listed in Table 1.

Soybean cultivar AN 5909 RGN was sown on 10/18/2013, in a 7x3 factorial arrangement, with seven Mg rates (a control without Mg and 25, 50, 100, 250, 500 and 1,000 g ha⁻¹), three application times (at phenological stages: V4, with four trifoliate leaves; R1, at the beginning of flowering; and R5.1, at the beginning of grain filling), and five replicates in a randomized complete block design. The corn (hybrid P30F53 HX Waxy) was sown on 11/10/2014, in a 7x2 factorial arrangement, with seven Mg rates (a control without Mg and 50, 100, 250, 500, 1,000 and 1,500 g ha⁻¹), two application times (during phenological stage V4, with four fully developed leaves, or during R2, the milk stage) and six replicates in a randomized complete block design. For both crops, the experimental units consisted of ten 15-m long planting rows that were spaced 0.5 m apart. The Mg source used for the foliar fertilization was magnesium sulfate heptahydrate (MgSO₄·7H₂O containing 9% Mg), which was applied in solution at a spray rate of 300 L ha⁻¹ using a CO₂-pressurized sprayer.

Before setting up the experiments, the following surface applications were conducted without incorporation: 1.3 Mg ha⁻¹ dolomitic lime, as well as 0.5 Mg ha⁻¹ agricultural gypsum, in the soybean

experiment and 2.0 Mg ha⁻¹ dolomitic lime and 0.5 Mg ha⁻¹ agricultural gypsum in the corn experiment; both applications were carried three months before planting. During the pre-sowing period of the soybean crop, 12, 60, 30, and 0.33 kg ha⁻¹ N, P₂O₅, K₂O, and B, respectively, were applied. For the corn experiment, 25, 120, 75, and 0.77 kg ha⁻¹ N, P₂O₅, K₂O, and B, respectively, were applied during pre-sowing. Moreover, 190 kg ha⁻¹ N fertilizer was applied as top dressing during the V4 phenological stage. Soil liming and fertilization were performed according to Sousa & Lobato (2004).

To determine the Mg concentration of the crops, leaves were collected when the soybean and corn plants were at the R6 and R2 phenological growth

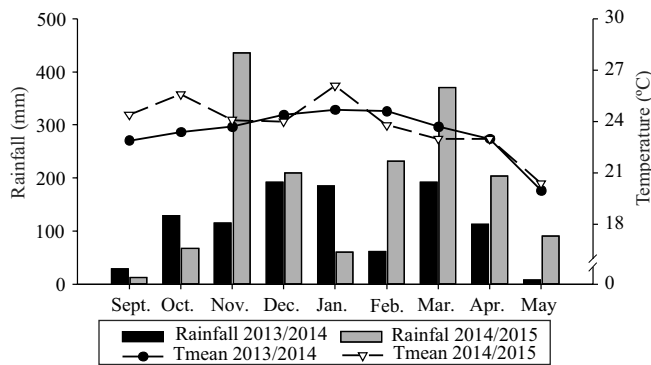


Figure 1. Monthly rainfall and mean temperature (Tmean) in the 2013/2014 and 2014/2015 corn (*Zea mays*) and soybean (*Glycine max*) crop seasons, respectively in the municipality of Uberlândia, in the state of Minas Gerais, Brazil.

stages, respectively. The collection of soybean leaves occurred later than that of corn leaves because the last foliar spraying in soybean was performed at the R5 phenological stage, whereas the corn leaves were collected one week after the last foliar application (at R2). The collected leaves were the third fully developed trifoliolate leaf counting from the apex of the soybean plant and the first corn leaf opposite the top ear. The leaf collection and Mg analysis procedures followed Malavolta et al. (1997). In both experiments, the leaves of ten plants were sampled per experimental unit. Before leaf collection, the SPAD index was determined in the same corn and soybean leaves that were collected for evaluating the Mg concentration. The index was determined with the SPAD 502 chlorophyll meter (Minolta Corp., Ramsey, Japan), which allows the leaf chlorophyll content values to be obtained indirectly in a non-destructive manner (Waskom et al., 1996).

The grain yield in both experiments was obtained by harvesting and weighing of the grains from ten central metres within four rows per experimental unit. Of the total grains harvested from each experimental unit, a subsample was collected to obtain the 100-grain weight with 13% moisture.

The data were subjected to the analysis of variance using the F-test, at the 5 and 10% probability levels. When the analysis of variance yielded significant results, the means were compared using Tukey's test, at 10% probability, and a regression analysis was conducted to evaluate the rate effects using the Sisvar statistical software (Ferreira, 2011).

Table 1. Chemical and physical characteristics of soils collected at the layers of 0–20, 20–40 cm in the experimental areas of soybean (*Glycine max*) and corn (*Zea mays*) in the municipality of Uberlândia, in the state of Minas Gerais, Brazil⁽¹⁾.

Soil layer (cm)	pH CaCl ₂	SOM (g dm ⁻³)	P (mg dm ⁻³)	S	Ca	Mg	K	Al	H+Al	SB	CEC	BS (%)	m	B	Cu	Fe	Mn	Zn	Sand	Silt	Clay
					----- (mmol _c dm ⁻³) -----										----- (mg dm ⁻³) -----				----- (g kg ⁻¹) -----		
Soybean																					
0–20	5.2	23	26	18	35	8	2.5	0	31	45.5	76.0	60	0.0	0.5	0.8	32	1.2	1.5	121	29	850
20–40	5.0	14	11	80	17	4	1.9	0	34	22.9	56.9	40	0.0	0.5	0.7	23	0.5	0.6	116	22	862
Corn																					
0–20	5.4	20	6	26	43	18	1.3	0	67	62.3	129.0	48	0.0	0.9	6.0	39	4.8	3.3	178	16	806
20–40	4.9	15	2	43	26	12	0.9	2	83	38.9	122.0	32	5.0	0.7	6.3	50	4.8	3.4	154	90	756

⁽¹⁾pH, CaCl₂ 0,01 mol L⁻¹; SOM, soil organic matter; P, extracted by anion and cation exchangeable resin; S, extracted with Ca(H₂PO₄)₂ 0,01 mol L⁻¹; Ca, Mg, and K, extracted by anion and cation exchangeable resin; H+Al, pH SMP; SB, sum of bases; CEC, cation exchange capacity; BS, base saturation; m, aluminium saturation. B, extracted with hot water; and Cu, Fe, Mn, and Zn, extracted with DTPA.

Results and Discussion

In soybean, the Mg foliar spray increased the SPAD index linearly with increases in the Mg rate (Table 2). This result can be explained by the increase in chlorophyll, since magnesium is the center of the molecule. Mg foliar spraying also increased the chlorophyll concentration in a study by Teklić et al. (2009), who observed an increase in the SPAD index with the Mg spraying. Despite the significant effect on the SPAD index in the present study, the Mg content

in soybean leaves did not vary with the Mg rates or application times. The late collection of soybean leaves (during the R6 phenological stage) could have been responsible for the absence of increased Mg levels in the leaves receiving the foliar Mg fertilization, probably because Mg is not only quickly absorbed by leaves but also mobile in the phloem, and thus redistributed to other plant compartments (Hermans & Verbruggen, 2005; Guo et al., 2016).

The Mg rate quadratically affected soybean yield, regardless of the application time (Table 3). The

Table 2. SPAD index and foliar Mg content in the soybean (*Glycine max*) crop fertilized with rates of Mg foliar spraying in different phenological stages (V4, R1, and R5.1) in the municipality of Uberlândia, in the state of Minas Gerais, Brazil.

Mg foliar spray (g ha ⁻¹)	SPAD index			Mean	Mg content (g kg ⁻¹)			Mean
	V4	R1	R5.1		V4	R1	R5.1	
0	38.3	38.3	38.3	38.3	3.31	3.31	3.31	3.31
25	40.7	39.2	41.2	40.4	3.26	3.19	3.17	3.20
50	39.3	43.2	42.2	41.6	3.10	3.10	3.19	3.13
100	40.9	41.3	42.6	41.6	3.18	3.18	3.00	3.11
250	40.1	40.4	42.3	40.9	3.16	3.41	3.46	3.33
500	41.1	42.2	42.8	41.7	3.04	3.19	3.25	3.16
1,000	42.5	41.9	42.1	42.2	3.14	3.02	3.17	3.11
Mean	40.4	40.9	41.5	-	3.17	3.20	3.21	-
P _{rate}		0.0619*				0.684 ^{ns}		
P _{stage}		0.4441 ^{ns}				0.220 ^{ns}		
P _{rate x stage}		0.9682 ^{ns}				0.549 ^{ns}		
R ² , linear regression		0.35				ns		
R ² , quadratic regression		ns				ns		
Coefficient of variation (%)		8.6				7.5		

^{ns}Nonsignificant. *Significant at 10% probability.

Table 3. Grain yield and 100-grain weight in the soybean (*Glycine max*) crop fertilized with rates of Mg foliar spray in different phenological stages in the municipality of Uberlândia, in the state of Minas Gerais, Brazil⁽¹⁾.

Mg foliar spray (g ha ⁻¹)	Grain yield (kg ha ⁻¹)			Mean	100-grain weight (g)			Mean
	V4	R1	R5.1		V4	R1	R5.1	
0	4,245	4,245	4,245	4,245	15.1a	15.1a	15.1a	15.1
25	4,400	3,905	4,282	4,196	14.5b	15.0ab	15.4a	15.0
50	4,199	4,190	4,359	4,250	15.0b	15.2ab	15.4a	15.0
100	4,334	4,513	4,322	4,390	15.2a	15.3a	15.2a	15.2
250	4,547	4,641	4,398	4,529	15.0a	15.1a	14.9a	15.0
500	4,385	4,473	4,699	4,519	15.1b	15.4a	15.5a	15.1
1,000	4,341	4,071	4,555	4,323	15.0a	14.8a	15.3a	15.0
Mean	4,350	4,291	4,409	-	14.9b	15.1ab	15.2a	-
P _{rate}		0.081*				0.897 ^{ns}		
P _{stage}		0.419 ^{ns}				0.054*		
P _{rate x stage}		0.466 ^{ns}				0.060*		
R ² , linear regression		ns				ns		
R ² , quadratic regression		0.87, y = -0.0012x ² + 1.2942x + 4,221.6				ns		
Coefficient of variation (%)		8.5				3.5		

⁽¹⁾Means followed by different letters differ among phenological stages by Tukey's test, at 10% probability. ^{ns}Nonsignificant. *Significant at 10% probability.

obtained equation ($R^2=0.87$, $p<0.10$) enabled an estimation of the Mg rate required to maximize the soybean yield. Calculations using the regression model indicate that a rate of 540.8 g ha^{-1} Mg would enable a maximum yield ($4,570 \text{ kg ha}^{-1}$), which is approximately 8% higher than the control yield ($4,245 \text{ kg ha}^{-1}$), corresponding to a gain of 325 kg ha^{-1} . Vratarić et al. (2006) obtained similar results, with increases of up to 9% in soybean yield after the foliar spraying of Mg. Teklić et al. (2009) also observed a significant effect of Mg foliar spraying on soybean yield; Reinbott & Blevins (1995) observed a positive effect as well, but with the joint application of B and Mg, which they attributed to the increase in the number of branches and pods on the main stem. Another explanation could involve the promotion of soybean grain filling. The Mg foliar spray during the R1 or R5.1 stages increased the 100-grain weight in soybean. However, this increase in the 100-grain weight was only dependent on the stage of Mg application, with no Mg rate effect. The yield increase observed in the present study could be related to the increased photosynthesis (evidenced by the increase in the SPAD index). This resulted in greater soybean shoot growth and increased crop yield components.

Although no significant effect of the Mg rate on the 100-grain weight was observed, a significant effect occurred not only for the application time but also for the interaction between application time and rate. The interaction analysis showed that, for the rates of 25, 50, and 500 g ha^{-1} Mg, the applications during the R1 or R5.1 stage resulted in a greater 100-grain weight than that obtained with the application at the vegetative stage (V4). One of the known Mg effects on plant nutrition is the translocation of photo assimilates and carbohydrates in the plant (Cakmak & Yazici, 2010). The increase in the 100-grain weight resulting from the application of Mg during the R1 and R5.1 stages may involve increased carbohydrate translocation induced by Mg.

In the corn crop, the Mg foliar spray did not increase the SPAD index but increased the leaf Mg content (Table 4). This result was the opposite of that observed for the soybean crop (Table 2). The observed differences may be related to the variation in the response of the two crops to Mg. Teklić et al. (2009) found that soybean cultivars vary in their response to Mg applied as a foliar spray. According to the

authors these differences most likely occurred due to difference between the crops in the stage at which their leaves were collected for the quantification of the SPAD index and the leaf Mg content. The corn leaves were collected during the R2 stage soon after Mg application (in V4 or R1), whereas the soybean measurements were performed later, at stage R6. The higher Mg levels in the corn leaves from the plants treated with the Mg rates may, therefore, be related to the rapid absorption of the element by the leaves and its high mobility in the phloem (Fernández et al., 2015). Together, these factors may have resulted in the higher Mg levels in the corn evaluation, which was performed only one week after the Mg application, which can be shown by the linear increase in the levels of Mg with increasing rates of Mg.

As verified for soybean, there was a significant effect of the Mg rate on corn yield (Table 5), regardless of the application time, with the Mg rate quadratically affecting the corn yield. The fitted equation ($R^2=0.81$, $p<0.05$) enabled the estimation of the Mg rate that would result in the maximum yield. Using the regression model, a rate of 888 g ha^{-1} Mg was predicted to result in the highest yield ($7,882 \text{ kg ha}^{-1}$), which was

Table 4. SPAD index and foliar Mg content in the corn (*Zea mays*) crop fertilized with rates of Mg foliar spray in different phenological stages in the municipality of Uberlândia, in the state of Minas Gerais, Brazil.

Mg foliar spray (g ha^{-1})	SPAD index		Mean	Mg (g kg^{-1})		Mean
	V4	R2		V4	R2	
0	57.3	57.2	57.3	1.93	1.93	1.93
250	58.6	59.1	58.8	1.85	2.13	1.99
500	57.9	55.5	56.7	1.82	2.15	1.99
1,000	51.7	58.8	55.3	2.28	2.18	2.23
1,500	56.4	54.2	55.3	2.18	2.10	2.14
Mean	56.4	57.0	-	2.01	2.10	-
P_{rate}	0.380 ^{ns}			0.088*		
P_{stage}	0.666 ^{ns}			0.263 ^{ns}		
$P_{\text{rate} \times \text{stage}}$	0.154 ^{ns}			0.229 ^{ns}		
$R^2\text{-LR}$	ns			68.8		
$R^2\text{-QR}$	ns			ns		
CV (%)	8.9			14.4		

^{ns}Nonsignificant. *Significant at 10% probability. LR, linear regression; QR, quadratic regression; and CV, coefficient of variation.

approximately 10% (or 737 kg ha⁻¹) higher than that observed for the control (7,145 kg ha⁻¹).

As in the soybean crop, the foliar spray of Mg also increased the 100-grain weight in the corn crop (Table 5). Moreover, a significant effect of Mg application time but not Mg rate occurred. In the case of corn, the Mg application at R1 resulted in a 100-grain weight of 34.6 g, which exceeded the weight obtained when the application was performed at V4 (33.9 g). Gerendás & Führes (2013) reported that Mg application generates better crop quality, but most of the studies do not elucidate the physiological mechanism involved in the response to Mg. A favorable effect of the Mg foliar spray on the plant photosynthetic rate is possible because the foliar application of Mg has been associated with an increase in leaf chlorophyll content (Teklić et al., 2009).

The present study showed the positive impact of foliar Mg on the yield performance of the soybean and corn crops. It is important to underline that a positive effect of the Mg foliar application on the corn crop occurred even in soil containing adequate Mg content – 18 and 12 mmol_c dm⁻³ in the 0–20 cm and 20–40 cm layers,

respectively (Table 1). Two factors may have favored the positive response of the corn crop in soil already containing adequate Mg content: the competition of Mg and other nutrients may have occurred, and soil Mg may have been limited by a local water deficit that occurred in January (Figure 1). The water deficit that occurred at the beginning of the reproductive period may have limited soil Mg absorption during a period of intense Mg demand by corn (Ciampitti & Vyn, 2013). A Mg foliar spray during the vegetative or reproductive periods proved to be a viable measure to improve plant nutrition and promote yield gains in soybean and corn crops.

Conclusions

1. Magnesium foliar spray favors and increases the SPAD index in soybean (*Glycine max*) and the leaf Mg content in corn (*Zea mays*).
2. Mg foliar spray, regardless of the phenological stage, promotes an increase in the grain yield of soybean and corn under the evaluated soil conditions.
3. The foliar spray of Mg during the reproductive stage increases the 100-grain weight in soybean and corn.

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Table 5. Grain yield and 100-grain weight in the corn (*Zea mays*) crop fertilized with rates of Mg foliar spraying in different phenological stages in the municipality of Uberlândia, in the state of Minas Gerais, Brazil⁽¹⁾.

Mg foliar spray (g ha ⁻¹)	Grain yield (kg ha ⁻¹)		Mean	100-grain weight (g)		Mean
	V4	R2		V4	R2	
0	7,145	7,145	7,145	34.1	34.1	34.1
250	7,447	7,878	7,662	33.5	35.3	34.4
500	7,491	7,624	7,557	34.1	34.5	34.3
1.000	7,696	8,248	7,972	34.0	34.9	34.5
1.500	7,410	7,635	7,523	33.9	34.4	34.2
Mean	7,438	7,706	-	33.9b	34.6a	-
P _{rate}	0.018*			0.724 ^{ns}		
P _{stage}	0.228 ^{ns}			0.001*		
P _{rate x stage}	0.448 ^{ns}			0.110 ^{ns}		
R ² -LR	ns			ns		
R ² -QR	0.81 ⁽²⁾			ns		
CV (%)	7.5			2.4		

⁽¹⁾Means followed by different letters differ among phenological stages, by Tukey's test, at 10% probability. ^{ns}Nonsignificant. *Significant at 10% probability. LR, linear regression; QR, quadratic regression; CV, coefficient of variation. ⁽²⁾y = -0.0009x²+1.5991x+7,172.5

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