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FERTIGATION AND FOLIAR APPLICATION WITH LIQUID MINERAL FERTILIZER DOSES ON LETTUCE

Fertirrigação e aplicação foliar com doses de fertilizantes mineral líquido em alface.

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Resumo – O presente trabalho avaliou o efeito de doses de fertilizante mineral líquido composto de macro e micronutrientes, fornecido via fertirrigação e aplicação foliar em alface (*Lactuca sativa* L.), cultivar Vera. Os tratamentos foram arranjados em delineamento inteiramente casualizado com três repetições, sendo resultado da combinação de quatro doses de fertilizante mineral líquido (0,05; 0,10; 0,40 e 0,80 ml planta^{-1}) com duas formas de aplicação (fertirrigação e aplicação foliar) e duas testemunhas adicionais (nitrogênio via aplicação foliar; nitrogênio+0,20 ml planta^{-1} de fertilizante mineral líquido via aplicação foliar). A maior dose do fertilizante (0,80 mL planta^{-1}) aplicada via aplicação foliar obteve 63,51, 59,35 e 42,08% de redução para matéria fresca comercial, matéria seca comercial e número de folhas comerciais, respectivamente, em comparação com via fertirrigação. Para as testemunhas adicionais, a aplicação foliar de nitrogênio obteve incremento de 63,48% da matéria fresca comercial da parte aérea e 32,55% do número de folhas comerciais, em relação à aplicação foliar conjunta de nitrogênio mais fertilizante mineral líquido. De acordo com os resultados, o aumento das doses de fertilizante mineral líquido via aplicação foliar causou redução linear na matéria fresca comercial da parte aérea e no número de folhas comerciais. Os efeitos deletérios observados na produção foram devido à alta quantidade de micronutrients no solo, principalmente o manganês.

Palavras-Chave – aplicação foliar, *Lactuca sativa* L., fertilizante mineral líquido, irrigação localizada, produtividade.

Abstract – This study evaluated the effect of liquid mineral fertilizer doses composed of macro and micronutrients applied through fertigation and foliar spraying on lettuce (*Lactuca sativa* L.) Vera cultivar. The treatments was arranged in a completely randomized design with three replications, being resulted from the combination of four doses of liquid mineral fertilizer (0.05; 0.10; 0.40 and 0.80 ml plant^{-1}) with two forms of application (fertigation and foliar spraying) and two additional treatments (nitrogen via foliar spraying; nitrogen+0.20 ml plant^{-1} of liquid mineral fertilizer via foliar spraying). The highest fertilizer dose (0.80 mL plant^{-1}) applied via foliar spraying obtained 63.51, 59.35 and 42.08% reduction for marketable shoot fresh matter, marketable shoot dry matter and number of marketable leaves, respectively, compared fertigation. For the additional treatments, the foliar spraying of nitrogen obtained increment of 63.48% of marketable shoot fresh matter and 32.55% of the number of marketable leaves in relation to the combined foliar spraying of nitrogen and liquid mineral fertilizer. According to the results, the increase liquid mineral fertilizer doses via foliar spraying caused linearly decreased marketable in shoot fresh matter and the number of marketable leaves. These deleterious effects on production were due high amount of micronutrients on used soil, mainly manganese.

Keywords – foliar spraying, *Lactuca sativa* L., liquid mineral fertilizer, localized irrigation, productivity.

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INTRODUÇÃO

Lettuce is a vegetable marketed and consumed fresh in the form of salad, being an option in horticulture for both protected environment and field cultivation (SOUZA et al., 2015).

In the protected environment, the form of nutrient application must be differentiated from the field due it is not common to lixiviate the nutrients. Therefore an incorrect fertilization management leads to contamination of underground water and it is not possible to attenuate the salinization of the soils (OLIVEIRA et al., 2014).

The use of fertilizers in liquid form via foliar spraying or fertigation is increasing in agriculture. Despite this increase, this practice is still considered new in agriculture, making it necessary the evaluation of the products available in the market for the correct indication of the best doses and application methods.

In the agricultural production, fertilization is one of the most expensive and that provides higher economic return practices (SILVEIRA et al., 2015). Foliar spraying complements the soil fertilization and is used when a given crop needs to recover quickly, in cases of nutrient deficiencies. The fertigation is another technique that allows the application of fertilizers. This technique enables the application of nutrients combined with the irrigation water, ensuring uniform distribution of nutrients on the area, labor saving and high efficiency of nutrients utilization, allowing also the fertilizer to be applied in the region with higher concentration of roots, besides better fractionation of doses (BISCARO et al., 2012).

One of bottlenecks to increase the productivity is to know the attribute of the soil as well as the need for the maintenance of satisfactory conditions of production, in that some soils even presenting appropriate levels of nutrients cannot supply for the vegetables, because this readiness depends on the dynamics between the nutrients and the composition of the soil. If treating of the fertilization with micronutrients, is recommended applications of amounts above the need of the plants, once these are usually strongly adsorbed and they are liberated the medium and long period for the vegetables (MOTTA et al., 2007)

Considering the context of vegetable growers seeking to increase yield and reduced costs due to an increasingly competitive market, the importance of researches on doses and forms of application of liquid fertilizers on lettuce in a protected environment is observed. Other context is fertilization on areas without chemical analyses that can waste inputs if were applied doses above of requested. These studies may help to reduce excessive applications of fertilizers that results in nutritional disturbances and the reduction of the net profit margin.

Based on the hypothesis that doses and fertilizer application methods alter crop yield components, this study aimed to evaluate the commercial production of lettuce (*Lactuca sativa* L.) Vera cultivar, due to the foliar spraying and fertigation of doses of commercial liquid mineral fertilizer.

MATERIALS AND METHODS

The experiment was conducted in a protected environment at the Irrigation Technical Center of the State University of Maringá (UEM), Maringá, Paraná, Brazil (23°25'57 "S; 51°57'08"W; 512 m). This location corresponds to the climate classification Cfa-Mesothermal Humid (Subtropical), characterized by abundant rainfall in summer and dry winters, according to Köppen-Geiger climate classification (PEEL; FINLAYSON; MCMAHON, 2007). The average minimum and maximum monthly temperature are 17 and 26 °C, respectively (CAVIGLIONE et al., 2000).

The soil of the experimental area is classified as Distroferric Red Nitossol (NVdf), according to Embrapa (2013). From the chemical analysis of the soil, carried out by the Rural Laboratory of Maringá (Table 1), it was verified the need for basal fertilization with 40 kg N ha^{-1} and 90 kg N ha^{-1} as top-dressing (TRANI, 2014). According to chemical analysis, the levels of micronutrients are appropriate to grow lettuce.

Initially, three plots were built (14.0 x 1.20 m each) raised to 0.20 m in height, equally spaced among them and the sides of protected environment. Each plot was divided into five equal areas along its length, and in half along its width, totaling ten experimental units per lot.

Each experimental unit had thirty-six plants, namely twelve plants per planting row, arranged parallel to each other in the longitudinal direction. From these, only the six central plants composed the useful plot size of each experimental unit, and the remaining ones were considered as borders.

According to the methodology proposed by Trani et al. (2007), curly lettuce seeds, Vera cultivar, were sown in polystyrene trays with 128 cells filled with substrate.

A completely randomized design with three replications was used. For the composition of the treatments, the factorial design with additional treatments was used (4 × 2 + 2), evaluating two factors, the first referring to the doses of the liquid mineral fertilizer and the second relating to its application methods.

The first factor was constituted by four doses of commercial liquid mineral fertilizer composed of macro and micronutrients (2.5% Ca, 0.7% Mg, 2.3% S, 1.5% Cu, 1.3% Fe, 0.6% Mn, 1.4% Mo and 0.8% Zn). The four doses tested were 0.05; 0.10; 0.40 and 0.80 ml $plant^{-1}$, comprising two doses above and two doses below the dosage recommended by the manufacturer (0.20 ml $plant^{-1}$). In that case, the manufacturer does not indicate any suggestion about dose in according to availability of those elements in soil. The second factor was represented by two forms of application of the fertilizer, fertigation and foliar spraying.

Two treatments were used as additional treatments. The first received only nitrogen (0.31 ml $plant^{-1}$) via foliar spray. Nitromax was used as source containing 30% nitrogen. The second additional treatment received nitrogen fertilization (0.31 ml $plant^{-1}$ of Nitromax) and 0.20 ml $plant^{-1}$ of the commercial liquid mineral fertilizer tested.

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For irrigation and fertigation, a drip type micro-irrigation system was used, composed of tubedrippers spaced at 0.20 m, and pressure compensating drippers, with an average flow of 0.90 L h^{-1} at operating pressure recommended by the manufacturer (10 mwc). After assembling the irrigation system, its uniformity was evaluated without the use of chemicals in the water by the Christiansen coefficient (CUC). The result determined by the CUC was 95.50%, characterized as excellent according to Bernardo, Soares and Mantovani (2006).

Operating time and volume of the fertigation system was 12.6 minutes and 20.4 liters per treatment. It was based on 108 drippers for each treatment and on recommended concentration of 1 ml fertilizer per 1 liter of water considering dosage recommended (0.2 ml $plant^{-1}$). For the treatments which received products applied via foliar spraying, the product was diluted in seven liters of water and applied with the use of manually operated knapsack sprayer.

Irrigations were carried out to keep the water tension in the soil always close to field capacity, avoiding to water deficit. The monitoring of the irrigation was performed using a set of three tensiometers installed at a depth of 0.15 m and arranged diagonally in the experimental area. Irrigation was performed when the tensiometers indicated the value of -15 kPa (SANTOS; PEREIRA, 2004).

Silva and Queiroz (2013) tested different water management of irrigation in lettuce and they obtained the highest production with use of Piche atmometer and class A pan. And so, a Piche atmometer was used to estimate the water depth to be replenished to the soil, according to Blanco and Folegatti (2004) methodology.

The crop was transplanted 25 days after sowing at a spacing of 0.20 m x 0.20 m, totaling 1080 plants. Five days after transplanting, 210 g a.i. ha^{-1} of imidacloprid was applied in a preventive manner to ensure seedling free of pests at fruit-set stage and avoid insecticide applications during the crop cycle.

Table 1. Results of the chemical analysis of the soil used in the experiment.

pH	H^++Al^{3+}	K^+	Ca^{2+}	Mg^{2+}	V	C	P	S	Cu	Zn	Fe	Mn	Na^+	B
$CaCl_2$	----------- $cmol_c$ dm^{-3} -----------				%	g dm^{-3}	----------------------------- mg dm^{-3} ---------------------------------							
6.9	2.19	0.82	6.04	1.57	79.39	13.43	201.98	45.4	11.5	12.5	44.0	134.0	29.3	0.53

Analysis performed at the Rural Laboratory of Maringá. Ca, Mg and Al: potassium chloride 1N; B: Barium chloride hot; S: ammonium acetate (acetic acid); P, K, Cu, Zn, Fe, Mn, Na: Mehlich extractor.

Six lettuce plants were harvested for each experimental unit at 50 days after transplanting. The leaves that had no marketable value were removed and discarded. To obtain the values of marketable shoot fresh matter (MSFM), the lettuces were taken to the laboratory, with controlled temperature and weighed on a precision digital scale (0.01 g).

To determine the marketable shoot dry matter (MSDM) leaves were dried in a forced-air oven at 65 °C until the samples reached constant mass, and then weighed on a precision scale (0.01 g). The number of marketable leaves (NML) did not consider leaves less than 4 cm wide.

The values obtained for the studied variables were subjected to analysis of variance to verify the significance of the factors and their interactions, using the statistical program Sisvar (FERREIRA, 2011).

Following the recommendations of Perecin and Cargnelutti Filho (2008), it was selected a more detailed study from the unfolding of a factor inside another, even in the absence of significant interaction between doses and methods, given the complexity of interactions in factorial experiments, observing the effects of the interaction "by comparisons" (between treatments) and "by experiment" (average interaction).

To comply with this condition, the study of the unfolding of the fertilizer doses was done using the polynomial regression analysis ($P<0.05$) and the study of the effect of the application methods for each fertilizer dose applying the F test ($P<0.05$). For the regression analysis, the significance of the coefficients of the adjusted models was tested applying the Student´s t-test ($P<0.05$).

For the additional treatments, the Dunnett test ($P<0.05$) was applied, comparing them individually with the main treatments.

RESULTS AND DISCUSSION

The liquid mineral fertilizer doses showed significant effects on marketable shoot fresh matter and number of marketable leaves. For the unfolding of the interaction of these variables, it was observed that the effect of the liquid mineral fertilizer doses was significant only via foliar spraying in MSFM and NML, showing no significant differences via fertigation (Table 2).

There was significant effect of the application methods on all studied variables. For the unfolding, significance was found for application methods for all variables only in the dose of 0.80 ml of fertilizer per plant, and at the dose of 0.40 ml on the number of marketable leaves.

It was noted a decreasing linear response to MSFM values for the treatments which received fertilizer doses via foliar spray. Using the fitted regression, there is a decrease of 14.15 g of MSFM for every increase of 0.10 mL $plant^{-1}$ in fertilizer dose (Figure 1). According to Faquin and Andrade (2004) and Prado (2008), most of the nutrients present in the evaluated fertilizer are classified as non-mobile and partially mobile. This causes the foliar spraying of high doses of the assessed fertilizer to provide high concentrations of these minerals, resulting in symptoms of phytotoxicity in lettuce leaves, therefore reducing yield. Other consideration is that most of these nutrients has already been in appropriate level on soil before applying the treatments.

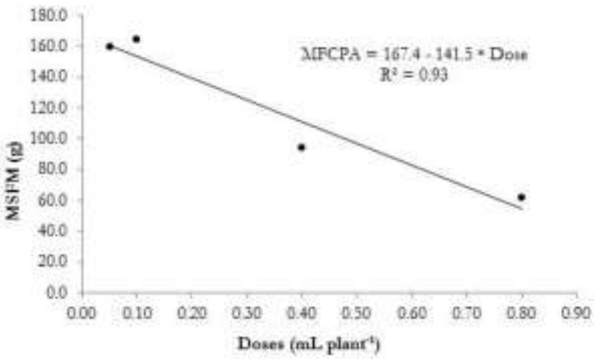

Figure 1. Marketable shoot fresh matter of lettuce plants, Vera cultivar, according to the foliar fertilizer doses, applied via foliar spray.

Zinc and molybdenum are nutrients present in the assessed fertilizer and, according to Resende, Yuri and Souza (2008) and Resende et al. (2010), the foliar spraying of zinc and molybdenum doses showed a quadratic response in marketable shoot fresh matter of crisphead lettuce. Luz et al. (2010) obtained higher fresh matter values of shoots of lettuce when testing a fertilizer with lower amount of copper, zinc and boron. However, Batista et al. (2012) concluded that the foliar application of fertilizer did not change the yield of lettuce, Elba cultivar.

It is understandable that the application of foliar product may result in positive or negative changes in yield components of vegetables, especially when possible interactions between products and plant and soil characteristics and even the interactions between nutrients are considered. In this study the decrease in the yield of shoot fresh matter, may have occurred due to the use of higher dosages to replace the dose recommended by the manufacturer, given that soil contents high level of micronutrients mainly manganese, that causing nutritional imbalances in plants.

The toxidez caused by the excess of manganese shows initially for the induction of the deficiency of iron (MOTTA et al., 2007). According to author, the iron is involved in different physiologic processes as the chlorophyll synthesis, reduction of the nitrate and of the sulfate and fixation symbiotic of the nitrogen.

The use of foliar spraying as a form of application of the liquid mineral fertilizer at the dose of 0.80 mL per plant caused decreases of 63.51% (MSFM) and 59.35% (MSDM) in relation to the fertigation (Table 3). It was also verified that the application of high doses of liquid mineral fertilizer via fertigation produced higher amounts of MSFM, NML and MSDM when compared to foliar spraying.

The application of the dose of 0.40 and 0.80 mL plant^{-1} of the commercial liquid mineral fertilizer via fertigation provided greater NML when compared to foliar spraying (Table 3). For the dose of 0.40 mL plant^{-1} via foliar spray, there was a NML decrease of 35.70% in relation to the fertigation, while at the dose of 0.80 mL plant^{-1} this decrease was 42.08%. These results suggest the idea that lettuce plants have lower sensitivity on the root system than on shoots, under nutritional imbalances.

The inhibition of phytotoxicity when high doses of fertilizer are applied through fertigation can be explained by nutrient complexation processes. The absorption of trace elements by the roots of plants is an important defense, and this function is performed by the vacuole and by intracellular binders such as phytochelatins that reduce nutrient cytoplasmic toxicity by complexation. On the other hand, in foliar applications, the high concentrations of trace elements on the surface of the leaves, such as zinc and copper, cause tissue "burns", giving no possibilities for the plants to reverse this scenario (PRASAD, 1995).

According to Pereira (2006), high zinc levels in shoots of lettuce plants caused reduction in dry matter production. In opposition, Moreira, Fontes and Camargos (2001) reported a positive effect on dry matter of lettuce with the use of the foliar fertilization technique with zinc in greenhouse. However, Silveira et al. (2015) found no significant difference for foliar spraying of zinc in lettuce crop.

It is worth to highlight that initial levels of micronutrients in the soil were high, however the availability of those nutrients are not known, because they can be complexed with the soil.

For the unfolding of the application methods, a decreasing linear model was adjusted on the NML variable depending on the liquid mineral fertilizer doses applied via foliar spray (Figure 2). From the adjusted model, a decrease of 0.68 in NML was observed as fertilizer dose was increased in 0.10 mL plant^{-1}.

A similar result was found by Pereira et al. (2010) with respect to the higher doses of foliar fertilizers, high concentration of nutrients caused nutritional imbalance in the plant, contributing to reduction in growth. Thus, the NML decrease may be due to the occurrence of symptoms of phytotoxicity as observed for MSFM, resulting in fewer marketable leaves at higher fertilizer doses.

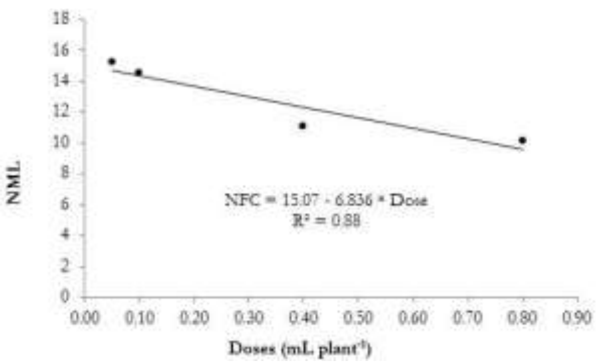

Figure 2. Number of marketable leaves of lettuce plants, Vera cultivar, according to the foliar fertilizer doses, applied via foliar spray.

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Table 2. Summary of the analysis of variance on marketable shoot fresh matter (MSFM), number of marketable leaves (NML) and marketable shoot dry matter (MSDM) of lettuce, Vera cultivar.

Variation Sources	DF	MSFM	NML	MSDM
		F calculated		
(Treatments)	(9)	(5.06**)	(11.73**)	(2.50*)
Dose (D)	3	5.14**	4.92*	1.42^{ns}
Form (F)	1	21.65**	65.35**	7.98*
Dose*Form	3	0.91^{ns}	4.32*	2.32^{ns}
(Dose/Fertigation)	(3)	(0.41)	(0.07)	(1.81)
b1	1	0.93^{ns}	0.00^{ns}	0.34^{ns}
b2	1	0.00^{ns}	0.01^{ns}	2.54^{ns}
Deviation of regression	1	0.30^{ns}	0.20^{ns}	2.56^{ns}
(Dose/ Foliar spraying)	(3)	(1.95)	(1.90)	(0.80)
b1	1	5.50*	5.05*	2.16^{ns}
b2	1	0.23^{ns}	0.65^{ns}	0.15^{ns}
Deviation of regression	1	0.12^{ns}	0.00^{ns}	0.10^{ns}
Form/0.05	1	0.61^{ns}	0.54^{ns}	0.21^{ns}
Form/0.10	1	1.32^{ns}	2.10^{ns}	1.96^{ns}
Form/0.40	1	3.21^{ns}	5.76*	0.00^{ns}
Form/0.80	1	4.39*	8.28*	8.28*
Additional treatments	1	5.71*	12.35**	2.58
Factorial vs Add. treatments	1	0.01^{ns}	0.20^{ns}	0.76^{ns}
Error	20			
Total adjusted	29			
CV(%)		24.86	9.62	30.3
General average		156.90	15.10	25.68

Dose = 0.05; 0.10; 0.40 and 0.80 mL fertilizer plant^{-1}. Method = F1: Fertigation and F2: Foliar Spray. Additional treatments = T1: foliar spraying of nitrogen; T2: foliar spraying of nitrogen and fertilizer. ** Significant (P <0.01) by the F Test. * Significant (P <0.05) by F Test. ^{ns}Not significant (P <0.05) by the F Test.

Table 3. Unfolding of the methods of application within each dosage for marketable shoot fresh matter (MSFM), number of marketable leaves (NML) and marketable shoot dry matter of lettuce (MSDM), Vera cultivar.

Variables	Forms of application	Fertilizer doses (ml plant^{-1})			
		0.05	0.10	0.40	0.80
MSFM (g)	Fertigation	199.00 a	222.72 a	185.11 a	168.11 a
	Foliar spraying	159.11 a	164.22 a	93.83 a	61.33 b
NML	Fertigation	17.17 a	18.22 a	17.28 a	17.56 a
	Foliar spraying	15.28 a	14.50 a	11.11 b	10.17 b
MSDM (g)	Fertigation	27.27 a	36.77 a	22.30 a	36.83 a
	Foliar spraying	23.77 a	26.13 a	22.40 a	14.97 b

Means followed by distinct lowercase letters in the same column are different by the F test (P <0.05).

Table 4. Average of the additional treatments for the production of marketable shoot fresh matter (MSFM), number of marketable leaves (NML) and marketable shoot dry matter (MSDM) of lettuce, Vera cultivar.

Variables	Control 1	Control 2
MSFM (g)	196.00 a	119.89 b
NML	16.94 a	12.78 b
MSDM (g)	28.30 a	18.1 a

Means followed by distinct letters in the same line are different by the F test (P <0.05). Control 1: foliar spraying of nitrogen; Control 2: foliar spraying of nitrogen and fertilizer.

The additional treatments differed statistically to MSFM and NML (Table 4). The use of nitrogen fertilization was sufficient to obtain more number marketable leaves (32.55%) and marketable shoot fresh matter (63.48%) compared to nitrogen fertilization combined with the commercial liquid mineral fertilizer.

It is reasonable to assume that the application of nitrogen via foliar spray may have promoted changes in the absorption capacity of the other soil nutrients according to Faquin and Andrade (2004) explanation on the effects of nitrogen foliar fertilization. According to this author, nitrogen sources such as urea are important in the practice of foliar fertilization, they increase their own absorption and the absorption of other ions.

In the present study, the use of foliar nitrogen fertilization alone probably had no negative effects on the absorption of other elements by the plants, however, in addition to this, the application of micronutrients and macronutrients promoted nutritional imbalance in the additional treatment, thus reducing the marketable shoot fresh matter and the number of marketable lettuce leaves.

For Souza et al. (2015) the fertigation with two combined products (nitrogen and potassium silicate) on lettuce, obtained higher values for dry matter with the application of the highest doses of the two products. However, Hosseini and Khoshgoftarmanesh (2013) tested the foliar application of nitrogen in two lettuce cultivars, verifying that there were no significant differences for fresh matter of shoots when compared to the control. Based on the present data, it can be inferred that there is no recommended for joint application of commercial liquid mineral fertilizer with nitrogen fertilizer for soils with high levels of micronutrients, mainly manganese.

It was also verified that the combined effect of fertilizers should be known so there is no possible nutritional imbalances and phytotoxicity, especially for micronutrients which are in the fertilizers, since, according to Faquin and Andrade (2004), these nutrients have a delicate limit of concentration which cause deficiencies or toxicities to agricultural crops.

CONCLUSIONS

Lettuce crop was lower sensitive on the root system than on shoot, under overdose.

It was verified that the application of liquid mineral fertilizer through fertirrigation promoted higher yield when compared to the foliar spraying for the conditions under which the experiment was conducted.

It is not recommended for joint application of commercial liquid mineral fertilizer with nitrogen fertilizer for soils with high levels of micronutrients, mainly manganese.

It is recommended to farmers, in the practice of foliar spraying very attention with levels of micronutrients of soil, give than on this form of application the probably of imbalance is more relevant.

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