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FOLIAR SPRAY OF WATER SOLUBLE FERTILIZER ENHANCES DROUGHT TOLERANCE OF CHILI PEPPER

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Abstract. This study aimed at examining the effect of fertilizer and water application through leaves to increase the growth and yield of chili pepper under drought stress conditions. The study was arranged in a split plot design with three replications. The main plot was plant cultivar (Kastilo, Lado and Romario), while the subplot was the application of fertilizer through leaves (no fertilizer and no water, application of 5 mL·L^{-1} foliar fertilizer, and water only). The results showed that different cultivars of chili peppers gave a positive response to the application of water and fertilizer through the leaves under drought condition (50% of field capacity), and the application of 5 mL·L^{-1} foliar fertilizer produced better growth and yields. Application of liquid fertilizer through leaves increased the growth of chili pepper by 57.43% - 82.49% and the production by 81.59% - 94.09%. The number of branches and fruit weight were strongly affected by the application of liquid fertilizer through leaves. The cultivar that were most responsive to the application of foliar fertilizer under drought stress conditions was Lado, followed by Kastilo and Romario. The Lado cultivar showed higher N, K, Ca and Mg contents than Kastilo and Romario.

Key words: *Capsicum annuum;* foliar fertilization; fertilizer technology; abiotic stress.

INTRODUCTION

Drought is an important threat to the sustainability of agriculture throughout the world. The drought stress directly or indirectly influences many physiological processes of plant [63]. A significant change in cellular metabolism is generally occurred that generally results in reduced plant growth, yield and quality [45]. Drought inhibits water absorption by plants due to reduction of water potential around plant roots. Plants experiencing drought stress will increase their osmotic potential by synthesizing proline and various sugars, so that water can enter plant cells. Decreased water availability in root zone due to drought also inhibits nutrient uptake by plant resulting in nutrient deficiency which will ultimately inhibit their growth and development, and causing serious yield reduction [2].

When root nutrient uptake is damaged, fertilization through leaves is an efficient way that can provide a quick beneficial effect on plant growth. It has been claimed that applying fertilizer through leaves was a simple way to correct nutrient deficiencies in plants when nutrient uptake by roots is restricted [37, 61, 62, 64]. Under adverse environmental conditions, the application of mineral or organic fertilizers or biostimulants through the leaves can be more effective by direct and faster supply and absorption of required minerals [7, 60].

The process of nutrient absorption by leaves could be different from roots because leaf surfaces are covered by a cuticle. This cuticular structure is permeable to nutrient ions present in aqueous forms [33, 54, 55]. Fageria *et al.* [23] suggested that ion uptake by leaves took place in three stages. Firstly, substances penetrated the cuticle and the cellulose wall via limited or free diffusion, then these substances were adsorbed to the surface of plasma membrane by some form of binding, and finally the absorbed substances were taken up into the cytoplasm in a process requiring metabolically derived energy. However, now it is also proved that ions also absorbed by leave stomata [9, 11, 20]. When the stomata are open, foliar absorption is often easier [10].

Studies have shown that applying liquid fertilizer containing macro and micro nutrients through leaves could increase the ability of plants to withstand drought stress [25, 29, 52, 67]. Thalooth *et al.* [67] reported that the application of Zn, K and Mg through leaves of green beans in drought condition positively affected plant growth and yield. Potassium showed a greater effect than the other two nutrients because K was the most mobile nutrient and played a role in osmotic regulation, so as to increase plant tolerance to drought stress by maintaining plant water balance [12].

Sajedi *et al.* [52] reported increased yield of corn under drought stress by the application of foliar liquid fertilizer containing micro nutrients. Increased plant growth as a result of micro nutrients fertilization through leaves also reported by Khalid [35] on *Pimpinella anisum*, *Coriandrum sativum* and *Foeniculum vulgare*. Furthermore Heidarzade *et al.* [29] found that spraying micro nutrients, especially Fe and Mo, on soybean was an acceptable strategy and reducing crop damage due to water shortages.

Foliar fertilizer studies on chili pepper under normal water condition have been reported by many authors [3, 8, 19, 21, 58, 66]. However, there have been limited reports on the investigation of foliar fertilization on chili pepper grown under water deficit condition [4, 39]. Azam *et al.* [4] claimed that drought tolerance in bell pepper could be improved by foliar application of calcium chloride at 15 mM. Manaf *et al.* [39] added that foliar spray of $CaCl_2$ on pepper grown under drought condition resulted in increment in growth and yield parameters and some biochemical constituents. Similarly, it has been shown that foliar application of organic fertilizers containing a range of macro and micro nutrients and amino acids can significantly improve the growth of chili pepper seedlings under cool temperature [64].

This study aimed at investigating growth and yield of three chili cultivars that were sprayed with fertilizer through leaves and compare them with those sprayed with water under drought conditions. The assessment on liquid fertilization through leaves under drought condition is crucial to obtain chili cultivars that are responsive to foliar feeding in drought stress. The finding is expected to support farmers to have choices on chili types with high quantity and quality of yields under restricted water availability.

MATERIALS AND METHODS

Research materials

The study was conducted in a plastic house in Pematang Sulur Sub-district, Jambi, Indonesia, from February to July 2017. The site lies at east longitude of 103° 40’ 1.67″ and south latitude of 01° 30’ 2.98″, and altitude of 35 m above sea level. It has a warm dry climate with daily temperature during the growing season was 21.2°C – 34.9°C. The average annual rainfall outside the plastic house was about 2,296.1 mm per year (191.34 mm per month), and relative humidity was 80% - 86%.

Plant materials used in this study were three chili cultivars, namely Kastilo (East West Seed Indonesia), Lado (East West Seed Indonesia), and Romario (PT. Aditya Sentana Agro). Lado and Kastilo are suitable for low to moderate land, and both resistant to bacterial wilt (*Pseudomonas solanacearum*). Kastilo is also resistant to stem rot disease (*Phytophthora capsici*) in addition to *P. solanacearum*. Whereas Romario is recommended for low to high altitude, and resistant to anthracnose (*Colletotrichum capsici*) and chili leaf curl virus (ChiLCV). Foliar fertilizer used was Bayfolan® (PT Bayer Indonesia). This liquid fertilizer contained 11% N, 8% P_2O_5, 6% K_2O, 0.019% Fe, 0.0162% Mn, 0.0102% B, 0.0081% Cu, 0.0061% Zn, 0.0009% Mo, and, 0.00035% Co.

Plant preparation and maintenance

Seeds were sown and germinated on a seed bed. Ten-day old seedlings were transferred to individual organic containers (made of banana leaves) and left for 21 days in nursery. Seedlings were transplanted to black polyethylene bags (25 cm x 40 cm) containing mixture of soil, sand and compost (2:1:1) each of 10 kgs. Plant care was carried out according to standard protocol for chili pepper cultivation in pots.

Liquid fertilizer (Bayfolan®) with concentration of 0.5% (v/v) was applied in weekly basis by foliar spray following one week until ten weeks of transplanting. This was obtained by diluting 5.0 mL of Bayfolan® in 500 mL of distilled water, thoroughly mixed, and topped up with distilled water to 1,000 mL. Spraying was done in the morning on all parts of the plant, and stopped when water droplets had formed at the tips of leaves.

Experimental design

This study employed a split plot design with three replications. The main plot consisted of fertilizer application (fertilizer spray, water spray, and no fertilizer or water spray), while the subplot consisted of different chili cultivars (Kastilo, Lado and Romario). The soil moisture content was set to 100% of field capacity (control) or 50% of field capacity (drought condition) before transplanting, which was measured by gravimetric method [59].

Observations on plant growth and yield, and data on determination of N, P, K^+, Ca^{2+} and Mg^{2+} content in plant tissues were observed and recorded at 8 weeks after transplanting. Variables observed were plant height, number of productive branches, total leaf area, dry weight (total and above-ground parts). Data on fruit number, and total weight of fruits per plant were recorded at 14 weeks after transplanting. Fruits were collected once every 3 days in the morning for 4 weeks.

Leaf samples for nutrient determination was prepared by wet ashing using H_2SO_4 and H_2O_2 method [6]. Following wet ashing, N content was determined using Kjeldahl procedure and spectrophotometry, and P, K^+, Ca^{2+} and Mg^{2+} contents were determined using Atomic Absorption Spectrometry (AAS). Leaf area was determined by the formulae: Leaf Area (cm^2) = $(x/y) \times z$, where x was dry weight of total leaves, y was dry weight of sample leaves, and z was area of sample leaves.

Statistical analysis

Data were analysed statistically using regression and correlation analysis module using SPSS Program Version 16.0 [65].

RESULTS

The application of liquid fertilizer or water through leaves increased growth and yield of chili pepper grown under drought stress condition. In the application of fertilizer, the highest increase was found in Lado (66.91%), followed by Kastilo (57.01%) and Romario (52.26%). The application of water through leaves also increased growth and yield of chili, but the increase was not as much as fertilizer application, where the greatest increase was recorded in Romario (24.50%), Lado (24.12%), and Kastilo (18.67%) respectively (Table 1).

Results also showed that growth and yield of chilies treated with foliar fertilizer under drought stress (50% field capacity) had not been able to provide the same growth and yields as of those planted in optimum (100% field capacity) condition (Table 2). However, foliar fertilization on Lado produced the highest growth and yield compared to other two cultivars.

Table 1. The increase of growth and yield (%) of three chili cultivars grown under 50% field capacity and treated with foliar fertilizer or water spray in comparison with control (no fertilizer or water)

Variables	Kastilo		Lado		Romario	
	Fertilized	Watered	Fertilized	Watered	Fertilized	Watered
Plant height	8.46	9.56	4.62	-1.32	16.34	12.06
Number of productive branches	82.05	21.79	93.33	60.67	72.09	53.49
Total leaf area	49.53	30.75	42.49	5.90	80.27	55.47
Shoot dry weight	69.25	17.31	84.18	12.99	47.31	6.39
Root dry weight	9.99	5.23	13.77	2.04	18.15	12.18
Total dry weight	63.83	16.86	77.98	11.80	48.69	10.30
Number of fruit	79.56	19.34	106.40	48.27	58.80	19.10
Fruit weight per plant	93.37	28.52	112.47	52.63	76.44	27.04
Overall increase in growth and yield	57.01	18.67	66.91	24.12	52.26	24.50

Negative sign indicates a decrease in the variable.

Table 2. The increase of growth and yield (%) of three chili cultivars grown under 50% field capacity in comparison with 100% field capacity and treated with foliar fertilizer or water spray

Variables	Kastilo			Lado			Romario		
	Without	Fertilized	Watered	Without	Fertilized	Watered	Without	Fertilized	Watered
Plant height	68.10	73.86	74.61	77.30	80.87	76.28	65.23	75.89	73.10
Number of productive branches	25.00	45.51	30.45	21.80	42.15	35.03	20.94	36.04	32.14
Total leaf area	27.95	41.80	36.55	30.74	43.80	32.55	20.35	36.68	31.63
Shoot dry weight	27.79	47.04	32.60	25.73	47.39	29.08	26.68	39.30	28.38
Root dry weight	63.47	69.81	66.79	67.81	77.14	69.19	59.55	70.36	66.80
Total dry weight	26.62	43.61	31.11	27.06	48.16	30.25	26.72	39.73	29.47
Number of fruit	36.49	65.52	43.55	33.24	68.62	49.29	32.79	52.07	39.05
Fruit weight per plant	35.63	68.90	45.79	32.88	69.86	50.18	29.99	52.91	38.10
Overall increase in growth and yield	38.88	57.01	45.18	39.57	59.75	46.48	35.28	50.37	42.33

Without = without foliar fertilizer nor water; Fertilized = with foliar fertilizer; Watered = with water only.

Application of Bayfolan® or water during drought conditions increased plant tolerance to drought stress. This can be seen in the increase of total weight of fruit per plant as the result of fertilizer application in comparison to without fertilizer (Figure 1). Lado showed a fairly increase in fruit weight compared to other two cultivars. However, when compared to those grown on optimum conditions (100% field capacity) the fruit number per plant was lower (Figure 2).

The chemical analysis of leaf tissues showed that there were increase in P and K, but lower in N, Ca and Mg contents in plants treated with foliar fertilizer or water spray (Table 3). Table 3 also indicates that the application of liquid fertilizer by leaf spraying could increase plant nutrient content and improve their ability to sustain drought stress, compared to those that were sprayed with water only.

Plants grown in drought condition and sprayed with liquid fertilizer showed a lower reduction in N content than to those sprayed with water only. The smallest decrease in N content was found in Lado (3.14%), followed by Romario (29.97%) and Kastilo (36.16%). The increase in P and K content was greater by the application of liquid fertilizer than water in all chili cultivars. The greatest increase in P and K was found in Lado i.e. 17.95% and 23.73%. The increase in K content due to foliar fertilization was accompanied by a decrease in Ca and Mg contents. The greatest decrease in Ca was found in Kastilo, while Lado provide the greatest decrease in Mg. Furthermore, there were more reduction in Ca and Mg contents due to foliar fertilization than water spraying (Table 4).

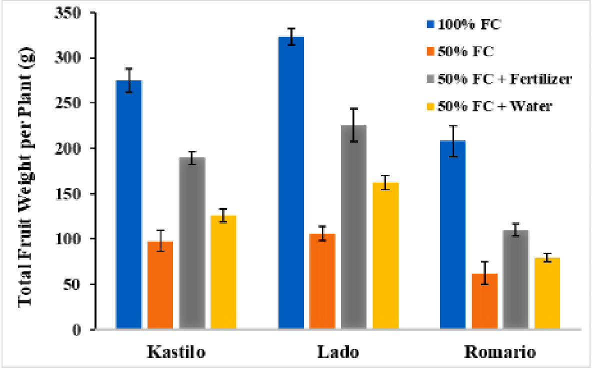

Figure 1. Fruit weight produced under 100% field capacity (FC) and 50% FC with or without fertilizer

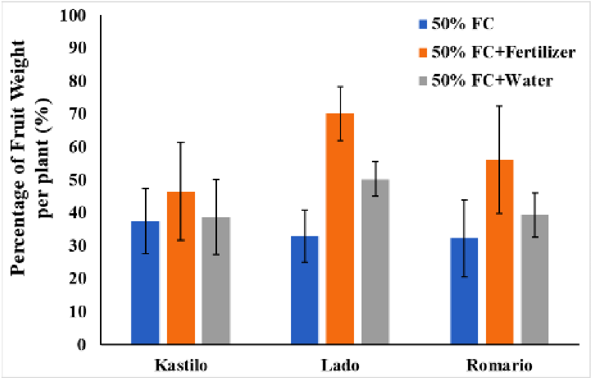

Figure 2. The percentage of fruit weight under 50% field capacity (FC) and treated with or without foliar fertilizer in comparison with those grown on 100% FC

Table 3. Leaf nutrient content of three chili pepper cultivars treated with foliar fertilizer and 50% field capacity at 8 weeks after transplanting

Fertilizer application	Kastilo	Lado	Romario
		….. N (%) …..	
50% field capacity	4.97	3.94	4.77
50% field capacity + fertilizer	3.65	3.82	3.67
50% field capacity + water	3.35	3.69	3.42
		….. P (%)…..	
50% field capacity	0.36	0.32	0.34
50% field capacity + fertilizer	0.39	0.39	0.38
50% field capacity + water	0.37	0.33	0.34
		….. K (%)…..	
50% field capacity	4.38	4.37	5.06
50% field capacity + fertilizer	5.53	5.73	5.57
50% field capacity + water	4.52	4.82	5.50
		….. Ca (%)…..	
50% field capacity	1.26	1.32	1.13
50% field capacity + fertilizer	0.88	1.03	0.84
50% field capacity + water	1.11	0.94	0.95
		….. Mg (%)…..	
50% field capacity	0.36	0.58	0.36
50% field capacity + fertilizer	0.32	0.39	0.26
50% field capacity + water	0.34	0.45	0.36

Table 4. Changes in nutrient content in three chili cultivars due to foliar fertilization and water spray at 8 weeks after transplanting

Fertilizer application	Changes (%)		
	Kastilo	Lado	Romario
		….. N …..	
50% field capacity + fertilizer	-36.16	-3.14	-29.97
50% field capacity + water	-48.36	-6.78	-39.47
		….. P …..	
50% field capacity + fertilizer	7.69	17.95	10.53
50% field capacity + water	2.70	3.03	0.00
		….. K …..	
50% field capacity + fertilizer	20.80	23.73	9.16
50% field capacity + water	3.10	9.34	8.00
		….. Ca …..	
50% field capacity + fertilizer	-43.18	-28.16	-34.52
50% field capacity + water	-13.51	-40.43	-18.95
		….. Mg …..	
50% field capacity + fertilizer	-12.5	-48.72	-38.46
50% field capacity + water	-5.88	-28.89	0.00

Negative sign indicates a decrease

DISCUSSION

Fertilizer or water given to plant through foliar spray increased plant growth as indicated by more dry weight gained. Increase in total dry weight due to fertilizer application was mainly due to the increase in shoot dry weight than the increase in root dry weight (r = 0.994 **; r = 0.745 **). The variance in shoot dry weight is determined jointly by the variance in the number of productive branches (X_1), total leaf area (X_2), and plant height (X_3). The equation obtained is $y = 5.855 + 0.005 X_1 + 0.009 X_2 - 0.061 X_3$ ($R = 0.805$; $R^2 = 0.648$), but the total leaf area has a more significant effect on shoot dry weight than the number of productive branches or plant height (r = 0.795 **; r = 0.590 **; r = 0.527 **).

The size of leaf area will determine the amount of substrates produced during photosynthesis. Table 1 shows that increase in total leaf area as the result of fertilizer application is followed by increase in fruit number and fruit weight per plant in three chili cultivars. The same relationship is also found in comparison of plant grown under 50% field capacity to 100% field capacity (Table 2). Proebsting [47] suggested that the fruit number to leaf area ratio during the fruit growing period was the most important factor for explaining fruit weight variation. In sweet cherry (*Prunus avium*), Cittadini *et al.* [17] found that leaf area had a strong relationship with photosynthetic capacity, and a high leaf area per fruit was essential for high quality fruits [50]. In general, average fruit weight decreased as fruit number to leaf area ratio increased [22].

Though it was known that drought stress reduced the area of newly developed leaf blades in order to diminish transpirational water loss [24, 49, 70], the spray of 0.5% liquid fertilizer could increase the total leaf area of chili plants during water shortage condition. The main cause of an increase in leaf area was the improvement of water regime in leaf tissues due to the application of fertilizer. In addition, macro-micro nutrients contained the fertlizer such as N, P and K, as well as Fe, Mn, B, Cu, Zn, Mo, and Co also played a physiological role in plants [43, 45, 63]. Ihsan *et al.* [32] suggested that the positive effect of N, P and K applied through leaves was related to its ability to maintain the proper leaf nutrient content and increase the photosynthetic capacity of plants. Meanwhile, Co though was not considered an essential micronutrient for plants, it was an essential component of several enzymes and co-enzymes [46] and helped green bean (*Phaseolus vulgaris* L.) plants to resist stresses caused by drought [26].

The study of Shabbir *et al.* [57] in wheat revealed that the combination of N, P and K fertilizers applied through leaves under stress and normal conditions was better than their sole application. Fertilization through leaves effectively increased the growth of plants that were sensitive to drought. Cakmak [13] stated that plants exposed to environmental stress require additional nutrients, especially N, K, Mg, Ca, Zn, and B to reduce stress damage.

Decrease in N content due to the application of foliar fertilizer at 8 weeks after transplantation (during flowering and fruit formation) was the result of mobilization to other plant parts. It was proved that nitrogen in the leaves could be remobilized to growing organs such as flowers and fruit, especially at the end of plant growth [41]. Although there was a decrease due to foliar fertilization, the level of N in chili tissues was categorized high (> 3.10% dry weight). That is why foliar fertilizer would be able to protect plants against detrimental effect of drought stress, and thus produce broader leaf area due to increase in cell division and enlargement.

Foliar fertilization had increased P content, and thus ability of plants to carry out photosynthesis. This was also in line with the increase in total leaf area. Nassar *et al.* [44] suggested that P was crucial in regulating total carbohydrates, dissolved sugars, mineral contents and essential oil production in *Chamomilla recutita* flowers. Furthermore Haryuni *et al.* [28] claimed that the availability of P in plants will affect the content of endogenous proline, an osmotic metabolite that plays a role in increasing plant resistance to drought stress. It was reported that the application of P (12 g per plant) in combination with bovine bio urine (20 $mL \cdot L^{-1}$ and 30 $mL \cdot L^{-1}$) produced the highest proline and chlorophyll contents in *Vanilla planifolia* seedlings [28].

The application of foliar fertilizer containing K might improve K content within plant tissues during water shortage situation as reported here. There is positive correlation between the increase in total leaf area the K content in plant tissue as the result of foliar fertilization. Potassium has important role in many biochemical and physiological processes including stomatal functions [40, 68], so that plants can maintain the availability of water for growth and development in drought conditions. In addition, K is important due to its association with photosynthetic activity in higher plants [41]. Increasing K content in plant tissues will increase the plants photosynthesis efficiency and photoassimilate translocation [53], and therefore increasing plant height and number of branches, which in turn increasing shoot, root and total dry weight as shown in our results on the three chili cultivars. These result is in line with the report of Bahrami-Rad and Hajiboland [5] who claimed that K application resulted in increasing activity of photosynthesis and transpiration, and decreasing water use efficiency (WUE) in tobacco plants under drought stress.

There was a decrease in Ca and Mg levels due to the application of fertilizer through leaves. Decrease in Ca and Mg levels was probably a consequent of increase in K levels due to ion antagonism [56]. However, Mg levels of chili plants were still in the optimum range (0.2% - 0.6%), while the Ca level were at a very low limit (<1.6%). Magnesium in plants is a constituent of chlorophyll, and it plays a role in photophosphorylation in photosynthesis and oxidative phosphorylation in respiration [41], so an increase in Mg content of chili plants due to the application of foliar fertilizer will promote plant photosynthesis. In addition to involving in many plant physiological and biochemical processes, Mg is crucial in defense mechanisms in abiotic stress situations [14-16, 27, 31, 42].

Table 3 shows that under 50% field capacity, higher K content was found in plants sprayed with liquid fertilizer or water. Changes in K content was higher in plants sprayed with liquid fertilizer than water (Table 4). This increase in K level is in line with the decrease in Ca and Mg contents, indicating that the higher K content suppresses Ca and Mg uptake, resulting in lower Ca and Mg levels in plant tissue. This finding is in accordance with Rhodes *et al.* [48] reports in sugarcane, where potassium application resulted in significant increase in K levels in leaves, along with increase in sucrose yields. Increased leaf K levels led to decrease in leaf Ca and Mg concentrations.

Our results showed that the application of leaf fertilizers containing micro nutrients Fe, Mn, B, Cu, Zn, Co, and Mo resulted in the better growth and yield of chili pepper under drought stress condition. This is in accordance with many studies on the role of these nutrients in decreasing the adverse effects of drought in crop plants [18, 51, 52, 69]. Reports of Abdelaziz and Taha [1] showed that the application of Zn and K could increase fruit weight, vitamin C content and total soluble solids of tomato exposed to water stress. Meanwhile Khan *et al.* [36] reported that the application of Zn and Mn might increase total chlorophyll and carotenoid contents of *Brassica juncea* grown under drought stress. Similarly, Karim and Rahman [34] claimed that foliar application of Zn, B and Mn increased grain yield as well as micronutrients concentration of the grain of *Oryza sativa, Zea mays* and *Triticum aestivum.*

The regression analysis on the effect of various growth factors on crop yields in term of fruit weight follows the equation $Y = 116.02 + 1,493\ X_1 + 0.088\ X_2 - 2,007X_3$ ($R = 0.919$; $R^2 = 0.845$). This means that the variance of fruit weights is determined jointly by the variance in number of productive branches (X_1), total leaf area (X_2), and plant height (X_3). The number of productive branches, total leaf area, and plant height significantly affected the variance of fruit weight. Correlation analysis showed a close relationship between fruit weight and number of productive branches and between fruit weight and total leaf area, but not plant height (r = 0.862 **, r = 0.670 **, r = 0.339 ns). Based on the analysis of regression and correlation it is clear that the increase of fruit weight due to foliar fertilization under drought condition, was the consequence of increase in the number of productive branches and total leaf area.

Increased plant growth as indicated by increase in shoot dry weight closely related to increase in total leaf area. The greater leaf area means more light interception for carrying out photosynthesis. If leaf area is low and intercepts only a fraction of radiation, it would be a factor limiting photosynthesis by plants [38]. Most of the reduction in leaf area appears to be the consequence of sensitivity to water stress [30]. Our results, however, indicated that the application of foliar fertilizer during drought period could overcome such stress problem, and resulted in greater leaf area than those of untreated plants.

Current study revealed that Lado which was susceptible to drought stress showed better growth and yield than Kastilo and Romario cultivars. The application of foliar fertilizer on plants grown under drought condition was able to promote the growth and yield of the Lado cultivar, exceeding the drought-tolerant Kastilo, while Romario was a drought-susceptible cultivar with lower growth and yields than Lado and Kastilo cultivars.

The nutrient content (N, K, Ca and Mg) of Lado treated with foliar fertilizer was higher than those of Kastilo and Romario, except for P. This was one of factors increasing the growth and yield of Lado to be higher than Kastilo and Romario. It was found that Lado is more responsive to foliar fertilization than the other two cultivars.

In conclusion, our study showed that the application of liquid fertilizer through foliar spray on chili pepper in drought stress condition provided better growth and yield compared to water spray only or without fertilizer nor water application, but had not been able to provide the same growth and yield as in normal conditions. The Lado cultivar was more responsive to foliar fertilization under drought stress condition, followed by Kastilo and Romario cultivars.

Conflict of interest. There is no actual or potential conflict of interest in relation to this article.

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