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Irrigation-yield response factor of processing potato for different phonological growth stages

Afrin Jahan Mila[1], Md. Hossain Ali[2]

[1]Irrigation and Water Management Division, Banglsdeah Agricultural Research Institute (BARI), Gazipur-1701, Bangladesh

[2]Agricultural Engineering Division, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh-2202, Bangladesh

ABSTRACT: *The yield response factor of processing potato (variety: BARI Alu-25 and BARI Alu-28) was determined from field experimental data conducted during two consecutive years (2013 and 2014) at Bangladesh Agricultural Research Institute, Gazipur. There were six irrigation treatments including full irrigation at three growth stages (stolonization, tuberization and bulking stages), single irrigation at each growth stage, irrigations at stolonization and bulking stage, and irrigation at tuberization and bulking stage. Results reveal that the crop yield response factor (k_y) and sensitivity index (λ_i) increased with the increase of intensity of water deficit at different phonological growth stages. Non-significant difference was found in paired t-test at 5% level of significant. On an average, the k_y for tuberization + bulking, stolonization + bulking, stolonization + tuberization, tuberization and stolonization was 0.23, 0.24, 0.28, 0.03, and 0.006 for BARI Alu-25, while 0.23, 0.24, 0.27, 0.04, and 0.007 for BARI Alu-28, respectively. According to the value of yield response factor, the most critical growth stages were in the order: stolonization + tuberization>stolonization + bulking>tuberization + bulking>tuberization>stolonization. For the entire growing season, the k_y values were 0.76, 0.86, 1.07, 0.71 and 0.07 for tuberization + bulking, stolonization + bulking, stolonization + tuberization, tuberization and stolonization for BARI Alu-25, while 0.98, 1.13, 1.86, 0.77 and 0.08 for BARI Alu-28, respectively. The $\lambda_i$fortuberization + bulking, stolonization + bulking, stolonization + tuberization, tuberization and stolonization stage was 0.12, 0.13, 0.19, 0.01, and 0.002 for BARI Alu-25, while 0.13, 0.15, 0.17, 0.01 and 0.003 for BARI Alu-28, respectively. A more sensitive growth stage has a higher value of lamda i, and therefore water supply is more important at stolonization + tuberization stage.*

Keywords -*Processing potato, yield response factor, sensitivity index, deficit irrigation*

I. INTRODUCTION

Availability of water is decreasing day by day due to climate change, rapid growth of population, excessive use of irrigation water and management practices (Hanjra and Qureshi, 2010;Kundzewiczet al. 2008; Rosegrant et al. 2002; Vorosmarty et al. 2000). To cope with this we have to depend on utilization of minimum water which will give optimum yield with maximum water productivity instead of maximum yield. This technique is called deficit irrigation and efficient utilization of water is possible. In addition to, this technique can save irrigation cost with negligible yield reduction consequently net farm income increase (Ali et al. 2007). When water deficit occurred in a crop at different growth stages, climatically occurred crop stress will differ. Orgezet al.(1992) reported that yield hampered by deficit irrigation is the effect of both the intensity and timing of water deficit. The term crop yield response factor is an important tool which helps to make irrigation scheduling under water deficit condition. Its value exceeds one indicate more stress and water must be available at that stage to get optimum yield. Also, the stage, which is most vulnerable to water, is called critical or sensitive growth stage. From the value of yield response factor sensitive growth stage can be determined. As a result, accurate irrigation scheduling under water scarce situation can be obtained.

For practical application in the field, Doorenbos and Kassem (1979) developed a reliable method which permits the quantification of crop yield response to water under full and deficit water supplies. This method expresses a quantitative relationship between relative yield decrease and relative evapotranspiration deficit. Therefore, this method can form an outline by providing directive for optimum crop production and water productivity for the rational planning of water management (Ali 2009). By using this method many scientists determined crop yield response factor for different crops throughout the growing season as well as individual growth stages (Ayas and Korukcu, 2010;Istanbulluoglu et al. 2010;Ali 2009;Moutonnet P. 2002;Kirdaet al.1999).

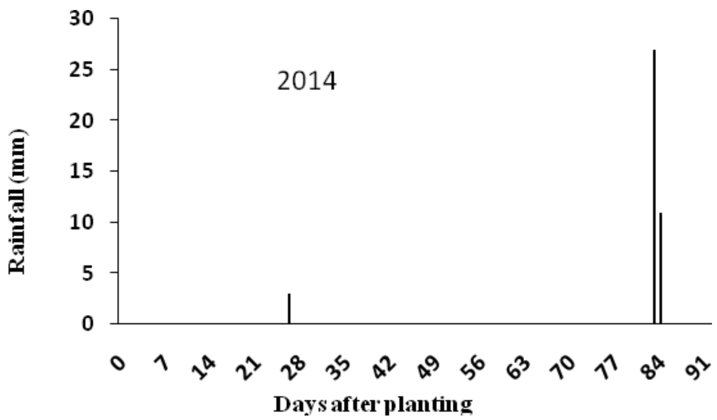
Ayas and Korukcu (2010) found crop yield response factor (k_y) of potato was 0.909 for the entire growth period in Yenisehir, Bursa. Doorenbos and Kassam (1979) reported the k_y value of 1.10 for whole growing season and the k_y value of 0.45, 0.80, 0.70 and 0.20 for early vegetative, late vegetative, yield formation and ripening stage. International Atomic Energy Agency (IAEA) estimated k_y values of 0.40, 0.33, and 0.46 for vegetative, flowering, and yield formation stage. Ayas (2013) did experiment on potato crop by using five pan co-efficient of 100%, 75%, 50%, 25% and 0%. He found the k_y value of 1.13 for total growing period. He also found the k_y values of 0.00, 0.94, 1.16, 1.19, and 1.11 for 100%, 75%, 50%, 25% and 0%, respectively. Darwish et al. (2006) found the k_y values of processing potato was 0.80 for entire growing period.

Though there is a few study occurred on this topic of processing potato crop, now its importance is increasing due to prevailing water crisis. From the above studies, it is clear that the value of response factor varies from location to location (depending on weather and soil), variety to variety, crop to crop, season to season and also for individual growth stages to entire growing season what Ali (2009) discussed in determining response factor of winter wheat in Bangladesh. Therefore, it is argent to determine location specific as well as variety specific response factor for efficient utilization of water. Processing potato is a winter loving and short durated tuber crop which can easily substitute Boro rice in Bangladesh as water is dwindling. Therefore, this study has been undertaken to quantify the effect of water deficit on processing potato (yield response factor or sensitivity factor) and to find out critical growth stages, which could be used for proper water management to minimize yield losses under situations of water deficit.

II. MATERIALS AND METHOD

Field experiment was undertaken during 2013 and 2014 growing season at the research fields of Bangladesh Agricultural Research Institute, Gazipur (latitude: 23°99´´N, longitude: 90°41´´E). The soil texture was sandy clay. The soil was alkaline pH (6.45), low in organic matter (0.94 %), and with basic infiltration rate of 5.42 $mmhr^{-1}$. The upper and lower limits of available water were 0.30 and 0.14 m^3m^{-3}.

The local climate is subtropical monsoon, with average annual rainfall of about 1898 mm and 1895 mm, respectively. The processing potato–growing period, November to March, is characterized by dry winter with 14 mm rainfall in the year 2014 (Fig.1). There was no recorded rainfall in the year 2013 during the growing season. At the initial stage reference ET_0 was higher and decreased at the mid-stage and again rose at the late stage (Fig.1).



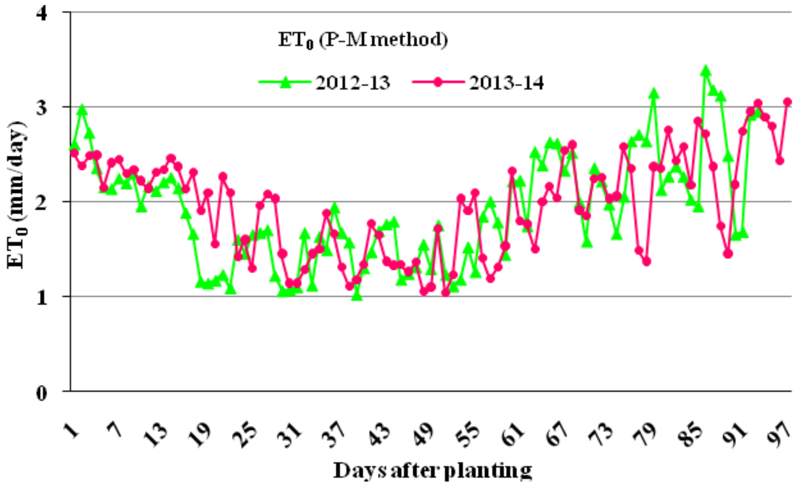


Figure 1:Rainfall and reference evapotranspiration (ET_0, Penman-Monteith method) during the study period

Two processing potato varieties of BARI Alu-25 and BARI Alu-28 is characterized by high specific gravity and dry matter content, and high yield potential (average 25 - 30 tha^{-1}) (ATHB 2014). Total growing period of this crop is 90-96 days depending on cultivar, climatic condition and management practices etc. The water deficit of different degrees was imposed at different phonological stages with the treatments. There are three phonological stages which are stolonization, tuberization and bulking stage. Irrigation treatments were arranged as full irrigation through the growing season; single irrigation at different stages and two irrigations at different growth stages (Table 1). Deficit irrigation was imposed according to the design of the treatments. Irrigation will be applied up to field capacity to meet the effective root zone depth of 60 cm where 80% of the root is concentrated. The layout of the experiments was completely randomized block design with three replications. The plot size and spacing were 4.2 m × 3 m and 60 cm× 25 cm, respectively. The crop was harvested manually and yield data was taken.

Table1 Definition of irrigation treatments corresponding to plant growth phases (with different DC)

Treatments	Irrigation at 3 plant growth phases with DC		
T_1	1	0	0
T_2	0	1	0
T_3	0	0	1
T_4	1	0	1
T_5	0	1	1
T_6	1	1	1

Note: DC =1 means irrigating 100% of the root zone deficit (i.e. FC – Mc) (that is, no deficit).

Crop sensitivity to water deficit was evaluated by Stewart (Stewart et al. 1977) model for the whole growing season as well as individual growth stages, while Jensen (Jensen 1968) model was used to calculate individual growth stages.

1.1 Calculation of crop response factor from Stewart model

Stewart model fits well in conditions where sensitivity differs significantly according to phonological growth stages. This model was derived from the relationship between relative yield decreases with relative evapotranspiration deficit in considering all production factors at their optimum level. The water deficit factor, determined as the ratio of actual to potential evapotranspiration (ET/ET_m) that control the final yield. The equation can be written as:

$$Y/Y_m = \prod_{n=1}^{m} [1-k_{y(n)}(1-ET/ET_m)_n] \qquad (1)$$

where Y is the actual yield, Y_m is the maximum yield with no water deficit during the growing season, ET is the actual evapotranspiration and ET_m is the maximum evapotranspiration, n is generic/total growth stage, *m* is the number of growth stage considered, and k_y is the yield response factor. In this equation Stewart used different coefficient for each growth stage. Therefore, k_y was determined by following the procedure given by (Doorenbos and Kassam, 1979). Maximum yield (Y_m) of processing potato was determined which dictated by climate, in considering water, fertilizer, pests and diseases do not restrict yield. Maximum evapotranspiration (ET_m) was calculated when crop water requirement is equal to available water supply. Actual evapotranspiration (ET_a) was calculated depending on factors relating to available water supply to the crop. Finally, actual yield (Y_a) under water deficit condition was determined by the relationship between relative yield decrease and relative ET deficit.

$$1 - Y_a/Y_m = k_y(1 - ET_a/ET_m) \quad \text{(2)}$$

or,

$$k_y(i) = \frac{1 - \frac{Y_a(i)}{Y_m(i)}}{1 - \frac{ET_a(i)}{ET_m(i)}} \quad \text{(3)}$$

Previously, the above two equations were used by many researchers (Ayas and Korukcu, 2010;Istanbulluoglu et al. 2010; Ali 2009;Damir et al. 2006; FAO 2002;Moutonnet P. 2002;Kirdaet al.1999) across the world for calculating crop response factor for different crops. For more detailed information, please refer to (Doorenbos and Kassam, 1979). Doorenbos and Kassam (Doorenbos and Kassam, 1979) estimatedk_y values for each phonological periods and also for whole growing period, for different crops. The k_y value for whole growing period was estimated on the effect of seasonal water used under water stress by using equation (2). On the other hand, stage specific $k_y$value was estimated on the effect of water stress for each growth period (i) by using equation (3). The k_y is a crop yield response factor that varies according to different species, variety, irrigation method and management practices, and different growth stages when deficit evapotranspiration is imposed (Kirda 2002). The value of k_y represents an indication of whether the crop is tolerant to water stress.

1.2 Calculation of Crop sensitivity index from Jensen model

Jensen model (Jensen 1968) was used to calculate crop sensitivity to water deficit at different growth stages and the equation was as follows

$$\frac{Y}{Y_m} = \prod_{i=1}^{n} \left(\frac{ET_i}{ET_m}\right)^{\lambda_i} \quad \text{(4)}$$

where, Y is tuber yield under water deficit condition, Y_m is the maximum yield when maximum evapotranspiration (ET_m) occurred under no water deficit during the whole crop growing period, ET_i is the actual evapotranspiration during the growth stage *i*, λ_I is the sensitivity index of crop to water deficit at *i*-th stage, and *i* the individual growth stage (for processing potato it was 3).

For easy application of irrigation practice, Tsakiris (Tsakiris 1982) proposed a modified method from Jensen model. He illustrated the procedure of this model using data for grain sorghum. However, crop sensitivity index,λ_i, was determine the procedure derived by Tsakiris (1982). Therefore, the equation (4) can be written as:

$$\frac{Yi}{Y_m} = \prod_{i=1}^{m} (\omega_i)^{\lambda_i} \qquad 0 < \omega_i < 1 \quad \text{(5)}$$

Where ω_i is the relative evapotranspiration ($= \frac{ET_i}{ET_m}$).

If water deficit is imposed to a certain growth stage, assume, i-th stage, then, ω_i =1 for all growth stages except that stage. Hence, the equation (5) can be written as:

$$\frac{Yi}{Y_m} = \omega_i^{\lambda_i}$$

or,

$$\log\left(\frac{Yi}{Y_m}\right) = \lambda_i \log \omega_i \quad \text{...} \quad (6)$$

Therefore, λ_i for individual growth stages can be calculated with the ratio of log ($\frac{Yi}{Y_m}$) and log ω_i.

1.3 Uniformity coefficient for the k_y and λ_i values

The uniformity coefficient (UC) of the yearly k_y and λ_i values were determined by following (Devittet al. 1992) as

$$\text{UC} = 1 - (\text{standard deviation / mean}) \quad \text{.....................} \quad (7)$$

III. Results and Discussion

1.1 Yield response factor for individual growth stage

Yield response (k_y) factor for individual growth stages is presented in Table 2. This value varies depending on season, location and intensity of water deficit. Among two varieties and treatments, paired t-test and uniformity coefficient was done and no statistical difference between two years data was found. During 2013, the highest yield response factor was found at stolonization + tuberization stage, followed by stolonization + bulking stages. The lowest was found in stolonization stage. This trend was consistent during the year 2014.

On an average, the yield response factor of 0.28 and 0.27 was found at stolonization + tuberization stage for V_1 and V_2. For V_1, the water stress at tuberization + bulking, stolonization + bulking, tuberization and stolonization stage exerted 17.86 %, 14.29%, 89.29 %, and 97.86% less stress than most stressed treatment (T_3), while 14.81%, 11.11%, 85.19% and 97.41% for V_2. Very little variation was found between two varieties in terms of k_y values. Martyniak (2008) reported that drought tolerance varies strongly between growth stages for many crops.Therefore, the order of water deficit for individual growth stages can be written as: stolonization + tuberization>stolonization + bulking >tuberization + bulking >tuberization>stolonization. Hence, it can be said that the stolonization + tuberization stage was the critical stage for processing potato cultivation.

Doorenbos and Kassam (1979) reported the k_y value for early vegetative, late vegetative, yield formation and ripening stage was 0.45, 0.80, 0.70 and 0.20, while International Atomic Energy Agency (IAEA) estimated k_y values of 0.40, 0.33, and 0.46 for vegetative, flowering, and yield formation stage, respectively. Ayas (2013) did experiment on potato crop by using five pan co-efficient of 100%, 75%, 50%, 25% and 0%. He found the k_y value for growing season was 0.00, 0.94, 1.16, 1.19, and 1.11 for 100%, 75%, 50%, 25% and 0%, respectively.

Table 2 The yield response factors (k_y) for individual growth stages

Treatments	Growth stages	k_y for individual growth stages		Mean	Standard deviation (SD)	Uniformity coefficient (UC)	Coefficient of variance (CV)
		2013	2014				
V_1							
T_1	Tuberization + bulking	0.24	0.22	0.23	0.014	0.94	0.06
T_2	Stolonization + bulking	0.24	0.23	0.24	0.0071	0.97	0.029
T_3	Stolonization + tuberization	0.27	0.29	0.28	0.014	0.95	0.51
T_4	Tuberization	0.03	0.03	0.03	0	1	0
T_5	Stolonization	0.006	0.006	0.006	0	1	0
V_2							
T_1	Tuberization + bulking	0.23	0.23	0.23	0	1	0
T_2	Stolonization + bulking	0.24	0.24	0.24	0	1	0
T_3	Stolonization + tuberization	0.27	0.26	0.27	0.0071	0.97	0.026
T_4	Tuberization	0.04	0.03	0.04	0.0071	0.82	0.18

T_5	Stolonization	0.007	0.006	0.007	0.00071	0.90	0.10

Table 3 Tuber yield (t ha^{-1}) under different treatments

Treatments[a]	Tuber yield (t ha^{-1})		
	2013	2014	Mean
V_1			
T_1	30.81G[b]	30.91G	30.86
T_2	30.70H	30.85G	30.78
T_3	30.19I	30.28H	30.24
T_4	36.76C	36.88C	36.82
T_5	37.71B	37.80B	37.76
T_6	37.92A	38.02A	37.97
V_2			
T_1	29.41J	29.51I	29.46
T_2	29.28K	29.39J	29.34
T_3	28.91L	29.00K	28.96
T_4	34.78F	34.90F	34.84
T_5	35.67E	35.76E	35.72
T_6	33.90D	35.98D	35.94
LSD (5%)	0.076	0.1134	-
CV	0.136	0.202	-

[a]T_1, T_2, T_3, irrigation at stolonization, tuberization, and bulking stage; T_4, irrigation at stolonization and bulking stage; T_5, irrigation at tuberization and bulking stage; T_6, irrigation at stolonization, tuberization and bulking stage. V_1= BARI Alu-25, V_2= BARI Alu-28.
[b]Mean values followed by different letter within columns differ significantly at $P<0.05$ according to Duncan's range test.

1.2 Yield response factor for whole growing period

Yield response factor (k_y) for entire growing season are represented in Table 4. The different values of response factor were observed for individual treatments during total crop period. This was increased according to the intensity of imposing water deficit. Paired t-test was done at 5% level of significant and no significant difference was observed between two years data. In addition to, uniformity coefficient range from 0.63 to 0.90 for V_1, whereas 0.43 to 0.80 for V_2, respectively. The highest value was observed in treatment T_3 where irrigation was applied 100% of the root zone deficit at bulking stage consequently; yield decreased (Table-3). The lowest was observed in treatment T_5 where irrigation was applied 100% of the root zone deficit at tuberization + bulking stage. In V_1, compare with most stressed treatment, treatment T_1, T_2, T_4 and T_5 exerted 28.97%, 19.63%, 33.64% and 93.46% less stress than thatof treatment T_3, while 47.31%, 39.25%, 58.60% and 95.70% for V_2. Also, it was found that V_2 experienced little bit more stress than that of V_1during the year 2013. This was due to the effect of rainfall in the year 2014 (Fig-1). On an average, the relative sensitivity to water deficit (k_y) for entire cropping period decreased followed by the order of water deficit treatment: $T_3>T_2>T_1>T_4>T_5$ for V_1 and V_2.

Ayas and Korukcu (2010) reported that the seasonal crop yield factor (k_y) of potato was 0.909. Doorenbos and Kassam (1979) reported the k_y value of 1.1 for whole growing season. Ayas (2013) estimated seasonal yield response factor of 1.13 for total growing period. Darwish et al. (2006) found the k_y values of processing potato was 0.80 for entire growing period.

Table 4 The yield response factors (k_y) for the total growth period of processing potato

Treatment	Growth stages	k_y for total growth period		Mean	Standard deviation (SD)	Uniformity coefficient (UC)	Coefficient of variance (CV)
		2013	2014				
V_1							
T_1	Tuberization + bulking	0.81	0.70	0.76	0.078	0.90	0.10
T_2	Stolonization + bulking	0.97	0.75	0.86	0.156	0.82	0.18
T_3	Stolonization + tuberization	1.24	0.89	1.07	0.247	0.77	0.23
T_4	Tuberization	0.89	0.52	0.71	0.262	0.63	0.37
T_5	Stolonization	0.08	0.05	0.07	0.021	0.70	0.30
V_2							
T_1	Tuberization + bulking	1.13	0.82	0.98	0.2192	0.78	0.22
T_2	Stolonization + bulking	1.46	0.77	1.13	0.4879	0.57	0.43
T_3	Stolonization + tuberization	2.6	1.11	1.86	1.504	0.43	0.57
T_4	Tuberization	0.88	0.66	0.77	0.156	0.80	0.20
T_5	Stolonization	0.10	0.05	0.08	0.035	0.56	0.44

1.3 Sensitivity index of Jensen model

The drought sensitivity index (lambda i, λ_i) of processing potato for three growth stages according to the treatment is represents in Table 5. This value was dictated by timing and amount of water stress. Non-significant variation was found in paired t-test at 5% level of significant within two years data. Besides, uniformity coefficients value was very close to one. Therefore, it can be reported that there was no statistical difference between two years data. The λ_i values among three growth stages with different degrees of water deficit were varied during two years but the trend was similar. During 2013, the highest sensitivity index (λ_i) was found at stolonization + tuberization stage and the lowest was observed at stolonization stage for both the variety. This was also similar for the year 2014. For V_1, the mean crop sensitivity to water deficit at tuberization + bulking, stolonization + bulking, tuberization and stolonization stage was 36.84%, 31.58%, 94.74% and 98.95% less than stolonization + tuberization stage (T_3), while 23.53%, 11.76%, 94.12% and 98.24% for V_2. Therefore, the order can be written as: stolonization + tuberization>stolonization + bulking>tuberization + bulking>tuberization>stolonization. Hence, it can be reported that stolonization + tuberization stage was the critical stage to irrigation for processing potato cultivation. This result was similar with the result obtained from yield response factor (k_y) for individual growth stages.

Table 5 Sensitivity index (λ_i, of Jensen model) of processing potato yield to water deficit at different growth stages

Treatment	Growth stages	λ_i – during different years		Mean	Standard deviation (SD)	Uniformity coefficient (UC)	Coefficient of variance (CV)
		2013	2014				
V_1							
T_1	Tuberization + bulking	0.12	0.12	0.12	0	1	0
T_2	Stolonization + bulking	0.14	0.12	0.13	0.014	0.89	0.11
T_3	Stolonization + tuberization	0.17	0.20	0.19	0.021	0.89	0.11
T_4	Tuberization	0.01	0.01	0.01	0	1	0
T_5	Stolonization	0.002	0.002	0.002	0	1	0
V_2							
T_1	Tuberization + bulking	0.12	0.13	0.13	0.0071	0.95	0.054
T_2	Stolonization + bulking	0.15	0.14	0.15	0.0071	0.95	0.047
T_3	Stolonization + tuberization	0.18	0.16	0.17	0.014	0.92	0.083

T_4	Tuberization	0.01	0.01	0.01	0	1	0
T_5	Stolonization	0.003	0.002	0.003	0.00071	0.76	0.24

IV. CONCLUSION

Yield response factor and sensitivity index of processing potato differs according to location, weather, variety, severity of water deficit and growth stages. For individual growth stages, the yield response factor $k_y$followed the order of sensitive growth stages to water deficit were stolonization + tuberization, stolonization + bulking, tuberization + bulking, tuberization, and stolonization for both variety. The sensitivity index (λ_i) for individual growth stages followed the same order like crop yield response factor for individual growth stages for BARI Alu- 25 and BARI Alu-28. The response factor for whole growth period was followed the order of sensitive growth stages to water deficit were stolonization + tuberization, stolonization + bulking, tuberization + bulking, tuberization and stolonization. Some water must be ensured at stolonization + tuberization stage for water scarce region to avoid severe yield loss.

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