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Response of Soybean in Cyst Nematode-Infested Soils at Three Soil-Water Regimes[1]

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Abstract: Large pot (2 years) and field experiments (1 year) were conducted to determine the response of susceptible soybean *Glycine max* (L.) Merr. cultivars (Essex and Hutcheson) grown in soybean-cyst-nematode (SCN), *Heterodera glycines*-infested soils at three soil water regimes. The soil water regimes were irrigation whenever soil water potential (ψ_s) 0.30-m deep was i) −30 kPa (I-30) or ii) −50 kPa (I-50), and iii) no irrigation. Cyst nematode levels in the pot experiment were either 0 or 20,000 second-stage juveniles (J2) per pot. The field experiment was conducted on soil naturally infested with a population of 145 to 475 cysts L^{-1} of soil. All growth parameters studied were drastically affected in the presence of SCN under nonirrigated conditions for the large pot tests; however, SCN did not influence growth parameters in the field experiment. Seed yield was lowest in the no irrigation treatment when all treatments were compared in both the pot and field experiments. The infested no irrigation treatment in the pot experiment had the lowest yield among soil water treatments.

Key words: Glycine max, Heterodera glycines, nematode, soil water regime, soybean, soybean cyst nematode.

Proper management of soybean cyst nematode (SCN), *Heterodera glycines* Ichinohe, has circumvented yield loss of soybean, *Glycine max* (L.) Merr., and returned millions of dollars to growers (2). Two management tactics for controlling SCN in soybean are the use of resistant cultivars and crop rotations. Over the years intensive efforts have been exerted to develop resistant soybean cultivars; however, a shift in race of SCN may result in the loss of resistance of a particular soybean cultivar within 3 to 4 years, thereby causing yield suppressions (11). The use of alternative crops in rotations may not be as profitable as soybean for a given year but over a 3-year period, the total returns may be high (4,5,12). In some areas, high-yielding susceptible cultivars no longer produce high yields because of SCN infestations, and the race present is one to which no cultivars have resistance. If growers will not use rotations, exploitation of other management tactics to minimize SCN damage is necessary.

A few studies have indicated that management tactics may alter nematode infection of soybean and thus limit associated yield losses. Wrather and Anand (15) reported that yields of susceptible soybean cultivars increased when SCN infection was delayed by 2 weeks after planting. Yields of a susceptible cultivar equalled those of a resistant cultivar when infection was delayed by 6 weeks. Johnson et al. (9) found that root penetration by SCN was decreased with increasing soil water potential during early vegetative growth of soybean. Little information is available on the influence of soil water status on the tolerance of susceptible soybean cultivars to SCN (7,16). Therefore, the objectives of this study were to quantify the effects of irrigation on soybean growth in SCN-infested soils and to quantify the effects of soil-water regime on the development of SCN.

MATERIALS AND METHODS

Pot experiment: Experiments were conducted during the summers of 1990 and 1991 at the Main Agricultural Experiment Station, Fayetteville, Arkansas. Aboveground plastic barrels (0.58 m diameter and 0.66 m high) were filled with cyst-nematode-free soil, collected from the 0 to 0.15 m depth of a Captina silt loam (Typic Fragiudult) having 23% sand, 68% silt,

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and 9% clay, to achieve a bulk density of 1.27 Mg m^{-3}. Before filling the barrels (will be referred to as pots hereafter), a representative soil sample was taken and the centrifugal-flotation technique (4) was used to separate any existing cyst nematode from the soil. Results from this analysis indicated that the soil did not contain cyst nematodes.

Each pot contained four passes of irrigation tube (0.051-m inside diameter) with eight emitters. The tube was installed in a spiral arrangement and connected to polyvinylchloride (PVC) pipes of the same size for uniform wetting. The PVC pipes were connected to a main water manifold. Tensiometers were installed 0.15 and 0.30 m deep in each pot to monitor soil water potentials (ψ_s) to determine when irrigation was needed. Only averages of ψ_s within irrigation treatments at 0.30 m deep are presented because no significant effects of replication were found. Fifteen seeds of SCN-susceptible Essex were planted in each pot on 1 June (1990 and 1991) and thinned to seven plants on 17 June at the V2 growth stage (3).

The experiment was a randomized complete block with three blocks and a 3 × 2 (3 irrigation levels and 2 SCN levels) factorial arrangement of treatments within a block. Irrigation treatments were as follows: i) no irrigation (NI) and irrigation when ψ_s at 0.30 m deep was ii) −30 kPa (I-30) or iii) −50 kPa (I-50) during the growing season. Cyst nematode levels were 0 or 20,000 second-stage juveniles (J2) per pot. Cysts of race 3 SCN were crushed, J2 suspension was obtained, and each SCN treated pot was drenched with the aqueous inoculum and incorporated into the top 0.03 m of the soil on 17 June of both years. Two pots were used for one replication of each treatment so one pot could be used for destructive measurements (D-pot), whereas the other was kept for seed yield (H-pot). Soil cores 0.075-m-d were taken from the center of each D-pot at 91 days after planting (DAP) and the soil washed through a sieve with 20-mesh openings. Roots remaining on the sieves were dried at 60 C for 24 hours and weighed.

Plant height was measured biweekly until 20 September (111 DAP). Plant leaf-area was measured at 103 DAP with a leaf-area meter (Model LI-3100). Leaf water potential (ψ_l) and plant dry weight were measured at 47, 61, 75, 89, 103, and 117 DAP. Leaf water potential and abaxial stomatal resistance (R_s) were measured in 1990 only. The instruments for measuring these parameters were not available in 1991; therefore, no data are presented for that year. Leaf water potential was measured with a pressure chamber by standard procedures on the petiole of the topmost three fully expanded leaves. Abaxial stomatal diffusive resistance was measured with a diffusion resistance poromter (Model 2095) from 0730 to 1730 hours Central daylight saving time at 37 and 39 DAP. Pods containing seeds were counted at 117 DAP and the same were used for analyses. All H-pots were harvested on 7 October (128 DAP) in both years, and seed yield was recorded.

To quantify the population change of SCN, a soil probe was used to take random soil samples 0 to 0.15 m deep of the infested pots 120 days after inoculation. Cysts, eggs, and J2 were extracted by sieving and centrifugal-flotation technique (8) and counted. Eggs and J2 were summed and classified as reproductive units.

Field experiment: This experiment was conducted during the summer of 1992 at the Pine Tree Station in eastern Arkansas to validate the pot experiments of 1990 and 1991. Soil in the study area was Calloway silt loam (Glossaquic Fragiudalf). One week before planting, an area 27 m wide and 33 m long was sampled on a 3 × 3 m grid 0.15 m deep, resulting in a total of 120 samples. An aliquot from each sample was obtained, and cysts were extracted by the sieving and centrifugal-flotation technique and counted. The data provided information on cyst population level (from 145 to 475 cyst L^{-1}) and ensured that the level would be high enough to damage susceptible soybean. A SCN race assay (13) indicated that the field was infested with race 9.

Experimental design was a randomized

complete block with a split-plot in strips, and blocks were replicated four times. Main units were the soybean cultivars 'Asgrow 5979' (resistant) and 'Hutcheson' (susceptible). Irrigation treatment was the subunit and was the same as in the pot experiments. The herbicides imazaquin {2-[4,5,-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid} at 0.14 kg a. i. ha^{-1}, and trifluralin [2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine] at 0.56 kg a. i. ha^{-1}, were mixed and applied before disking. Additional weed control during the growing season was done by hand. Seeds were planted 15 June at a rate of approximately 30 seed m^{-1} row, and rows were 0.91 m apart. Our intention was to plant on 1 June, but the field was inaccessible to planting equipment due to heavy precipitation, which caused the soil to be saturated. The field was cultivated, on 29 June, before trickle irrigation tubes were installed 0.04 m deep in the soil between rows. Trickle irrigation was employed in this experiment to confine irrigation to the proper plots as scheduled. Dry matter accumulation was measured at 93 DAP, and plants were harvested for seed yield on 14 October (121 DAP).

Statistical analyses: Statistical Analyses System procedures (14) were employed to determine significance of main effects and interactions ($P \leq 0.05$). Preliminary analysis across years indicated that no significant differences occurred for pod number or seed yield in the pot experiments. Thus, in the final statistical analysis, year was treated as a replication of the treatments. Multivariate analysis was used to determine irrigation and SCN effects on plant height, dry matter accumulation, R_s, and ψ_1. Statistical analyses of changes in levels of SCN in the pot experiments were based on final egg, J2, and cyst densities.

Results and Discussion

Weather and irrigation: Rainfall was below normal during the 1990 and 1991 growing seasons, and multiple irrigations were needed. Monthly rainfall during the 1990 growing season was 86, 17, 30, and 165 mm from June through September, respectively. During the 1991 season, monthly totals were 44, 18, 109, and 106 mm from June through September, respectively. Irrigation was applied six times to I-30 and two times to I-50 pots in 1990, and four times to I-30 and two times to I-50 pots in 1991. Average maximum air temperatures during the 1990 and 1991 growing seasons (June through September) were 30 and 29 C, respectively. Highest average maximum air temperature of 32 C and highest average maximum soil temperature were recorded in August in each year. However, with the exception of these temperatures, soil temperature range during the growing seasons for all pots was 22 to 24 C. Soil water potentials of the NI treatments in 1990 and 1991 varied during the growing season and were slightly different between years, with the 1990 growing season having somewhat higher ψ_s (Fig. 1). The ψ_s in the NI treatment (Fig. 1) was higher than expected for both years because construction and placement of the pots did not allow for adequate

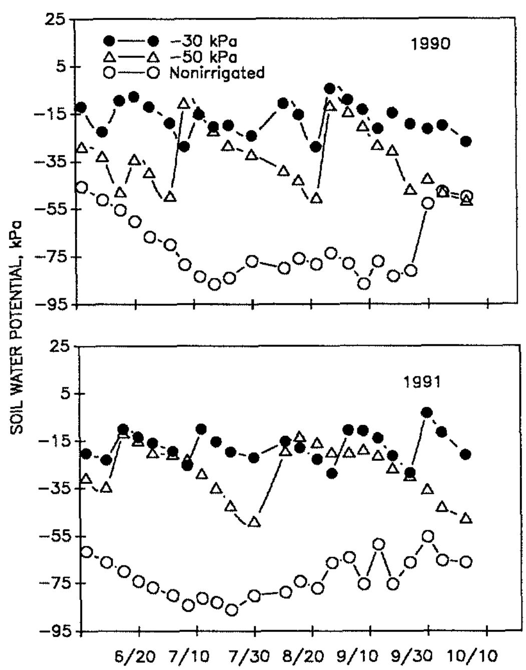

FIG. 1. Seasonal ψ_s for irrigation thresholds at −30 kPa, −50 kPa, and no irrigation in above-ground pots in 1990 and 1991.

drainage, and water was retained in the pots.

Total rainfall on the field plots during the 1992 growing season was 549 mm. This amount of rainfall was 45% above normal for this location and was about 96% of the total rainfall for 1990 and 1991 combined. Rainfall amounts were 279 mm in June, 107 mm in July, 113 mm in August, and 50 mm in September. This represented 429, 611, 174, and 40% of the mean rainfall from June through September of 1990 and 1991. Although the 1992 growing season was relatively wet, the I-30 plots were irrigated five times and the I-50 plots were irrigated three times. Average maximum air temperature during the growing season was 26 C, which was about 3 C less than in 1990 and 1991. July had the highest mean air temperature of 30 C. Soil water potential in the NI treatments for both cultivars was beyond the range of the tensiometer (−100 kPa) after 4 September (Fig. 2), thus indicating drought stress.

Soybean cyst nematode numbers in 1990 and 1991: Numbers of cyst nematode after harvest was affected ($P = 0.05$) by irrigation of all infestation levels in both years (Table 1). Cyst levels were highest in the I-30 treatment and lowest in the NI treatment. However, reproductive units were highest in I-50 and lowest in NI only in 1990. The population density of SCN juveniles may influence the magnitude of infection of the host. As was observed in this study, soil water status also influenced cyst formation. The large numbers of cysts and lower numbers of reproductive units in the I-30 treatment indicated that the life cycle of SCN may have occurred faster under soil conditions with relatively high ψ_s.

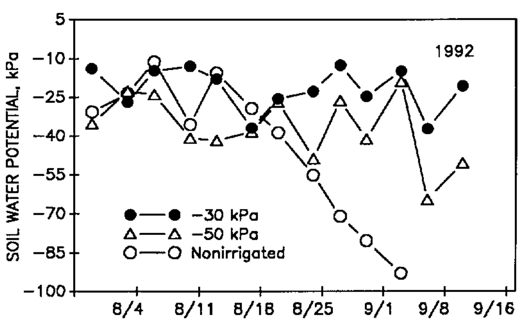

FIG. 2. Seasonal ψ_s for irrigation thresholds at −30 kPa, −50 kPa, and no irrigation in the field in 1992.

TABLE 1. Numbers of soybean cyst nematode cysts and eggs and second-stage juveniles J2 (units L^{-1} soil) in pots as affected by irrigation 120 days after inoculation in 1990 and 1991.

Irrigation treatment†	Cysts	Eggs and J2
	1990	
NI	466	1,102
I-50	661	4,549
I-30	813	3,520
$LSD_{(.05)}$	63	756
	1991	
NI	527	1,246
I-50	657	1,547
I-30	722	1,365
$LSD_{(.05)}$	16	186

Numbers are means of three replications.
† NI = not irrigated; I-50 = irrigated when Ψ_s was −50 kPa; I-30 = irrigated when Ψ_s was −30 kPa.

Soybean growth components and seed yield in pot experiment: Soybean plants grown in the NI treatment of the pot experiment were generally shorter at 60 DAP than those in the I-30 and I-50 treatments in both years; however, from 61 through 117 DAP, plants in the I-30 and I-50 treatments were taller ($P = 0.05$) than those in the NI treatment in 1990 (Fig. 3). When plant heights within irrigation treatments were compared, only plants in the 1990 NI-infested treatment were shorter ($P = 0.05$) than those in the NI noninfested treatment at 117 DAP.

Dry matter production was lowest in the NI plants in both years. Beginning at 47 DAP, SCN-infested NI soybean plants accumulated less dry matter than did NI noninfested plants (Fig. 3). Suppression ($P = 0.05$) in the rate of dry matter production by soybean in the NI SCN-infested treatment began at 61 DAP in both years.

Leaf area was increased ($P = 0.05$) by irrigation but was not affected by SCN level in both years (data not presented). Leaf water potential decreased as irrigation frequency decreased (Fig. 4). The NI

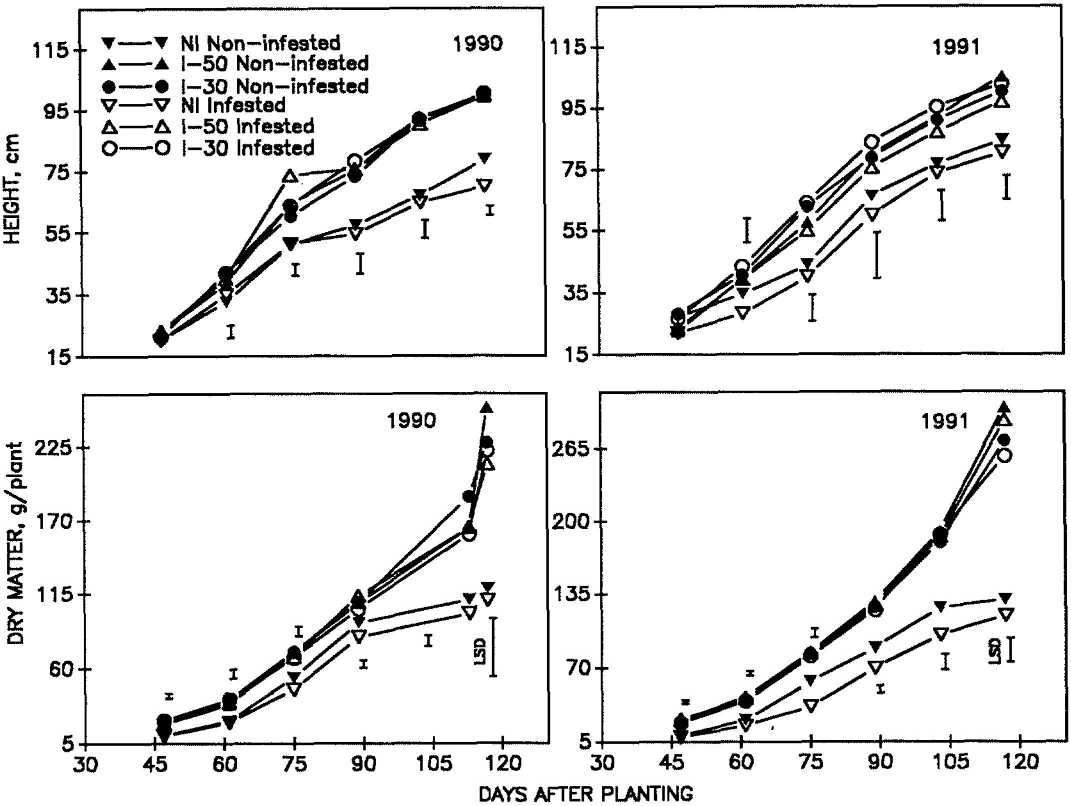

FIG. 3. Height and dry matter of SCN-infected and noninfected soybean at three ψ_s in above-ground pots in 1990 and 1991. Vertical bars represent $LSD_{(0.05)}$.

treatments had lower ψ_l; however, ψ_l values were consistently lower (P = 0.05) during the sampling periods in the SCN-infested NI treatment. Diurnal patterns of R_s were consistently higher as irrigation frequency decreased (Fig. 5).

Pod number was affected by irrigation and SCN in both years (Table 2). Pod number was lower (P = 0.05) at the lower irrigation frequency. The NI SCN-infected soybean had fewer pods than did soybean in either irrigation level. Relative seed yield (seed yield of infested pot-seed yield of corresponding noninfested pot) across both years was 0.97 for I-30, 0.98 for I-50, and only 0.68 for the NI treatments. Seed yield from the NI noninfested treatment was greater (P = 0.05) than from the NI SCN-infested treatment and for all infested treatments, average seed yield was 46% higher for I-30 and 42% higher for I-50 when compared to NI. The consistently lower dry matter accumulation and height of soybean grown in the NI SCN-infested treatment was indicative of the added stress on the soybean caused by the presence of SCN under nonirrigated conditions. Shoot dry weight is a good indicator of the suppressive effects of SCN on seed yield (1). The present study indicated that well-watered, susceptible soybean may alleviate the yield-restricting effects of SCN. The high relative seed yields in both I-30 and I-50 imply that SCN-susceptible soybean cultivars may exhibit some degree of tolerance under well-irrigated conditions.

Yield and yield components in field experiments: Seed yield and dry matter accumulation in the field experiment followed a similar trend as in the pot experiment, but simple effects between cultivars were not significant (Table 3). Seed yield and dry matter accumulation were only slightly but

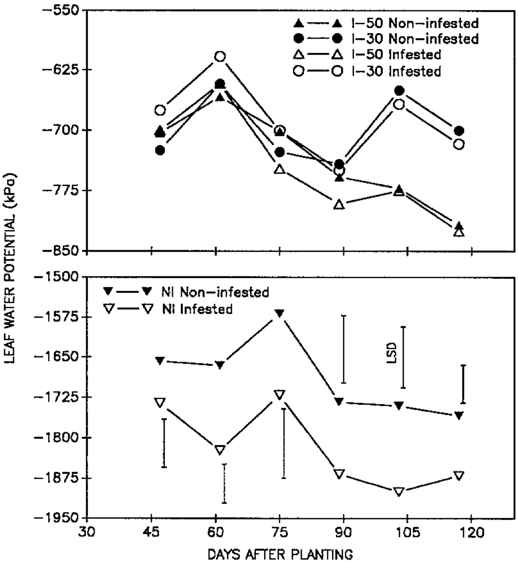

FIG. 4. Leaf water potentials of SCN-infected and noninfected soybean at three ψ_s in above-ground pots in 1990. Vertical bars represent $LSD_{(0.05)}$.

significantly higher in irrigated plots than in NI plots ($P = 0.05$). For overall cultivar performance, SCN-resistant Asgrow 5979 yielded more than SCN-susceptible Hutcheson ($P = 0.05$). A significant block effect was observed, which might have been caused by a shallow fragipan in some parts of the field. An increase in irrigation frequency resulted in only slight increases in seed yield and dry matter production for both cultivars. The use of Calloway silt loam and the race 9-susceptible Hutcheson was intended to reproduce the results of the pot experiment under field conditions with a different soil series, SCN race, and soybean cultivar, but only irrigation had a slight effect on the plants.

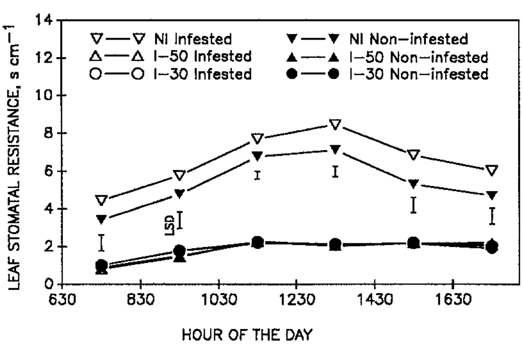

FIG. 5. Diurnal pattern of R_s of infected and non-infected soybean at three ψ_s in 1990. Vertical bars represent $LSD_{(0.05)}$.

TABLE 2. Numbers of pods per plant and seed yield (kg/pot) of Essex soybean for three irrigation treatments across two levels of SCN infestation averaged over 2 years in above-ground pots (1990 and 1991).

Irrigation treatment†	SCN level (J2/pot)	Pod number	Seed yield
NI	0	174	0.156
NI	20,000	74	0.106
I-50	0	268	0.188
I-50	20,000	252	0.182
I-30	0	364	0.204
I-30	20,000	350	0.197
$LSD_{(.05)}$	Within irrigation	38	0.012
$LSD_{(.05)}$	Between irrigation	58	0.021

Numbers are means of three replications.
† NI = not irrigated; I-50 = irrigated when Ψ_s was −50 kPa; I-30 = irrigated when Ψ_s was −30 kPa.

The lack of significant difference in seed yield between I-30 and I-50 suggests that either of the ψ_s could be used as an irrigation threshold for optimizing yields of susceptible and resistant cultivars in SCN-infested fields. However, the I-30 treatment required considerably more irrigation water and would be discouraged as a recommended irrigation treatment. High soil water potential has been shown to reduce soil oxygen diffusion rate to SCN, thereby decreasing the number of organisms penetrating the root system (9).

Results of this study differ somewhat from those of Young and Heatherly (16), who found seed yield to be suppressed by

TABLE 3. Seed yield (kg ha^{-1}) and dry matter (kg m^{-2}) of Asgrow 5979 (resistant) and Hutcheson (susceptible) soybean cultivars grown under three levels of irrigation in the field in 1992.

Irrigation treatment†	Seed yield‡ A5979	Seed yield‡ Hutcheson	Dry matter‡ A5979	Dry matter‡ Hutcheson
NI	2,183	2,028	0.538	0.414
I-50	3,380	3,154	0.710	0.693
I-30	3,442	3,376	0.735	0.655
Mean	3,002a	2,853b	0.661a	0.587b

Numbers are means of four replications.
† NI = not irrigated; I-50 = irrigated when Ψ_s was −50 kPa; I-30 = irrigated when Ψ_s was −30 kPa.
‡ Seed yield or dry matter value with the same letter do not differ ($P = 0.05$).

the presence of SCN under wet soil conditions (−20 to −40 kPa). Heatherly et al. (7) reported that irrigation beginning at the R1 growth stage did not overcome SCN stress of soybean. Their results, in comparison to ours, support the hypothesis that SCN infection during the vegetative stages of soybean may influence seed yield. Delay in soybean infection of soybean roots for 2 or 6 weeks after emergency optimizes soybean yields of susceptible cultivars (15). Syncytia of SCN are initiated 1 day after penetration of roots by J2 (6). Under moderately dry soil conditions (−60 to −80 kPa), syncytia were located primarily in the stele of susceptible soybean roots 16 days after inoculation (10). Syncytium formation in the stele of soybean roots interferes with water and nutrient transport. Results of these experiments indicate that providing adequate moisture to SCN-susceptible cultivars during the growing season may limit yield reductions to SCN.

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