Boron Management and Remediation in Almond

Project No.: WATER12.BROWN

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Project Cooperators and Personnel:

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A. Summary

Soil boron (B) leaching was examined in five soil series common in high B regions that exhibit a range of soil textural and pH properties. In each case, more water was required to leach excessive B than reported by established guidelines. For example, if a 50% reduction in B concentration is needed, it is necessary to add from 4.1 to 11.5 pore volumes (saturate the soil 4 to 11 times). Irrigation water at the orchard study site (Westwind Farms Inc., Woodland, California) contains around 2 ppm B, at least double the safe amount for almonds, and contributes to soil B retention. In order to mitigate almond B toxicity in high B areas, technology was developed to scrub B from irrigation water. Over the course of the past year, the Westwind Farms B removal system has been re-engineered. During the year, experiments were conducted to measure optimal flow rates of water through the system to optimize efficiency and recharge. This new mobile containerized IX system will be operational for the 2021 growing season. With this improved system, reliable delivery of varying rates of B (0.5, 1, 3 ppm B as well as varying times of B exposure (spring, summer, fall) will commence as experimental treatments to meet objective 1 for the 2021 growing season. Over the last two years, the baseline average hull B of all data plots is 287 ppm. Treatment results compared with the previous 2 years of baseline data will begin in 2021 and proceed for 2-3 more years.

B. Objectives

1. To determine how irrigation water boron (B) concentration, time of exposure and life-stage of the orchard interact to cause B toxicity, productivity loss and orchard decline.

2. Measure soil B leaching by different soil types and remediation strategies, so new B leaching guidelines are established.

C. Annual Results and Discussion

1. Boron field experiment

Following the failure of the original OEM company, (a partner in Boron Solutions USA) to deliver the proper equipment, process and control systems for the project, its contract was terminated, and Boron Solutions USA was wound down. Work has continued tirelessly throughout this year to prove and test the B removal theory and to prepare for and build a new system to be operational for the 2021 season.

In January 2020 a new partnership was formed between Kirk Pumphrey of Westwind Farms and Ken Aoki of K&D Farms to continue the work started. Todd Jeffery joined as project manager and partner. The original system and processes were tested, and it was clearly identified that the foundation of the process; the removal of B through Ion Exchange, was sound and achievable. The failure was determined to be in the Ion Exchange regeneration process and shortfalls in the equipment provided to carry out that essential step in the process. In addition, the original OEM had failed to sufficiently document flow rates and B removal statistics. Over the course of the summer, tests were carried out at small scale to ascertain the missing information and confirm the viability of the project. Those meaningful results provided the basis for designing a new system

By fall of 2020, the partnership had identified and entered into an MOU with an OEM with a wealth of experience and the expertise to assist with the development of a system capable of achieving the B removal levels expected. The contract to build and deliver the main body of system has been signed and payments made to secure the delivery of the equipment by February 2021 and it is expected that the system will be tested and operational in time for the 2021 season.

Hull B concentrations have been monitored in all years. This year at harvest (2020), hull B averaged at 297.52 ± 12.97 ppm. In 2019, hull B at harvest measured 275.7 ± 7.94 ppm. These hull B values are considered excessive (>150 ppm) in almond (Brown 2002). Orchard irrigation water contained 1.96 ppm B. Minor to no B toxicity symptoms were seen on the trees. Rate treatment and seasonal treatment results will be delayed by 2-3 years.

2. Soil Boron Leaching

Breakthrough curves (BTC), describing B concentration measured at the effluent, are plotted in figure 1. The influence of pH on boron leaching is not clear, although some contribution can be noticed. For example, for Yolo soil the effluent curve is shifted to left when pH 9 solution was used. Despite this fact, from the remaining curves, it seems reasonable that regular water can be successfully used to leach boron.

Concentration peaks at Rincon and Corning series were far from 3 ppm, possibly due to interactions with soil particles such as adsorption. Final B values of soils from the pH 6.0 and pH 9.0 treatments tended to be around 1.0 ppm due to the B concentration added at those treatments.

Breakthrough curves can be interpreted according to shape. The effluent concentrations were calculated as Boron fraction (BF = observed value/maximum value). The results were plotted separately for each soil as shown in figure 2.

When there is no interaction between the leachate and the soil, the retardation factor (R) is 1 and the BF would be, in this case, equal to 0.5 for one pore volume. If the BF is 0.5 after one pore volume, than B is being retarded, most likely by adsorbtion to soil particles, and available for leaching. If the BF is 0.5 with less than one PV, it can be seen as desorption of B by soil (Skaggs and Leij 2002).

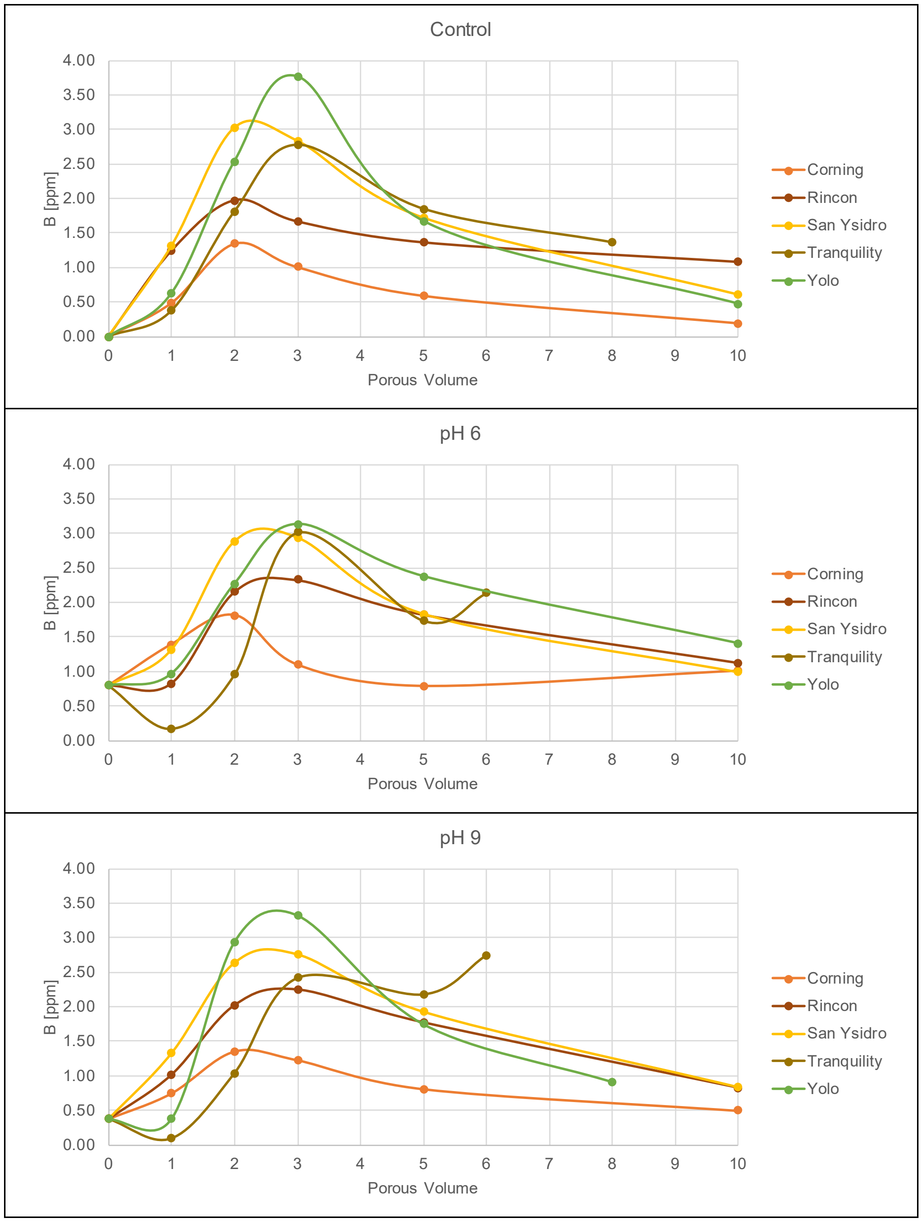
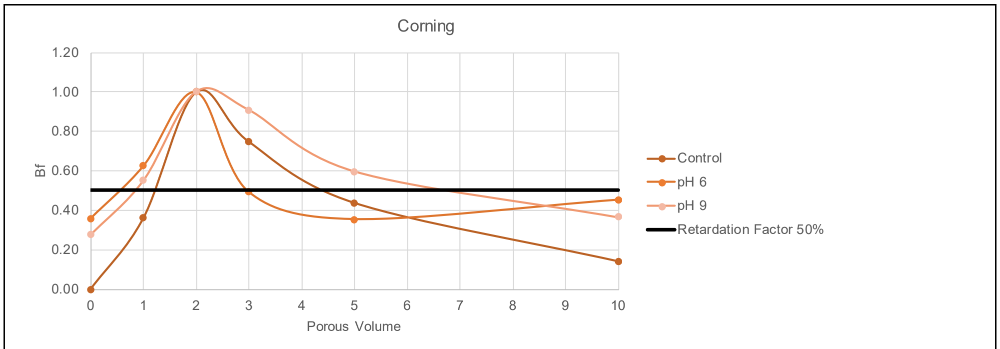
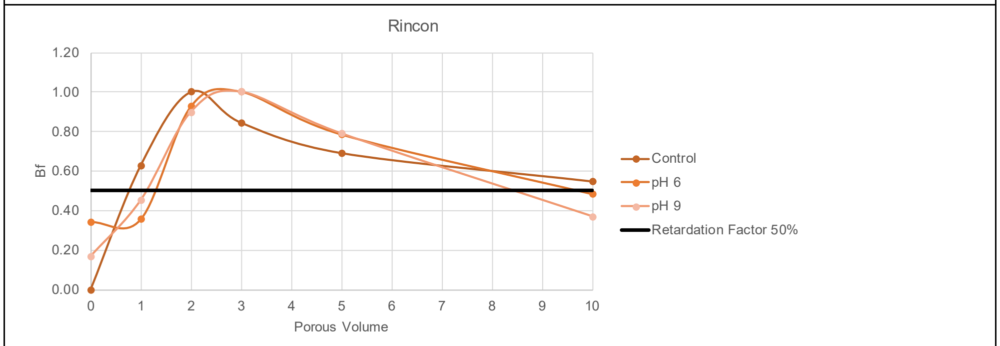
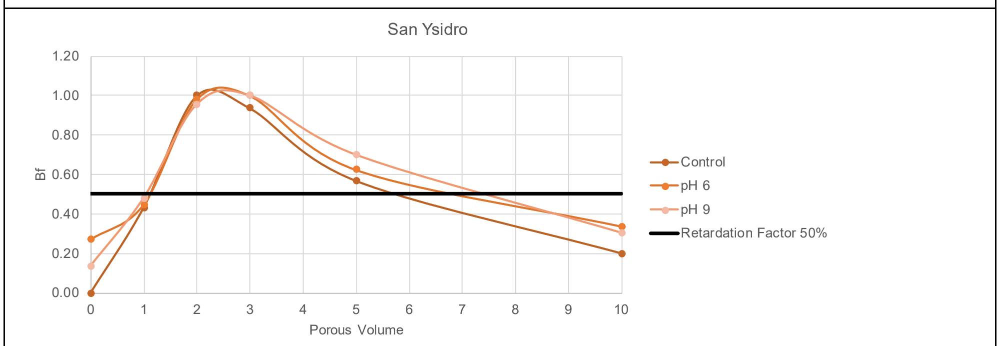
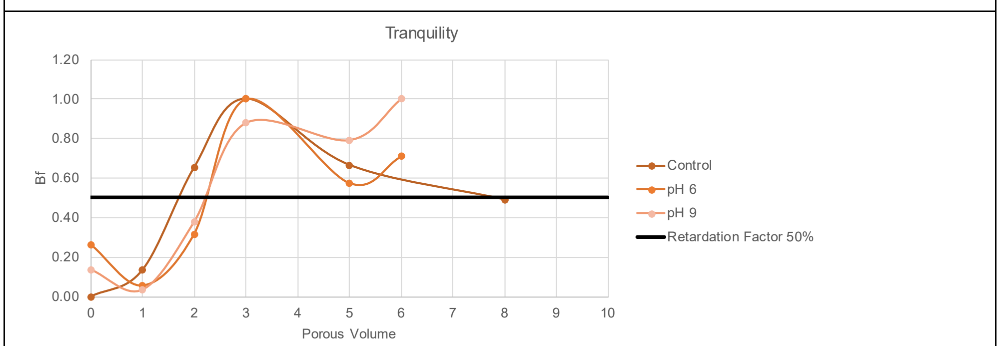


Fig. 1. Boron effluent concentration with three different water solutions of different soil series (Corning, Rincon, San Ysidro, Tranquility and Yolo series).


Corning
Bf
Porous Volume
Control
pH 6
pH 9
Retardation Factor 50%


Rincon
Bf
Porous Volume
Control
pH 6
pH 9
Retardation Factor 50%


San Ysidro
Bf
Porous Volume
Control
pH 6
pH 9
Retardation Factor 50%


Tranquility
Bf
Porous Volume
Control
pH 6
pH 9
Retardation Factor 50%

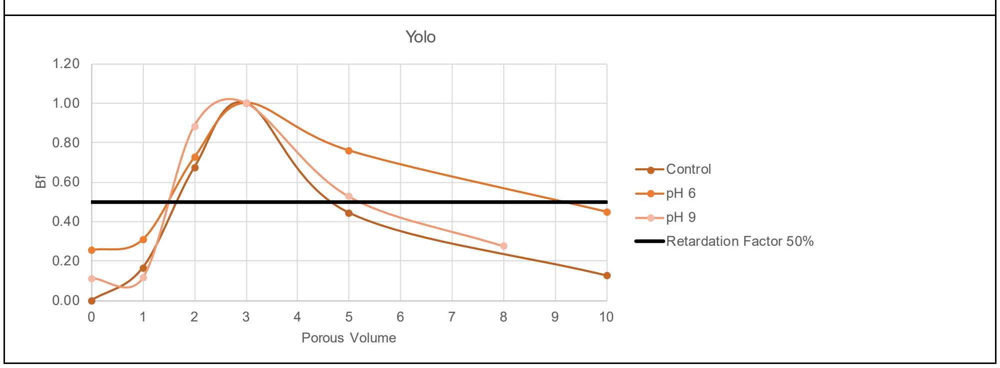

Yolo
Bf
Porous Volume
Control
pH 6
pH 9
Retardation Factor 50%

Fig. 2. Boron fraction leached from the different soil series (Corning, Rincon, San Ysidro, Tranquility and Yolo).

Except for the Rincon control treatment and the Corning pH 6 and 9, the control solution took more than 1 PV to reach 50% BF, indicating that B interacts with soil particles (figure 2). Similar behavior was seen by Suarez et al. (2012) for the Bonsall, Fallbrook and Pachappa soil series. For all soil series in this study, the maximum BF was obtained at 2 to 3 pore volumes, confirming that it takes two or three times more water to leach boron than salinity, considering that 50% fraction for salts would be obtained with 1 PV (Oster et al. 1984).

Retardation factors (R) are listed in table 1. B takes longer to leach out of the Yolo and Tranquility series (control, pH 6 or pH 9) than the other soil series suggesting that B interacts more with soil particles in the Yolo and Tranquility series, possibly due to higher clay content as listed in table 3.

Table 1. Retardation factor for different soils (Corning, San Ysidro, Yolo, Rincon, Tranquility). Treatments with the same letters within the same column are not statistically different by Tukey-Kramer's HSD test ($p < 0.05$).

	Treatment	**Corning**	**Rincon**	**San Ysidro**	**Tranquility**	**Yolo**
	Control	1.09 ± 0.06 ab	1.39 ± 0.05 a	1.05 ± 0.02 a	1.43 ± 0.31 a	1.43 ± 0.31 a
R (Retardation factor)	pH 6	1.14 ± 0.05 a	1.20 ± 0.14 a	1.09 ± 0.06 a	2.12 ± 0.05 ab	1.70 ± 0.09 a
	pH 9	1.00 ± 0.03 b	1.12 ± 0.21 a	1.17 ± 0.17 a	2.56 ± 0.42 b	1.33 ± 0.22 a

BORON LEACHING GUIDELINES

The Oster et al. (1984) study is considered a useful reference to understand Boron leaching in California soils. These authors plotted BF as C/Co as can be seen in figure 3. Rather than using pore volume, they used d_W/d_S (ratio between applied water and soil depth). Result from this study (control treatment) were compared to Oster et. Al (1984) and plotted in figure 3 using the same units. Due to different porosities, the equivalent d_W/d_S to pore volume are Corning (2.76), Rincon (2.32), San Ysidro (2.59), Tranquility (2.15) and Yolo (2.19). It is clear that the Rincon and Tranquility series require more water for B leaching than other series. In fact, all series evaluated in this study required more water than reported by Oster et. al. (1984).

A 50% reduction in boron concentration (BF=0.5) could reclaim most soils in California. This study suggests that to leach B, it is necessary to achieve 1.6 to 5.0 d_W/d_S, which is equivalent to adding from 4.1 to 11.5 pore volumes (saturate the soil 4 to 11 times), depending on soil series. In addition, due to practical difficulties and impacts of altering irrigation pH, the use of unaltered available irrigation water will sufficiently leach B. Steps are presented to leach excessive B out of the soil root zone (table 2).

For the most part, there is still lessons to be learned and gaps to be filled. B established leaching procedures do not include guidelines for a wide soil textural and organic matter content range, like the field conditions from California orchards, or take into account environmental changes consequences, such as the forthcoming water use restriction policies. Updating leaching guidelines of excessive salts is needed to guide growers on the adoption of B mitigation strategies.

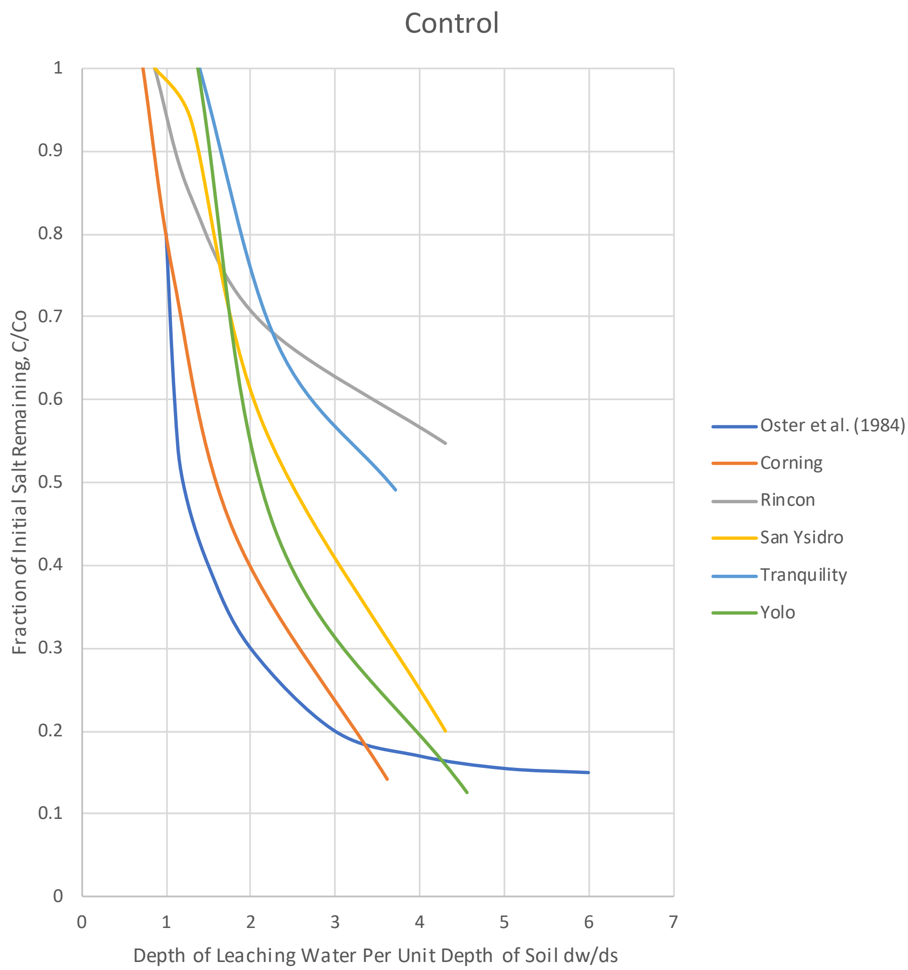


Fig. 3. Water needed to leach B in different soil series (Corning, Rincon, San Ysidro, Tranquility and Yolo series) compared to guidelines proposed by Oster et al. (1984), expressed in depth of water (dw) per unit depth of soil (ds). Boron removal is expressed as the fraction C/C_0, where C represents the effluent concentration and C_0 the maximum concentration found in soil solution.

Table 2. Steps needed to leach B excess out of the soil root zone.

How to leach B excess out of the soil?
Step 1. Quantify B concentration in irrigation water. If above 1.0 mg/l of B, will be toxic to many sensitive plants, blending of water sources must be adopted.
Step 2. Quantify B concentration in soil solution (saturated paste).
Step 3. Define homogeneous areas according to its soil properties spatial variation, irrigation needs and B soil concentration.
Step 4. Determine Irrigation water need (in/day) for optimal growth of the crop.
Step 5. Calculate depth of water needed for B leaching (equation 2), which will vary with the root zone layer depth and B concentration.
Step 6. Execute the leaching program (Fig. 8) based on the similarity to soil physical and chemical properties presented at tables 3 and 5.

D. Outreach Activities

Due to the pandemic, no outreach was done in person.

E. Materials and Methods

1.1 Boron field experiment

A Randomized Complete Block Design (RCDB) has been developed at Westwind Farms for both rate treatments and seasonal treatments. No treatments were delivered due to unforeseen proplems with the B removal system. Leaf and fruit was collected in spring and fall. Plant tissue is ground, digested and B is measured on an Agillent ICP-MS quadropole system.

Results for objective 1 will be delayed 2 years due to the redevelopment of B removal system

1.2 Development of new B removal system

Westwind Farms Inc. has committed to the cost and labor to redevelop and improve the infrastructure necessary to deliver varying levels of B water to fufill the objectives of this study in 2021 and beyond.

2. Soil Boron Leaching

In order to evaluate soil B leaching at different soil types under varied remediation strategies, soil columns (n=45) were established in the lab. To ensure representativeness and to interpolate different environmental conditions, soil columns were built and loaded with soils from a wide soil textural range and properties (pH levels). The five soil series selected were Corning, Rincon, San Ysidro, Tranquility and Yolo series and b leached under irrigation water at control, pH 6.0 and 9.0 conditions. Prior to leaching, incubation was carried out at the field capacity of each soil in order to standardize different soil B concentrations. B levels at the soil solution were increased to toxic levels (3 ppm) as in Goldberg and Suarez (2011).

The soils were air dried, sieved to 2 mm, and packed into 7-cm-diameter polystyrene columns 30.0 cm high. Solutions at pH 6.0 were prepared from ultrapure water with 2 $mmol_c$ L^{-1} of Mg^{2+}, 2 $mmol_c$ L^{-1} of Na^+, 4 $mmol_c$ L^{-1} of Cl^-, and 0.082 mmol L^{-1} of B (as HBO_3). Minor pH adjustment was made with HCl. Solutions at pH 9.0 were prepared with 2 $mmol_c$ L^{-1} of Na^+, HCO_3^-, Mg^{2+}, and Cl^-, and 0.082 mmol L^{-1} of B (as NaH_3BO_3) (Suarez et al. 2012). Control solutions were obtained as suggested by OECD/OCDE guidelines for the testing of chemicals (EPA 2004) with 0.01 M $CaCl_2$ solution in ultrapure water.

Soil columns were packed as described in table 5. Porosity was calculated from soil mass and soil volume when packed, assuming a soil mineral density of 2.65 Mg m^{-3}.

Table 3. Soil columns physical parameters for different soils.

Soil Series	Bulk Density [g cm^{-3}]	Porosity	Clay content
Corning	1.69	0.37	20
Rincon	1.51	0.43	30
San Ysidro	1.63	0.38	27
Tranquility	1.42	0.46	55
Yolo	1.44	0.46	30

Soil columns were first saturated and equilibrated from the bottom by capillarity with artificial rain solutions (Control) free of B. Then the surface of each soil column was treated with the respective treatment to leach at almost 10 pore volumes (PV). B concentration was measured at the effluent solution to get breakthrough curves (B concentration vs porous volume).

D. Publications that emerged/will emerge from this work

Manuscript in preparation: “Boron management and leaching on irrigated agriculture”. Target Audience: California growers, researchers and other agricultural professionals.

E. References

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