Use of Cucurbitacin Vial Traps to Predict Corn Rootworm (Coleoptera: Chrysomelidae) Larval Injury in a Subsequent Crop of Corn[1]

Eli Levine and Michael E. Gray

Office of Agricultural Entomology, University of Illinois and
Illinois Natural History Survey, 607 East Peabody Drive
Champaign, IL 61820 USA

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ABSTRACT Root injury by western corn rootworm, *Diabrotica virgifera virgifera* LeConte, and northern corn rootworm, *Diabrotica barberi* Smith and Lawrence, larvae was evaluated in ten cornfields where adult densities had been monitored the previous August with cucurbitacin vial traps. Traps consisted of 60-ml perforated plastic vials containing an acetate strip coated with carbaryl and powdered squash with high levels of cucurbitacin, a feeding arrestant. Traps were attached to corn plants at ear height, and the beetles were collected and sexed at various intervals throughout the month of August. For all sampling intervals except the last week of August, female trap capture data explained a significant ($P < 0.05$) amount of variability in root injury the following summer. In contrast, the only case in which combined male and female trap capture explained a significant amount of variability was for the third week of August. However, even for this time interval, female trap data explained nearly twice as much variability as did total beetle capture. The best regression equations for predicting larval injury were based on mean female capture for the entire month of August ($R^2 = 0.77$, n = 9, $P < 0.01$), mean female capture for the last 3 wk of August ($R^2 = 0.73$, n = 10, $P < 0.01$), and mean female capture for the third week of August ($R^2 = 0.82$, n = 10, $P < 0.001$). This study underscores the need to develop a trap that captures only female corn rootworms.

KEY WORDS *Diabrotica virgifera virgifera, Diabrotica barberi,* sex ratio, sampling.

The western corn rootworm, *Diabrotica virgifera virgifera* LeConte, and the northern corn rootworm, *Diabrotica barberi* Smith and Lawrence, are the most serious insect pests of continuous corn (corn not rotated with another crop) in the midwestern United States and Canada. Larvae of both species feed almost exclusively on corn roots and can cause extensive root injury. This injury can interfere with water and nutrient uptake and can also make the plant susceptible to lodging (Levine and Oloumi-Sadeghi 1991). Yield losses are most extreme when lodging occurs (Spike and Tollefson 1991). Rootworm beetles oviposit primarily in the soil of cornfields in August and early September (Hein and Tollefson 1985a).

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Ever since the northern and western corn rootworm became significant pests of corn, the need has developed for a reliable method of estimating densities of corn rootworm adults in a cornfield so that growers or crop consultants can predict which cornfields might benefit from a soil insecticide the following season. Because of the tremendous amount of labor involved in sampling rootworm eggs, and the general failure of egg density estimates to account for a significant amount of variability in subsequent root injury (Tollefson 1990), entomologists have attempted to use adult densities to predict injury the following year. Both visual counts of beetles on corn plants and sticky traps have been used to provide these estimates.

Visual counts of beetles on corn plants are greatly affected by environmental conditions (e.g., temperature, wind speed, time of day), which in turn affect the number of beetles counted by the sampler (VanWoerkom et al. 1980, 1983). Also, visual beetle counts require frequent sampling of the field over the course of the oviposition period (generally from early August to mid-September, Hein and Tollefson 1985a). Finally, to maintain accuracy and efficiency, trained samplers are required to make the counts. Despite these problems, the visual beetle count method has become the standard rootworm scouting tool throughout the Corn Belt, and nominal economic thresholds have been proposed (Hein and Tollefson 1985b) and recommended (Gray and Steffey 1994). Because a higher percentage of female western corn rootworms was found in first-year cornfields than in continuous cornfields, Godfrey and Turpin (1983) concluded that different economic thresholds should be used for the two cropping systems.

Sticky traps (e.g., Steffey et al. 1982, Hein and Tollefson 1984, 1985b) were developed to overcome some of the difficulties encountered with the visual beetle count method. These traps can be left in the field and retrieved after a number of days, thereby reducing the effects of environmental conditions, beetle emergence, and beetle movement (the extended sampling period would monitor the insect population density fluctuations during the entire time period rather than measuring the density at just one specific time). The use of traps also can reduce the need for high levels of training for field scouts to perform the visual beetle counts and reduce the variation in sampling efficiency from scout to scout. Despite these advantages, the traps need to be replaced frequently (Karr and Tollefson 1987) because they lose their stickiness, they are messy to handle, and commercially available traps are not inexpensive (approximately $1 per trap). More importantly, determining the sex of beetles captured on these traps is made difficult by the coating of sticky material the insects receive when they get caught on the traps. All these factors have prevented sticky traps from becoming widely accepted by farmers and crop consultants.

Hein and Tollefson (1985b) found that the Pherocon AM sticky trap and the visual beetle count method were equally effective in predicting subsequent larval injury, but neither method could account for more than about 27% (R^2) of the variability in the root injury. In a study to assess corn rootworm adult population density estimates as predictors of larval injury in continuous cornfields, Foster et al. (1986) found significant relationships between adult densities determined with the visual beetle count method and larval injury, but they also found that much of the variation in injury was not explained by their model. Consequently, a better sampling method is needed, perhaps one that also takes into account sex ratios.

Illinois researchers have developed a trap, hereafter referred to as a cucurbitacin vial trap, that is small and easily handled, inexpensive to make, and without sticky material (Briggs and Shaw 1983, Shaw et al. 1984). The trap uses a 60-ml perforated plastic vial containing an acetate strip coated with insecticide and powdered squash with high levels of cucurbitacin. Cucurbitacins, a group of compounds found in bitter squash, cucumbers, and melons, have been identified as feeding arrestants for both northern and western corn rootworm adults (Rhodes et al. 1980). Beetles enter the trap seeking shelter and feed on the squash mixture, ingesting a lethal dose of the insecticide (Fielding and Ruesink 1985).

Shaw et al. (1984) showed that the traps could be left in the field for as long as 12 d and still retain their effectiveness; the capture rate remained about the same regardless of the time period the traps were left in the field. They also showed that there was a high correlation between vial trap catch and peak visual beetle counts on plants ($r = 0.80$). However, Shaw et al. (1984) did not regress rootworm larval injury the following year on adult trap capture data. They found, like Godfrey and Turpin (1983), that western corn rootworms dispersing into first-year cornfields were predominately female and concluded that recommendations for the use of a soil insecticide based on beetle density may need to be different for first-year and continuous corn.

The objectives of this study were to establish the relationship between the number of adults caught in cucurbitacin vial traps (both male and females or females only) and subsequent larval injury, and to determine what trapping periods were critical for accurately predicting subsequent larval injury. This was accomplished by reanalyzing raw data from the studies of Shaw et al. (1984) along with data recently collected from three additional fields. The ultimate goal was to determine the accuracy of vial traps in predicting economic root injury the following year. Should vial traps provide reliable estimates of economic root injury, producers might be able to base soil insecticide decisions upon this management input.

Materials and Methods

Trap Construction. The traps were made from 60-ml amber-colored plastic vials with snap caps as described by Shaw et al. (1984). The bottoms of the vials were replaced with wire screen to prevent condensation within the traps. Ten holes, each 5 mm in diam, were drilled in the sides of the vials to allow beetles to enter. Inserts for the vial traps were prepared by spraying both sides of 21.6 cm × 27.9 cm sheets of acetate transparency film with a 1:1 mixture (by volume) of carbaryl (Sevin XLR; Rhone-Poulenc, Research Triangle Park, NC) and water. Powdered squash was sprinkled on the film and allowed to dry. The film was then cut into 2.5 × 7.6 cm strips and inserted into the vial traps, one strip per trap. Approximately 0.5 g of squash was applied to each insert. The powdered squash came from a dried *Cucurbita andreana* × *C. maxima* cross grown in 1979. Only fruit with high levels of cucurbitacin was used (see Shaw et al. 1984).

1981-1982 and 1982-1983 Studies. Male and female corn rootworm beetle trap catch data were obtained from the authors of the Shaw et al. (1984) paper for the seven fields in which corn rootworm injury was assessed the next year. Shaw et al. (1984) collected data on both male and female trap counts but only reported the total number of beetles captured. All of their studies were conducted in Champaign County, IL. Three fields were used in 1981, and four fields were used in 1982. One field in the 1981 study was a first-year cornfield, and the remaining two fields had been in continuous corn production for at least 2 yr. In the 1982 study, one field was a first-year cornfield, and the remaining three fields had been in continuous corn production for at least 2 yr. Traps were positioned approximately 10 m apart and were attached at ear height to corn plants with twist ties. Twenty traps were placed in each field and emptied every 8 d. Traps were installed in late July (six fields) or early August (one field) and monitored throughout August. Rootworm beetle populations consisted of approximately 97% western and 3% northern corn rootworms. The following spring (1982 for the 1981 field studies and 1983 for the 1982 field studies), each grower left untreated check plots (no soil insecticide) in his fields. In July, corn roots were randomly selected and dug from each field's untreated area and then washed; the amount of injury was categorized using a 1-6 rating scale where 1 was no injury and 6 was three nodes of roots destroyed (Hills and Peters 1971).

1991-1992 Study. In 1991, as part of a larger project to determine how effectively Pherocon AM yellow sticky traps could be used by farmers on a large-scale basis to predict subsequent corn rootworm larval injury, three producers in two northern Illinois counties (Mercer and DeKalb) also volunteered to install twelve cucurbitacin vial traps throughout one of their cornfields that would be devoted to corn production in 1992. The vial traps were installed (by each producer or the county extension adviser) in mid-July and replaced every 7 d with fresh traps through early September. Vial traps were attached to corn plants at ear height with twist ties. Vial traps were located at least 10 m apart and at least 8 m from Pherocon AM traps. Upon removal from the field, each vial trap was labelled and placed in a separate plastic bag (to prevent the loss of beetles through the holes of the vial traps) and returned to the laboratory, where the beetles were counted by species. Up to 50 beetles of each species per trap were sexed to establish the sex ratio of the trapped insects. This was determined by examining the shape of the last abdominal sternite under a dissecting microscope (White 1977). The rootworm beetle populations consisted of 99.8 - 99.9% western and 0.1-0.2% northern corn rootworms for the two Mercer Co. fields (Thomas and Brown fields, respectively) and 68.7% western and 31.3% northern corn rootworms for the DeKalb Co. field (Larson field). In the spring of 1992, each grower left four untreated check plots (no soil insecticide; each plot measured 4 rows by 122 m long) in his fields. In mid-July, 20 roots in each of the four check strips were dug, washed, and rated for rootworm injury as in the 1981-1982 and 1982-1983 studies.

Data Analysis. Correlations between vial trap catch (beetles per trap per day) and subsequent larval injury (root ratings) were calculated, and regression equations to describe the relationships were computed (PROC CORR and PROC REG, SAS Institute 1982). Because nine of the ten fields had very low densities of northern corn rootworm adults, only the combined western and northern corn rootworm catch was used as the independent variable. Hein and Tollefson (1985a) determined that 70% of the seasonal rootworm oviposition in Iowa took place during the month of August, with the bulk (60%) occurring in the last 3 wk of that month. To determine what trapping periods were most useful in predicting subsequent larval injury, mean trap catch and peak trap capture for various August sampling intervals were examined. Peak population density estimates were used in addition to mean capture because scouting recommendations often use this variable for determining the potential for subsequent larval injury. Correlations and regressions also were developed with female trap count data and log (base 10) transformations of total and female trap count data (multiplied by 10 to avoid negative values) as the independent variable in attempts to improve injury predictions.

Results and Discussion

In nearly every case, log transformation of the raw data improved the relationship between trap capture and subsequent root injury. Attempts to further improve the regressions by using quadratic terms did not add to the predictive ability of the equations. Table 1 shows the coefficients of determination (R^2) for the relationship between root injury and trap counts (combined male and female counts as well as female counts alone) for various sampling periods in August. For all sampling intervals except the last week of August, mean female or peak female trap capture data explained a significant ($P < 0.05$) amount of variability in root injury (as measured by the R^2) the following summer. In contrast, the only case in which combined male and female trap capture explained a significant amount of variability was for the third week of August. However, even for this time interval, female trap data explained nearly twice as much variability as did total beetle capture. For the last week of August, neither independent variable explained a significant amount of variability. Peak capture was no more helpful in predicting subsequent rootworm injury than mean capture (Table 1).

The best regression equations for subsequent larval injury were based on mean female capture for the entire month of August ($R^2 = 0.77$, Fig. 1), mean female capture for the last 3 wk of August ($R^2 = 0.73$, Fig. 2), and mean female capture for the third week of August ($R^2 = 0.82$, Fig. 3). Corn was in the blister through dent stages of development during these sampling periods.

Godfrey and Turpin (1983) found a higher density and percentage of female western corn rootworms in first-year cornfields than in continuous cornfields during the major portion of the oviposition period. They concluded that the use of the same beetle count threshold for both types of fields could underestimate the injury potential in first-year cornfields. Although their correlation coefficients for the regression of root injury rating against whole plant beetle counts were significant ($P < 0.05$), their equations could explain only 24% of the variability for first-year cornfields and 26% for continuous cornfields. These researchers did not use female counts in their regressions because whole plant beetle counts were "the type of population density estimate used in IPM systems."

Table 1. Coefficients of determination (R^2) for relationships between adult corn rootworm population density estimates and subsequent larval injury, 1981-1982, 1982-1983, 1991-1992.

Sampling method and period in August	R^2	n
Mean capture, wk 1-4	0.34	9
Mean female capture, wk 1-4	0.77**	9
Peak capture, wk 1-4	0.37	9
Peak female capture, wk 1-4	0.63**	9
Mean capture, wk 2-4	0.27	10
Mean female capture, wk 2-4	0.73**	10
Peak capture, wk 2-4	0.22	10
Peak female capture, wk 2-4	0.66**	10
Mean capture, wk 1	0.37	9
Mean female capture, wk 1	0.65**	9
Mean capture, wk 2	0.22	10
Mean female capture, wk 2	0.44*	10
Mean capture, wk 3	0.42*	10
Mean female capture, wk 3	0.82†	10
Mean capture, wk 4	0.12	10
Mean female capture, wk 4	0.25	10

* $P < 0.05$, ** $P < 0.01$, † $P < 0.001$. Trap catch data were log transformed.
Sampling conducted at 7-8 d intervals in August.

Hein and Tollefson (1985b) found that the Pherocon AM trap and the visual whole plant beetle count method were equally successful in predicting subsequent larval injury, but neither method could account for more than 27% of the variability in rootworm injury. In contrast to our results, however, Hein and Tollefson (1985b) found that using female counts as the independent variable did not improve injury-predicting abilities. All fields in their study were fields of corn grown without rotation (Gary L. Hein, personal communication). The lack of improvement in injury prediction by using female counts can be explained, at least in part, by more closely examining the cropping history of a field. That is, continuous cornfields would be more likely to have a lower density and lower percentage of female beetles in them than would first-year cornfields (Godfrey and Turpin 1983, Shaw et al. 1984). Thus,

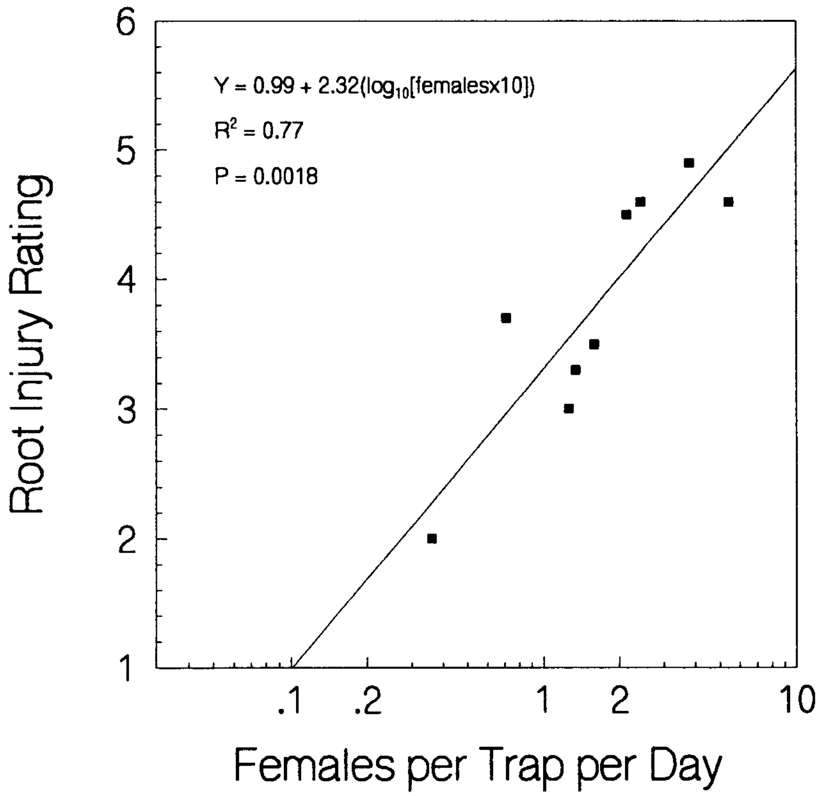

Fig. 1. Relationship between subsequent root injury rating (1-6 scale) and the mean number of female corn rootworm beetles caught by cucurbitacin vial traps during wk 1-4 of August, 1981-1982, 1982-1983, 1991-1992.

total beetle counts would more likely mirror female counts in continuous cornfields than they would for a combination of continuous and first-year cornfields.

It is worth noting that our results relative to the presence of more female beetles in first-year cornfields correspond with those of Godfrey and Turpin (1983). For the last 3 wk in August, vial traps from our first-year cornfields captured beetles that were 74.7 ± 3.7% (mean ± SEM, n = 3 fields) female while vial traps from the continuous cornfields captured beetles that were 32.9 ± 7.5% (n = 7) female. However, due to the small number of first-year cornfields studied (n = 3), we decided not to compare slopes (injury) and intercepts (beetle capture) of the regression equations for continuous and first-year cornfields.

A root injury index of 2.5-3.0 has frequently been cited as the economic injury level (Turpin et al. 1972, Mayo 1986). With a root economic injury level of 3.0 (several roots eaten off to within 3.8 cm of the plant), economic thresholds of

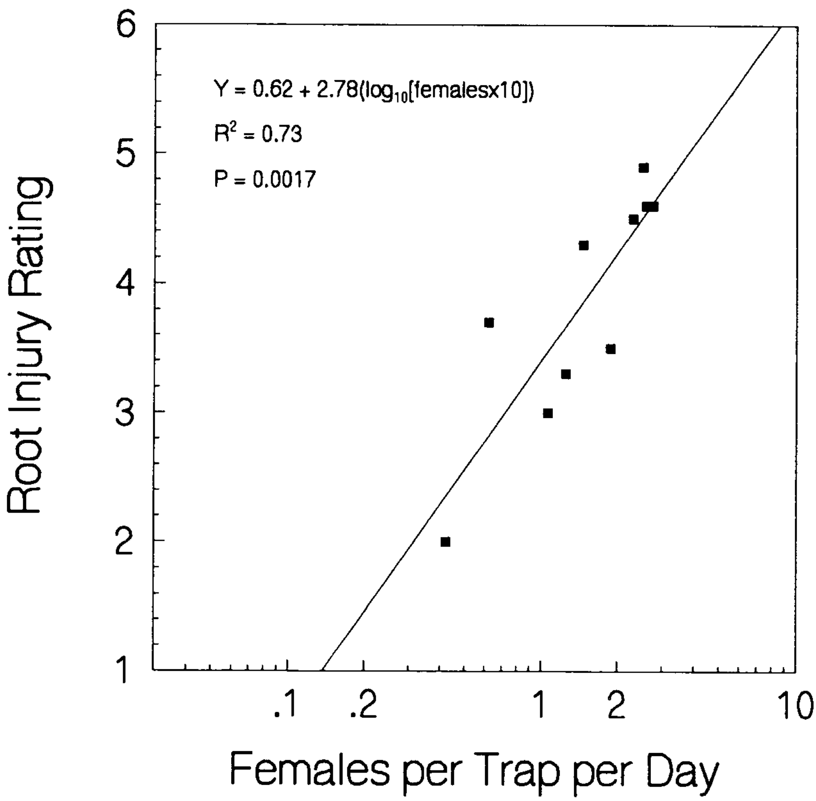

Fig. 2. Relationship between subsequent root injury rating (1-6 scale) and the mean number of female corn rootworm beetles caught by cucurbitacin vial traps during the last 3 wk of August, 1981-1982, 1982-1983, 1991-1992.

0.7, 0.7, and 0.6 females per trap per day were obtained for sampling periods of the entire month of August, the last 3 wk of August, and the third week of August, respectively. Some entomologists, however, believe that an index of 2.5-3.0 is too low and that a root rating of 4.0 (one node or the equivalent of one node of roots destroyed) may be more realistic (Sutter et al. 1990). Using a root economic injury level of 4.0, economic thresholds of 2.0, 1.6, and 1.7 females per trap per day were obtained for sampling periods of the entire month of August, the last 3 wk of August, and the third week of August, respectively.

Current adult corn rootworm sampling thresholds do not directly take into consideration the number of female corn rootworms present in the field. An adult sampling threshold based on female counts during the oviposition period should more precisely forecast which fields have the potential of developing damaging infestations of corn rootworm larvae the next year. Fields identified

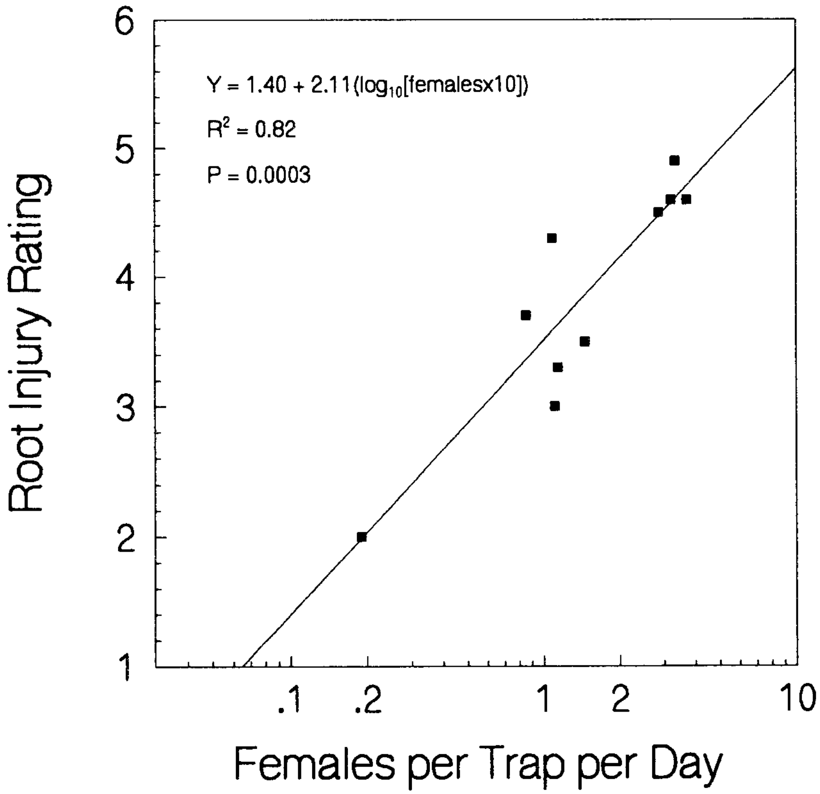

Fig. 3. Relationship between subsequent root injury rating (1-6 scale) and the mean number of female corn rootworm beetles caught by cucurbitacin vial traps during the third week of August, 1981-1982, 1982-1983, 1991-1992.

as high risk could be planted with a nonhost crop or treated with a soil insecticide if planted back to corn. Low risk fields would not need to be treated. This approach would further the effort to reduce the number of fields needlessly treated each spring by producers on a prophylactic basis. Gray et al. (1993) were able to document that in 1990 and 1991, only 26 of 58 producers' fields had root injury at or above the economic injury index of 3.0. If a root injury index of 4.0 is used as the economic benchmark, then not a single growers' field in 1991 required an insecticide application in the Gray et al. (1993) study. Despite these findings, 88% of the continuous corn grown in Illinois is treated (about 1,000,000 ha) annually primarily for rootworm control (Pike and Gray 1992). In essence, soil insecticides are used as insurance rather than a component within an integrated management system. In light of increasing environmental concerns, it is doubtful that the general public will find this approach acceptable.

The cucurbitacin vial trap may not be very useful for producers and consultants who lack the time or knowledge to identify the sex of trapped beetles. However, this study underscores the need to develop a trap that captures only female corn rootworms. Our results also indicate that the sampling period need not cover a long period of time; 1-4 wk during August should be sufficient (although corn planted very late with flowering extending into August may be an exception to this).

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