Bell pepper (Capsicum annum) is an important fruiting vegetable crop in the USA representing a value of $642 million in 2013 (USDA, 2014). With approximately 21,000 acres, California is the number one producing state in the US. In the Coachella Valley about 5,000 acres of bell peppers are grown, on raised beds, covered with black plastic mulch on sandy soils. Growers in this area have two pepper crops per year, with a spring planting under black plastic mulch in early February and harvested in June followed by a non-mulched fall planting in August/September and harvested into December or to the first frost.

Root-knot nematodes (Meloidogyne species) are economically important nematode pests of bell pepper. Although within this group of nematodes, there are many different species, the southern root-knot nematode (M. incognita) is by far the most prevalent species infesting bell pepper in California. Another species: the Javanese root-knot nematode M. javanica, that is often found in California infecting other vegetable crops appears uncommon in bell peppers. In some other countries however this certain populations of species have been reported as pathogens of bell peppers. Although all root-knot nematodes share a common lifecycle, and generally have a wide host range, different species may have different preferences as far as preferred host plants and soil temperature optimum. The second-stage juveniles (J2) hatch from the eggs and are worm-shaped. They move through the soil and enter into the roots of a host plant. Once inside the roots, they stop moving, modify the root cells of the host, while the host roots typically react to the infestation with the formation of galls. While the presence of galls is indicative of a root-knot nematode infection, the size and shape of the galls differs in different crops. The galls on pepper roots are generally not as obvious and large as in some other vegetable crops such as tomato or cucurbits. Still, an infected pepper root system may still carry several million root-knot nematode eggs. Inside these galls, the nematodes develop into adult females. Each female can produce up to 400 eggs which are contained in a gelatinous material. The eggs are generally deposited on the outside of the roots. From these eggs new J2 can emerge again. The soil temperature mostly determines how fast a life cycle (from J2 to J2) can be completed, but under warm conditions (about 82F) the life cycle can be completed in less than four weeks, and during one cropping season several life cycles can be completed. Thus, low nematode levels at planting can quickly increase to high populations when conditions are favorable. In the Coachella Valley, the relatively warm soil temperatures in combination with the predominant light soil types, sufficient soil moisture, and the frequent cropping of excellent host crops provides an ideal scenario for root-knot nematodes to increase to damaging population levels. In bell peppers, root-knot nematodes can cause direct yield reduction (i.e. fewer/smaller fruits), but because of wilting and stunting of infested plants, fruits are also more susceptible to sun-burn leading to considerable loss in marketable yields.
To control nematodes and avoid damage, soil fumigants can be applied prior to transplanting. Because of the negative impact of fumigants on air quality and human health, soil fumigation in California is subject to ever stricter regulations with respect to required buffer zones, air quality monitoring, sealing, posting etc. Thus, to manage root-knot nematodes, it is necessary that alternative management strategies are tested and developed.

In the initial stage of this study, we visited a number of spring season pepper fields in the Coachella Valley where plants showed symptoms (wilting, stunting, yellowing) that could indicate a nematode infestation. A first sampling in April yielded very few positives, but a in second sampling during late May several fields tested positive for root-knot nematodes, with sometimes very high populations levels in the soil samples taken from the pepper beds. All nematodes were identified as *M. incognita*. One method to control nematode damage is to use resistant varieties. Although nematode-resistant varieties are not commercially grown in the Coachella Valley, two open-pollinated bell pepper cultivars: ‘Carolina Wonder’ and ‘Charleston Belle’ with resistance to *M. incognita* have been developed. In repeated greenhouse tests, we exposed these resistant varieties to the nematodes that came from Coachella Valley pepper fields. The variety ‘Carolina Wonder’ showed a high degree of resistance, and the roots remained virtually free of galls. The variety ‘Charleston Belle’ still allowed some nematode multiplication, and also had some root galling, although much less than the susceptible variety ‘Baron’ which was included as a control. In a field trial in 2018, the resistant ‘Carolina Wonder’ and the susceptible ‘Baron’ were tested at two locations, each infected with root-knot nematodes. In one location at the Coachella Valley Agricultural Research Station (CVARS), the initial nematode levels were low, and both varieties had similar yields. However, the final numbers of nematodes per 100 g soil

<table>
<thead>
<tr>
<th>Pepper Variety:</th>
<th>Initial nematode</th>
<th>Final nematode</th>
<th>eggs/g root</th>
<th>galling</th>
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<tr>
<td></td>
<td>R</td>
<td>S</td>
<td>R</td>
<td>S</td>
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<td>SCREC-site</td>
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<td>41</td>
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<td>869</td>
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</table>

Table 1. Pre-plant and at-harvest soil nematode counts (per 100 g soil), root infestation levels (eggs/g root) and root galling on susceptible ‘Baron’ (S) and resistant ‘Carolina Wonder’ (R) pepper at two root-knot nematode infested field sites.
at harvest, the number of eggs on the pepper roots, and the root
galling were much lower on the resistant pepper. At the other
location at the South Coast Research and Extension Center
(SCREC) at Irvine, the initial nematode numbers were higher. At
this site, the results were very similar with much lower nematode
levels and galling on the resistant pepper.

At the SCREC field, the resistant pepper also yielded about 40%
more than the susceptible variety. Therefore, the use of nematode-
resistant varieties looks promising as it leaves a lower nematode
infestation level, and the plants may yield more under high initial
nematode pressure. The suitability of such pepper varieties under
commercial growing practices remains to be tested.

Although bell pepper in general appears more tolerant to root-
knot nematodes than some other vegetable crops, the relationship
between pre-plant soil nematode levels and the growth, yield, and
at-harvest nematode levels has not been determined for root-knot
nematodes and bell pepper under California growing conditions and
pepper varieties. Therefore, it is difficult to predict risks on crop
damage and decide on nematode management strategies based on
the results from pre-plant soil samples. We are currently planning
experiments to provide such data for California pepper varieties and
root-knot nematodes occurring in California pepper fields.

In the last few years, we have been evaluating several new non-
fumigant nematicides in different vegetable crops and in different
field trials. Several are consistently showing good efficacy and have
the advantage that they are environmentally more friendly, are
more specific with respect to targeting plant-parasitic nematodes,
are much less toxic, do not require long re-entry intervals, and can
be used closer to transplanting or seeding. First field trials with
these compounds on pepper also showed promise, and they may
eventually provide an alternative to pre-plant fumigation.

The authors wish to thank the California Pepper Commission for
financial support.