Understanding the Impact and Risk of *Delia radicum* (Diptera: Anthomyiidae) Infestations on California Broccoli[1]

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Abstract Cabbage maggot, *Delia radicum* (L.) (Diptera: Anthomyiidae), is an important pest of brassicas worldwide, including on the Central Coast of California. Although *D. radicum* larval feeding and damage are reported, the impact of infestation on plant growth and the potential effects of soil type on larval survival have not been fully investigated. Thus, the objectives of this study were to determine (1) the effects of *D. radicum* infestation on broccoli growth and (2) the performance of *D. radicum* larvae when exposed to various soil types on the Central Coast of California. As a case study, a *D. radicum*-infested broccoli field was selected 8 weeks after plant emergence. The health status of plants on the basis of vigor and *D. radicum* infestation was established using a 1–6 rating scale. Health status and plant development were monitored for 5 weeks. The results demonstrate that *D. radicum* infestation caused asynchronous plant growth and development of florets, which can potentially result in complete crop loss. Of 18 soil types evaluated on the basis of a laboratory experiment with turnip discs, the Diablo Clay, Lockwood Loam, and Oceano Sandy Loam soils resulted in reduced *D. radicum* feeding activity relative to other soil types sampled from the Central Coast of California. *Delia radicum* larval mortality was greatest on the Diablo Clay soil. Thus, vegetable fields with Diablo Clay, Lockwood Loam, and Oceano Sandy Loam soils may benefit from reduced *D. radicum* densities for *Brassica* production.

Key Words *Delia radicum*, cauliflower, *Brassica*, Salinas Valley

The cabbage maggot, *Delia radicum* (L.) (Diptera: Anthomyiidae) became a serious pest of *Brassica* crops in North America and Europe (Coaker and Finch 1971) and has become one of the major pests on the Central Coast of California (Johnsen and Gutierrez 1997, Joseph and Martinez 2014). Many *Brassica* crops, such as broccoli (*Brassica oleracea* var. *italica* Plenck), cauliflower (*B. oleracea* L. var. *botrytis*), cabbage (*B. oleracea* L. var. *capitata*), napa cabbage, (*B. rapa* subsp. *pekinensis* [Loureriro] Kitamura), rapini (*B. rapa* var. *ruvo* L.H. Bailey), turnip (*B. rapa* var. *rapa* L.), radish (*Raphanus sativus* L.), bok choy (*B. rapa* subsp. *chinensis* L.), kale (*B. oleracea* L. var. *acephala*), broccolini (*B. oleracea* var. *italica* × *alboglabra*), and Brussels sprouts (*B. oleracea* L. var. *gemmifera*), are grown in fields on the Central Coast of California and are at risk of *D. radicum* infestation (Johnsen and Gutierrez 1997, Joseph 2023, Joseph and Martinez 2014, Natwick et al. 2022). On the Central Coast of California, *Brassica* crops were grown on >57,589 ha and valued at

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>US$957.6 million (MCCR 2022; SBCCR 2022a, b; SCCCR 2022; SLOCCR 2022). In Monterey County alone, the combined value of broccoli and cauliflower was >US$465 million (MCCR 2022). Clearly, brassicas are an important crop group on the Central Coast of California.

Females of *D. radicum* oviposit ~300 eggs around the base of *Brassica* plants in soil (Finch 1974). After hatching, the white apodous larvae colonize the taproot system (Natwick et al. 2022). Feeding damage to roots can affect the growth and development of *Brassica* plants as the movement of photosynthates and water is constrained (Schuh 2017). Third-instar larvae pupate in soil, and developmental time varies across different regions on the basis of temperature (Harris and Svec 1966). Adult flies eclose within 4–5 weeks (Harris and Svec 1966). Feeding injury causes yellowing and stunting and delays plant growth (Natwick et al. 2022).

Diapause is widely reported in *D. radicum* populations from most *Brassica*-producing regions of the world (Collier et al. 1988, Finch and Collier 1983). Because temperatures on the Central Coast of California rarely decrease and persist below or above freezing point during the winter, diapause is rarely reported in *D. radicum* populations in this region (Johnsen and Gutierrez 1997). In the Central Coast region, the summer temperatures mostly remain below 28°C. *Brassica* crops in this region, especially broccoli and cauliflower, are grown year-round, providing ideal conditions for *D. radicum* populations to thrive throughout the year.

Management strategies for *D. radicum* infestation have been developed for *Brassica* crops with insecticide applied as foliar and basal sprays, seed dressing, and greenhouse tray-drench (Ester et al. 2003, Joseph and Iudice 2020, Joseph and Zarate 2015, Natwick et al. 2022). The best timing for basal spray of insecticide is 3 weeks after plant emergence (WAP) for direct-seeded crops, such as broccoli and turnip (Joseph 2016, Joseph and Martinez 2014). However, the impact of the *D. radicum* infestation and larval feeding damage on *Brassica* plant growth is poorly characterized on the Central Coast of California. In many instances, *D. radicum* infestation on broccoli or cauliflower produces no significant damage, whereas in other instances, *D. radicum* infestation causes 100% crop loss (Joseph 2013). Furthermore, sometimes broccoli plants produce florets asynchronously, resulting in multiple field harvest passes and crop loss. It is unclear if the *D. radicum* infestation contributes to asynchronous floret emergence in the field. No published study from the region attempted to understand the effects of infestation levels on changes in plant vigor and development. This information is critical to determine appropriate pest management and marketing decisions.

In Monterey County, California, 83 soil types have been reported (SSMC 1978). However, all soil types are present in the arable land where crops are produced. Although *D. radicum* populations are widespread on the Central Coast, it is unclear if certain soil types favor or discourage the development of larvae. Once infested, larvae constantly interact with the root system of broccoli and the soil as they develop. The young larvae are exposed to soil substrates as they feed on root tissue, and soil type characteristics could influence their development. Thus, understanding how soil type influences *D. radicum* larval development may help growers to be informed and make appropriate management decisions depending on vulnerability to infestation and the soil type in which they are growing *Brassica* crops. This information could also trigger more follow-up research where soil factors, such as organic matter, clay, or sand content, specifically affect *D. radicum* larval development.

The objectives of the current study were to determine (1) the effects of the infestation of *D. radicum* on the growth and development of broccoli plants and (2) the feeding and survival of *D. radicum* larvae when exposed to various soil types on the Central Coast of California.

Materials and Methods

***Delia radicum* infestation and impact: a case study.** A case study was conducted in a 4.1-ha grower field in Chualar, CA (Monterey County) in 2013. In the commercial field 'Imperial' broccoli seeds were planted in two rows of 101.6-cm-wide beds. The plants were thinned to ~15-cm plant-to-plant spacing 4 WAP. Standard production practices, such as routine fertilizer application and irrigation procedures, were administered. However, the grower did not apply any insecticide for *D. radicum* control. The grower reported a natural infestation of *D. radicum* at 7 WAP. The infestation was evident as *D. radicum* larvae were on the root system, and several plants were wilted. Thus, this field was selected for this case study, and the experiment was set up on 16 June 2013 at 8 WAP. Blocks of broccoli and lettuce fields surrounded the selected broccoli field. The monitoring and sampling experiment was used in the first 22 beds from the border facing no adjacent crop field, and the beds were 50 m long.

To assess the vigor of broccoli plants infested with *D. radicum* larvae, plants were visually scored using a health scale system (1–6) where plants were categorized on the basis of plant vigor. Plants were assigned a score of 1 when plants were vigorously growing with no signs of wilting, dark green foliage, and active growth status; 2 when plants were vigorously growing but 20% smaller in size than those plants scored 1; 3 when plants were showing mild signs of stunting as the lower leaves (at least four lower leaves) were mild green or chlorotic; 4 when plants were moderately stunted as lower leaves were completely chlorotic and leaves were small sized around the growing point; 5 when plants were severely stunted with extensive chlorosis and struggling to grow; and 6 when plants had no vigor and were almost dead. At the beginning of the experiment (8 WAP), six broccoli plants were selected from each row (block) to represent each health score (HS) and characterize the health scale system. Twenty plants were randomly selected from 20 rows (blocks) for each HS category (1–6). The spacing between plants within a row was not the same. Thus, the arrangement was a randomized complete block design (RCBD) with 20 plant replications. The selected, scored plants were carefully extracted from the soil with intact taproot systems using a shovel, transferred to plastic bags, and transported to the University of California Cooperative Extension (UCCE) laboratory in Salinas, CA. Within 24 h, plants with roots were removed from the bags and the number of *D. radicum* larvae in each plant root was picked from the soil and quantified. The roots were individually weighed (Ohus®, Parsippany, NJ) after cutting the stem from the soil level.

In addition, 20 plants were again randomly selected and flagged with various colors for each HS at 8 WAP. Every row (block) had six individual plants randomly selected under each HS, which was the treatment. The experiment was in a RCBD with 20 replications. An individual broccoli plant served as a replication. The plant rows were blocked from the edge of the field. The selected plants were nondestructively evaluated using the same HS system at 8 WAP every week up to 13 WAP. Plants from two border rows were not used in the experiment, as some plants in these rows were apparently stressed because of non-*D. radicum* infestation-related causes.

Table 1. Details of soil type, towns where field samples were collected in the Salinas Valley, and composition of clay, sand, and organic matter in the soil. The laboratory experiment was conducted to determine how *Delia radicum* larvae interacted with these soil types.

Soil Type[a]	Sample Collection Town	Clay (%)	Sand (%)	Organic Matter (%)
Arroyoseco Gravelly Loam	Chualar	13.0	45.4	2.00
Chualar Loam	Salinas	14.0	44.8	2.50
Cropely Silty Clay	Gonzales	50.0	5.3	2.00
Danville Sandy Loam	Salinas	25.0	57.0	2.50
Diablo Clay	Castroville	47.5	23.3	2.50
Elder Fine Sandy Loam	Watsonville	13.0	67.0	2.50
Elkhorn Fine Sandy Loam	Prunedale	15.0	65.4	4.00
Hanford Gravelly Sandy Loam	Salinas	12.5	67.9	0.75
Lockwood Loam	Greenfield	22.5	39.8	3.50
Metz Complex	Soledad	10.0	63.5	0.75
Mocho Silt Loam	Gonzales	23.0	25.0	3.00
Oceano Sandy Loam	Moss Landing	3.5	80.4	1.00
Pacheco Clay	Soledad	31.0	35.4	3.00
Rincon Clay	Greenfield	35.0	30.0	1.50
Salinas Clay Loam	Gonzales	31.0	35.0	2.50
Santa Ynez Sandy Loam	Castroville	15.0	65.4	3.50
Clear Lake Clay	Salinas	50.0	22.1	2.50
Pico fine Sandy Loam	King City	16.0	64.5	2.50

[a] OSWGM 2024; SSMC 1978.

At 11 WAP, florets began (<5 cm diameter) to emerge from >50% of plants scored 1. Florets were nondestructively evaluated at 7-d intervals for 3 weeks after 3 July (11 WAP). After a nondestructive evaluation of florets at 13 WAP on 23 July, florets were harvested from all plants in the experiment. To be consistent, florets from each plant were cut at the base where the last floret emerged. Florets were immediately transferred to plastic bags and transported to the UCCE laboratory. In the laboratory, the diameter of florets was measured using a ruler and they were weighed individually using a balance (Ohus) within 2 h after harvest.

Soil type and *D. radicum*. Eighteen soil types were sampled from the Salinas Valley on the Central Coast of California. Soil type and town from where samples were collected, as well as sand, clay, and organic matter content of soil sampled in the experiment, are listed in Table 1. Topsoil (~350 cm deep) was collected where *D. radicum* larvae are typically found, using a shovel from each site, transferred into a

plastic bag, and transported to the entomology laboratory at the UCCE, Salinas, CA. An assay was developed for the experiment in which a 15-mm-diameter × 15-cm-long polyvinyl chloride (PVC) tube was used. Turnip root discs, ~14 mm (diameter) × 0.5 mm (thickness) and ~ 2.2 g, were prepared using a knife. A turnip disc was placed at one end of the PVC tube and was secured intact inside the tube using parafilm. The turnip discs were weighed on an enclosed weighing balance (Ohus) before being placed into the PVC tube. Turnip discs were used in the experiment because *D. radicum* larvae are naturally attracted to brassicas as a food source. As needed, the soil was gently pulverized with fingers to break the small soil blocks and added from the open end to fill the PVC tube. A PVC tube assay was the experimental unit, and assays were vertically placed on tube holders. The second instar of *D. radicum* was field collected after extracting the roots of broccoli plants from a broccoli field. The *D. radicum*-infested roots were transported to the laboratory and the larvae were extracted using forceps and put into 9-cm (diameter) Petri dishes with a moist paper towel.

Before introducing *D. radicum* larvae to the tube assay, the soil column was moistened by adding 10–15 ml of water so that water dripped through the parafilm at the bottom of the tube assay. Three *D. radicum* larvae were introduced to the soil surface of each tube assay. *Delia radicum* larvae bored into the soil surface within 15 min after introduction. The assay was retained on the laboratory bench for 7 d at 21°C and 40% relative humidity. The assay was kept inside a laboratory drawer with no light as the larvae were inside the soil column. The treatment was soil type (Table 1) and was replicated 30 times except for Lockwood Loam, Elder Fine Sandy loam, and Metz Complex soil types, which were replicated 20 times. After 7 d, the column of soil and turnip disc inside the tube was pulled out and *D. radicum* larvae were recovered. The numbers of dead and live larvae were quantified from each tube. As larvae die, they turn brown and do not move after poking with a needle. The turnip discs were visually evaluated for the percentage of turnip consumed by larvae. The discs were weighed again using an enclosed weighing balance.

Statistical analyses. All data analyses were performed using Statistical Analysis System (SAS) software (SAS Institute 2024). The numbers of larvae and root weight data were natural log-transformed ($\ln[x + 1]$) and subjected to analysis of variance (ANOVA) in the general linear model using the PROC GLM procedure in SAS. The HSs were the treatment with 20 replications. The nontransformed HS data collected on plants from 9 to 13 WAP were subjected to ANOVA by date in the general linear model using the PROC GLM procedure in SAS. At 13 WAP, the diameter and floret weight data were natural log-transformed ($\ln[x + 1]$) and subjected to ANOVA in the general linear model using the PROC GLM procedure in SAS. The HSs were the treatments with 20 plant replications every week. The normality of the residuals was checked using the PROC UNIVARIATE procedure in residuals in SAS. The treatment and replication were the fixed effects in all the analyses. The means were separated using Tukey's honestly significant difference (HSD) test ($\alpha = 0.05$). Means and standard errors for the nontransformed data were calculated using the PROC MEANS procedure in SAS.

Pearson's correlation analysis was performed between the number of *D. radicum* larvae and root weights at 8 WAP to determine the association between these factors using the PROC CORR procedure in SAS. Pearson's correlation analyses were also performed between the root weight at 8 WAP and the diameter of the broccoli floret at 13 WAP, as well as between the root weight at 8 WAP and the

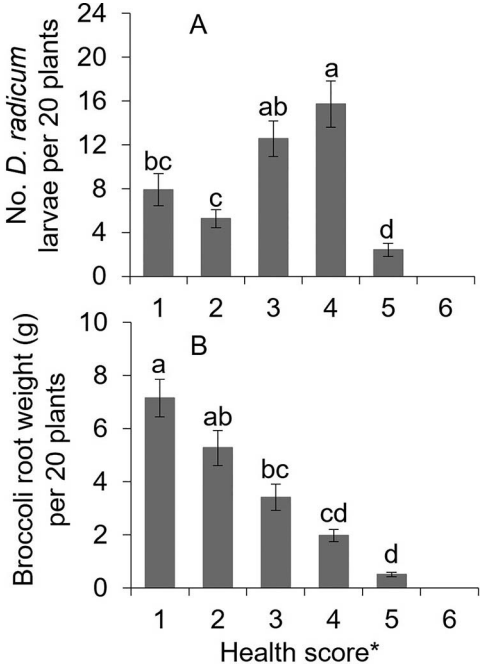

Fig. 1. Mean (±SE) (A) number of *Delia radicum* larvae and (B) root weight (g) on broccoli quantified or assessed by the visual health scale system at 8 weeks after plant emergence (WAP) in the field experiment. Bars with the same letters within a figure are not significantly different at α = 0.05 using Tukey's honestly significant difference test. The health scale system used to visually assess the health of broccoli plants infested with cabbage maggot is 1 = vigorous; 2 = vigorous but smaller in size; 3 = mild stunting; 4 = moderate stunting; 5 = severe stunting; and 6 = dead at 8 WAP.

broccoli floret weight at 13 WAP. Only the data from plants with HSs 1–3 were used for this analysis.

To determine the effects of soil type, the visual score (proportion of volume fed by larvae) and proportion of post- and preweight turnip disc data were transformed by arcsine square root. The dead *D. radicum* larvae data were not transformed. The data were subjected to ANOVA using a general linear model using the PROC GLM procedure in SAS. The means were separated using Tukey's HSD method ($\alpha = 0.05$). Means and standard errors for the nontransformed data were calculated using the PROC MEANS procedure in SAS.

Results and Discussion

***Delia radicum* infestation and impact: a case study.** At 8 WAP, the number of *D. radicum* larvae was significantly greater for the HS 4 treatment than for the HS 1, 2, and 5 treatments ($F = 14.9$; df $= 4, 72$; $P < 0.001$; Fig. 1A). There was no

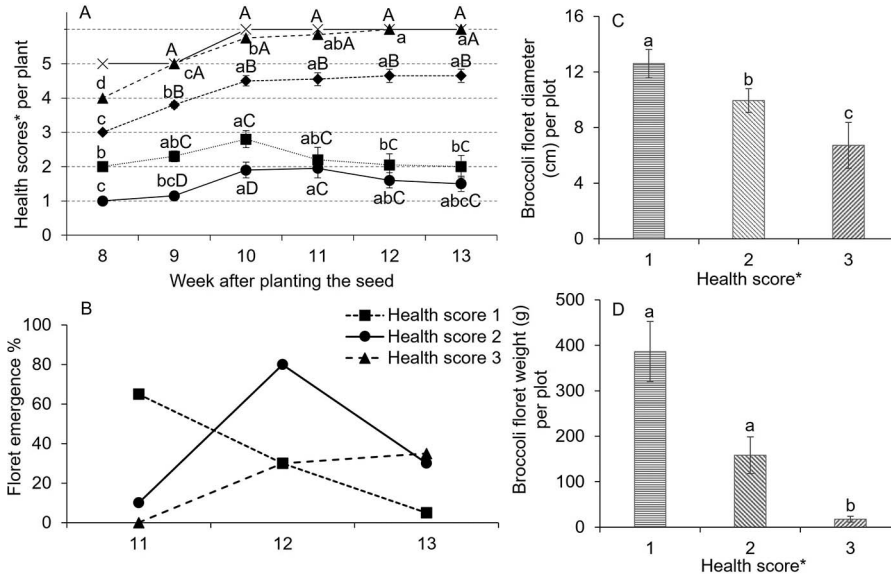

Fig. 2. (A) Mean (±SE) change in the visual health rating score from 8 to 13 weeks after planting (WAP), (B) emergence of broccoli florets (floret diameter <5 cm) at 11–13 WAP, (C) mean (±SE) diameter (cm), and (D) weight (g) of broccoli florets at 13 WAP in the field experiment. At 8 WAP, all the plants were categorized and initially rated from 1 to 6 using the health score (HS) system, where 1 = vigorous; 2 = vigorous but smaller in size; 3 = mild stunting; 4 = moderate stunting; 5 = severe stunting; and 6 = dead. For (A), data points with the same letters (uppercase letters within a WAP and lowercase letters between WAPs within a HS treatment are significantly different at $\alpha = 0.05$ using Tukey's honestly significant difference (HSD) test. For (C) and (D), bars with the same letters within a figure are not significantly different at $\alpha = 0.05$ using Tukey's HSD test. *Plants were rated on the basis of a 1–6 health scale system at 8 WAP.

significant difference in counts of *D. radicum* larvae between HS 3 and 4 treatments. The weight of the broccoli shoot was significantly greater for the HS 1 treatment than for the HS 2, 4, and 5 treatments ($F = 108.0$; df = 4, 68; $P < 0.001$; Fig. 1B).

For HS 1, scores significantly increased at 10–12 WAP than at 8 WAP ($F = 8.8$; df = 5, 95; $P < 0.001$; Fig. 2A). For HS 2, scores significantly increased at 10 WAP than at 8, 12, and 13 WAP ($F = 3.8$; df = 5, 95; $P = 0.004$). Those plants scored 1 and 2 at 8 WAP were not significantly different at 13 WAP. For HS 3, scores significantly increased at 10–13 WAP than at 8 and 9 WAP ($F = 36.9$; df = 5, 95; $P < 0.001$). For HS 4, scores significantly increased at 11–13 than at 8 and 9 WAP ($F = 205.7$; df = 5, 95; $P < 0.001$). For HS 5, there were no significant changes among WAP.

When analyzed by week, HS 4 and 5 treatments were not significantly different from each other at 9 ($F = 332.2$; df = 4, 76; $P < 0.001$) and 10 WAP ($F = 96.4$; df = 4,

76; $P < 0.001$) but were significantly greater than HS 3, followed by HS 2 and then HS 1 treatments (Fig. 2A). HS 4 and 5 treatments were significantly greater than HS 3, followed by HS 2 and 1 treatments at 11 ($F = 71.9$; df = 4, 76; $P < 0.001$), 12 ($F = 115.6$; df = 4, 76; $P < 0.001$), and 13 ($F = 114.7$; df = 4, 76; $P < 0.001$) WAP. There was no significant difference in scores between HS 4 and 5 treatments at 11–13 WAP.

At 11 WAP, approximately 60% of floret development was first initiated on HS 1 plants at 8 WAP. In contrast, <10% of floret initiation was observed on HS 2, and none on plants scored 3–5 (Fig. 2B). At 12 WAP, more florets were initiated. HS 2 plants had >80% of florets initiated. In contrast, approximately 30% of floret initiation was observed on HS 3 plants at 8 WAP (Fig. 2B). Plants scored 4 and 5 had no floret initiation. At 13 WAP, no change in the floret initiation was observed on HS 3 plants (Fig. 2B).

At 13 WAP, the diameter of the florets was significantly greater for the HS 1 treatment than for the HS 2 treatment, followed by HS 3 treatment ($F = 29.5$; df = 2, 25; $P < 0.001$; Fig. 2C). The weight of the florets was significantly greater for the HS 1 and 2 treatments than for the HS 3 treatment ($F = 22.2$; df = 2, 25; $P < 0.001$; Fig. 2D).

Pearson's correlation analysis showed a significant negative association (at $\alpha = 0.1$) between the number of *D. radicum* larvae and root weights at 8 WAP ($r^2 = -0.185$; $P = 0.075$; $n = 93$). Significant correlations were observed between root weight at 8 WAP and broccoli floret diameter at 13 WAP ($r^2 = 0.369$; $P = 0.013$; $n = 45$), and root weight at 8 WAP and broccoli floret weight at 13 WAP ($r^2 = 0.342$; $P = 0.022$; $n = 45$).

Soil type and *D. radicum*. On the basis of the *D. radicum* damage score, the proportion of damage was significantly lower for the Diablo Clay, Lockwood Loam, and Oceano Sandy Loam treatments than for the Arroyoseco gravelly loam, Chualar Loam, Danville Sandy Loam, Hanford Gravely Sandy Loam, Salinas Clay Loam, and Clear Lake Clay treatments, followed by Mocho Silt Loam treatment ($F = 15.0$; df = 17, 492; $P < 0.001$; Fig. 3A). There were no significant differences between Diablo Clay, Lockwood Loam, Oceano Sandy Loam, Rincon Clay, and Santa Ynez Sandy Loam treatments. The proportion of turnip discs unfed by *D. radicum* larvae was significantly greater for the Oceano Sandy Loam than for the Danville Sandy Loam, Metz Complex, and Lockwood Loam treatments ($F = 15.0$; df = 17, 424; $P < 0.001$; Fig. 1B). *Delia radicum* larval mortality was significantly greater for the Diablo Clay treatment than for the Santa Ynez Sandy Loam treatment, followed by the Hanford Gravelly Sandy Loam, Danville Sandy Loam, Elkhorn Fine Sandy Loam, Mocho Silt Loam, and Pacheco Clay treatments ($F = 9.8$; df = 17, 492; $P < 0.001$; Fig. 1C).

The results indicate that plants with milder *D. radicum* larval infestation (fewer than six larvae per plant) with mild wilting at 8 WAP recovered over time and produced florets earlier than severely affected plants (Figs. 1, 2). However, those plants in poor health at 8 WAP did not survive or recover to normal development in the subsequent weeks. This study showed that *D. radicum* larval infestation and its severity are not uniform across the field. Some plants have more larvae infested than others, which produces a disproportionate response across the field, leading to the asynchronous development of plants, floret initiation, and maturity of florets. Broccoli growers abandon affected fields entirely and accept crop loss when there are more than two or three harvest passes. Asynchronous development in broccoli florets creates a

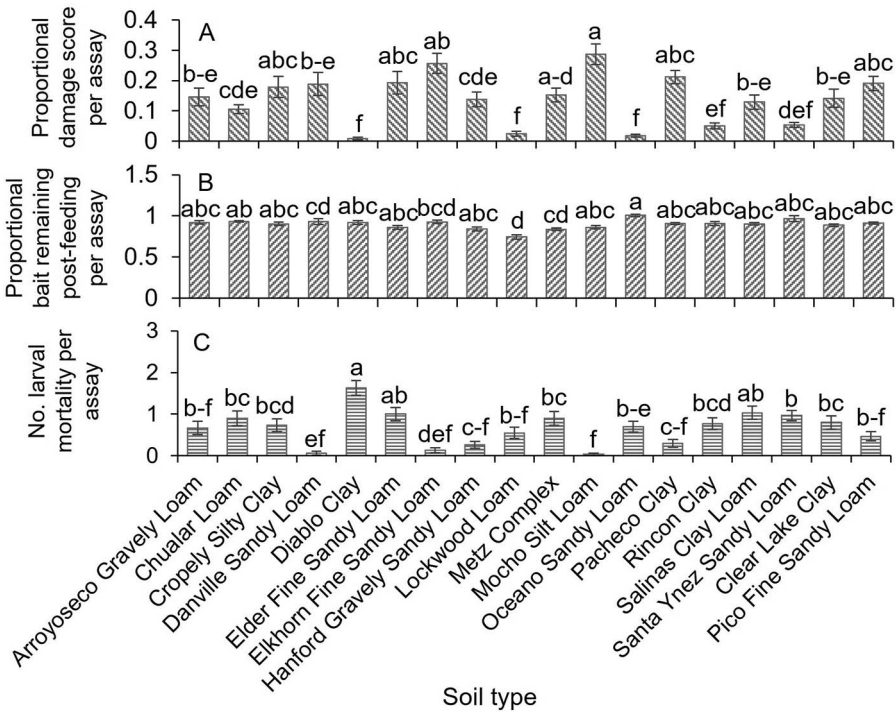

Fig. 3. Mean (±SE) of (A) the proportion of turnip visual scores exposed to *Delia radicum* larval feeding for 3 d; (B) the proportion of turnip weight post- and pre-exposure to *D. radicum* larvae, and (C) *D. radicum* larval mortality after 3-d exposure in the laboratory experiment. Three *D. radicum* larvae were introduced on a column of soil in a 15-mm-diameter × 15-cm-long polyvinyl chloride pipe and the feeding damage of turnip placed in the bottom of the soil column was assessed. Bars with the same letters within a figure that are not significantly different using Tukey's honestly significant difference test at $\alpha = 0.05$.

logistical harvest challenge for broccoli growers, and data indicate that *D. radicum* infestation can be a contributing factor. Growers face crop loss if the entire field does not yield in limited harvest passes. Given the cost of each harvest, growers prefer to avoid more than three harvests because of logistical constraints and labor shortages. Thus, *D. radicum* infestation can cause asynchronous plant growth and floret development, increasing the risk of economic loss to growers.

Larvae activity of *D. radicum* was not similar across various soil types that occur on the Central Coast of California (Fig. 3). Reduced larval feeding was observed with Oceano Sandy Loam soil, Diablo Clay, and Lockwood Loam soils, although the exact reason is unknown. The data showed that these soil types might hinder larval activity and reduce damage. Other soil types evaluated besides Oceano Sandy Loam soil, Diablo Clay, and Lockwood Loam did not affect the development of *D. radicum* larvae, as they could perform feeding and movement within the soil column exposed to the soil

type. More research is warranted to determine the precise mechanisms primarily driven by soil properties that support or deter the feeding and movement behaviors of *D. radicum* larvae in soil.

In summary, the data from the case study suggest that, if not managed, *D. radicum* larval feeding can devastate broccoli production, leading to 100% crop loss on the Central Coast of California. *Delia radicum* infestations can lead to the asynchronous development of broccoli florets, interfering with harvest and marketability. Thus, managing *D. radicum* is necessary to reduce infestation and prevent asynchronous development of plants and florets. Data also showed that certain soil types, such as Oceano Sandy Loam soil, Diablo Clay, and Lockwood Loam, may affect the performance and survival of *D. radicum* larvae. Thus, areas with Oceano Sandy Loam soil, Diablo Clay, and Lockwood Loam may reduce the risk of *D. radicum* problems. More research is needed to validate the findings in field conditions.

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References Cited

Coaker, T.H. and S. Finch. 1971. The cabbage root fly, *Erioischia brassicae* (Bouché). Report of the National Vegetable Research Station for 1970. Pp. 23–42.

Collier, R.H., M. Hommes, S. Finch, A.N.E. Birch, E. Brunnel, J. Freuler and H. Den Ouden. 1988. Induction of diapause in populations of cabbage root fly pupae; relationship between site latitude and critical day length. WPRS/OILB Bull. 1988/XI/I.

Ester, A., H. de Putter and J.G.P.M. van Bilsen. 2003. Filmcoating the seed of cabbage (*Brassica oleracea* L. convar. *Capitata* L.) and cauliflower (*Brassica oleracea* L. var. *Botrytis* L.) with imidacloprid and spinosad to control insect pests. Crop Prot. 22: 761–768.

Finch, S. 1974. Feeding and associated behaviour of the adult cabbage root fly *Erioischia brassicae* (Beh.) (Dipt., Anthomyiidae) under laboratory conditions. Bull. Entomol. Res. 63: 661–671.

Finch, S. and R.H. Collier. 1983. Emergence of flies from overwintering populations of cabbage root fly pupae. Ecol. Entomol. 8: 29–36.

Harris, C.R. and H.J. Svec. 1966. Mass rearing of the cabbage maggot under controlled environmental conditions, with observations on the biology of cyclodiene-susceptible and resistant strains. J. Econ. Entomol. 59: 569–573.

Johnsen, S. and A.P. Gutierrez. 1997. Induction and termination of winter diapause in a Californian strain of the cabbage maggot (Diptera: Anthomyiidae). Environ. Entomol. 26: 84–90.

Joseph, S.V. 2013. Root maggot pest on brassicas in the Salinas Valley. Salinas Valley Agriculture. University of California Agriculture and Natural Resources (https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=9804) (Last accessed 20 March 2025).

Joseph, S.V. 2016. Timing of insecticide application for cabbage maggot (Diptera: Anthomyiidae) control in seeded turnip in Central Coast of California. Southwest Entomol. 41: 625–632.

Joseph, S.V. 2023. Relative susceptibility of brassicas to cabbage maggot (Diptera: Anthomyiidae) infestation. Insects 14: 411. doi: 10.3390/insects14050411.

Joseph, S.V. and S. Iudice. 2020. Evaluation of seedling tray drench of insecticides for cabbage maggot (Diptera: Anthomyiidae) management in broccoli and cauliflower. Florida Entomol. 103: 172–179.

Joseph, S.V. and J. Martinez. 2014. Incidence of cabbage maggot (Diptera: Anthomyiidae) infestation and plant damage in seeded brassica fields in California's central coast. Crop Prot. 62: 72–78.

Joseph, S.V. and J. Zarate. 2015. Comparing efficacy of insecticides against cabbage maggot (Diptera: Anthomyiidae) in the laboratory. Crop Prot. 77: 148–156.

[MCCR] Monterey County Crop Report, 2021. 2022. Office of Agricultural Commissioner-Monterey County, California. 21 July 2023. (https://www.co.monterey.ca.us/home/showpublisheddocument/113214).

Natwick, E., S.V. Joseph and S.K. Dara. 2022. UC IPM pest management guidelines for cole crops: cabbage maggot. UC ANR Publication 3442. Oakland, CA. 21 July 2023. (https://ipm.ucanr.edu/agriculture/cole-crops/cabbage-maggot/).

[OSWGM] Open SoilWeb GMap. 2024. UC Davis, NRCS, University of California Agriculture and Natural Resources. 21 July 2023. (https://casoilresource.lawr.ucdavis.edu/soil-properties/).

SAS Institute. 2016. Version 9.4, SAS Institute Inc., Cary, NC.

[SBCCR] San Benito County Crop Report, 2021. 2022a. Office of Agricultural Commissioner–San Benito County, CA. 21 July 2023. (https://www.sanbenitocountyca.gov/home/showpublisheddocument/9289/638013491788500000).

[SBCCR] Santa Barbara County Crop Report, 2021. 2022b. Office of Agricultural Commissioner–Santa Barbara County, CA. 21 July 2023. (https://www.countyofsb.org/469/Crop-Reports) (Last accessed 20 March 2025).

[SCCCR] Santa Cruz County Crop Report, 2021. 2022. Office of Agricultural Commissioner-Santa Cruz County, CA. 21 July 2023. (https://www.agdept.com/Portals/10/pdf/Final%20Online%20-%202021%20Crop%20Report.pdf?ver=l87OElCLz3q_RcQe8X6GZw%3d%3d).

Schuh, M. 2017. Early-emerging cabbage maggot mows down and tunnels through roots of cole crops. Michigan State University Extension. 21 February 2025. (https://www.canr.msu.edu/news/cabbage_maggots_of_cole_crops).

[SLOCCR] San Luis Obispo County Crop Report, 2021. 2022. Office of Agricultural Commissioner-San Luis Obispo County, CA. 21 July 2023. (https://www.slocounty.ca.gov/Departments/Agriculture-Weights-and-Measures/Department-News/2021-Annual-Crop-Statistics-Released.aspx).

[SSMC] Soil Survey of Monterey County, California. 1978. Natural Resources Conservation Service. 21 July 2023. https://archive.org/details/usda-soil-survey-of-monterey-county-california/page/n37/mode/2up).