Feasibility of Managing Slugs in Cabbage

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INTRODUCTION

Slugs are an increasing threat to cabbage production: The board of the New York Cabbage Research and Development Program made "slug control" one of their highest research priorities for the first time in 2009. Slugs are considered a sporadic pest in cabbage and are favored by cool and moist conditions, especially where crop residues are left on the soil surface. In conventional production of cabbage, slugs tend to be a problem later in the growing season along tree lines and hedgerows and in weedy patches within the field. Slugs leave large holes in the leaves with the veins intact (Figure 1), and can be a contaminant in the heads when they squeeze between the leaves (Figure 2). During the cool wet growing season of 2009, slug contaminants were the cause of several rejected loads of cabbage in New York. It is predicted that the frequency of slug problems in cabbage will increase, because more cabbage is being grown in rotation following field corn. The newer varieties of field corn are Bt-tolerant and have tougher stalks that take longer to break down, thus, these fields have more crop residue and are more favorable for slugs. It is worthwhile to investigate whether there are cost effective means for growers to manage sporadic infestations of slugs in cabbage.

Slugs like it cool and moist: In New York, probably the most common slugs found in cabbage fields are the garden slug, *Arion hortensis*, and the field slug, *Derocereas reticulatum*. Garden slugs are small and blackish reaching up to 3 cm in length. Field slugs are grey/fawn in color with darker flecks and up to 4 cm in length. In New York, slugs have 1.5 to 2 generations per year. Slugs over winter in any life stage including eggs, juveniles and adults. Slug activity begins in the spring when temperatures are consistently above 40˚F. Two main reproductive peaks occur; the first in June when the overwintering adults mate and lay eggs and when the overwintering eggs hatch, and the second occurs in October. Slugs prefer high humidity and low temperatures, 50 – 60˚F, for egg hatch, egg laying and feeding activity. Slugs are prone to desiccation and, temperatures in the 90s are lethal. Slugs are active at night and are favored by dewy windless conditions. During the day, they hide in crevices and cracks in the ground, and under debris, stones and pieces of wood. In cabbage, they seek the moist environment that occurs at the base of the plant and in between the leaves (Figure 3).

Slugs are not insects and not killed with insecticides: Slugs belong to the phylum Mollusca along with snails, clams and squid. They are not insects, but gastropods, and therefore are generally not killed by insecticides. Slug management with pesticides is difficult because of the slug's biology and the lack of materials that are effective. Because of the slug's ability to "slime", most toxins that are contact poisons are sloughed off. The only true molluscicide in

the United States is metaldehyde, which is commonly marketed as Deadline Bullets. The activity comes from its ability to cause the mucus-producing cells found in slugs to burst, causing death of the slug. To be effective, good coverage is essential (preferably 4-5 pieces per square foot) and its recommended rate for vegetables is 20 to 40 lbs per acre. Several studies in minimum tillage field corn and soybeans in Ohio, Virginia and Delaware have shown that metaldehyde applied preventatively (i.e. at the 3-4 leaf stage of corn) provided excellent control of slugs with significantly fewer slugs per plant, less damage and increased yields compared to the untreated. The challenge with using metaldehyde bait in cabbage is getting the pellets to the soil surface through the plants' large prostrate leaves, because the pellets are not allowed to contaminate the edible portions of the plant. If metaldehyde bait were applied to cabbage once the slugs had already entered into the heads, it is questionable whether they would still be attracted to the bait and come out of the heads.

Other options to control slugs: The most effective means of controlling slugs is with Mesurol® 50% HB (hopper box), active ingredient, methiocarb, which is no longer labeled for slug control in the United States (although permitted for slug control in Europe). When it was labeled as a 24(c) in corn in Ohio in the 1980s, it was applied at 20 lbs of prepared bait (1 lb of Mesurol in 100 lb of cracked corn) per acre and had a 120 day pre-harvest interval (PHI). Due to such a long PHI, using methiocarb in cabbage would be impossible.

Applying concentrated liquid fertilizer, which is caustic to the slug, has reportedly worked well in field corn. In one experiment in Maryland, 10 gal of 30% urea-based nitrogen applied with 10 gal of water (total 20 gpa) provided 74% control of slugs over the untreated. The challenges with using high concentrations of fertilizer are first, that it needs to come in contact with the slugs, which may be challenging in cabbage even if it is applied on a wind-free night, and second, it may be phytotoxic to the crop.

Lannate LV (EPA No. 352-384), active ingredient methomyl 29% has a 2(ee) Recommendation for control of slugs in field corn and soybeans in Delaware, Maryland, Pennsylvania, Virginia and West Virginia. It is labeled to apply 1.5 pt/acre when slug populations reach locally determined economic thresholds at 5 to 7 day intervals for up to 10 and 3 applications, in field corn and soybeans, respectively. It is recommended to make applications in the early evening through early morning when slugs are active and feeding. Best results follow direct spraying of the target insect. In Canada, Lannate Toss-N-Go, methomyl 90%, is labeled for control of slugs (larvae of grey garden slug) in Brussels Sprouts: apply one application of 775 g/hectare late in the evening using sufficient water to obtain good coverage, PHI is 30 days. Similarly, it is also labeled on strawberries to control slugs for a single application only at mid-bloom. In New York, Lannate LV is labeled on cabbage for control of worm pests at 1.5 to 3 pts/acre per application, up to 24 pints and 15 applications per crop, with a minimum spray interval of 2 days and a PHI of 48 hours.

Another bait that is available to control slugs is iron phosphate, which includes trade name Sluggo and many others. Several labels of iron phosphate are OMRI approved for organic use and several are available for home gardens, because it is has low mammalian toxicity. Data suggest that iron phosphate generally is comparable in effectiveness to metaldehyde, but it tends to break down quicker during moist conditions.

Copper has been shown to work as a repellant to slugs. It is believed that copper reacts with the slime that slugs secrete, causing disruption in their nervous system similar to an electric shock. Copper sulfate has long been used with great success in tropical countries to clear disease-carrying snails from ditches and lakes, although it can be toxic to water plants and fish. It has been found to be especially effective against the field slug when sprayed on the soil. It is a contact poison and would be most effective when slugs are active. In New York, there are certain formulations of copper sulfate, such as Cuprofix 40 Disperss (basic copper sulfate 71.1%) that are labeled on cabbage for black rot and may be applied several times at 7-10 day intervals.

Browseban is used as a deer and raccoon repellent in cabbage. Its active ingredients, capsaicin and related capsaicinoids, are derived from hot peppers and it serves as a sensory irritant causing burning of the mouth, throat, eyes and skin. It has never been tested against slugs, but it is conceivable that it could serve as a skin irritant to slugs and deter them from entering into or to evacuate a treated cabbage plant.

OBJECTIVE

To investigate the efficacy and economic feasibility of various strategies to minimize contamination of slugs in cabbage.

PROCEDURES

Field Study: A small plot field trial was set up in a grower's cabbage (c.v. Blue Thunder) field that was bypassed for a number of reasons including serious slug contamination. The trial was set up as a randomized complete block design with 6 treatments (Table 1) and 5 replications. Each treatment replicate consisted of 3 rows of cabbage spaced 30 inches apart by 20 feet long (Figure 4).

Deadline MP (mini-pellets) was included, because it is the only known molluscicide with known activity against slugs. It was applied by hand between the cabbage rows, taking care not to contaminate the edible portions of the cabbage plants. The desired rate of 30% urea-based liquid nitrogen was 10 gal nitrogen + 10 gal of water, but we only had enough nitrogen at the time of mixing to make up a half rate treatment. Due to a calculation error, Browseban was applied at 15 fl oz per acre, which is 15 times the recommended rate that is used on cabbage as a deer repellent (e.g. 1.28 fl oz per acre). Asana XL was included in the trial at the highest labeled rate in cabbage at the request of the grower cooperator. Unfortunately, we were unable to obtain a bactericide that contained basic copper sulfate in time to include in our trial.

A single application of each treatment was applied on September 10, 2010 during perfect conditions for peak slug activity: at night between 11:30 pm and 12:30 am, relative humidity was 85% and there was a heavy layer of dew on the cabbage, air temperature was 53 ˚F and wind speed was 0-2 mph. Deadline MP was broadcasted by hand in between the cabbage rows. The liquid treatments were applied using a CO^2 pressurized backpack sprayer with three XR8005 nozzles spaced 19 inches apart, with 30 psi delivering 40 gpa. The nitrogen treatment was applied at 20 gpa.

After 3 days, the trial was harvested. In rep 1, all of the heads in the center row were harvested (12 to 16 heads), but in the essence of time (i.e. the field was being disked so that wheat could be planted) for reps 2 to 5, only 5 randomly selected heads in the middle row were harvested. Per plant, the total number of slugs was counted on both the head, which included two wrapper leaves, and on all of the remaining outer leaves (Figure 5). Any dead slugs found on cabbage plants were recorded. For the Deadline MP treatment, the total number of dead slugs observed per replicate plot was counted.

Table 1. Selected materials evaluated for control of slugs in cabbage, field trial, Elba, NY, 2010.

Treatment	Active ingredient	Rate (applied once)	Application details
Untreated control	--	--	--
Deadline MP (mini pellets)	metaldehyde 4%	20 lbs per acre	Spread by hand between rows
30% urea-based liquid nitrogen	30-0-0 N-P-K	5.5 gal N + 10 gal water (0.55:1)[1]	20 gpa, 30 psi
Lannate LV + Induce	methomyl 29%	3 pts per acre + 0.25% v/v	40 gpa, 30 psi
Asana XL[2] + Induce	esfenvalerate 8.4%	9.6 fl oz per acre + 0.25% v/v	40 gpa, 30 psi
Browseban	capsaicin and related capsaicinoids 2%	15 fl oz per acre[3]	40 gpa, 30 psi

[1]less than desired rate, wanted 10 gal N + 10 gal water, did not have enough 30-0-0 on hand.
[2]this treatment was requested by the grower cooperator.
[3]this rate is 15x higher than the label rate to repel deer (1.28 fl oz/gal) due to a calculation error.

Bioassay: If a treatment did not control slugs in the field, it could be because it does not have efficacy against slugs or because the slugs did not come into contact with it. Therefore, we conducted a bioassay where we exposed slugs directly with the different treatments to determine their efficacy. Slugs were collected from the field trial to use in our bioassay. Treatments included Deadline MP, Lannate LV and Asana XL as described in the field trial. Also, the originally targeted rates of 30% urea-based liquid nitrogen at 1:1 N: water in 20 gal, and 1.28 fl oz/acre of Browseban were used. Sluggo, iron phosphate 1% at 20 lb/acre was also included. Each treatment was replicated 4 times.

Each replicate consisted of a 12 quart plastic Sterilite® bin, in which a cabbage leaf that was free of chemicals was placed. Five slugs ranging in size from small (< 1 cm), medium (1-2 cm) and large (> 2 cm) were placed on the cabbage leaf, which was then spritzed with water (Figure 6). The bait treatments were measured out according to the 12.5" x 8" area of the containers and sprinkled into each container by hand. The liquid treatments were applied to the containers with the exposed slugs using the backpack sprayer as described for the field trial. After the treatments were applied, each container was closed with tulle fabric allowing the slugs to breath. The bioassay was set up on September 17, 2010 and evaluated after 4 days on September 22, 2010. The number and size of live, dead and missing slugs were recorded. Missing slugs were not presumed dead or alive.

Unfortunately, the vast majority of the slugs had desiccated in our first bioassay by the time that it was evaluated. Consequently, another bioassay was set up with a few modifications: 1) Slugs were collected from brush-like vegetation bordering a commercial cabbage field; 2) To ensure adequate moisture, the bins were lined with a moist paper towel on top of which the cabbage leaf was placed, and another paper moist paper towel was placed over top of the treated and spritzed cabbage leaf; 3) Slug status (i.e. alive, dead or missing) was evaluated and the slugs rehydrated 14, 36 and 60 hours after the treatments were applied. This bioassay was set up on September 25, 2010 and evaluated on September 26th, 27th and 28th.

Statistics: Differences among treatments were analyzed using General Analysis of Variance and Fisher's Protected LSD test ($\alpha = 0.5$).

RESULTS AND DISCUSSION

Field trial (Table 2): Slug pressure at this site was high with 95% of the plants and 80% of the heads infested and a total average of 3.2 slugs per plant in the untreated check. No significant differences occurred among treatments with respect to the percentage of plants or heads (2 wrapper leaves only = marketable portion) infested with slugs. Numerically, the untreated check had the highest slug infestation. The treatments did not appear to reduce slug infestation of whole plants with all treatments having 79% or more slug infestation except Browseban, which had 72%. Slug contamination of the cabbage heads was considerably reduced to one third of the untreated with Deadline MP (29% infested) and to 43%, 51% and 54% infested with Browseban, Lannate LV and 30% urea-based nitrogen, respectively. No significant differences occurred among treatments with respect to the number of slugs per whole plant and in the outer frame leaves, although dead slugs were found in the Deadline MP and the Lannate LV treatments. Significant differences occurred among treatments with respect to slug contamination in the cabbage heads with all treatments except Asana XL having significantly fewer slugs than the untreated. Numerically, Deadline MP and Browseban had the fewest slugs per head (0.6). Dead slugs were observed in the heads of Deadline MP and Lannate LV treatments. We found an average of 16.25 dead slugs per 100 ft2 on the soil surface in the Deadline MP treatment (Figure 7). We noticed that the Browseban treatment turned the cabbage leaves a light green (Figure 8). Otherwise, no phytotoxicity was observed.

Our results show that Deadline MP and Lannate LV kill slugs and have potential to be used as a rescue treatment to reduce slug contamination in cabbage heads. Theoretically, slug control would be improved if either of these products were used preventatively or when multiple applications are made. In this study, Browseban applied at a 15x rate showed potential as a slug repellent; trialing it at the 1.28 fl oz rate is warranted. We observed Browseban residue, which is orange compared to other treatments that were not visible, in the leaf axils of the lower frame leaves of the cabbage plants, a strong indication that using 40 gpa and 30 psi was adequate in delivering the sprays to the target area where the slugs reside (Figure 9). The fact that there were significantly fewer slugs in the cabbage heads treated with Deadline MP is an indication that the slugs left the heads to eat the bait.

Table 2. Efficacy of selected rescue treatments for controlling slugs in cabbage, 3 days after a single application, September 13, 2010: field trial, Elba, NY, 2010.

Treatment and Rate (per acre)	% infested with slugs		Total No. of slugs per plant		No. of slugs on outer frame leaves per plant[3]		No. of slugs per head[3]	
	whole plant[3]	head[3]	total	dead	total	dead	total	dead
Untreated	95	80	3.2	0.0	1.6	0.0	1.6 a[4]	0.0
Deadline MP @ 20 lb	79	29	2.2	0.1	1.6	0.1	0.6 b	0.03
30% urea-based nitrogen @ 0.55:1 H: water in 20 gal[1]	92	54	2.4	0.0	1.5	0.0	0.9 b	0.0
Lannate LV @ 3 pts	83	51	3.1	0.7	2.3	0.7	0.8 b	0.07
Asana XL @ 9.6 fl oz	92	70	2.6	0.0	1.4	0.0	1.1 ab	0.0
Browseban @ 15 fl oz[2]	72	43	2.3	0.0	1.7	0.0	0.6 b	0.0
P Value (α = 0.05)	***NS[5]***	***NS***	***NS***	***--***	***NS***	***--***	***0.0019***	***--***

[1]lower than the recommended rate for field corn of 1:1 ration in 20 gal. [2]15x higher than the label rate of 1.28 fl oz per acre due to a calculation error. [3]**whole plant:** includes slugs found in head and all wrapper and lower frame leaves on plant. **head:** includes slugs found only in the head with 2 wrapper leaves, presumably the marketable portion of the plant. [4]Numbers in a column followed by the same letter are not significantly different, Fisher's protected LSD test, $p<0.05$. [5]**NS:** not significant, Fisher's Protected LSD test, $P>0.05$.

Bioassays (Table 3): Although the vast majority of the slugs had desiccated by the time we were able to evaluate the treatments after 4 days in the first bioassay, we did make the following observations when we were setting up the trial: 1) within 5-10 minutes of application, dead or dying slugs were observed in the Lannate LV (Figure 10) and 30% urea-based nitrogen treatments (Figure 11); 2) slugs were eating the Deadline mini pellets (Figure 12), and ; 3) slugs treated with Browseban appeared irritated and quick to escape to the untreated underside of the cabbage leaf (Figure 13). These results demonstrated that: 1) Lannate LV and 30% urea-based nitrogen have contact activity against slugs; 2) slugs are attracted to Deadline MP bait, and; 3) Browseban repels slugs.

In the second bioassay, significant differences occurred among treatments 36 and 60 hours after the treatments were applied. Although not significant, 14 hours after treatment, 30% urea-based nitrogen had 30% dead slugs, Deadline MP had 11.2% dead slugs and Browseban and Sluggo had 6.3% and 5%, respectively. Thirty-six hours after treatment, Deadline MP had significantly higher slug mortality (66.3%) than all other treatments with Lannate being the only treatment with no mortality. Sixty hours after treatment, Deadline MP still had significantly higher slug mortality (71.2%) than all other treatments, while Lannate LV had none. The second and third highest slug mortality occurred in the 30% urea-based nitrogen (35%) and Sluggo (16.2%) treatments, respectively. The vast majority of the slugs that were killed in all treatments were small (< 1 cm). The only treatment where any large slugs were killed was Deadline MP.

It does not make sense that there was no slug mortality in the Lannate LV treatment in the second bioassay, because we observed slug mortality in the field trial and in the first bioassay; perhaps human error in treatment application is at fault. Our preliminary results indicate that of the two baits, Deadline MP was more effective. However, Sluggo is known to be more slow acting than Deadline MP, so there is the possibility that slug mortality would have increased over time. In this bioassay, we observed that the slugs in the Sluggo treatment were hiding under and feeding on the cabbage leaf, never did we observe slugs feeding on the bait like we did with Deadline MP. The observed habit of the slugs to promptly escape contact with Browseban and its relatively low slug mortality suggest that it has potential to work as a repellent.

Table 3. Efficacy of selected treatments for control of slugs: bioassay, 2010.

Treatment and Rate (per acre)	**% of slugs dead (No. of hours after treatment)**			**Size of dead slugs**
	14 h	**36 h**	**60 h**	
Untreated	0.0	6.3 b[1]	6.3 c	Small – 100%
Deadline MP @ 20 lb	11.2	66.3 a	71.2 a	Small – 61%, Medium – 31%, Large – 7.7%
30% urea-based nitrogen @ 1:1 N: water in 20 gal	30.0	30.0 b	35.0 b	Small – 86%, Medium – 14%
Lannate LV @ 3 pts	0.0	0.0 b	0.0 c	
Asana XL @ 9.6 fl oz	0.0	6.3 b	6.2 bc	Small – 100%
Browseban @ 1.28 fl oz	6.3	16.3 b	16.2 bc	Small – 66%, Medium – 33%
Sluggo @ 20 lbs	5.0	26.3 b	31.2 b	Small – 66%, Medium – 33%
P Value (α = 0.05)	***NS[2]***	***0.0048***	***0.0015***	

[1]Numbers in a column followed by the same letter are not significantly different, Fisher's Protected LSD test, p <0.05. [2]NS: not significant, Fisher's Protected LSD test, P>0.05.

Economic analysis (Table 4):

Even though Deadline MP gave best control of slugs with 71% clean heads at harvest, it was also the most expensive at $50 per acre, which is the lowest label rate. Using higher rates or more than one application (i.e. preventatively) may provide improved control, but potentially at a prohibitive cost. Browseban, Lannate LV and 30% urea-based nitrogen cost one third to one half of the cost of Browseban, but provided only mediocre control. The advantage of Lannate LV and Browseban is that in addition to reducing slug contamination, they help to control worm pests and to repel deer in cabbage, respectively.

RECOMMENDATIONS AND FUTURE RESEARCH

At this time, the only recommendation that we can make for controlling slugs in cabbage is to try Deadline MP. The challenge will be for growers to spread Deadline MP without

contaminating the edible portions of the cabbage plants. Lannate LV, Browseban and 30-0-0 show potential, but require further research and labeling at this time.

In 2011, we would like to investigate the following:

- Evaluate a preventive vs. a rescue application of Deadline MP, as well as the 40 lb rate.
- Evaluate Browseban in the field at the labeled rate of 1.28 fl oz.
- Evaluate Lannate LV again, at both 1.5 pt and 3 pt rates, possibly with multiple applications.
- Evaluate a bactericide with basic copper sulfate as an active ingredient, since this was not available for our trials in 2010. Copper bactericides are relatively inexpensive (~$6 per acre per spray) and are commonly used in cabbage for management of black rot. It would be good to know if they had any activity against slugs.

Table 4. Cost of a slug control in cabbage, field trial, Elba, NY: 2010.

Treatment and Rate (per acre)	**Approximate Cost (per acre)[1]**	**% clean heads at harvest**	**Comments**
Deadline MP @ 20 lb	$50	71%	Labeled up to 40 lb = $100
Browseban @ 15 fl oz[2]	$15	57%	Labeled rate of 1.28 fl oz = $1, needs to be field- tested. Repellent for deer and raccoons.
Lannate LV @ 3 pts[2]	$26	49%	Labeled on cabbage to control worm pests. Does not include cost of Induce (NIS surfactant).
30% urea-based nitrogen @ 0.55:1 N:water in 20 gal	$15	46%	Try higher rate 1:1 N:water in 20 gal = $27

[1]single application, Deadline MP - $2.50/lb; 30-0-0 - $2.71/gal ($450/ton); Lannate LV - $70/gal; Browseban - $110/gal.

[2]Not labeled specifically for slug control, but cabbage is labeled.

Figure 1. Slug feeding damage; large holes with veins intact.

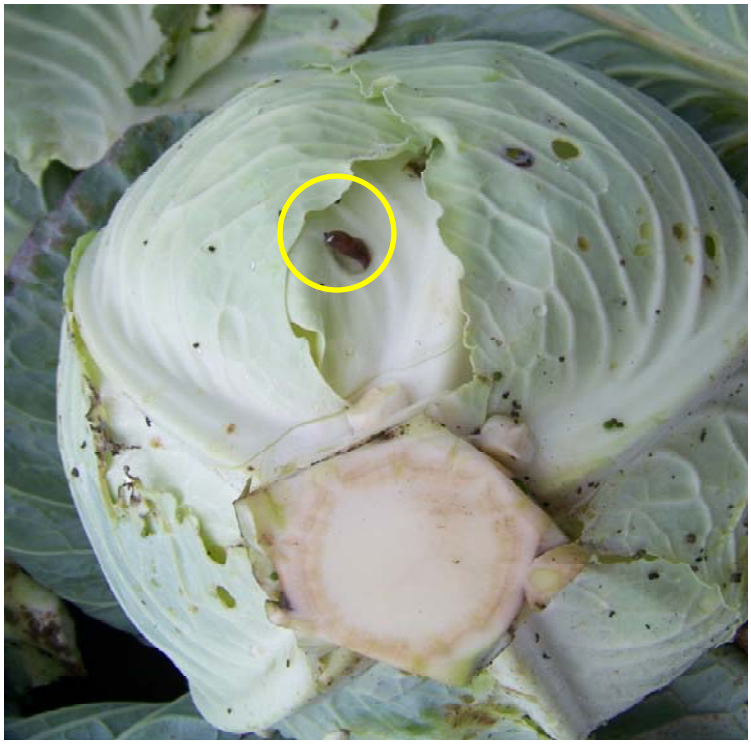

Figure 2. Slug contamination inside cabbage heads where they squeeze between the leaves.

Figure 3. Slug seeking moist environment at the base of cabbage plant.

Figure 4. Field trial to evaluate selected materials to control slugs in cabbage, Elba, NY, 2010.

Figure 5. Katie Klotzbach, CVP and Mike Riner, CY Farms, assessing selected treatments for control of slugs in cabbage: field trial, Elba, NY, 2010.

Figure 6. Slug bioassay #1: each replicate consisted of a 12 qt plastic bin, in which a cabbage leaf with 5 slugs was placed and spritzed with water prior to applying the treatment.

Figure 7. Dead slugs observed on soil surface 3 days following application of Deadline MP.

Figure 8. Cabbage leaves turned light green after treatment with 15 fl oz per acre of Browseban (15x label rate for repelling deer).

Figure 9. Residue of Browseban located in the leaf sxils of lower frame leaves, indicating that coverage when spray is applied at 40 gpa and 30 psi reached the target area where the slugs reside.

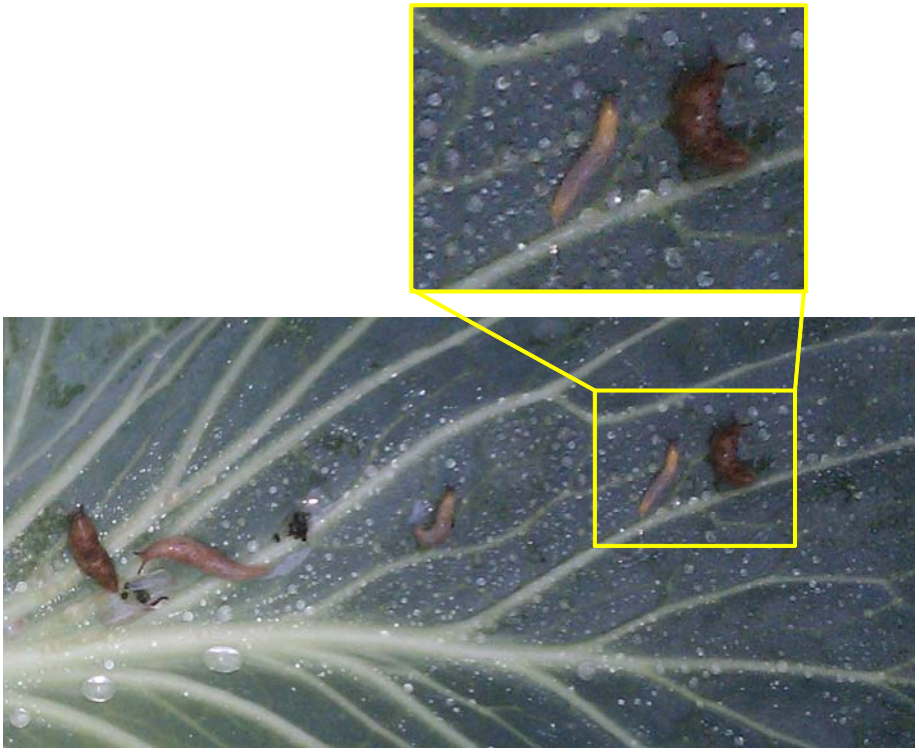

Figure 10. Slugs looking sickly 10 minutes after application with Lannate LV @ 3 pts per acre: bioassay #1.

Figure 11. Slugs dead within 5 minutes after application with 30% urea-based nitrogen @ 1:1 N: water in 20 gpa.

Figure 12. Slugs eating Deadline MP.

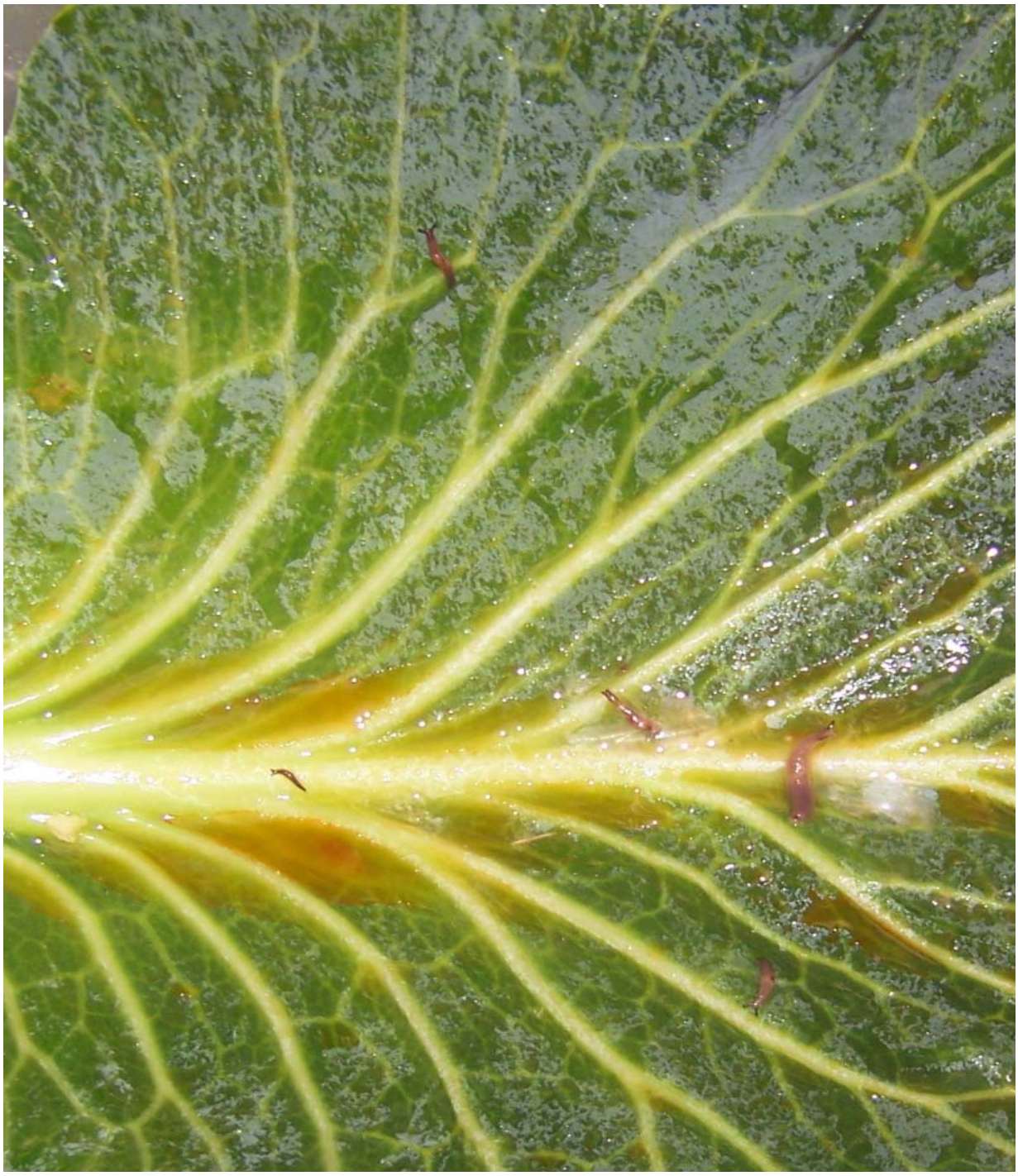

Figure 13. Slugs appearing irritated and promptly relocating themselves to the undersides of the leaf immediately after treatment with Browseban.