Graduate Student CERES Grant Final Report

1. Project Title: Spatiotemporal pattern of hog foraging in apple orchards when grazed for orchard floor management

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4. Accomplishments:
Our study was conducted in an organic apple orchard in Eaton County, MI USA in 2013. The apple trees in the orchard are 30 years old and spaced 10 ft apart, and the drive rows are 15 ft wide. The orchard was maintained and harvested using organic production practices. We established a total of eight plots in the orchard. Each plot was 0.5 acre in size (545 ft long and 80 ft wide), and contained three rows of trees that each had 45 trees. Six of the plots were grazed by hogs, and the other two plots served as controls. The hog plots were fenced using poly rope and step-in poly fence posts. The fence was connected to the farm power grid to electrify it. The grower rented 33 Duroc-mix hogs from a nearby hog producer from June 11 to July 5, 2013. The hogs had been raised on organic pasture prior to being rented and each weighed ~60 lb when introduced to the apple orchard. The 33 hogs were divided into three groups of 11 hogs and penned separately on the north border of the apple orchard. Hogs had *ad libitum* access to water and were fed a grain mixture each morning while in the apple orchard. Hogs were rotated through the six plots, and spent 9 d in each plot. Hog Group 1 was rotated through plots 1 and 2; Hog Group 2 was rotated through plots 3 and 4; Hog Group 3 was rotated through plots 5 and 6. Grazed plots 1, 3, and 5 comprised the first set of plots along with control plot 1. Grazed plots 2, 4, and 6 comprised the second set of plots along with control plot 2. Hogs were released into the first set of plots on June 16, 2013 and into the second set of plots on June 25, 2013.

Objective 1: *Determine the pattern and severity of hog ground disturbance of a set stocking density in apple orchards*
Objective one was addressed through measurements and observations made in the apple orchard. We established three 90 m transects along tree rows under the canopy in each plot. We evaluated ground cover every 24 h in the six grazed plots and approximately every 3 d in the two control plots. Measurements were taken every 3 m along the transects. Over nine days in the first set of three grazed plots (1, 3, 5), the hogs increased bare ground from a mean of 1.4% to 43.4% (Δ 42%), decreased grass from a mean of 63.7% to 33.9% (Δ 29.8%), and decreased forbs from a mean of 35% to 22.5% (Δ 12.5%) (**Fig. 1**). While in control plot 1 over the first 9-day period, grass cover remained between 78.1% and 79.7%, forbs remained between 19.8% and 22.3%, and bare ground remained <1% (**Fig. 2**). Over nine days in the second set of three grazed plots (2, 4, 6), the hogs increased bare ground from a mean of 9.4% to 55.4% (Δ 46%), decreased grass from a mean of 55.9% to 28.3%(Δ 27.6%), and decreased forbs from a mean of 34.6% to 16.1% (Δ 18.5%) (**Fig. 3**). While in control plot 2 over the second 9-day period, grass cover remained between 80.4% and 84.8%, forbs remained between 14.8% and 19.1%, and bare ground remained <1% (**Fig. 4**).

Overall, hogs increased bare ground and reduced grass and forbs ground cover (**Fig. 1 & 3**). In addition, hog experience seems to affect how quickly hogs disturb ground cover. Hogs took 4 days to increase the amount of bare ground to ~25% in the first set of plots, but only took 2 days to do so in the second set of plots. Also, the hogs took 7 days to increase the amount of bare ground to ~50% in the second set of plots, but had not achieved the same level of disturbance in the first set of plots at the end of the 9 day period. Hogs may need several days to acclimate and explore a new environment to feel comfortable. Practitioners of hog grazing for pest management should take this acclimation period into account when planning how long to leave hogs in an orchard for the first and subsequent times. Hogs will need less time to forage once they are acclimated to an orchard.

We also divided each plot into a grid, such that each quadrant in a tree row contained a single tree. Disturbance severity was measured in each quadrant every 24 h by assessing the percentage of undisturbed, grazed vegetation, partially rooted, and completely bare areas. A rating of 0 to 4 was assigned to each category, where 0=0%, 1=25%, 2=50%, 3=75%, and =100%. In order to create spatial figures showing the disturbance severity across time, we created a weighted composite value for each quadrant. The composite value can range from 0 to 1, where 0 represents no disturbance and 1 represents completely bare ground. The general pattern of hog foraging in this study conducted in 2013 closely resembled the pattern observed in the 2012 preliminary results. As in 2012, we again observed hogs concentrating their most severe rooting in the ends of plots, but also foraging in nearly all quadrants after only 2 or 3 days (**Fig. 5-7**). Again, hog experience appeared to affect how quickly hogs disturbed ground cover and the extent of disturbance throughout the entire plot. In the first set of plots, hogs took 2-3 d to disturb ground cover to some degree in ~50% of quadrants, but only 1 d in the second set of plots (**Table 1**). However, hog experience did not seem to account for the severity of rooting across plots. In the first set of plots, hogs took 5 d or less to disturb ~10% of quadrants to mostly bare ground (**Table 2**). Whereas in the second set of plots, it took two of the hog groups the entire 9 d to reach that level (**Table 2**). The area in and around the apple orchard had 3.38 in of accumulated rainfall while the hogs were in the first set of plots and 0.71 in of rain while the hogs were in the second set of plots. The higher amount of rain may have made the soil softer and easier for hogs to root in while they were in the first set of plots and potentially explain why a lower percentage of quadrants had a majority of bare ground in the second set of plots.

Table 1: Number and percentage of quadrants with any level of ground cover disturbance by day for all grazed plots.

	First Set of Grazed Plots						Second Set of Grazed Plots					
	Plot 1		Plot 3		Plot 5		Plot 2		Plot 4		Plot 6	
Day	#	%	#	%	#	%	#	%	#	%	#	%
1	11	4.1	96	35.6	32	11.9	156	57.8	221	81.9	131	48.5
2	70	25.9	161	59.6	133	49.3	179	66.3	235	87.0	173	64.1
3	127	47.0	183	67.8	179	66.3	203	75.2	252	93.3	200	74.1
4	147	54.4	201	74.4	204	75.6	210	77.8	258	95.6	205	75.9
5	158	58.5	204	75.6	215	79.6	213	78.9	265	98.1	207	76.7
6	175	64.8	222	82.2	218	80.7	216	80.0	267	98.9	209	77.4
7	178	65.9	231	85.6	222	82.2	219	81.1	267	98.9	214	79.3
8	185	68.5	233	86.3	223	82.6	225	83.3	268	99.3	215	79.6
9	193	71.5	235	87.0	223	82.6	225	83.3	268	99.3	218	80.7

Table 2: Number and percentage of quadrants with a majority of bare ground by day for all grazed plots.

	First Set of Grazed Plots						Second Set of Grazed Plots					
	Plot 1		Plot 3		Plot 5		Plot 2		Plot 4		Plot 6	
Day	#	%	#	%	#	%	#	%	#	%	#	%
1	0	0	14	5.2	4	1.5	10	3.7	0	0	0	0
2	2	0.7	24	8.9	14	5.2	14	5.2	1	0.4	3	1.1
3	8	3.0	32	11.9	22	8.1	19	7.0	2	0.7	5	1.9
4	11	4.1	41	15.2	29	10.7	26	9.6	7	2.6	7	2.6
5	25	9.3	49	18.1	33	12.2	28	10.4	11	4.1	8	3.0
6	34	12.6	51	18.9	38	14.1	29	10.7	14	5.2	11	4.1
7	43	15.9	58	21.5	46	17.0	33	12.2	19	7.0	16	5.9
8	45	16.7	62	23.0	54	20	34	12.6	22	8.1	21	7.8
9	47	17.4	65	24.1	56	20.7	36	13.3	25	9.3	23	8.5

Objective 2: *Determine the number of days needed for hogs to achieve desired level of dropped fruit removal in apple orchards during "June drop" period.*

Objective two was addressed through measurements and observations made in the apple orchard. Dropped fruit was quantified beneath 20 randomly selected trees in each plot. The number of fallen apples was counted beneath the selected trees every 24 h. The rate of apples falling off the trees remained relatively low while the hogs were in the first set of plots. As seen in **Fig. 8**, the amount of apples found beneath trees in the first set of grazed plots (1, 3, 5) and control plot 1 averaged below 20 apples per tree in the first 9 days. However, the rate of apples falling off the trees increased greatly during the time the hogs were in the second set of plots. As seen in **Fig. 9**, the average number of apples found beneath trees in control plot 2 peaked on day 3 (June 29, 2014) with a mean of 148 apples found per tree. There was no difference between the amount of dropped apples in the control plot and first set of grazed plots (**Fig. 8**), but the hogs greatly decreased the amount of dropped apples in the second set of grazed plots compared to the control plot (**Fig. 9**). From day 3 on in the second set of plots, the number of dropped apples per tree was ≥ 129 in the control plot and the mean number of dropped apples per tree was ≤ 17 in the grazed plots (**Fig. 9**). It appeared hogs only needed a single day following the peak day of fallen apples to sufficiently reduce the amount of apples found beneath the trees. If growers wish to reduce the amount of ground disturbed by hogs and focus on reducing the amount of dropped apples, they should aim to time hog grazing to coincide with the week where the rate of falling apples is greatest. Hogs could potentially only need 4 days or less to consume most dropped apples in an orchard.

We noted the hogs appeared to prefer consuming larger apples, so we gathered some preliminary data. On July 2, 2014, we gathered 90 dropped apples from trees we were not sampling and designated three apple size categories: small, medium, and large. Small apples had a diameter of 1 to 2 cm and a circumference of 4 to 5 cm. Medium apples had a diameter of 2 to 3 cm and a circumference of 7 to 9 cm. Large apples had a diameter of 4 to 5 cm and a circumference of 13 to 15 cm. We gave each group of hogs a set of 30 apples with 10 apples from each size category. The apples were placed on a bare patch of ground near the hogs and after 10 minutes we counted any unconsumed apples. The hogs clearly preferred the large apples, since two groups ate all of the large apples and the third group ate all but one of the large apples (**Table 3**). All three hog groups ate a majority of the medium apples and less than half of the small apples (**Table 3**). The hogs' preference for larger apples may explain why there was no difference in the amount of dropped apples found in the control and grazed plots for the first 9 days due to dropped apples being smaller and less developed earlier in the 'June drop' period.

Table 3: Hog apple size consumption preference—the number of apples consumed out of 10 given for each size category.

Pig Group	Large Apples	Medium Apples	Small Apples
1	10	6(2)	0(3)
2	9(1)	9(1)	5
3	10	6(4)	2(1)

Numbers in parentheses are the number of apples that were chewed or partially consumed.

The day the hogs were removed from the second set of plots, we selected 6 of the trees we had been sampling for dropped apples and collected all the dropped apples that remained. We then measured the diameter and circumference of the apples. All of the apples collected had a mean diameter of less than 2 cm and a mean circumference of less than 6 cm, placing all of them in the small size category (**Table 4**). The presence of only small dropped apples on the orchard floor after 9 d of hog grazing further suggests the hogs prefer to consume only larger sized apples. A preference for larger apples can likely be attributed to an increase of sugar content as the apples develop. A study showed an increase in sugars is the primary contributor to change in dry weight of apples as they develop, where sugars comprised 24.1% of dry weight in apples collected 51 days after full blossom and 71% of dry weight in apples collected 205 days after full blossom[1].

Table 4: Mean size and number of apples not consumed at the end of 9 d in the second set of plots (2, 4, 6) from a sampling of 6 trees per plot.

Grazed Plot	# Collected Apples	Mean # Dropped Apples per Tree	Mean Apple Diameter (cm)	Mean Apple Circumference (cm)
2	233	38.8	1.8	5.7
4	97	16.2	1.7	5.5
6	25	4.2	1.6	5.1

Objective 3: *Determine the impact of hog foraging on insect pest populations in apple orchards*
We were unable to detect adult insect pest populations in any of the plots. This was most likely due to extremely low populations as a result of crop failures from spring frosts in two of the three preceding years. We assessed the amount of fruit with insect damage during the 'June drop' period on June 18, 2013 to determine a level of insect presence. We sampled 450 apples in each plot for damage from Plum Curculio, Codling Moth, and Oriental Fruit Moth. We were interested in those three particular insect pest species because the larvae of all of them are internal feeders in apples and reduce yield. Less than 0.02% of the sampled apples showed any damage from the three insect species of interest, and there was no difference between the six grazed plots and two control plots (**Figure 10**). The extremely low incidence of fruit damage indicated that population levels were in fact extremely low and difficult to detect, rather than the possibility of trap failure. Undetectable populations levels meant we could not determine the impact of hog foraging on the populations of Plum Curculio, Codling Moth, and Oriental Fruit Moth.

Conclusions and Next Steps:
The hogs provided a valuable service by removing fruit and weeds from the orchard floor in the apple orchard. The three groups of young hogs have shown they are capable of consuming nearly all fallen apples larger than a 2cm diameter, as well as disturbing ground cover in over 50% of 0.5 acre plots in only a few days. Hogs are an effective method for removing dropped apples

[1] Robertson, R.N and J.F. Turner. (1951). The physiology in growth of apple fruits II: respiratory and other metabolic activities as functions of cell number and cell size in fruit development. *Australian Journal of Biological Sciences* 4(2): 92-107.

from an orchard in the 'June drop' period, if their grazing periods are timed well to the frequency of dropped apples. Hogs also demonstrated they can contribute to weed management when grazed during the 'June drop' period by reducing weeds up to ~50% (reduced grass cover up to ~30% and reduced forbs cover up to ~20%).

If planning on implementing hogs as a pest management tool, growers should keep a few factors in mind: stocking rate of hogs, hog size, hog experience, and potentially orchard plot shape. All of these factors will influence how long hogs should be allowed to graze in an orchard. Based on this study and previous work, we recommend using hogs in the weight range of 40 to 80 lb and keeping the stocking rate at or below 12 hogs per acre. Stocking rate may be altered based on hog size and possibly hog experience. When choosing larger sized hogs or more experienced hogs, a grower may wish to reduce the stocking rate to prevent larger areas of severe ground disturbance. Even young hogs are capable of severe and extensive rooting, if given enough time. Fewer days of grazing time will be needed when using higher stocking rates, larger hogs, or more experienced hogs.

For research purposes, we have used fairly small plot sizes and rotated hogs through plots. Most of the growers we have worked with over multiple studies have indicated small plot sizes and frequent rotations are labor and time intense. However, the advantage of small plots is a more even distribution of ground disturbance. The pattern of hog rooting being severest at the ends of the rectangular shaped plots in this study indicates small square shaped plots may achieve the most even distribution of hog ground disturbance. If weed management is an important goal along with dropped apple removal, we recommend plot sizes of 2 acres or less. If a grower wishes to focus completely on the removal of dropped apples, then greatly increasing plot size while keeping the stocking rate lower than the above recommendation might be feasible.

While this study begins to answer questions on stocking rates of hogs for the purpose of pest management, more research is needed. A study examining different stocking rates for 1-acre plots versus 10-acre plots would be a good next step. After determining an ideal stocking rate(s), a study examining the effect of plot shape on hog patterns and distributions of disturbance would be insightful. Further studies comparing the effectiveness of hogs as a weed management tool to other methods, such as the Swiss Sandwich strip tilling system, would also have great value.

5. Impacts

Our work contributes to the growing body of literature on livestock-crop reintegration. The reintegration of livestock into crops will provide growers with services such as weed reduction, orchard floor sanitation, and pest management. Our research will provide growers with desired information on how effective the method is and how to implement the method. Many growers have expressed interest in this project at presentations in the past, so we plan to present this data to growers in an online seminar, as well as at industry meetings such as the Great Lakes Fruit, Vegetable and Farm Market Expo. Research will also be made available on the Organic Pest Management website: http://www.opm.msu.edu . Providing growers with this information is important, and we will continue this research in order to expound upon what we have learned thus far.

6. Figures

Fig. 1: Mean percentage ground cover of grass, forbs, and bare ground along transects for grazed plots 1, 3, 5 over the course of the first 9 days.

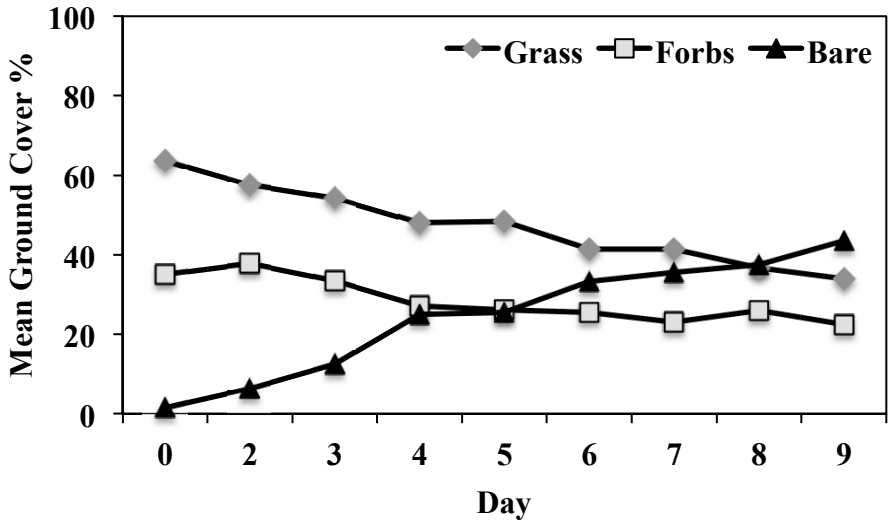


Fig. 2: Mean percentage ground cover of grass, forbs, and bare ground along transects for ungrazed control plot 1 over the course of the first 9 days.

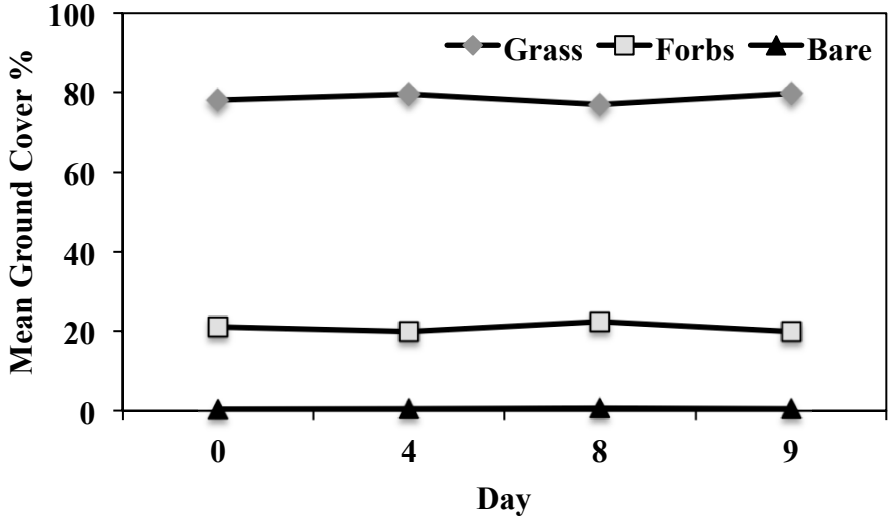


Fig. 3: Mean percentage ground cover of grass, forbs, and bare ground along transects for grazed plots 2, 4, 6 over the course of the second 9 days.

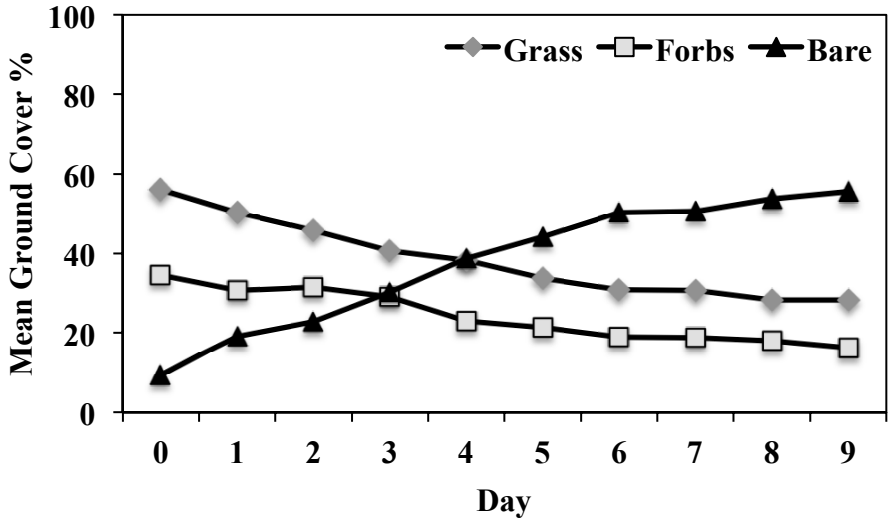
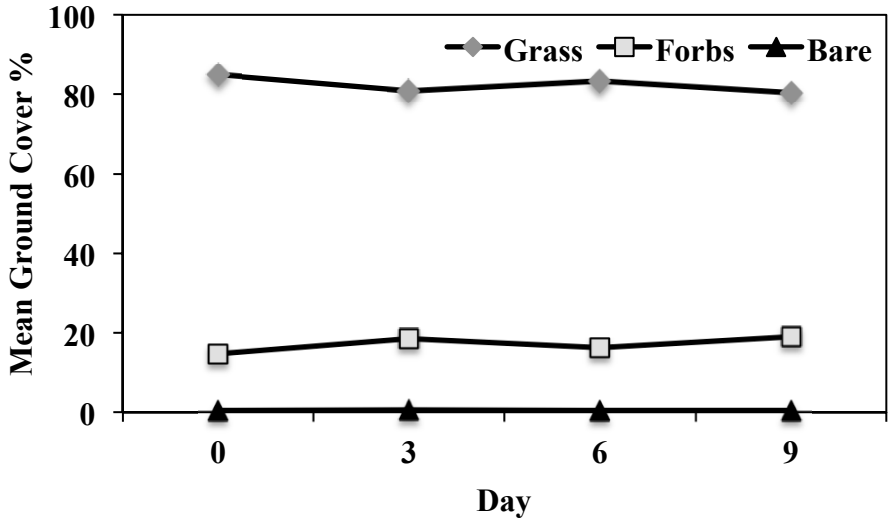


Fig. 4: Mean percentage ground cover of grass, forbs, and bare ground along transects for ungrazed control plot 2 over the course of the second 9 days.



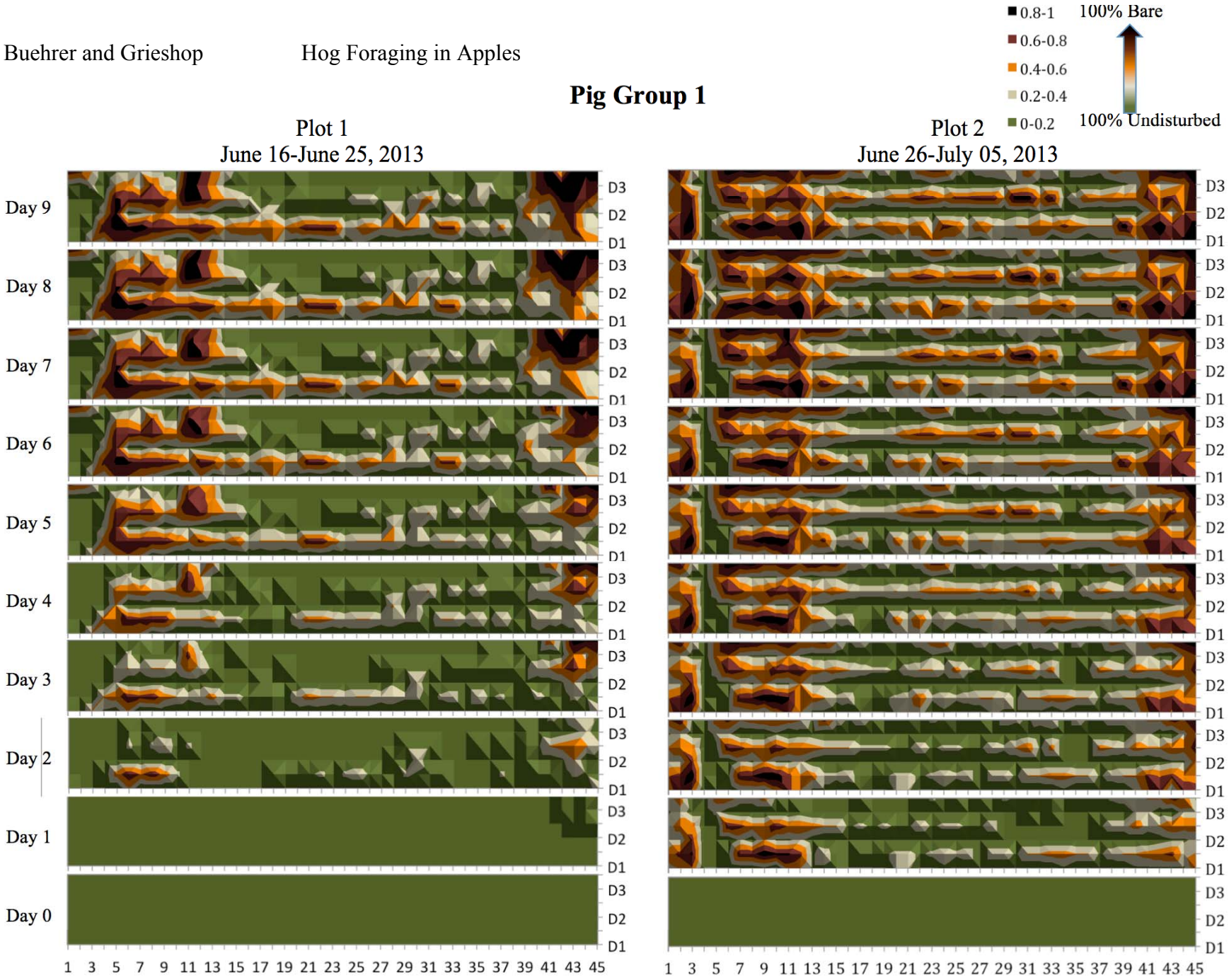


Fig. 5: Pattern of ground cover disturbance by Pig Group 1 in grazed plots 1 and 2. Each figure shows the plot as 45 trees by 6 rows (3 tree rows and 3 drive rows).

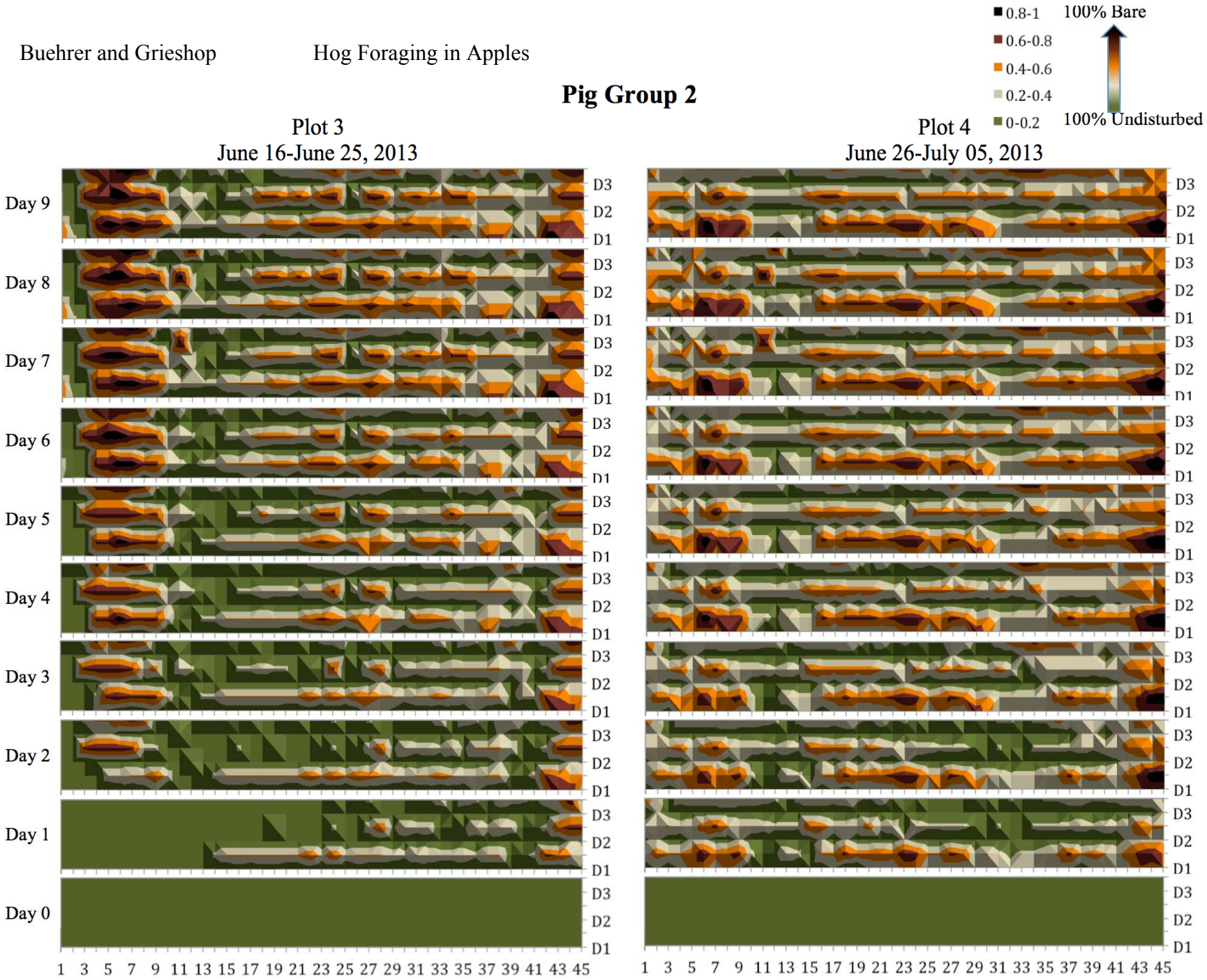


Fig. 6: Pattern of ground cover disturbance by Pig Group 2 in grazed plots 3 and 4. Each figure shows the plot as 45 trees by 6 rows (3 tree rows and 3 drive rows).

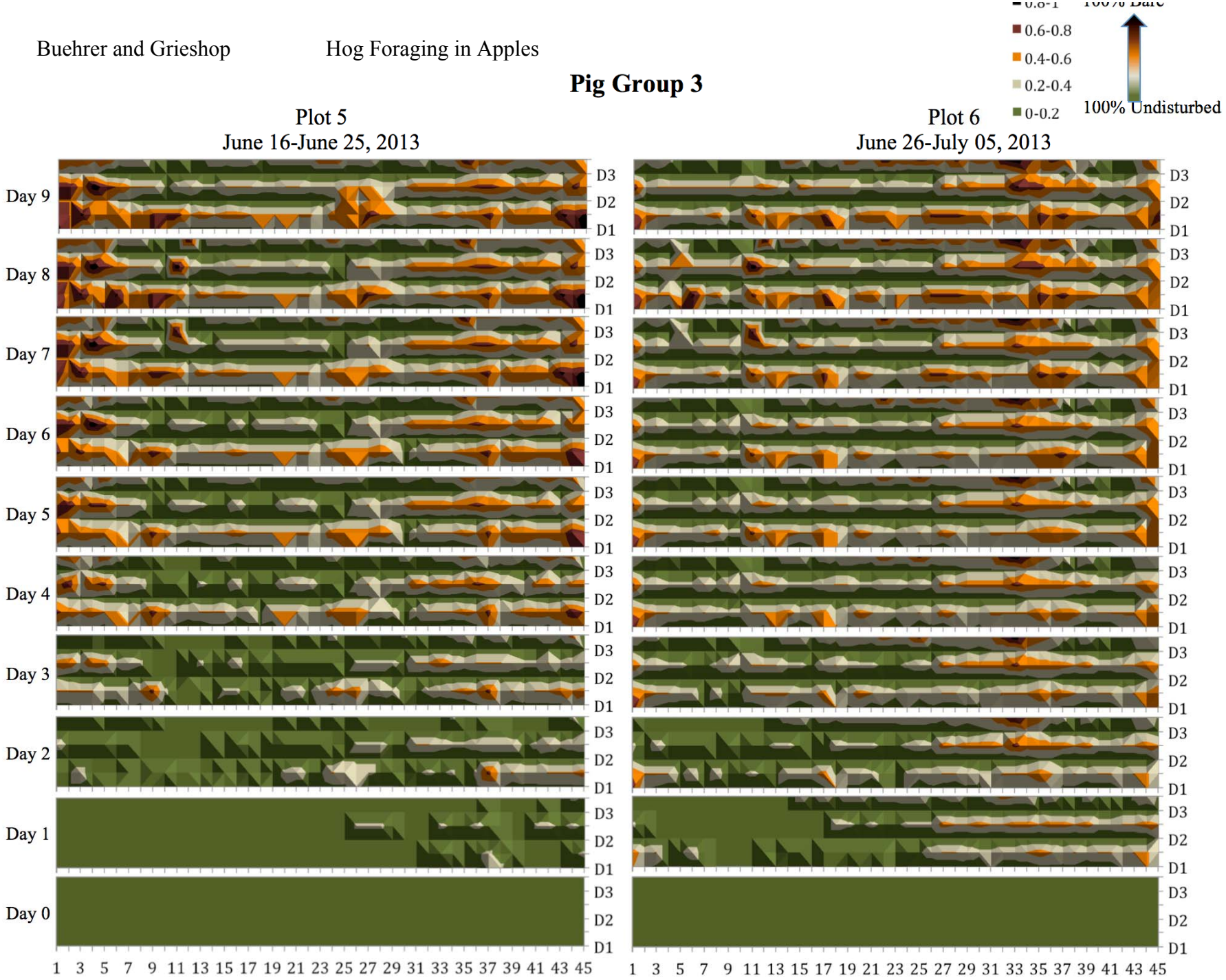


Fig. 7: Pattern of ground cover disturbance by Pig Group 3 in grazed plots 5 and 6. Each figure shows the plot as 45 trees by 6 rows (3 tree rows and 3 drive rows).

Fig. 8: Mean number of dropped apples per tree for the first set of grazed plots (1, 3, 5) and control plot 1 over the course of the first 9 days.

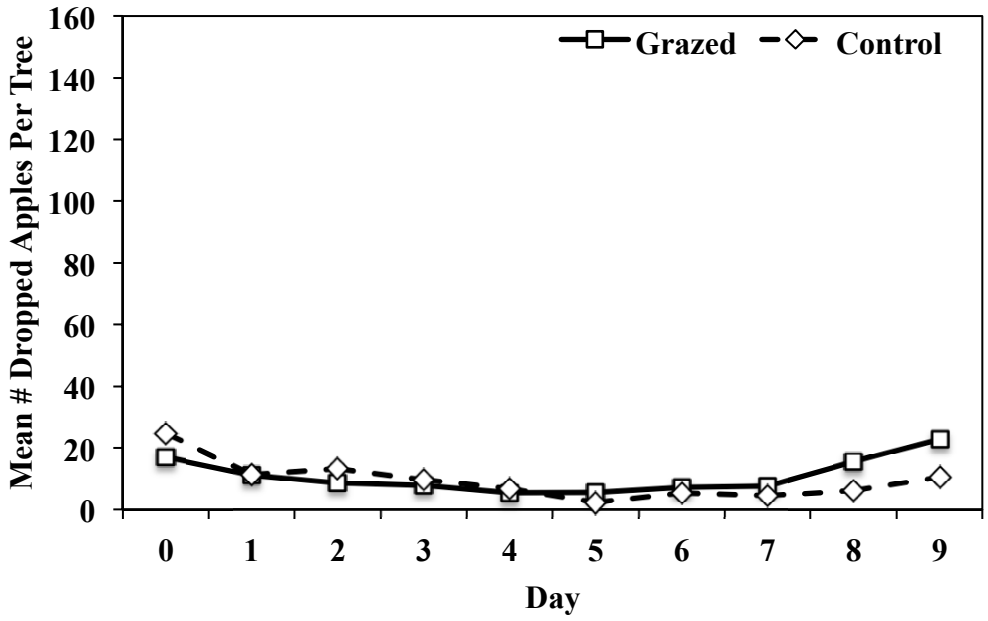


Fig. 9: Mean number of dropped apples per tree for the second set of grazed plots (2, 4, 6) and control plot 2 over the course of the second 9 days.

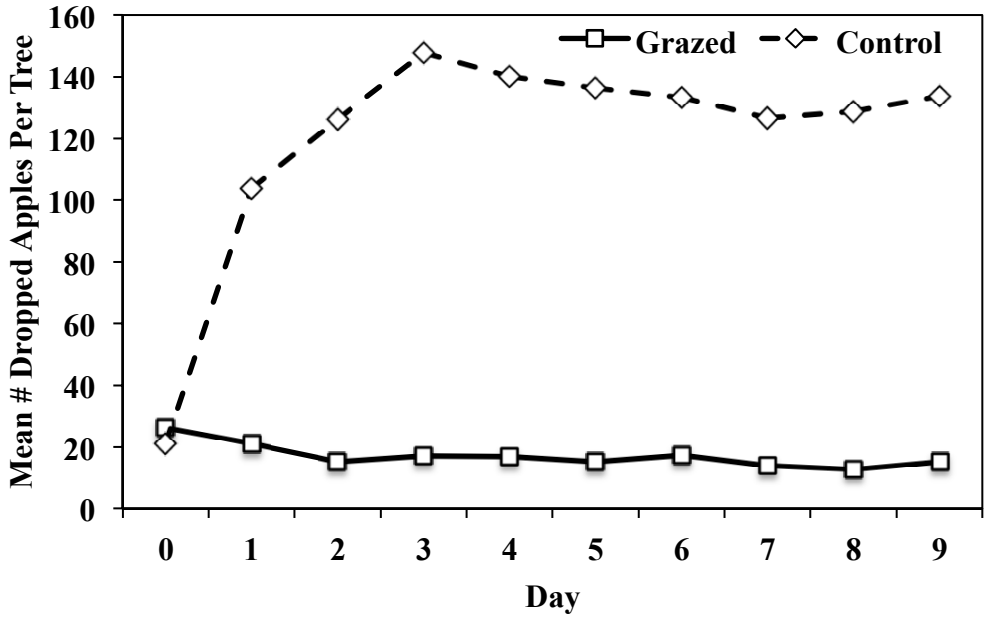


Fig. 10: Mean percentage of fruit with insect damage ±SEM on June 18, 2014. PC stands fro Plum Curculio. CM stands for Codling Moth. OFM stands for Oriental Fruit Moth.