Grant Report to PA Vegetable Marketing and Research Program- 2016
PA Vegetable Growers Association

Title:
The Effect of Cover Crops on Weed Control in Organic Production of Tomatoes and Brassicas

Personnel:
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Introduction:
One of the biggest challenges in diversified organic vegetable production is weed management. The organic grower may use mechanical cultivation, mulching techniques and even hand pulling, but the most effective control of soil weed seed banks occurs over multiple seasons. Using cover crops to prevent weed germination and smother out seedlings can be very effective, but a diversified vegetable grower will have limited opportunities to incorporate a cover crop into the rotation, particularly a multi-season cover crop. In this funded trial, Rodale Institute explored simultaneous cover cropping using strips of clover mixed with oats between cash crops of tomatoes and brassicas to more effectively manage weed suppression in these fields, reducing labor and tillage costs. In addition, the clover has the added benefit of fixing nitrogen in the soil for future cash crops and is easy to manage with a mower.

Objectives:
1. To determine if cover cropping reduced weed pressure in an organic vegetable production system.
2. To measure soil health and fertility impacts of zero, one or two years of cover crop usage in a vegetable production system.
3. To compare tomato and broccoli productivity between plots with and without cover crops.

Description of Work:
The Rodale Institute is a 501 c (3) non-profit organization in Kutztown, Pennsylvania located on a 333-acre experimental, diversified, certified organic farm. Much of the work done at the Rodale Institute is based around research and education, however a small amount of acreage is also devoted to production of grains, livestock and vegetables that is either sold directly to the consumer or wholesale markets.

Each year 40-50 different varieties of vegetables are grown on 5-6 acres throughout the growing season for the Agriculture Supported Communities (ASC) farm share program; a pay-as-you-go CSA model with the goal of reaching more people from broader economic backgrounds, particularly low-income communities with limited access to fresh organic produce. The ASC is also a vehicle for farmer training, so we are constantly striving to expose new farmers to organic techniques that will increase efficiency and improve overall sustainability.

The vegetables are rotated throughout the growing space in blocks according to plant family, growing habits, and maintenance practices (Brassicas, Solanaceous, leafy greens, roots, etc.). Weeds are managed within these blocks by the use of black plastic mulch or repeated cultivation and hand weeding.

In 2015, an observational experiment simultaneously alternating cash crop beds (i.e. tomatoes and brassicas) with cover crop beds (i.e. medium red clover mixed with an oat nurse crop) for the duration of the season was initiated to improve weed management and reduce labor. This allows mowing of weeds close to the cash crop beds and in cover crop beds to prevent them from going to seed attempting to reduce the weed seedbank over time. In 2016, with funding from PVGA, the project expanded to include increased data collection and within field replication of beds with zero, one or two years of cover crops. In 2016, most of the cash crops were transplanted into beds that had previously been in cover crops (in 2015); in other words, the cash crop beds flip-flopped with the cover crop beds. The project expansion helped us understand cover crops' benefits to weed management, nitrogen fixation, soil fertility, and yield.

Planting and Maintenance:
Soil was prepared using a Celli spader as soon as it could be worked in the spring; both clover beds and cash crop beds were tilled under. Due to the unseasonably warm winter and clover's vigorous root system, the clover beds needed to be spaded twice which may be a disadvantage during similar climatic years. Early spring broccoli beds were established during the last week of March in areas that were either in the oat-clover cover crop in 2015 or had a cash crop in 2015 with no cover crop. By partitioning a 10-foot grain drill into an active 5-foot seeding zone, oats and clover were drilled in to every other 5-foot bed, leaving space for broccoli in the 5-foot beds between the cover crops. There were also two control beds where cash crops had been planted two years in a row with no cover crop incorporated into the rotation. Two other beds remained in medium red clover for a second year to compare weed suppression, fertility, and yields in replications with varying years of continuous cover cropping. Broccoli was transplanted with a water-wheel transplanter in three successions – i. first week of April, ii. two weeks later, and iii. two weeks after the second succession – directly into the soil and then covered with row-cover for frost and pest protection. Broccoli beds were then mechanically cultivated as needed (2-3 times total before harvest) and row cover removed after the second cultivation. The oat/clover mix acted as a simple maintenance system between the beds as well as a walkway for cash crop maintenance and harvest. The cover crop was mowed as needed (average of every 2-3 weeks) using either a 48" rotary mower or a walk-behind BCS flail

mower; the act of mowing continued to stimulate the growth of the clover and smother weed seeds.

The first planting of broccoli was the most successful harvest; due to the unseasonably warm and dry late spring, the second and third successions of broccoli bolted early and saw unusually high pest pressure from flea beetles in 2016. However, the clover cover crop between the broccoli was planted at a perfect time to proliferate and effectively smother weeds (observationally). These beds were double cropped with carrots in the fall and cover crops may have an additional benefit of releasing nitrogen later in the season as cover crop residues break down.

The tomato beds were located in a different field that was planted to broccoli the previous year. The goal was to lay a plastic mulch and drip tape following tillage in late March/early April and then immediately broadcast the oat/clover cover crop in the 5-foot beds between the plastic mulch. However, in early April, when these beds should have been prepped, it rained for two weeks and was impossible to lay plastic mulch or seed the clover in a timely manner. The beds were finally prepared and seeded with clover by the first week of May. The combination of the late-seeded clover and an unseasonably hot and dry May resulted in a very poor cover crop stand between the tomatoes. The lesson learned from this field is that to maximize the benefits of a spring seeded cover crop of clover, it needs to be planted by early April at the latest for the most effective germination.

Tomatoes were planted into the plastic mulch in conjunction with the last frost date in mid-May using a water wheel transplanter. They were staked and tied regularly to keep fruits from contacting the ground. The holes in the plastic were also weeded regularly, and the strips between the plastic were mowed with a walk-behind BCS flail mower every 2-3 weeks for regular maintenance. Again, two beds were left as a control where tomatoes were planted directly following a cash crop with no cover crop in between, and two beds were left as a cover crop of medium red clover for a second year to determine if soil planted in cover crops for multiple years is beneficial. Each tomato bed was planted to a different type and variety making it difficult to compare yields between treatments.

Results and Discussion:

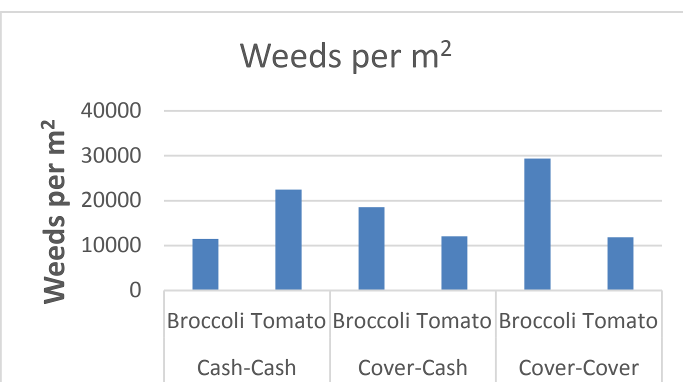

Figure 1. Weed seedbank densities. Total weed counts converted to a per meter squared basis in broccoli and tomato beds following 0 (cash-cash), 1 (Cover-Cash), and 2 years (Cover-Cover) of a spring planted, full season clover-oats cover crop between cash crop beds. Columns are averages of two beds.

***Weed Seedbank*:** A weed seedbank experiment was conducted to determine the quantity of buried weed reserves between treatments of 0, 1, or 2 years of cover crop with continuous mowing. In mid-March, six 3.2 cm diameter cores were taken to a depth of 20 cm from each bed within the replicated trial area. All soil from each bed were mixed in a 1:1 ratio with vermiculite and placed in a tray in the greenhouse. Trays were repeatedly watered and emerging weed seedlings counted. Every four weeks after all weeds had germinated the soil was re-mixed to germinate additional weeds that may have been buried. This occurred twice and the weeds were counted for three months. Total weed seedbank data is presented in Figure 1 and Appendix: Table 1. There were no consistent trends across the two crops and treatments. In the broccoli beds, weeds were lowest after two years of cash crop production and increased with each year beds were in cover crop. This is counter to our expectations and may be explained by the cash crop beds having been in black plastic production the prior year which smothered weeds and acted as a weed barrier. In tomato production beds, this trend was reversed with the lowest weed densities observed after 1 and 2 years of cover crop. This suggests that alternating cash crop beds with cover crop beds may be a favorable weed management method for organic vegetable crop systems that rely on cultivation but more investigation is necessary. It should be noted however that this system was designed for ease of maintenance in trellised systems that make it difficult to cultivate between beds after crops are staked. For that reason, we believe there is important application of this technique in warm season vegetable crops where black plastic mulch and trellis is utilized. It should be noted that weed seedbank reserve analysis has rarely been performed on vegetable crop production but in conventional field crop systems, weed densities above 1,000 per square meter require heavy mechanical cultivation or chemical control to prevent yield losses (Forcella, Eradat-Oskoui, and Wagner 1993). This may not necessarily translate into vegetable or organic systems since studies in organic and conventional field crop production found field crops grown in organically managed soils have less yield loss in relation to weed densities than conventional soils (Ryan et al. 2010; Ryan et al. 2009). Therefore, weed thresholds established in conventional cropping systems may not be applicable to organic systems and there is a need to better understand how weeds limit yields in organic vegetable production.

Mid-season weed density counts: Weed density counts and weed identification was made in broccoli production on the 10th of May, approximately one month before harvest. Within each bed, three 0.5 m^2 quadrats were randomly sampled for weed densities. All weeds that could be identified were counted and recorded and all weeds that were too small to be identified were counted as 'other'. There was a trend towards higher weed counts in beds with a cover crop compared to beds with a cash crop the previous year (Figure 2). Average counts for all weed species were higher in beds with a cover crop the previous year (Appendix: Table 2). The beds used for broccoli production in 2016 were cropped to tomato in black plastic mulch in 2015. Taking this data together with the weed seedbank data it appears that the use of black plastic mulch reduces weed pressure for the following crop better than continuous mowing of cover crops. As stated above, this system was originally adopted for ease of management between trellised vegetable crops that are often grown using black plastic mulch. Therefore, this method may still be a viable option for plasticulture systems that do not have a reliable method to control weeds between beds once crops have been staked, preventing the use of tractors for cultivation or herbicide application.

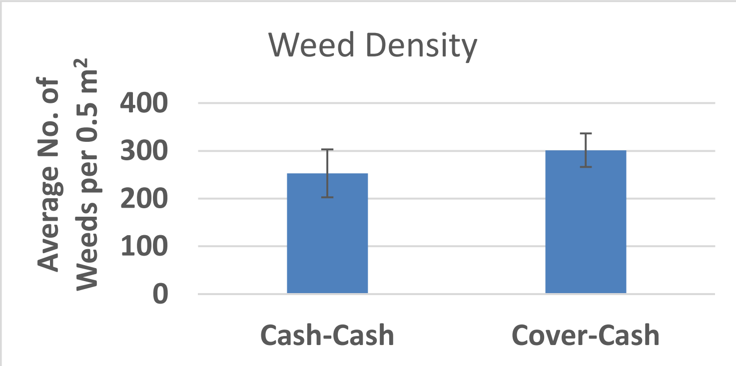

Figure 2. Mid-season weed density. Columns are the average count of weeds within three 0.5 m^2 quadrats per bed in two beds where broccoli was grown following tomato production the previous year (Cash-Cash) or two-beds where a clover-oat cover crop was grown the previous year.

***Soil health and fertility*:** Soil samples were taken in the spring just before planting, mid-summer, and in the fall after harvest. In each bed during each sampling period, six 2 cm diameter cores were taken to a depth of 20 cm, mixed to create a composite sample, air-dried and sieved before being sent to Penn State Agricultural Analytical Labs for chemical analysis. In the middle of the growing season and following harvest, subsurface compaction was measured using a penetrometer. The depth to 300 psi was recorded from twelve measurements from each bed on each sampling date.

Nitrogen in the form of nitrate (NO_3) was highest following one year of cover crop (Cover-Cash) (Figure 3). Nitrate is the most plant available form of nitrogen and this result suggests that establishing a cover crop on vegetable beds may allow the soil to build up nitrogen that is available to the plant once the cover crop is incorporated in to the soil.

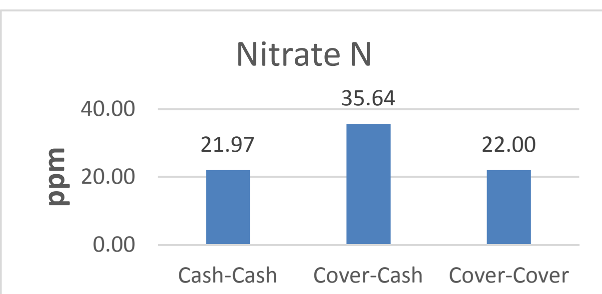

Figure 3: Total nitrate nitrogen. Columns are average nitrate nitrogen as parts per million (ppm) in four beds per treatment and three separate sampling dates.

Early in the season nitrate levels were similar between treatments in both broccoli and tomato plantings but were higher in beds with cover crop incorporated in the middle and later part of the season (Figure 4). This should have the benefit of available nitrogen during periods of maximum fruit fill (August-September in field grown tomatoes) and for a second fall crop (carrots, beets, brassicas, leafy greens following a spring crop).

Observations of total fertility (Appendix: Table 2) reflect major differences between fields but not necessarily between treatments. Macro- and micro- nutrient levels were higher in the broccoli field than the tomato field for all measurements. Total % carbon was highest in the broccoli plots with no cover crop (Cash-Cash) compared to 1 or 2 years of a cover crop. In tomatoes, 1 and 2 years of cover crop did increase % carbon in the soil over the no cover crop treatment. In both crops, % carbon was higher following 2 years of cover crop than 1 year of cover crop. The general trend is that increased cover crops increases %

carbon in the soil and is consistent with recommendations to utilize cover crops to build soil health and fertility.

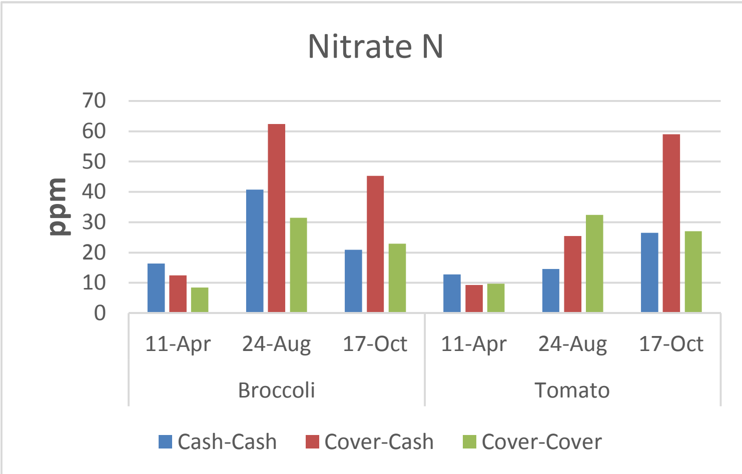

Figure 4: Nitrate nitrogen levels over time. Columns are the average of two beds per treatment per crop over three soil sample periods in 2016.

Compaction did not differ between treatments with no cover or 1 year of clover cover crop (Figure 5). The compaction layers in each treatment remained mostly the same between mid-season and post-harvest measurements. Measurements were also made in beds that had grown a cash crop the previous year and were in cover crop in 2016. All beds that were seeded to cover crop in 2016 had a shallower compaction layer. Establishment of the cover crop or perhaps activity over top of the beds seeded to cover crop appear to increase compaction in these beds. Future recommendations would be to plant tillage radish interseeded with clover and oats in the spring.

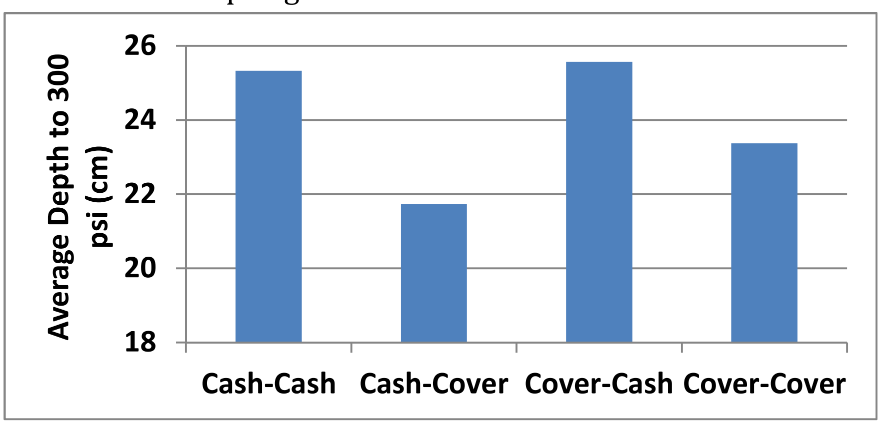

Figure 5. Average depth to 300 psi. Columns are the average depth to 300 psi for all beds taken during mid-season and post-harvest measurements.

Yield: Good measurements of yield were only obtained in the first succession of broccoli. This was a direct measurement of the same variety planted on the same date. At maturity, twenty heads per bed were randomly harvested by cutting the stem at the soil surface. The total biomass (Kg) was recorded for each head. All leaves were removed and the stem was cut 25 cm from the top of the head for each head harvested. This was considered the marketable product and a marketable biomass measurement was recorded for each head. The Harvest Index was calculated as the marketable yield divided by the total biomass. This provides a measure of how efficiently the plant converts energy in to the marketable product. Total biomass and marketable yield were higher in the treatments that had one year of cover crop (Cover-Cash) compared to beds with no cover crop (Cash-Cash) (Figure 6). There was no real difference in Harvest Index between treatments. This was expected as the same variety was planted in each bed and the harvest index is usually used as a method to evaluate production differences between varieties. Considering nitrate levels increased later in the season in the cover-cash treatments, it is likely that real yield differences between treatments would be realized later in the season. Poor carrot germination made it difficult to make good comparisons between these same beds in the fall.

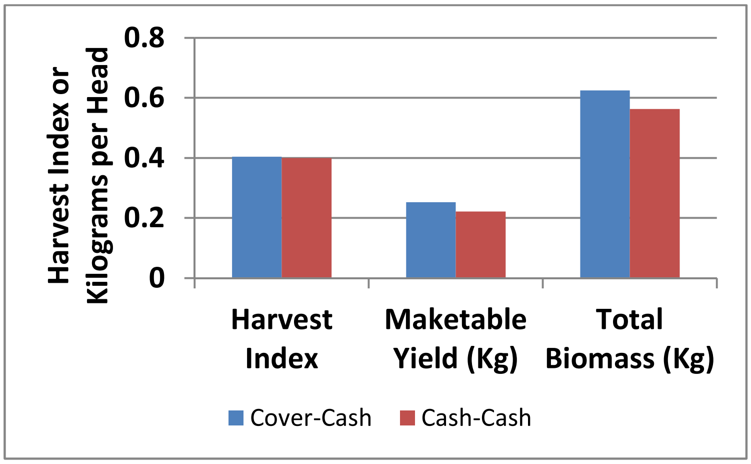

Figure 6: Broccoli yield. Columns are actual harvest index, marketable yield, and total biomass from one broccoli bed per treatment. Measurements were taken on June 8th, 2016.

***Project Summary*:**

Weed Pressure: The data collected regarding the effects of cover cropping on weed suppression were the most surprising and somewhat conflicting in nature. While the results showed that weed pressure was reduced in the cover-cash replications in the tomato field, the collected data reflects that the weed pressure was the lowest in the cash-cash replications in the broccoli field. Another interesting figure was that the second lowest weed count was in the cover-cover replication in the tomato field, but the highest weed count was in the cover-cover replication in the broccoli field. This may have been a result of prior year management with lowest weed counts where plastic mulch was used previously but research with greater replication and over a longer time period is necessary to achieve conclusive results. Measuring weed counts at various times during the season will also help to determine a full spectrum of weed cycles in the fields. Regardless of the data collected, observationally and operationally, the strips of clover cover crop made the field very easy to manage with a riding mower or walk-behind BCS flail mower, especially in trellised tomato fields using plastic mulch where it would be impossible to use mechanical cultivation.

Soil Fertility and Yields: Based on data collected in our trials, incorporating a simultaneous cover crop of clover into vegetable production operations in a strip bedding technique has positive results on soil fertility and potential marketable yields. The plant available nitrate levels were higher in the beds where a cover crop had been grown for at least one year. However, the increased fertility was more available in the mid-to late season, which could be better utilized by a late summer or fall harvested crop such as tomatoes, fall broccoli, or root crops. Future research should focus on the yield potential of late season or double crop vegetable production following a clover cover crop.

Soil Compaction: Another unexpected result was that subsurface compaction was increased in beds maintained in cover crops compared to continuous cash crops. This may have been the result of foot and occasional equipment traffic over these beds during bed preparation, planting, and harvesting. A future recommendation would be to reduce or eliminate traffic over these beds and to use tillage radish in combination with oats and clover planted in the fall. This should grow well in the spring and fall and continuous mowing should prevent the radish from going to seed.

References Cited:

Forcella, Frank, Kazem Eradat-Oskoui, and Steven W Wagner. 1993. 'Application of weed seedbank ecology to low-input crop management', *Ecological Applications*: 74-83.

Ryan, MR, DA Mortensen, L Bastiaans, JR Teasdale, SB Mirsky, WS Curran, R Seidel, DO Wilson, and PR Hepperly. 2010. 'Elucidating the apparent maize tolerance to weed competition in long-term organically managed systems', *Weed Research*, 50: 25-36.

Ryan, MR, RG Smith, DA Mortensen, JR Teasdale, WS Curran, R Seidel, and DL Shumway. 2009. 'Weed–crop competition relationships differ between organic and conventional cropping systems', *Weed Research*, 49: 572-80.

Appendix:

Table 1: Weed seedbank counts

	Total	Grass	Yellow Nutsedge	Pigweed	Lambsquarter	Ragweed	Galinsoga	Velvetleaf	Chickweed	Other	Monocot	Dicot
Cash-Cash	**366.25**	**78**	**1.25**	**111**	**7**	**9.75**	**75.75**	**3.5**	**8.25**	**71.5**	**79.25**	**287**
Broccoli	248	36	0	16	2.5	15	129	6.5	12.5	30	36	212
Tomato	484.5	120	2.5	206	11.5	4.5	22.5	0.5	4	113	122.5	362
Cover-Cash	**329.25**	**75.25**	**2.25**	**28.75**	**13.25**	**3.5**	**140.25**	**5.25**	**20.25**	**39.5**	**77.5**	**251.75**
Broccoli	399	59	0	15.5	26	4	222.5	5	30	35.5	59	340
Tomato	259.5	91.5	4.5	42	0.5	3	58	5.5	10.5	43.5	96	163.5
Cover-Cover	**444**	**148.25**	**3**	**14**	**26**	**5.75**	**150**	**9**	**14.75**	**72.5**	**151.25**	**292.75**
Broccoli	633	230	1	16.5	50	5	253.5	12.5	15.5	48.5	231	402
Tomato	255	66.5	5	11.5	2	6.5	46.5	5.5	14	96.5	71.5	183.5

Table 2. Average mid-season weed counts per 0.5 m^2 quadrat in broccoli production on May 10th, 2016

Treatment	Total	Grass	Nutsedge	Pigweed	Lambsquarter	Ragweed	Other
Cash-Cash	252.83	25.00	0.50	6.67	3.67	2.83	214.17
Cover-Cash	301.33	29.33	1.83	8.83	15.00	1.83	244.50

Table 2: Soil fertility

System/Crop	Total C%	Total N%	pH	CEC	Macronutrients - ppm				% Base Saturation			Totals			
					P	K	Mg	Ca	K % Sat	Ca % Sat	Mg % Sat	Zn	Cu	S	NO_3
Cash-Cash	**2.713**	**0.303**	**6.71**	**11.37**	**223.08**	**125.75**	**151.58**	**1630.76**	**2.78**	**72.72**	**11.11**	**5.17**	**13.15**	**17.25**	**21.97**
Broccoli	2.82	0.31	6.83	12.27	264.00	145.83	178.50	1821.83	3.02	75.28	12.15	6.50	17.85	17.47	26.00
Tomato	2.57	0.31	6.60	10.47	182.17	105.67	124.67	1439.68	2.55	70.15	10.07	3.83	8.45	17.03	17.95
Cover-Cash	**2.677**	**0.301**	**6.73**	**11.68**	**207.42**	**118.58**	**143.50**	**1721.37**	**2.63**	**74.48**	**10.37**	**4.79**	**12.67**	**16.04**	**35.64**
Broccoli	2.67	0.29	6.79	11.35	225.33	130.67	154.50	1799.17	2.95	79.88	11.43	5.32	16.75	15.52	40.03
Tomato	2.68	0.31	6.66	12.02	189.50	106.50	132.50	1643.57	2.32	69.08	9.30	4.27	8.58	16.57	31.24
Cover-Cover	**2.757**	**0.309**	**6.79**	**11.10**	**225.00**	**156.08**	**146.92**	**1692.16**	**3.60**	**76.48**	**11.09**	**5.08**	**12.83**	**16.07**	**22.00**
Broccoli	2.76	0.30	6.88	10.93	246.33	166.83	169.67	1748.23	3.90	80.22	13.00	5.87	16.98	15.40	20.93
Tomato	2.75	0.32	6.71	11.27	203.67	145.33	124.17	1636.08	3.30	72.73	9.18	4.28	8.68	16.73	23.08