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Effects of Selected Soil Amendments and Mulch Type on Soil Properties and Productivity in Organic Vegetable Production †

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Abstract: The potential benefits of different types of soil amendments and mulch ground covers on soil chemical and biological properties, crop development and yield, and disease and pest issues in organic vegetable production, as represented by legume (green snap bean), cucurbit (green zucchini squash), and brassicaceous (turnip) vegetable crops, were evaluated in a two-year field trial in Maine, USA. Soil amendments evaluated (following an initial fertilizer base) included a commercial organic fertilizer alone, composted dairy manure, compost plus fish meal, and compost plus Wollastonite, a natural source of silicon (Si). A paper mulch was also compared with a woven polypropylene fabric mulch for their performance and effects as weed barriers within these systems. Mulch type significantly affected soil properties, with the fabric mulch associated with increases in soil moisture, organic matter, and other soil chemical and biological properties relative to the paper mulch. The fabric mulch also resulted in earlier emergence and earlier harvests for bean and zucchini. Soil amendments affected soil properties and crop growth and yield of bean and zucchini, with compost amendments increasing soil pH, organic matter, and several nutrient concentrations, as well as crop emergence and yield relative to a fertilizer-only treatment. Compost treatment also reduced the infestation and damage caused by mites on beans in 2018. Addition of fish meal increased most nutrient element concentrations and microbial respiration, and Si amendment increased emergence of beans, and reduced powdery mildew on squash and late season browning of beans. These results help define specific management practices to improve organic vegetable production and provide useful information and options for growers.

Keywords: snap bean; zucchini; turnip; mulch; compost; silicon; organic vegetables; soil properties

1. Introduction

Organic vegetable farming involves balancing many complex factors. In the Northeastern USA, organic vegetable production tends to be small-scale but highly diversified, involving several production crops and requiring knowledge and expertise on the management of numerous different crops and crop types. The management of organic matter and soil fertility, balancing practices that will help improve soil quality and build sustainability with supplying the basic nutrient needs of the current vegetable crop, is a crucial production challenge for organic vegetable growers. The timing, amounts, and types of organic amendments used can dramatically affect soil properties and soil fertility now and into future years.

Compost and related types of amendments that supply large amounts of organic matter to soil are fundamental building blocks for soil health and sustainable organic production [1]. Organic matter profoundly affects all aspects of soil physical, chemical, and biological properties, supplying food for the soil biota, stabilizing soil structure and water relations, and increasing soil fertility [1,2]. However, the nutrients derived from compost and other organic matter sources also may take considerable time to break down or be converted into plant-available forms, and thus more readily available, soluble sources of nutrients may also be needed for adequate crop growth and development [3]. For example, amendments such as fish meal, feather meal, or blood meal have a high N content that is more readily available to plants for immediate needs. Determining this balance of what types of soil amendments will work best in specific organic vegetable cropping systems are needed to optimize production and productivity.

Weed management is another critical area in organic production. Black plastic mulch has several benefits and is often used as a weed barrier in organic vegetable production [4]. However, problems associated with its removal, disposal, and potential soil health issues make its use less than ideal for organic agriculture and more sustainable alternatives are needed [5]. Paper mulch is a more natural option and various forms of paper mulch (which does not have to be removed and disposed, as it breaks down in the soil) have been used with varying success [6–9]. Another potential alternative is a woven polypropylene fabric ground cover, which is sturdy, permeable to water, and durable enough to be re-used year after year. Woven fabric mulch has been used extensively as ground cover in landscape planting beds and perennial systems where it is covered by organic mulches or other materials and left in place [10,11]. However, there is little previous research assessing its annual use as a weed barrier in organic vegetable production.

Another amendment that may be useful in organic vegetable production is silicon or silica (Si). Although Si is abundant in the environment, plant-available Si may be somewhat limiting, and additions of Si in an available form can improve responses of plants to both biotic and abiotic stresses [12–14]. However, the utility of Si amendments in organic vegetable production has not been assessed.

The purpose of this research was to assess the usefulness of selected soil amendments for improving soil quality and crop production in organic vegetable production, as well as to evaluate alternative mulching approaches as weed barriers within these production systems. Thus, in this research, four different soil amendments and two mulch types were assessed for their effects on soil properties, crop growth and yield, and pest and disease issues in three different organic vegetable crops (snap bean, zucchini squash, and turnips) in an organic vegetable production system over two full cropping seasons in central Maine. The soil amendments assessed included an organic fertilizer-only treatment, compost, compost plus fish meal, and compost plus silica. The ultimate goal of this and other related studies is to develop and optimize improved production systems for organic vegetables that maximizes sustainability and productivity.

2. Materials and Methods

2.1. Field Design and Management

Field experiments were conducted at an organic research site located in St. Albans, ME (N 44°53′, W 69°25′) over two consecutive growing seasons (2017–2018). The trial was established as a split-block design (with mulch type as main plot, soil amendment treatments as sub-plots) with four replicate blocks for each of three different vegetable crops. Each main plot was 11.0 × 6.1 m, consisting of 4 subplots (1.8 × 6.1 m) containing 2 rows of vegetable crops each. There was a gentle (~5%) slope running from the Northwest to Southeast end of the field, and there were two soil types within the study area, a Thorndike-Bangor silt loam, a loamy-skeletal, isotic, frigid Lithic Haplorthod across the upper portion of the field; and a Monarda silt loam, a loamy, mixed, active, acid, frigid, shallow Aeric Endoaquept, across the middle and lower portions of the field. Due to these differences in soil type and possibly previous land usage, there were substantial differences in initial soil properties associated with the upper and lower portions of the field (Table 1). The effects of these differences in soil properties on experimental results were mitigated through blocking. The field is certified organic and has been in organic hay production for the last several years. Tillage for all plots at the start of the study consisted of primary tillage with a chisel plow and then secondary tillage with a disc harrow prior to planting.

Table 1. Selected soil chemical properties and nutrient concentrations in Spring 2017 at the field study site (with differences noted between upper and lower parts of the field) in St. Albans, ME.

Field Location		OM	(mg/kg Soil)							
	pH	(%)	NO_3	NH_4	P	K	Mg	Ca	Na	S
Upper part (Thorndike) [y]	6.50 a [z]	6.20 a	3.6 a	3.4 a	219 a	48.8 a	64.0 a	3611 a	26.0 a	8.8 a
Lower part (Monarda)	5.99 b	3.61 b	2.8 a	3.8 a	5.9 b	46.2 a	34.6 b	1243 b	17.4 b	5.4 b
LSD	0.15	0.84	1.3	1.2	48.1	16.6	16.1	541	3.8	0.9

[y] The field site consisted of two different soil series, a Thorndike silt loam on the upper part and a Monarda silt loam on the lower part of the field, each having somewhat different initial properties. [z] Values within columns followed by the same letter for each parameter are not significantly different from each other based on ANOVA and Fisher's protected LSD test ($p < 0.05$).

The field trial was dependent on natural rainfall for all watering needs. Environmental conditions (air temperature, relative humidity, and rainfall) were monitored at an on-site weather station and used to determine daily, weekly, and monthly average conditions throughout the cropping season. In addition, environmental conditions of air temperature and relative humidity were monitored within plots at canopy level, and soil temperature and soil moisture (measured by Watermark sensors) were monitored within plots in each block at 15 cm depth for (a) under the paper weed barrier, (b) under the fabric weed barrier, and (c) outside the mulched plots under bare ground using Watchdog data loggers (model 450, Spectrum Technologies, Plainfield, IL, USA) throughout the season [9].

2.2. Soil Amendment Treatments

Soil amendments evaluated represented different soil fertility amendments. All plots received a baseline level of a commercial organic fertilizer (Fertrell Feed-n-Grow, Fedco seeds, Clinton, ME, USA) with a 3-2-3 NPK content (from blood meal, bone meal, feather meal, peanut meal, alfalfa meal, aragonite, sulfate of potash, greensand, and kelp) broadcast applied to soil at the rate of 500 kg/ha prior to mulch covering and vegetable planting. The soil amendment treatments (after baseline fertilizer) consisted of (1) additional organic fertilizer alone, (2) composted dairy manure, (3) compost plus fish meal, and (4) compost plus Wollastonite (a natural mineral source of silicon). The fertilizer-only treatment received an additional 500 kg/ha (above the baseline level) of the commercial fertilizer and no other treatment. The composted dairy manure was applied at a rate of 76 m^3/ha (~18 Mg/ha dry weight), which was tilled into the soil prior to planting. Average compost composition (dry weight basis) was 25.5% C, 1.9% N, 0.8% K, 0.5% P, and a C:N ratio of 13. The fish meal used (Fedco Seeds) was 10-4-2 NPK and applied to soil at a rate of 500 kg/ha and incorporated prior to vegetable planting. The soluble-grade natural mineral Wollastonite (52% SiO_2, 48% CaO) (Fedco Seeds) was 95% pure and used to supply silicon to the soil, but is also a source of calcium. It was applied at the rate of 3.5 Mg/ha and incorporated into soil prior to vegetable planting. The same plots were used both years of the study with the same treatments applied each year, but the vegetable crops within plots were rotated each year.

2.3. Weed Barrier Mulches

Two types of weed barrier mulches were evaluated as alternatives to traditional black plastic polyethylene mulch commonly used in vegetable production. The first was a commercial biodegradable paper mulch (Organic, standard weight, brown color, WeedGuardPlus, Aurora, CO, USA, OMRI listed) weed barrier. For each plot, two 0.91 × 6.4 m strips were used and held down by burying with soil around the edges. The other mulch used was a woven polypropylene fabric ground cover (DeWitt Sunbelt, Sikeston, MO, USA), which is permeable and reusable, and comes in a 1.8 m width. Both mulches were cut for plot length and planting holes (7.6 cm diameter) were pre-cut at the appropriate spacing for each vegetable crop prior to application in the field. Mulches were cut to 0.3 m longer than plot length (6.4 m) to allow for burying ends with soil, and holes were cut with a hand drill for the paper mulch and through melting with a propane garden torch for the fabric mulch using a pre-made plywood template with holes cut at the appropriate size and spacing. Mulches were placed in the field after all soil amendments were applied and immediately prior to planting. Additional weed control in the areas between plots was provided by periodic hand cultivation. At the end of each season, the fabric mulch was removed, cleaned, and then reused again the following year, whereas the paper mulch was left in place and incorporated into the soil with a rotavator.

2.4. Soil Chemical and Biological Properties

Initial soil samples were collected throughout each block in May 2017 prior to field preparation and planting crops to assess soil properties at the start of the experiment. In each of three zones in each block, 6 to 8 soil cores (2.5 × 15 cm) were collected and combined into one composite sample, sieved through a 2-mm screen, air-dried, and used for soil physical and chemical analyses. The following year, after one year of amendments and vegetable crop growth, soil samples were collected from each plot in Spring 2018, after soil amendments added, but prior to vegetable planting for 2018, for analyses of effects of the various treatments on soil properties. Soil properties measured included pH, organic matter content, cation exchange capacity, and concentrations of nutritionally important elements and compounds. Potentially available N, as nitrate (NO_3^-) and ammonium (NH_4^+) was determined using cold water bath KCl extractions. Soil concentrations of P, K, Ca, Mg, Al, B, Fe, Mn, Na, S, Cu, and Zn were estimated using Modified Morgan extraction procedures [15] and analyzed using inductively coupled plasma optical emission spectroscopy (ICP-OES) by the University of Maine Analytical Lab (Orono, ME, USA). Average soil properties for initial samples collected in 2017 prior to the start of the study are presented (Table 1).

Testing of soil samples for selected biological properties was also done for both the 2017 and 2018 soil samples. Microbial biomass was estimated through CO_2 respiration using the Solvita CO_2-burst assay [16], and additional testing of soil samples collected in the Fall of 2018, at the conclusion of the growing season, consisted of a soil labile amino nitrogen assay (Solvita SLAN test, Woods End Laboratory, Mt. Vernon, ME, USA), and microbial activity based on the BIOLOG (Biolog, Inc., Hayward, CA, USA) substrate utilization assay using BIOLOG GN2 plates [17], in addition to the CO_2-burst assay.

2.5. Vegetable Crops

Vegetable crops grown were organic green snap beans (*Phaseolus vulgaris* L.), green zucchini squash (*Cucurbita pepo* L.), and turnips (*Brassica rapa* L.), as representative examples of legume, cucurbit, and brassicaceous vegetable crops. The snap bean was organic variety 'Provider' a bush-type green snap bean, planted at 15-cm spacing in 2, 6.1-m rows (0.91 m between rows) per plot for a total of 40 plants per row. The zucchini was 'Dunja', a dark-green straight hybrid (F1) zucchini, planted at a spacing of 0.61 m (between row spacing 0.91 m), but plants staggered, with 2–3 seeds planted per hole, and later thinned to one plant, for a total of 10 plants per row. The turnip variety used was 'Purple Top White Globe', a traditional white turnip, planted at 15-cm spacing (0.91 m between rows) with multiple seeds planted and later thinned to one plant (40 plants per row). All vegetable seeds were obtained from organically-grown sources (Johnny's Selected Seeds, Winslow, ME, and High Mowing Organic Seeds, Wilcott, VA, USA). In 2017, planting of all three vegetable crops was completed on June 7, with some limited replants done in areas of poor germination on June 22. In 2018, beans and zucchini were planted on May 22 and turnips on May 28, followed by replants where needed on June 8. After planting and prior to emergence, squash plots were covered by an insect netting (ProtekNet, Johnny's Seeds, Winslow, ME, USA) laid over steel hoops to protect plants from squash bugs and other insects during early growth stages, as previously described [9]. Emergence (as percentage of emerged seedlings relative to total seeds planted) was assessed for all crops periodically through the first 30 days after planting (DAP). Vegetable crops were planted in the same plots each year, but individual crops were rotated, with blocks 1 and 4 following a bean-squash-turnip rotation and blocks 2 and 3 following a bean-turnip-squash rotation. All seed, products, equipment, inputs, and methodologies used throughout these trials were certified organic and/or approved for use in organic production.

2.6. Crop Growth, Yield, and Disease Evaluations

All crops were monitored in the field for signs and symptoms of foliar and soil-borne diseases as well as insect pests. Vegetables were harvested by hand as they ripened to maturity and weighed and recorded by row. In 2017, squash harvests began on July 20, and were conducted 2–3 times each week for a total of 9 weeks, ending on September 13. Bean harvests began on July 31, with one harvest per week through September 11, for a total of 8 harvests. Turnips were harvested as needed beginning July 25 through September 8, for a total of 4 harvests. In 2018, squash, turnip, and bean harvests began on July 9, 12, and 19, respectively, and continued over a period of 8 weeks for bean and turnip, and 9 weeks for squash. Yield was evaluated as the total weight of harvested vegetables per 6.1-m harvest row in each plot at each harvest date and as the total for all harvest dates and converted to the equivalent value expressed as Mg/ha. During the final month of harvest in both years, visual assessments of symptoms of disease development, such as powdery mildew, various leaf spots, or necrosis, were recorded (as the percentage of total plot leaf area affected) periodically as needed.

2.7. Statistical Analysis

Soil properties, yield estimates, and disease assessment data were analyzed in a split-block design using standard analysis of variance (ANOVA). Data from each crop year were analyzed separately, and then data from both years were also combined and analyzed together (with year as an additional factor and appropriate interaction terms) to evaluate average and overall effects over the course of the study. Significance was evaluated at $p < 0.05$ for all tests. Mean separation was accomplished with Fisher's protected LSD test. All analyses were conducted using the Statistical Analysis Systems ver. 9.4 (SAS Institute, Cary, NC, USA).

3. Results

3.1. Environmental Conditions and Overall Crop Growth

Environmental conditions varied during the vegetable growing seasons over the two years of the study. Daily temperatures averaged above normal throughout the summer in both 2017 and 2018, with notably higher temperatures in August 2018 compared with the long-term (30-year) averages for the area (Table 2). Rainfall was variable from month to month and year to year, with 2017 having a wet spring (May, June) followed by a relatively dry summer (July, August). In 2018, a relatively dry start to spring (May) was followed by a wet June, drier than normal July, a normal August, and a dry September. Overall, there was a rain deficit of 3.5 and 6 cm for the summer growing season in 2017 and 2018, respectively, compared to long-term average conditions (Table 2).

Table 2. Average daily temperature and total rainfall for the months of May through September at the St. Albans, ME research site for 2017 and 2018 compared with long-term (30-year) average (LTA) conditions.

Treatment	Average Daily Temperature (°C)			Rainfall (cm)		
	2017	2018	LTA	2017	2018	LTA
May	11.6	13.9	12.0	16.1	6.0	9.5
June	17.9	17.4	17.0	11.0	13.7	9.9
July	21.8	21.3	19.8	4.9	6.8	8.7
August	19.4	25.7	18.9	4.2	9.5	8.6
September	17.7	16.9	14.2	6.8	4.6	9.6
Season avg	17.7	19.1	16.4	8.6	8.1	9.3

Soil temperature and soil moisture conditions measured at a 15-cm depth under the paper and fabric mulches in relation to under bare ground were monitored throughout the growing season. Soil moisture generally fluctuated with rainfall (Figure 1). In 2017, early spring rains kept soils under all three systems moist (< −30 kPa matric potential) through early July, but began showing moisture stress (> −60 kPa), particularly in the under paper and under bare ground areas (Figure 1A). August rains temporarily restored adequate moisture, but then lack of rain later in the month resulted in dry conditions until September. During the August dry period, the bare ground showed the most water stress, followed by under paper mulch, but the soil under the fabric mulch demonstrated significantly better moisture retention throughout the summer. Overall, the under bare ground and under paper mulch sensors recorded 20–22 days of moderate to severe water stress (daily average > −60 kPa), with the period in August lasting 13 days under bare ground, whereas under the fabric mulch, there were only 6 days that averaged above that water stress level, and no period that lasted longer than 3 days (Figure 1A). In 2018, a dry spring resulted in water stress through most of June, and significantly wetter soils under the mulches than bare soil. By July, distinct differences in water stress were demonstrated among the three different systems, with bare soil most stressed, under paper partially stressed, and under fabric retaining more moisture than the other two systems (Figure 1B). From mid-August on, soil under bare ground showed severe water stress the rest of the summer, with more moisture retained under both mulches. By the end of August, soil under both mulches showed comparable levels of water stress into September. Overall, soil under bare ground averaged 53 days of water stress > −60 kPa, whereas soil under paper mulch averaged 26 days and under fabric mulch 20 days of water stress throughout the summer (Figure 1B). Thus, the fabric mulch improved soil moisture retention over the paper mulch as well as bare soil. Soil temperature, however, did not vary substantially among the three soil location types throughout the season, and were generally within 1–2 °C of each other (data not shown).

Despite the fluctuating moisture conditions, crop growth was generally good in both years. In 2018, drier conditions may have led to a slightly lower overall yield of turnips (~8% reduction) in 2018 than 2017, and the drier conditions as well as some issues with insect damage on beans, resulted in ~20% lower yields in 2018. However, the zucchini plants thrived in 2018 and yielded over 40% greater in 2018 than 2017. Plant diseases were not a major concern either year, with only the occurrence of some late season powdery mildew on zucchini, and some general leaf chlorosis and necrosis emerging late in the season on beans and zucchini both years.

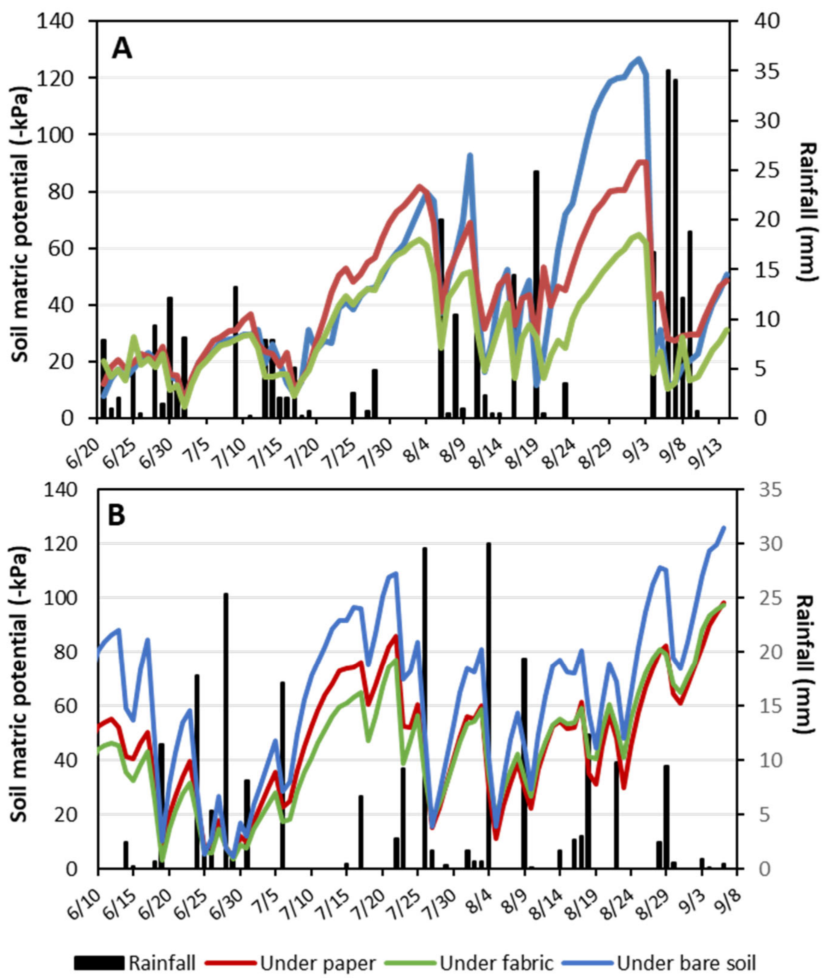

Figure 1. Daily rainfall totals and daily average soil moisture (soil matric potential) readings throughout the (**A**) 2017 and (**B**) 2018 growing season at organic vegetable field site in St. Albans, ME, USA, as measured within plots under a paper mulch weed barrier (under paper), under a woven polypropylene fabric mulch (under fabric), and outside of mulched plot boundaries representing bare soil (under bare soil).

3.2. Treatment Effects on Soil Properties

Soil amendment treatments and mulch type each had significant effects on many soil properties, but interactions between the two factors were not significant as determined in 2018 analyses of soil samples. Wollastonite (silica) amendment resulted in higher pH, higher Ca content, and higher CEC than all other treatments, and higher P content than the fertilizer-only treatment (Table 3). Fish meal amendment was associated with higher NO_3 and NH_4 content, as well as higher K, Mg, and Na concentrations than all other amendment treatments. The fertilizer-only treatment was responsible for the lowest pH and organic matter content, and the lowest concentrations of K, Mg, Na, and CEC than all other treatments, as well as lower NO_3 than silica and fish meal, lower P than silica, and lower Ca than silica and fish meal treatments (Table 3). For other minor elements, fertilizer-only treatment resulted in the highest and silica the lowest concentrations of Al and Fe than all other treatments. Fertilizer-only also had lower B, and fish meal higher Mn than all other treatments (data not shown).

Mulch type also significantly affected some soil properties. The fabric mulch was associated with higher organic matter, higher NO_3 and NH_4 content, as well as higher concentrations of K, Ca, Na, and CEC than soil in the paper mulch treatment (Table 3). Previous vegetable crop generally had minimal effects on soil properties in 2018 analyses, with the exception of lower pH (5.2 vs. 5.8–6.2), Ca content (2359 vs. 2692–2697), and CEC (8.4 vs. 9.4–9.7) following turnip compared to the other two vegetable crops. Previous vegetable crop also did not significantly interact with the other treatment factors.

Table 3. Selected soil chemical properties and nutrient concentrations in spring 2018 as affected by mulch type and soil amendments.

		OM	(mg/kg soil)							
	pH	**(%)**	**NO_3**	**NH_4**	**P**	**K**	**Mg**	**Ca**	**Na**	**CEC**
Mulch type										
Fabric	6.13 a [z]	6.12 a	61.4 a	7.0 a	93.7 a	171.8 a	124.4 a	2737 a	34.2 a	9.5 a
Paper	6.13 a	5.37 b	50.6 b	3.6 b	73.7 a	141.0 b	109.3 a	2429 b	30.2 b	8.9 b
LSD	0.12	0.45	6.6	3.4	25.9	27.7	15.7	289	3.9	0.6
Amendment										
Silica	6.77 a	5.90 a	52.8 b	2.4 b	101.0 a	168.6 b	142.3 ab	3219 a	32.3 b	10.7 a
Compost	5.97 b	5.94 a	48.3 bc	2.5 b	86.5 ab	165.6 b	123.4 b	2387 bc	32.8 b	8.8 b
Fish meal	6.00 b	6.03 a	80.6 a	13.3 a	88.4 ab	215.3 a	148.8 a	2583 b	41.0 a	9.2 b
Fertilizer	5.78 c	5.11 b	42.2 c	3.2 b	59.0 b	76.1 c	52.8 c	2141 c	2.8 c	8.0 c
LSD	0.16	0.64	9.4	5.4	36.6	39.2	22.2	408	5.5	0.8

[z] Values within columns followed by the same letter for each parameter are not significantly different from each other based on ANOVA and Fisher's protected LSD test ($p < 0.05$). Interaction between mulch type and soil amendment factors was not significant for any property ($p > 0.05$).

Soil microbial properties, as represented by CO_2 respiration (Solvita test) in both the spring and fall of 2018 was not affected by mulch type, but there were significant amendment effects, with fish meal resulting in higher microbial respiration than the fertilizer treatment in spring samples, and higher than the compost and fertilizer soils in fall samples (Table 4). Microbial activity as indicated by average well color development (AWCD) in substrate utilization tests, was also higher for the fish meal amendment than all other treatments, and higher for silica than compost and fertilizer treatments. The fabric mulch was also associated with higher AWCD than paper mulch, as well as higher levels of labile amino-N as detected in the SLAN test for samples from fall of 2018 (Table 4).

Table 4. Soil microbiological properties in the spring and fall of 2018 as affected by mulch type and soil amendment, and as measured by CO_2 respiration and soil Amino-N (Solvita CO_2 burst test and SLAN test) and microbial activity based on average well color development (AWCD) in substrate utilization (BIOLOG) plates.

Treatment	**Spring**	**Fall**		
	CO_2 resp.	**CO_2 resp.**	**Amino-N**	**AWCD**
	(mg/kg soil)	**(mg/kg soil)**	**(mg/kg)**	**(optical density)**
Mulch				
Fabric	148.0 a [z]	145.4 a	158.8 a	0.511 a
Paper	143.7 a	143.2 a	141.3 b	0.419 b
LSD ($p = 0.05$)	12.9	8.1	14.7	0.032
Amendment				
Silica	143.3 ab	146.6 ab	159.0 a	0.479 b
Compost	143.6 ab	140.8 bc	153.0 a	0.426 c
Fish meal	161.0 a	155.6 a	147.5 a	0.531 a
Fertilizer	135.5 b	132.1 c	140.5 a	0.426 c
LSD ($p = 0.05$)	18.2	11.5	20.8	0.045

[z] Values within columns followed by the same letter for each parameter are not significantly different from each other based on ANOVA and Fisher's protected LSD test ($p < 0.05$). Interaction between mulch type and soil amendment factors was not significant for any property ($p > 0.05$).

3.3. Treatment Effects on Crop Growth and Yield

Crop emergence of beans and zucchini was significantly affected by amendment and mulch treatments in both 2017 and 2018 growing seasons with no interactions observed between soil amendments and mulch type, but with some different results observed each year (and year by treatment interactions were significant). The fabric mulch resulted in higher early emergence (7–8 DAP) than paper mulch for beans in both 2017 and 2018, as well as at final emergence counts (24 DAP) in 2018 (Table 5). For zucchini, fabric mulch resulted in higher early emergence in 2018 only. Soil amendment significantly affected seedling emergence in both years, with fertilizer-only treatment resulting in lower early and final emergence counts for beans and zucchini than most other treatments in 2017, but in 2018 the fish meal treatment resulted in lower early emergence than other treatments for both bean and squash (Table 5).

Mulch type did not significantly affect total yields of green bean in either year. However, when yield was broken down into early (first 4 weeks) and later (last 4 weeks) yield totals, there were significant mulch effects, with fabric mulch resulting in higher early yields (significantly greater in 2018) and paper mulch having significantly greater late yield totals in both years (Table 6). Although mulch type did not affect zucchini yields in 2017, fabric mulch was associated with greater early and total zucchini yield in 2018, and overall yield totals were substantially higher in 2018 than 2017. Soil amendments had significant yield effects for both beans and zucchini in both years, with the fertilizer-only treatment consistently associated with the lowest observed yield totals for early, late, and total yields for both green bean and zucchini in both years (Table 6). All other amendment treatments resulted in significantly higher vegetable yield than the fertilizer treatment for early and total yield for beans in 2017 and early, late, and total yields for 2018, as well as late and total zucchini yields in 2018. In addition, silica treatment produced higher late yield for beans than fertilizer in 2017, and higher early yield than compost and fish meal treatments as well in 2018. Bean yields in the fertilizer treatments were especially low in 2018, posting total yields of roughly half of those observed with the other amendments. For zucchini, fish meal resulted in greater early and total yield than fertilizer in 2017, and compost produced greater total yield than fish meal and compost and silica treatments resulted in greater early yield than both fish meal and fertilizer in 2018 (Table 6). Although variable effects between years resulted in some significant interactions between year and mulch and year and amendment, the average total yield for beans and zucchini demonstrated the consistently lower yields observed in the fertilizer treatments than all other amendment treatments across both years (Figure 2).

Table 5. Effect of mulch type and soil amendments on early and final emergence counts of green bean and zucchini squash seedlings in 2017 and 2018 plantings.

Treatment	Crop Emergence (% of Seeds Planted)							
	Green Bean				Zucchini			
	2017		2018		2017		2018	
	Early	Final	Early	Final	Early	Final	Early	Final
	8 DAP	25 DAP	7 DAP	24 DAP	9 DAP	23 DAP	9 DAP	25 DAP
Mulch								
Fabric	84.5 a [z]	94.4 a	82.3 a	82.9 a	42.7 a	45.6 a	37.8 a	49.1 a
Paper	77.4 b	95.4 a	71.6 b	74.4 b	41.5 a	44.2 a	31.1 b	48.2 a
LSD	5.4	3.2	5.1	5.1	2.9	1.8	2.9	1.8
Amendment								
Silica	85.0 a	98.1 a	83.7 a	83.3 a	32.5 ab	47.8 a	44.7 a	47.5 ab
Compost	82.6 a	93.3 b	76.4 ab	78.6 ab	44.1 ab	44.1 a	42.8 a	50.0 a
Fish meal	89.4 a	96.3 ab	69.5 b	74.7 b	48.4 a	45.9 a	21.6 b	47.2 b
Fertilizer	66.9 b	88.3 c	78.1 a	78.1 ab	27.2 b	39.7 b	43.2 a	49.7 ab
LSD ($p = 0.05$)	7.6	2.3	7.3	3.5	19.0	5.0	4.2	2.5

[z] Values within columns followed by the same letter for each parameter are not significantly different from each other based on ANOVA and Fisher's protected LSD test ($p < 0.05$). Interaction between mulch type and soil amendment factors was not significant for any property ($p > 0.05$).

Table 6. Vegetable yield of green bean and zucchini, representing early yield (first 4 weeks), late yield (last 4 weeks), and total yield, as affected by mulch type and soil amendments in 2017 and 2018 growing seasons.

Treatment	Yield (Mg/ha)						
	Green Bean				Zucchini		
	Early	Late	Total		Early	Late	Total
Mulch							
Fabric	8.40 a [z]	6.07 b	14.53 a		30.79 a	25.53 a	56.26 a
Paper	8.24 a	7.70 a	15.93 a		31.60 a	26.34 a	57.94 a
LSD	1.36	0.60	1.41		5.20	4.82	8.56
Amendment				2017			
Silica	8.35 a	7.70 a	16.04 a		30.79 ab	27.53 a	58.32 ab
Compost	8.46 a	6.99 ab	15.50 a		31.92 ab	26.23 a	58.21 ab
Fish Meal	10.03 a	6.88 ab	16.91 a		36.69 a	28.51 a	65.15 a
Fertilizer	6.29 b	6.18 b	12.41 b		25.37 b	21.46 a	46.83 b
LSD	1.90	0.87	2.01		7.37	6.83	12.09
Mulch							
Fabric	6.16 a	6.19 b	12.36 a		56.53 a	32.90 a	89.48 a
Paper	4.72 b	6.88 a	11.65 a		46.50 b	31.22 a	77.72 b
LSD	0.76	0.60	1.14		4.34	3.41	6.72
Amendment				2018			
Silica	7.10 a	7.26 a	14.36 a		55.12 a	32.63 a	87.75 ab
Compost	5.91 b	7.21 a	13.12 a		61.08 a	33.71 a	94.80 a
Fish Meal	5.42 b	7.86 a	13.28 a		47.26 b	34.80 a	82.06 b
Fertilizer	3.31 c	3.85 b	7.21 b		42.71 b	27.21 b	69.86 c
LSD	1.14	0.81	1.57		6.18	4.82	9.54

[z] Values within columns followed by the same letter for each parameter and year are not significantly different from each other based on ANOVA and Fisher's protected LSD test ($p < 0.05$). Interaction between mulch type and soil amendment factors was not significant for any property ($p > 0.05$).

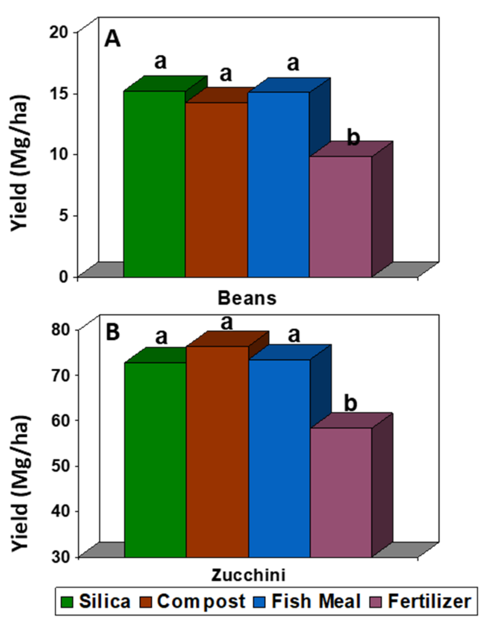

Figure 2. Average total yield of (**A**) green snap beans and (**B**) zucchini squash over two consecutive growing seasons (combined data for 2017 and 2018) and as affected by different soil amendments. Bars topped by the same letter for each vegetable are not significantly different based on Fisher's protected LSD test ($p < 0.05$). Compost = Composted dairy manure; Silica = Compost plus silicon (Si) as Wollastonite; Fish meal = Compost plus organic fish meal (high N fertilizer); Fertilizer = commercial organic fertilizer-only treatment (no compost).

For turnips, emergence and yield totals, as well as mulch and treatment effects were very consistent in both years, with no appreciable variability or differences between years (and no significant interactions). Thus, crop emergence and yield data for turnips were combined for 2017 and 2018 and presented as averages over both years. Neither mulch type nor amendment treatments had any significant effects on crop emergence or yield, including yield of turnip greens (the above-ground biomass of the plant), which were also harvested and weighed for this crop (Table 7). Production was consistent across all treatments and across both years.

Table 7. Average early and final emergence and total, early, and late harvest vegetable yield, as well as total yield of turnip greens for turnip crop combined over the 2017 and 2018 growing seasons, and as affected by mulch type and soil amendments.

	Emergence (%)		**Yield (Mg/ha)**			
	Early	**Final**	**Early**	**Late**	**Total**	**Greens**
Mulch						
Fabric	65.6 a [z]	81.4 a	5.85 a	1.91 a	7.53 a	9.65 a
Paper	63.9 a	80.2 a	6.02 a	1.70 a	7.92 a	9.49 a
LSD	6.4	4.0	1.30	0.43	1.3	1.30
Amendment						
Silica	63.1 a	80.6 a	5.64 a	1.61 a	7.26 a	9.38 a
Compost	68.4 a	82.5 a	5.91 a	1.92 a	7.86 a	9.97 a
Fish Meal	65.8 a	79.8 a	6.78 a	1.90 a	8.67 a	10.19 a
Fertilizer	61.8 a	80.4 a	5.37 a	1.78 a	7.15 a	8.67 a
LSD	12.6	10.0	1.84	0.60	1.57	1.84

[z] Values within columns followed by the same letter for each parameter are not significantly different from each other based on ANOVA and Fisher's protected LSD test ($p < 0.05$). Interaction between mulch type and soil amendment factors was not significant for any property ($p > 0.05$).

3.4. Treatment Effects on Pests, Diseases, and Other Issues

Although overall, pest and disease problems were minimal throughout the study, there was an issue with a mite infestation on beans in the latter part of the 2018 season. Towards the end of July, following a period of hot, dry weather, two-spotted spider mites (*Tetranychus urticae*) were first observed on some plants in the fertilizer-only treatments. With the hot, dry conditions persisting, the infestations grew larger and mites began appearing on plants in other treatments, causing noticeable damage to the leaves of affected plants. The progress and damage caused by the mites were monitored through the rest of the season, and is depicted in Figure 3. The problem was more prominent and severe on the fertilizer-only treated plots throughout the year, reaching a high of ~60% of the foliage affected by the end of the season, and resulting in much lower yield and production. However, even in the absence of mite damage, in both years, bean plants also showed some general decline and yellowing and browning of leaves towards the end of the season, and this effect was more apparent in some treatments than others. In 2017, the silica treatment showed less yellowing and browning of leaves than any other treatment, whereas the fertilizer treatment showed the most severe symptoms (Figure 4A). In 2018, this overall decline could not be distinguished from the damage caused by mites, so the estimates include both mite damage and decline, and showed the fertilizer treatment with substantially more damage than the other treatments, and the fish meal amendment showing less effects than silica.

The only crop disease that was noted and specifically identified was powdery mildew (*Podosphaera xanthii*) on zucchini plants, and that was only observed late in the season to a small degree in 2017 and was more prevalent in 2018, after most of the vegetable harvest was complete. However, there were differences among the amendment treatments in the development of the disease in both years. In 2017, the fish meal and fertilizer treatments were associated with higher incidence of powdery mildew than the silica and compost treatments, although the disease was affecting less than 7% of the foliage (Figure 4B). In 2018, with higher disease incidences at the end of the season, the compost and fertilizer treatments were associated with the highest disease levels, and the silica treatment maintained the lowest incidence of disease among all the amendments (Figure 4B). Mulch type did not affect disease development in either year.

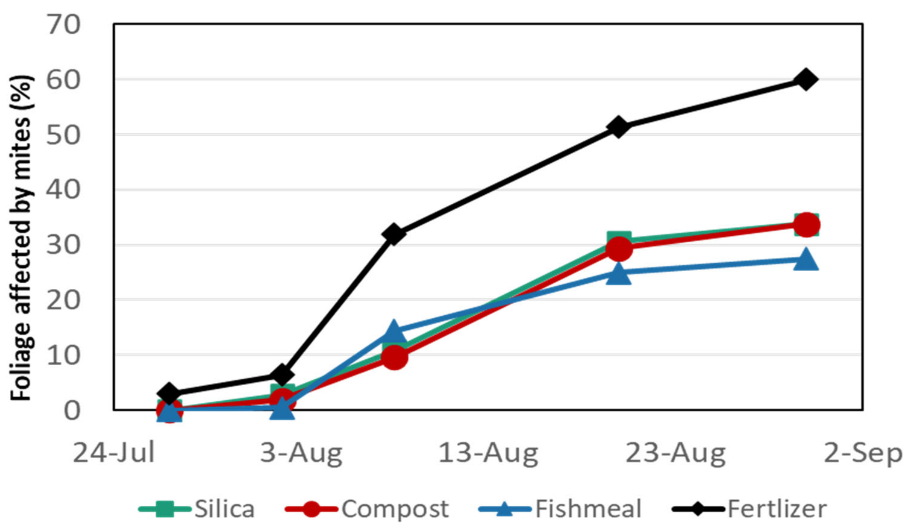

Figure 3. Effect of soil amendments on the development and damage caused by spider mite infestation on green beans in in 2018 season. Compost = Composted dairy manure; Silica = Compost plus silicon (Si) as Wollastonite; Fish meal = Compost plus organic fish meal (high N fertilizer); Fertilizer = commercial organic fertilizer-only treatment (no compost).

Overall, both mulch types provided adequate weed control within plots through most of the season, as no weeds occurred within the plots (other than within the planting holes, which were periodically removed by hand). However, towards the end of the season, particularly in 2018, the paper mulch did begin to break down, resulting in spots of bare ground and weed emergence issues. This was particularly noted in the turnip crop because, unlike the other crops, when the turnips were harvested, the whole plant was removed. This led to more rapid degradation of the paper mulch, to the degree that appreciable parts of the plots became uncovered, allowing weeds to take over. To document this, on two dates in 2018, August 20 and 30, ground cover remaining was estimated in all the turnip plots. In the fabric mulch plots, close to 100% ground cover was retained in all plots, but in the paper mulch plots, an average of only 55.3% ground cover remained on 8/20 and 44.1% on 8/30.

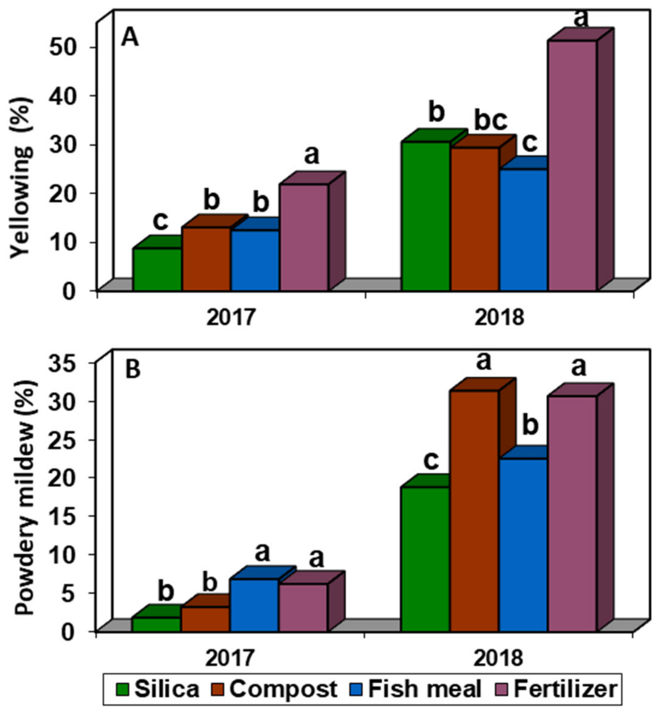

Figure 4. Effect of soil amendments on (**A**) late season yellowing and browning of green beans and (**B**) powdery mildew on zucchini squash in 2017 and 2018 growing seasons. Compost = Composted dairy manure; Silica = Compost plus silicon (Si) as Wollastonite; Fish meal = Compost plus organic fish meal (high N fertilizer); Fertilizer = commercial organic fertilizer-only treatment (no compost). Bars topped by the same letter for each year are not significantly different from each other based on ANOVA and Fisher's protected LSD test ($p < 0.05$).

4. Discussion

In this research, two alternative mulches to traditional black plastic were evaluated for their effectiveness as ground covers and effects on soil and crop properties, and organic soil amendments of compost and compost plus fish meal or silicon were compared with a fertilizer-only treatment for their potential benefits to organic vegetable production of three different crops. Although both mulch types performed adequately as weed barriers, the fabric mulch demonstrated superior traits regarding beneficial effects on soil moisture, soil fertility, and crop yield. All the amendments containing compost provided improvements in soil properties and crop growth and yield relative to the fertilizer-only treatment, and the additional components of silicon or fish meal generally provided only marginal improvement over compost by itself, but still showed some positive enhancements for some traits.

Both the paper and fabric mulches provided acceptable alternatives to black plastic polyethylene mulch, which although permissible in organic production is generally considered as not being appropriate or compatible with the concepts and principles of organic agriculture due to the generation of large quantities of plastic waste that needs to be disposed of each year [5]. In addition, black plastic mulch, being impermeable, leads to additional issues with water relations and soil degradation [4]. For these reasons, black polyethylene mulch was not used in these trials. The woven polypropylene fabric mulch is permeable, sturdy, and reusable over several years, eliminating or reducing many of the issues with traditional black plastic mulch. In this research, the fabric mulch provided notable improvements in soil moisture retention during dry periods throughout the season relative to both bare ground and the paper mulch, reducing the number of days crop plants would be exposed to water stress. In addition, the fabric mulch improved retention of organic matter and most major and minor nutrients relative to the paper mulch. The fabric mulch also supported earlier emergence and early yield differences for most crops, and early yields may be important in a crowded marketplace where supply and competition affect price and returns. Previous studies evaluating fabric mulches have focused almost exclusively with their use as more permanent forms of ground cover in landscape planting beds and perennial systems where they are generally covered by organic mulches or other materials and left in place, whereas their use as seasonal weed barrier mulches in vegetable plantings has largely not been addressed [18]. A recent review summarizing the status and advances in mulching materials and practices over the past 25 years did not mention polypropylene fabric mulches as a potential option [19].

Although the paper mulch did provide acceptable weed control for most of the season, it did break down before the end of the season. This breakdown resulted in patches of bare ground which led to weed issues, greater evaporative loss of soil moisture, and possibly greater loss of organic matter and soil nutrients. Previous studies that used heavy kraft paper as a mulch also observed substantial breakdown before the end of the season and sometimes lower yields [20,21], whereas others observed good weed control and yield [22]. However, most of these previous studies used paper types that may not have been specifically designed for agricultural use [6,8]. In a previous organic vegetable study [9], we used a more heavyweight grade of paper and the paper was not degraded enough by the end of the season, making incorporation more difficult, so we switched to the standard grade in this study, and it broke down too quickly. Thus, although the paper mulch can work and be acceptable as a weed barrier within organic vegetable systems, the fabric mulch was more effective across the board, providing improved soil moisture, organic matter, soil fertility, crop emergence, and early yields.

In this study, soil temperature was not observed to be significantly affected by either the paper or fabric mulches, whereas black plastic has generally been shown to increase soil temperature [5]. The lack of effect on soil temperature in our study is most likely due to the permeability of the paper and fabric mulches providing more air exchange and thus not heating up, yet still providing improved retention of soil moisture. The permeability of woven fabric mulches to not only water but also nutrients has been demonstrated [23].

Both the paper and fabric mulches have higher initial material costs than black plastic (with paper averaging 2 to 2.5× and fabric 3 to 3.5× that of black plastic), and require additional upfront costs in labor and preparation at the beginning of the season to prepare the mulches (cutting, making holes, and laying mulch). Fabric mulch also requires end season costs for removal, storage, and cleaning, but the fabric can be used for several years, reducing overall costs for subsequent seasons. The paper mulch has an advantage in not having to be removed at the end of the season and being biodegradable and incorporated into the soil.

Notably, for the turnip crop, neither mulch type nor soil amendments had much effect on emergence or yield at any time in this study, whereas significant effects were observed for most parameters for both bean and zucchini. Turnip crop development was steady regardless of soil properties or amendment differences and effects. This may be related to the fact that turnip, as a root crop in which the crop is the tap root itself, only one vegetable is produced per plant, and thus does not produce the numbers or biomass that other fruit-bearing vegetable crops do, and may be less influenced by seasonal variations and fluctuations in environmental conditions and soil properties.

In this study, the fertilizer-only treatment was clearly inferior to the other amendment treatments, resulting in the lowest pH and organic matter content, as well as lower soil fertility and soil biological properties throughout the study, which was then associated with lower crop emergence and yield for beans and zucchini. However, based on soil chemical analyses and basic fertility requirements, the fertilizer treatment should have had sufficient N and other essential elements to provide good yields, yet this treatment lagged behind all others. This emphasized the importance of the compost (as all other treatments contained compost) as an amendment that provides more than just elemental nutrition.

Compost amendments are known to affect a wide variety of soil physical, chemical, and biological properties, improving soil quality, and are a fundamental tool for building healthier soils [24–27]. The increases in organic matter from compost are crucial for many key attributes of these systems. Organic matter amendments improve soil structural stability through increases in aggregate stability, and also improvements in bulk density, aeration, porosity, water-holding capacity, water movement, and facilitating nutrient cycling [28–30]. Compost amendments have been shown to be related to an increase in microbial biomass and microbial activity, changes in community structure and composition, and enhancements of specific groups of microorganisms [25,31–36]. These changes are often associated with increased yields. In previous research, compost amendments affected soil microbial communities and successfully improved yield in both conventional and organic production systems [37–42]. In a recent review of agricultural management practices across Europe and China, addition of organic matter had the most favorable effect on yield as well as several other indicators of soil quality among all the various management practices [43]. Overall, yields observed in this study were quite high for beans and zucchini, as the average yields were well above the regional and national averages for those crops [9].

The silicon and fish meal amendments were included to determine whether these additions to the compost amendment would provide any additional benefits over and above those provided by the compost, either to soil properties or crop production. Silicon, although not considered an essential nutrient, has been shown to provide numerous benefits to a variety of crop plants, including plant disease resistance, reductions in insect feeding and damage, and tolerance to various abiotic stresses [12–14]. Increased Si content in plant tissue enhances the plant's physical structure, increasing the mechanical strength and protective layer of the plant, as well as stimulating production of plant defense chemicals and responses and activation of biochemical processes that mitigate the impact of abiotic stresses [14]. Recent reviews have highlighted the potential benefits and available research on the beneficial effects of Si in agriculture, but little research has been done with organic systems [44,45]. Although for most parameters in this study the effects of the silica amendment were not significantly different from compost alone, silica treatment did improve early emergence of beans in 2017, and showed some effects on diseases, reducing powdery mildew on squash and late season browning on beans to a greater degree than other amendments. Due to some technical issues, Si content of the plant tissue was not able to be determined for this study, so it could not be determined how well the crop plants took up the Si, or whether Si content in the treated plants was significantly greater than in other treatments. Thus, information on dosages needed for effective uptake and utilization of natural Si amendments is still lacking.

The primary purpose of fish meal amendment is to provide a N boost, as it contains very high N level. In this study, the fish meal amendment did boost soil N substantially, as well as other nutrient concentrations, but based on soil tests, the N and other nutrients supplied were more than were needed, and could lead to higher leaching and losses of NPK and other nutrients. The fish meal amendment did provide greater early yields for both bean and zucchini in 2017, but not 2018, and also resulted in higher microbial respiration and activity in 2018. This may have been a response to the enriched nutrients, but also probably a temporary boost. Overall, in this study, the fish meal amendment did not appear to provide a worthwhile enhancement to the compost amendment.

Although there were no substantial disease issues with any of the crops and pest issues were limited to a late season mite infestation on beans in 2018, there were still some indications of reductions in pests and diseases with the amendments. All of the compost amendments maintained lower mite damage than the fertilizer-only treatment, as well as lower levels of late season yellowing and browning in beans, in addition to the reduction in powdery mildew observed with Si amendment. Both Si and compost have been reported to have the potential for reducing diseases and, in some cases, insect pests [14,34,46].

This research assessed the potential benefits of different types of soil amendments and weed barrier mulches within a diversified organic vegetable production system. In addition to efficacy as a weed barrier, mulch type can affect many other aspects of vegetable production and the choice of mulch should incorporate these effects on soil properties, crop growth and development, and environmental sustainability as well as cost and efficacy in weed control. In this research, a woven polypropylene fabric mulch demonstrated characteristics superior to a paper mulch, including improved retention of soil moisture, maintaining higher organic matter and soil fertility, and improved crop yield. Soil amendments containing compost provided improvements in soil properties such as pH, organic matter, soil fertility, and crop emergence and yield relative to an organic fertilizer-only treatment, whereas the additions of fish meal and silicon provided only marginal changes or improvement over compost alone, but may have some specific benefits and uses under the right circumstances. These results emphasized the importance of compost and additions of organic matter for improving soil quality and supplying the soil properties, nutrition, and microbiology needed for enhanced crop performance and yield in organic vegetable production. This research provides information on specific management practices and approaches to help improve the sustainability and productivity of organic vegetable production.

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