ABSTRACT

BROWN, MELISSA ANN. The Use of Marine Derived Products and Soybean Meal as Fertilizers in Organic Vegetable Production. (Under the direction of Jeanine M. Davis).

Seaweed extract, fish emulsion, and soybean meal (SBM) are United States Department of Agriculture (USDA) National Organic Program (NOP) allowed substances used by organic vegetable growers as fertilizers.

Soil applied SBM and foliar applied seaweed, fish, fish/seaweed, 20-20-20, and a water control were tested on field-grown sweet peppers, broccoli, and lettuce to determine their effects on plant nutrition and crop yield. The SBM was applied at three rates: 0, 2466, and 4932 $kg \cdot ha^{-1}$ (0, 2200, and 4400 $lb \cdot acre^{-1}$). To test the duration of the SBM as a soil fertilizer, peppers, broccoli, and lettuce were grown in succession on the same beds after the initial SBM application. The foliar fertilizers were also tested on peppers on a certified organic farm for comparison to the research station study. In 2002, transplanting one day after SBM application caused fertilizer burn to the pepper roots. In 2003, peppers were planted one week after SBM application without harm to plant roots. SBM positively increased the nutrient level and yield of broccoli in 2002 and peppers in 2003. Lettuce yield was not affected by the SBM treatments because the previous pepper and broccoli crops had likely exhausted the SBM fertilizer. The foliar sprays did not affect plant nutrient levels or yields in any crop at either location.

Greenhouse studies were conducted to investigate the effect of SBM on germination and growth of eight common vegetables. Treatments included five rates of SBM: 0, 1093, 2186, 3279, and 4372 $kg \cdot ha^{-1}$ (0, 975, 1950, 2925, and 3900 $lb \cdot acre^{-1}$) and two application methods: surface applied (SA) and incorporated (IN) into the media. For all vegetables combined, at applications of 1093 and 2186 $kg \cdot ha^{-1}$ IN SBM, shoot weight increased by 20% and 10%, respectively, compared to the unfertilized control. At the same rate of SA SBM, shoot weight was reduced by 6% and 18% respectively. At all rates of SA SMB,

shoot weight was more reduced in small seeded vegetables (spinach, lettuce, carrot, and radish) than in large seeded vegetables (squash, cucumber, bean, and pea). At 3279 and 4372 $kg \cdot ha^{-1}$ of IN SBM, shoot weight of small seeded vegetables was reduced by 8% and 46%, respectively. The EC and pH of the media increased with increased rates of SBM and were greater with SA SBM than with IN SBM. Levels above pH 6.5 and EC 1.0 $dS \cdot m^{-1}$ were measured on day 7 for media at all SBM rates. These levels could be inhibitory to germinating seeds. Because SBM reduced growth of small seeded vegetables, it is not recommended that small seeded vegetables be surface fertilized with SBM or that they be sown directly into soil where SBM has been recently incorporated. SBM incorporated at low rates (<2186 $kg \cdot ha^{-1}$) could prove to be a useful fertilizer for large seeded crops without concerns of inhibition by SBM.

Field studies were conducted to investigate the optimal rate and timing of SBM fertilization in plasticulture sweet pepper production. SBM was applied at three rates: 0, 2421, and 4842 $kg \cdot ha^{-1}$ (0, 2165 and 4330 $lb \cdot acre^{-1}$). Sweet peppers were then transplanted at four intervals following SBM incorporation and black plastic application: one day, three days, seven days, and fourteen days. Growth was initially inhibited in peppers planted into the high rate of SBM less than one week after incorporation. By the end of the season, these peppers had recovered and had a biomass greater than the unfertilized control. Peppers fertilized with the low rate of SBM did not suffer an initial inhibition and had the highest yield of marketable peppers at all planting times. This study suggests a moderate rate of SBM should be applied at least two weeks before the intended planting date.

The Use of Marine Derived Products and Soybean Meal as Fertilizers in Organic Vegetable Production

by

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BIOGRAPHY

Melissa Ann Brown was born on January 16, 1977 to Bruce and Irene Pline. She grew up on a family farm near St. Johns, Michigan with her older sister Wendy Ann Srnic and her younger brother Kevin Michael Pline. She was active in 4-H, raising calves, vegetables, and flowers for show at the Clinton County Fair.

After graduating from St. Johns High School, Melissa attended Aquinas College in Grand Rapids, MI. While enrolled, she spent a semester at a sister school, Dominican University, in San Rafael, California and a semester abroad in Tully Cross, Ireland. In 2000, she obtained her Bachelor of Science degree with a major in biology and a minor in writing.

Melissa spent the summer following her graduation at Merck Forest and Farmland Center in Rupert, Vermont. As an intern, she studied and participated in organic agriculture and direct marketing on the non-profit farm. Melissa worked a year longer as the CSA (Community Supported Agriculture) coordinator and vegetable grower.

In January of 2002, Melissa returned to school as a Master's student in the Department of Horticultural Science at North Carolina State University. On November 29, 2003, she married Eric Christian Brown. The couple has settled in Ronda, NC to start an organic farm named Milk and Honey Farm.

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LITERATURE REVIEW

Organic agriculture is one of the fastest growing segments of U.S. agriculture today. In 2000, domestic sales of organic products topped $7.8 billion, with fresh produce the top-selling organic category (Dimitri and Greene, 2002). The growing popularity of organically grown foods has generated new market opportunities for both wholesale and direct-market organic produce farmers.

To provide consumers, growers, and industry with a common definition of organic, Congress drafted the Organic Foods Production Act of 1990 (OFPA). Under this law, the United States Department of Agriculture (USDA) was mandated to write regulations for organic production. As of October 21, 2002, growers selling their products as “organic” in the United States must follow the Final Rules of the USDA National Organic Program (NOP) (USDA, 2002a). Under these uniform national standards, an organic label certifies that specific guidelines were followed to produce, handle, and process the product.

Organic production, as defined by the National Organic Standards Board, is “a production system that is managed in accordance with the Act and regulations in this part to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity” (USDA, 2002b). Specifically, the Act requires that growers manage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials. Many growers rely primarily on these organic processes to supply crop nutrients (Fernandez-Cornejo et al., 1998).

Requirements for organic fertilizers

Under the Act, growers are also allowed to add soil and plant amendments. The Final Rule of the NOP includes the National List of Allowed and Prohibited Substances. This section states the criteria used to evaluate substances used in organic production and lists the allowed synthetic substances and the prohibited non-synthetic substances (USDA, 2002c). The synthetic substances allowed by the NOP may be used provided the substances do not contribute to the contamination of crops, soil, or water.

Liquid fish products are considered synthetic plant or soil amendments because acid is often added to adjust the pH. The NOP allows the addition of sulfuric, citric, or phosphoric for this purpose, but the amount of acid used cannot exceed the minimum needed to lower the pH to 3.5 (USDA, 2002c). Extracts from aquatic plants are also considered synthetic plant or soil amendments because potassium hydroxide and sodium hydroxide are often used in the extraction process. To be allowed by the NOP these additives are limited to the amount necessary for extraction (USDA, 2002c).

Soybean (*Glycine max*) meal (SBM), a byproduct of soy oil extraction, is allowed as a non-synthetic plant or soil amendment. There is still debate concerning the use of SBM derived from genetically modified organism (GMO) soybeans, such as those with the Round-Up Ready® gene (Monsanto, St. Louis, MO). The USDA NOP does not allow the use of methods to genetically modify organisms or to influence growth and development by means that are not possible under natural conditions (USDA, 2002c). The use of GMO seeds in organic production, therefore, is prohibited, but the regulations do not specifically prohibit fertilizing with meals made from GMO seeds.

The Organic Materials Review Institute (OMRI) is a nonprofit organization that interprets the National List and generates generic and specific (brand name) lists of materials allowed and prohibited for use in organic production. To make decisions on the use of products that contain or may contain GMO products, OMRI utilizes a decision tree. The OMRI decision tree states that if the GMO material does not transfer to the product that is being sold as organic the GMO product can be used in organic production. As it is unlikely that the GMO materials found in meals used as fertilizers could transfer to the crop in field conditions, GMO or unknown status meals are currently allowed as a crop production material (Organic Materials Review Institute, 2003).

Organic fertilizer amendments can be expensive when used in large quantities, so they are often used only for supplementary nutrition, if they are used at all. In a 1994 nationwide survey of 300 certified organic growers, when asked about fertilizer sources, 78% reported using animal manure, 77% used legume cover crops, and 61% used compost in their farm operations. Fish products were used by only 20% of those surveyed, meal (cottonseed (*Gossypium hirsutum* L.) and/or soybean) by 7.3%, and extracts from aquatic plants by 5.6% (Fernandez-Cornejo et al., 1998). The effective use and the economic value of fish, seaweed, and SBM in organic agriculture have yet to be verified by scientific research. Organic farmers also need information on how these materials can best be integrated into their overall fertility management plans.

Marine products used as organic fertilizers

Throughout the history of agriculture, coastal farmers have derived fertility from the sea by bringing seaweed and fish ashore to use as mulches in gardens and fields. West of Ireland on the Aran Islands, seaweed was combined with sand to create “soil,” permitting the cultivation of crops and vegetables on a rocky island (Booth, 1965). Seventeenth century New England settlers applied one to four fish per hill of corn (*Zea mays*), fertilizing with up to 1,000 to 3,000 fish per acre (400 to 1,200 fish per hectare) annually (Ceci, 1975).

Raw seaweed and fish are still used as fertilizers in subsistence farming around the globe. The use of sea- based fertilizers by commercial growers has been minimal since the advent of synthetic fertilizers. Some organic growers, on the other hand, rely heavily on fish and seaweed products for supplementary nutrition in transplant and crop production. While Fernandez-Cornejo et al. (1998) found 20% of the organic growers they surveyed used fish products, a 1995 survey of organic Florida citrus and vegetable producers, reported 71% of the respondents used fish emulsion as a secondary nutrient source (Swisher and Monaghan, 1995).

There are two main types of liquid fish products on the market – fish hydrolysates and fish emulsions. Fish hydrolysates, or “fish digests,” are produced by enzymatically breaking down the organic components of the fish

(Baker, 1996). The main components of hydrolysates are ‘by-catch’, a term referring to fish of unmarketable size and species. Fish emulsions are made primarily from the by-products of cleaned fish as well as inedible fish such as menhaden. Menhaden is a bony, oily, Atlantic Ocean and Gulf of Mexico dwelling fish harvested for use as bait, meal, and oil. For production of fish emulsion, fish are cooked and then passed through a screw press to extract the liquids and oils. The solids are then processed into fishmeal and sold as animal feed and other products. The liquid, called stickwater, is centrifuged and the oil is skimmed off and sold as pure fish oil. The remaining liquid is boiled down to a thicker solution and sold as fish emulsion. A small amount of phosphoric acid is added to the emulsion to lower the pH to 4.5 to prevent the enzymes from further breaking down the proteins. The emulsion is sold as flavoring for cat and dog food, a protein additive in animal feed, and as a plant fertilizer (Ginn, 2003).

Seaweed fertilizers are derived from a number of seaweed species around the globe. Most commercial seaweed products, though, are made from fresh cut North Atlantic kelp (*Ascophyllum* spp.) harvested off the coasts of Canada and Norway (Eris et al., 1995). To prepare the liquid extracts, the seaweed is often shredded and hydrolyzed under pressure. Preservatives are then added to stabilize the liquid and prevent further decay (Verkleij, 1992). These additives, however, must meet NOP standards for the product to be used in organic production.

Foliar Fertilization

Growers can use seaweed and fish products in many aspects of production, such as drench fertilizing during transplant production and injecting through the irrigation system, known as fertigation, during field production. One of the most common uses of these sea-based products, though, is as foliar fertilizers. Foliar fertilization is the application, via spraying, of nutrients to leaves and stems where they are absorbed into the plant (Alexander, 1985).

A wide range of minor and major nutrients, plant hormones, and growth stimulants may be applied to plants as foliar fertilizers for a number of reasons. In some cases, foliar applications of fertilizers can supply the plant with nutrients more rapidly than methods involving root uptake (Marschner, 1986). Growers, therefore, can apply foliar fertilizers to quickly correct nutrient deficiencies, such as boron deficiency in cotton (Guertal et al., 1996). Growers also use foliar fertilizers to supplement soil-applied nutrients, to compensate for decreased root activity, and to increase protein content of cereal seeds and calcium content in fruits (Marschner, 1986). Studies have also shown that foliar fertilizers promote root nutrient absorption (Alexander, 1985).

Foliar fertilization has some drawbacks, mainly due to the structure of the leaf and the temporary nature of the nutrient supply. Leaves, particularly those with thick cuticles, have low penetration rates. Therefore, multiple applications of liquid fertilizers may be necessary to supply a sufficient quantity of the nutrient. Further, once applied, foliar nutrients may be washed off by rain or irrigation water before the plant absorbs them. To counter this loss, surfactants can be used to increase the efficiency of penetration of the leaf surface and the duration of the sprays on the leaf. Finally, applications of high nutrient concentrations of foliar fertilizers can cause severe leaf damage due to phytotoxicity (Marschner, 1986). Repeated applications of dilute formulations, therefore, may be necessary to supply the plant's nutrient requirements without damaging the foliage.

Active constituents of seaweed and fish foliar fertilizers

The use of fish and seaweed products has been reported to improve crop yield, seed germination, insect and fungal disease resistance, and low temperature tolerance (Booth, 1965). Despite these other potential benefits, fish and seaweed products are mainly sold as fertilizers. Yet, these marine derived foliar fertilizers have very low NPK values (e.g. fish 2-4-1 and seaweed 0-0-1) when compared to most soil applied fertilizers. It would be cost prohibitive to rely on these products alone to meet the macronutrient requirements of crops. Most growers spray these materials either bi-weekly throughout the growing season or as a mid-season boost. In either use, the idea is to supplement rather than replace the soil-based fertilization program.

Since extracts are applied at low rates compared to the annual needs of the plant, it is likely the active components of these fertilizers are effective in very low amounts, such as micronutrients. Seaweed and fish products do contain a number of micronutrients in small quantities including Mg, S, Fe, Mn, Zn, B, Cl, and Na. Plants deficient in these trace elements could respond noticeably even if only small amounts are added. Magnesium, Mn, Z, and B deficiencies in citrus were eliminated by the addition of a 1:25 dilution of seaweed extract to a deficient culture solution (Aitken and Senn, 1965). Further, trace elements in seaweed extracts are often in the chelated organic form instead of the inorganic form. A chelate is a chemical compound made up of a metallic ion and an organic molecule (Brady and Weil, 2000). The chemical bonds between these two components prevent a chelate from reacting with soil particles. This allows a chelate to remain in solution until it comes into contact with a root, where it is either taken up in its entirety or just the cation is absorbed. Fernandon and Chamel (1988) also reported that the translocation of chelated Fe, Mn and Zn within the plants was 1.5 to 6 times faster than those same trace elements in the inorganic form. This illustrates a significant improvement in the efficiency of micronutrient application.

Researchers have also found that seaweed contains a number of plant growth hormones, including cytokinins, gibberellins, abscisic acid, and indoleacetic acid, as well as phenolic compounds (Verkleij, 1992) but it is not clear to what extent these externally applied organic compounds improve plant growth.

Efficacy of seaweed and fish foliar fertilizers

An extensive body of literature exists on the use of seaweed extracts on a range of crops. Review articles by Abetz (1980), Aitken and Senn (1965), and Verkleij (1992) summarize the results of many studies in this area over the past 50 years.

Researchers have found that seaweed extract applications can lead to increased plant growth and changes in plant tissue composition. From their work with greenhouse cucumbers *(Cucumis sativus* L.), Nelson and Van Staden (1984) found that seaweed concentrate applied as a root soak at transplant and as a weekly foliar spray increased overall plant dry mass and root growth. Lynn (1972) found that peppers (*Capsicum annuum* L.) treated with soil applied seaweed extract had improved utilization of trace elements and Tourte et al. (2000), in one year of a two year study, found that organic tomatoes (*Lycopersicon esculentum* Mill.) sprayed four times during the season with a seaweed/fish blend had significantly higher foliar NO_3 concentrations than the controls, despite a lack of improvement in yield or fruit quality.

A variety of plants have seen an overall increase in yield in response to seaweed extract applications. Foliar application of seaweed extract increased harvestable bean (*Phaseolus vulgaris* L.) yields by an average of 24% (Temple and Bomke, 1989), staked tomato yields up by up to 99% (Csizinszky, 1984), early yield of one variety of greenhouse cucumber (Passam et al., 1995), and greenhouse tomato total fruit fresh weight by 17% (Crouch and Van Staden, 1992). Other researchers have reported that the application of seaweed extract did not affect yield at all. Seaweed extract foliar sprays failed to increase the yield of wheat (*Triticum aestivum* L.) (Miers and Perry, 1986), onions (*Allium cepa* L.) (Feibert et al., 2003), and field tomatoes (Tourte et al., 2000).

In conclusion, the success of seaweed extract in crop production appears dependent on a number of factors, including the crop, the rate of seaweed application, the composition of the seaweed extract used, and the application method (soil or foliar applied). Yet most authors conclude that seaweed extracts could have some beneficial effects as supplemental foliar fertilizers. The adoption of the practice, however, is limited due to the cost of the sprays, the labor of application, and the inconsistent crop responses.

Studies in the literature investigating the use of fish products are quite limited in comparison to the extensive research conducted on seaweed. When applied as a soil drench fertilizer to greenhouse-grown plants, growth and yield of plants receiving fish soluble nutrients (FSN) were comparable to plants receiving an inorganic fertilizer (Aung and Flick, 1980; Emino, 1981). Further, soil fertilization with FSN increased the mineral content of the edible components of peas (*Pisum sativum* L.), tomatoes, lettuce (*Lactuca sativa* L.), and radish (*Raphanus sativus* L.) above those same vegetables fertilized with standard Hoagland nutrient solution (Aung et al., 1983). When applied as a foliar spray to field-grown tomatoes and grain, however, there was no increase in yield compared to the control (Miers and Perry, 1986, Tourte et al., 2000). In conclusion, the benefits of fish derived fertilizers are mixed depending on the crop, the type of fish and the processing method, and the fertilizer application method (soil or foliar).

Most of the studies on seaweed and fish sprays were conducted in conventional agricultural systems. Further work needs to be done to investigate the use of these products in organic systems. As seaweed and fish foliar fertilizers continue to grow in popularity among organic growers, these materials need to be analyzed for their scientific value for plant growth and cost effectiveness.

Soybean meal as a natural fertilizer

Soybean is one of the most widely cultivated plants in the world today and is valued for both its oil and meal (Hasegawa et al., 2002). Soybean meal (SBM) is a byproduct of soybean oil extraction. Processing a bushel (60 lbs. or 27 kg) of soybeans produces 10.5 pounds (5 kg) of oil and 48 pounds (22 kg) of meal and hulls; the rest is waste and water (INFOsource, 2002). SBM contains 44% to 47% protein and is a leading source of protein in poultry, swine, dairy, and beef diets (Erickson, 1995). It is also used in pet foods and aquaculture.

In the last century, SBM was used as a slow release N fertilizer (Kubo et al., 1994). With the advent of chemically synthesized fertilizers, the use of organic fertilizers declined (Rubins and Bear, 1942). Today there is renewed interest in SBM as a fertilizer (7N-1.2P-1.5K) in organic vegetable production systems.

SBM has been found to increase biomass production in tomatoes. In a test of 13 organic fertilizers for the production of greenhouse tomato transplants, SBM increased shoot dry weight 40% above the unfertilized control (Gagnon and Berrouard, 1994). In another study looking at the use of seed crop meals to control nematodes, SBM applied at 1000 to 2000 $lb \cdot acre^{-1}$ (1121 to 2242 $kg \cdot ha^{-1}$) significantly increased the foliar fresh weight and dry weights of tomatoes compared to the control (Hafez and Sundararaj, 1999).

There is evidence that high rates of SBM, though, can have phytotoxic effects on weeds and vegetables. At a rate of 4000 $lb \cdot acre^{-1}$ (4484 $kg \cdot ha^{-1}$) tomatoes suffered severe stunting, necrosis, and death (Hafez and Sundararaj, 1999). In another study, when SBM was used as a comparison to corn gluten meal (CGM), SBM inhibited perennial ryegrass (*Lolium perenne* L.) growth at 3046 $lb \cdot acre^{-1}$ (3414 $kg \cdot ha^{-1}$) and completely stopped growth at higher levels compared to the control (Liu et al., 1994).

Many other organic materials have shown similar inhibition of germinating seeds. Cottonseed meal (CSM) mixed into soil at 200 and 300 $lbs \cdot acre^{-1}$ (224 and 336 $kg \cdot ha^{-1}$) reduced corn seed germination by 75% compared to soil alone (Sherwin, 1923). The seeds germinated but died before reaching the soil surface. The absence of root hairs and the widespread decay of roots were attributed to the CSM decomposing fungus attacking the plant root system. Chopped alfalfa (*Medicago sativa* L.) at 22 and 44 $t \cdot acre^{-1}$ (4600 and 9200 $g \cdot m^{-2}$) inhibited germination and seedling growth of cucumbers (Ells et al., 1991). The authors attributed the damage to toxic levels of ammonia produced during the decomposition of the alfalfa in the soil. Manure extracts of 10% and 30% inhibited cress (*Lepidium sativum* L.) seed germination and root growth (Hoekstar et al., 2002). The damage was ascribed to phytotoxic nitrogenous compounds, such as cyanide, amines, and phenolic compounds, and high salinity levels (EC). Corn gluten meal (CGM), another grain byproduct, was found to inhibit vegetable and weed seed germination (Liu and Christians, 1997). Alaninyl-alanine, a dipeptide, was identified as being one of the inhibitory compounds in CGM (Unruh et al., 1997). Christians (1991) patented CGM as a natural preemergence herbicide and Christians et al. (1994) patented corn gluten hydrolysate as a preemergence weed control product. CGM contains approximately 10 percent N by weight (Gardner et al., 1997) and can be used as a fertilizer. To avoid germination inhibition, though, CGM is usually applied one to four months before direct seeding crops. Direct application of CGM to established plantings, such as turf, can serve as a natural fertilizer and a preemergence herbicide (Christians, 1993).

The precise inhibitory factor in SBM is unknown. Future research may decipher if the observed phytotoxicity is due to a particular compound such as was found in CGM or due to a more generic reaction such as ammonium toxicity. Research with SBM should also investigate management practices that would utilize SBM's phytotoxic properties for weed control and its nutrient value as a slow release fertilizer. Research could also focus on development of fertilizer products derived from SBM. Hasegawa et al. (2002) found that SBM degraded with *Bacillus circulans* HA12 increased root hair density of Chinese cabbage (*Brassica campestris* L.) to three times that of the untreated SBM and increased yield of potato (*Solanum tuberosum* L.) by 37% compared to a chemical fertilizer. As the public's concern over the long-term ecological effects of synthetic agricultural chemicals continues to grow, there will be more interest in natural products, such as SBM, for weed control and fertilizers.

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Chapter One

Supplemental Organic Foliar and Soil Fertilization of Sweet Peppers, Broccoli, and Lettuce

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Supplemental Organic Foliar and Soil Fertilization of Sweet Peppers, Broccoli, and Lettuce

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Abstract. Foliar and soil applied organic fertilizers were tested on sweet peppers (*Capsicum annuum* L.), broccoli (*Brassica oleracea* L.), and lettuce (*Latuca sativa* L.) to determine their effects on plant nutrition and crop yield. The experimental design was a split-plot, arranged in a randomized complete block with four replications. Main-plot treatments were soil applications of soybean (*Glycine max*) meal (SBM) at three rates: 0, 2466, and 4932 $kg{\cdot}ha^{-1}$ representing a total N application of 0, 168, and 336 $kg\ N{\cdot}ha^{-1}$. Sub-plot treatments were foliar applications of fish, seaweed, fish/seaweed, 20-20-20, and a water control. Peppers, broccoli, and lettuce were grown in succession on the same beds after the initial SBM application to test the duration of the SBM as a soil fertilizer. The foliar fertilizers were also tested on peppers on a certified organic farm for comparison to the research station study.

In 2002, transplanting one day after SBM application at these rates caused fertilizer burn to the pepper roots. In 2003, peppers were planted one week after SBM application without harm to plant roots. SBM significantly

increased the nutrient level and yield of broccoli in 2002 and peppers in 2003. Lettuce was not affected by the SBM treatments presumably because the previous pepper and broccoli crops had likely exhausted the SBM fertilizer. The foliar sprays did not affect plant nutrient levels or yields compared to the control in any crop at either location.

As of October 21, 2002, growers selling their products as “organic” in the United States must follow the Final Rules of the United States Department of Agriculture’s (USDA) National Organic Program (NOP) (USDA, 2002). Specifically, the Act requires that growers manage crop nutrients and soil fertility through rotations and cover crops. Growers are also allowed to add soil and plant amendments in accordance with the National List of Allowed and Prohibited Substances (USDA, 2002).

Organic amendments can be expensive when used in large quantities, so they are often used for supplementary nutrition if they are used at all. In a 1994 survey of 300 certified organic growers, 78% reported using animal manure, 77% legume crops, and 61% compost in their farm operations, while fish products were used by only 20%, cottonseed (*Gossypium hirsutum* L.) or soybean meal (SBM) by 7.3%, and extracts from aquatic plants by 5.6% (Fernandez-Cornejo et al., 1998). The effective use and economic value of fish, seaweed, and SBM in organic agriculture have yet to be verified by scientific research. The purpose of this study was to examine the effects of some of these foliar and soil applied fertilizers on plant nutrition and crop yield in sweet peppers, broccoli, and lettuce.

Material and Methods

Research Station

Field studies were conducted during the summer and fall of 2002 and the spring and summer of 2003 at the Mountain Horticultural Crops Research Station in Fletcher, North Carolina. The soil series was a Comus sandy loam (course-loamy, mixed, mesic Fluventic Dystrochrepts). Experimental design was a split-plot, arranged in a randomized complete block with four replications. Main-plots, 38 m long, were soil fertilizer treatments (high SBM rate, low SBM rate, and no SBM), and sub-plots, 5.5 m long, were spray treatments (fish, seaweed, fish/seaweed, 20-20-20, and water).

Soybean meal, commercially available as an animal feed, was hand broadcast at a low rate of 2466 $kg \cdot ha^{-1}$ equivalent to 168 $kg\ N \cdot ha^{-1}$, 30 $kg\ P_2O_5 \cdot ha^{-1}$, and 37 $lb\ K_2O \cdot ha^{-1}$ and a high rate of 4932 $kg \cdot ha^{-1}$ equivalent to 336 $kg\ N \cdot ha^{-1}$, 59 $kg\ P_2O_5 \cdot ha^{-1}$, and 74 $lb\ K_2O \cdot ha^{-1}$. The control received no SBM. Beds, 76 cm wide on 1.5 m centers, were then machine formed and covered with black polyethylene plastic mulch. Irrigation was by twin wall 10 mm drip tape (Chapin Watermatics, Inc., Watertown, N.Y.) laid in bed centers, 5 cm below the soil surface.

Test 1

Crops grown were 'X3R Camelot' sweet peppers (*Capsicum annuum* L.), 'Acadia' broccoli (*Brassica oleracea* L.), and 'Walmann's Green Grand Rapids' leaf lettuce (*Lactuca sativa* L.) (Twilley Seed Co., Hodges, S.C.). All transplants were grown in 50 cell flats (cell size = 16 cm^2) (Winstrip, Inc., Fletcher, N.C.).

The foliar fertilizers tested in the study were Fish Hydrolysate (2-4-1), Seaweed Plant Food (0-0-1), and Fish/Seaweed Blend Fertilizer (2-3-1) (Neptune's Harvest, Gloucester, Mass.), 20-20-20 (Southern Ag, Palmetto, Fl), and a water control. The fish and seaweed products were applied at a diluted rate of 7.8 $mL \cdot L^{-1}$ with about 0.8 L of concentrate applied per hectare per application. 20-20-20 was applied at a diluted rate of 7.5 $g \cdot L^{-1}$ with about 0.75 kg of concentrate applied per hectare per application. Starting at transplanting, peppers were sprayed at 14-day intervals and received a total of seven sprays. The broccoli and lettuce were sprayed at 7-day intervals and received a total of five and four sprays, respectively. The spray was applied with a Solo 425 Backpack Sprayer (Solo, Inc., Newport News, Va.) until the spray began to drip off from the foliage. Applications were made before 10:00 a.m. on application days. Control plots were sprayed with tap water.

To investigate continuous cropping with SBM within the study, peppers, broccoli, and lettuce were grown in succession on the same plots. Eight-week old pepper plants were machine transplanted 15 May 2002 in a single row at 46 cm spacing the day following soil fertilization, bed formation, and black plastic application. Peppers were harvested 12 Aug and the plants were removed from the field. Seven-week old broccoli plants were hand transplanted into the pepper holes 30 Aug. The broccoli was harvested and the stalks were allowed to break down through the winter. Four-week old lettuce plants were hand transplanted 8 May 2003 into holes punched between the broccoli holes. The lettuce was ended after lettuce harvest.

Test 2

In 2003, peppers were grown in a different location on the research station. Ten-week old ‘X3R Camelot’ plants were hand transplanted 9 June one week after soil fertilization (as described above), bed formation, and black plastic application. The peppers were sprayed six times at 14-day intervals as described above.

On-farm Study

To supplement the research station studies, a field study was conducted in 2002 at a certified organic farm in Madison County, North Carolina. The experimental design was a randomized complete block with four replications. Three spray treatments and a control (fish, seaweed, fish/seaweed, and water) were applied as described for Test 1. The 20-20-20 treatment was not used because of conflicts with organic certification standards. Three-meter long plots were established on 1.2 m wide beds. Irrigation was by twin wall 10 mm drip tape (Chapin Watermatics, Inc., Watertown, N.Y.) laid in bed centers on the soil surface. The beds were then covered with black woven polypropylene landscape fabric. The peppers were hand transplanted into precut holes in the landscape fabric, two rows to a bed, staggered at 46 cm spacing. 'Red Knight X3R' sweet pepper (*Capsicum annuum* L.) (Johnny's Selected Seeds, Albion, Maine) transplants were organically grown on the farm for the study.

Sampling and analysis.

Crop yield and grade, plant tissue, and soil measurements were taken to assess treatment differences. Peppers were harvested at maturity from the middle ten pepper plants per subplot over two (2002) and three (2003) harvests and graded according to USDA grading standards for sweet bell peppers. Number and weights were recorded for each grade from each subplot. Broccoli heads were harvested at maturity from twelve plants per subplot over five harvests. The number of harvested heads and weight were recorded for each subplot. Lettuce heads from the middle ten lettuce plants per subplot were harvested in one harvest and weighed individually within each subplot.

Plant nutrient levels were tested by sampling the first fully expanded leaf below the growing point from each crop at the end of the growing season (NCDA, 2003). The samples were collected from plants in the control spray treatments in each of the 12 main plots for each crop. The tissue was analyzed at the North Carolina Department of Agriculture (NCDA) Analytical Laboratory for N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, and B. In 2002, pepper leaf tissue was also sampled by subplot (15 treatments X 4 reps = 60 samples).

Soil was sampled in 15 cm increments to a depth of 90 cm following the lettuce harvest in 2003, just after pepper planting in 2003, and after the final pepper harvest in 2003 (12 cores in main plots). The North Carolina State University Analytical Service Laboratory performed analyses for NO_3-N and NH_4-N (LACHAT Instruments, Model QUICHEM IV) after 1M KCl extractions (Keeney and Nelson, 1982). The uppermost 15 cm of soil were also analyzed for P, K, Ca, Mg, Mn, Zn, Cu, and pH by the NCDA Soil Testing Lab. All NCDA procedures were carried out on a volume basis of soil.

Data were analyzed using the means and GLM procedures of the SAS statistical package (SAS Institute, Cary, NC). There were no significant interactions between soil and foliar fertilizers so the main effects (soil and foliar fertilizers) are discussed separately. Pairwise comparisons of means were performed using the Fisher's Protected LSD (alpha = 0.05).

Results and Discussion

Soybean Meal Soil Fertilizer

Test 1 – First Crop: Peppers

In 2002, peppers transplanted one day after application of both rates of SBM suffered severe root damage (Figure 1). As a result of this production practice, there was 33% mortality at the high SBM rate and 10% mortality at the low SBM rate compared to no mortality in the unfertilized control (Table 1). The SBM fertilized peppers that survived remained severely stunted throughout the growing season. End of season above-ground plant dry weight was reduced by 82% and 70%, respectively, at the high and low rates, compared to the unfertilized control (Table 1). Similarly, total marketable season pepper yield was reduced by 87% and 64%, respectively, by the high and low SBM rates, compared to the control.

The SBM also reduced fruit grade (Table 1). Eighty four percent of the peppers harvested from the unfertilized pepper plants were grade fancy or number one, while only 52% and 63%, respectively, of the high and low SBM rate peppers were grade fancy or number one. End of season P, K, S, and Cu levels were also greater in the unfertilized pepper leaf and petiole tissue compared to the SBM fertilized pepper leaf and petiole tissue (Table 2). In contrast, Mn and Zn levels were lower in the unfertilized pepper leaf and petiole tissue than the SBM fertilized leaf and petiole tissue.

Test 1 – Second Crop: Broccoli

Both rates of the SBM applied prior to the summer 2002 pepper crop contributed to an earlier fall 2002 broccoli harvest than the unfertilized control. Only 17% of the heads from the unfertilized broccoli plants were harvested at the first harvest, while 35% and 36%, respectively, of the high and low rate fertilized broccoli were harvested at the initial harvest (Table 3). For the total season yield, broccoli planted into the high and low rates of SBM produced 20% and 12%, respectively, heavier heads ($kg \cdot head^{-1}$) than the unfertilized control (Table 3). Broccoli fertilized with the high and low rates of SBM also had a 20% and 13%, respectively, higher total yield ($kg \cdot ha^{-1}$) than the control (Table 3). Broccoli leaf tissue levels of N and Mn were also higher with the high rate of SBM than the unfertilized control (Table 2).

Test 1 – Third Crop: Lettuce

There were no effects of the original SBM fertilization (15 May 2002) on spring 2003 lettuce yields, plant tissue nutrition, or soil nutrient levels of P, K, and Ca (data not shown). There were also no differences in soil nitrate and ammonium levels at depths to 30 cm (Table 5). From depths 30-60 cm, nitrate alone and ammonium plus nitrate (total) levels were greater at the high SBM rate than the low SBM rate and the unfertilized control (Table 5). These nutrients, though, were likely outside of the root zone of the drip-irrigated crop and, therefore, represent leaching of nitrate. These findings suggest caution needs to be taken not to over apply organic fertilizers. Leaching wastes fertilizer and increases the possibility of groundwater contamination.

Test 2 - Peppers

The same rates of SBM were applied to the Test 2 peppers in 2003 as were applied to the peppers in Test 1 in 2002. To reduce the chance of fertilizer burn in 2003 peppers were transplanted one week after SBM fertilization. Peppers planted into SBM treatments showed some initial signs of inhibition (wilting), but appeared to recover quickly. The delayed planting and the high amount of rain throughout the season may have contributed to the reduction in fertilizer injury compared to what occurred in 2002, which was a drought year.

At the initial harvest, SBM fertilized peppers produced higher yields of marketable peppers than the unfertilized control (Table 6) with the low rate of SBM producing 23% more marketable peppers than the high rate. The initial reduced production at the high rate of SBM could be attributed to excess N causing a flush of foliage instead of fruit production. The plants may also have been recovering from earlier root burn from the high rate of SBM. Marketable yield between the soil treatments was not different at any other harvest times or for the overall season (Table 6).

Marketable fruit weight was greater for fertilized peppers than unfertilized peppers at all harvest times and for the overall season (Table 6). This could be attributed to the greater percent of fancy grade peppers for the fertilized peppers compared to the unfertilized control. The unfertilized peppers had a total season higher percent of number one grade peppers.

At the end of the season, pepper leaf and petiole tissue N, Mg, and Mn levels were greater in SBM fertilized treatments than unfertilized treatments while P levels were lower (Table 2).

One month after SBM application, there were no differences between treatments for soil pH and nutrient levels from 0-15 cm (Table 4) or in ammonium and nitrate levels from 0-90 cm (data not shown). By the end of the season, eleven weeks later, the soil pH from 0-15 cm was lower in the high and low SBM treatments compared to the control (Table 4). Phosphorous levels also decreased from the high rate to the low rate to the control. Ammonium and nitrate levels at the 0-15 cm depth were greater for the high SBM than the low rate and the control (Table 5). Compared to the initial measurement, levels of ammonium had decreased and nitrate levels had increased at the 0-15 cm depth. This nitrate increase is attributed to the nitrification of ammonium derived from the decomposing SBM. Nitrate levels were also greater at depths 15-45 cm compared to the start of the season (data not shown). This represents a leaching of nitrate for all treatments.

Continuous Cropping with SBM

Because the first crop (pepper) in Test 1 was inhibited by the SBM, nutrients were not taken up as would be expected of a typical pepper crop. A high level of nutrients, therefore, remained for the second crop (broccoli) to utilize. The yield of the fertilized broccoli was greater than the unfertilized control broccoli (Table 3). There was no effect of the SBM fertilizer on the third crop (lettuce), presumably because the previous crop had exhausted the nutrient supply. Due to the high mortality of the pepper crop, Test 1 was not a representative test of a continuous pepper, broccoli, and lettuce system. In Test 2, though, 496 kg $N \cdot ha^{-1}$ remained after the final pepper harvest (16 weeks after SBM application) in the high SBM treatments compared to only 100 kg $N \cdot ha^{-1}$ in the unfertilized plots (Table 5). This suggests the initial high rate application of SBM could have supported a successive crop, such as broccoli.

Continuous cropping with polyethylene-mulched vegetables and drip irrigation has been found to reduce costs and energy use by more completely utilizing mulch, fertilizer, fuel, and labor (Clough and Locascio, 1990). The challenge with multiple cropping is to provide adequate fertilization for the successive crops. In most long-term systems, it is necessary to supplement the successive crops with fertilizers applied through the irrigation lines (Mayfield et al., 2002). Further work needs to be done to test the duration of organic fertilizers, such as SBM, on continuous cropping with polyethylene mulch. Due to its slow release nature, one high rate application of SBM might support at least two crops.

Foliar Sprays

While SBM affected soil and plant nutrient levels and crop yields, the foliar sprays in this study had no effect on any of the crops tested. There were no significant differences or trends for any variable measured for any crop attributable to the foliar spray treatments for the research station studies (Table 7). There were also no significant differences in yield or fruit grade among the spray treatments for the on-farm study (Table 7). On-farm pepper yields were comparable to the pepper yields from the research station study.

The effectiveness of foliar fertilization is highly dependent on plant species, physical and chemical properties of the nutrient solution, nutritional status of the plant, and current growing conditions (Marshner, 1995). Foliar fertilization is most successful when used as a supplementary nutrient supply when some element is lacking in the plant, such as boron deficiency in cotton (Boynton, 1954; Guertal et al., 1996). Most authors agree it would be difficult to meet the macronutrient needs of a growing plant with foliar fertilizers alone. Multiple applications would be necessary to supply a sufficient continuous supply of the nutrients. The marine derived foliar fertilizers used in this study had very low NPK values (fish 2-4-1 and seaweed 0-0-1). Even with up to seven applications during the growing season, the amount of macronutrients actually provided to the plants in this study was minimal.

Foliar fertilizers may work in part by being absorbed by roots when excess solution drips onto the soil. In this study, the polyethylene mulch, and to a lesser extent the landscape cloth, could have prevented this possibility, except for what ran down the plant stem into the planting hole. The success of these products may be in part through indirect soil fertilization and therefore would find better success applied to plants grown in bare ground or with organic mulch, such as wheat straw.

Conclusion

Organic vegetable growers regularly use supplementary fertilizers, including SBM, seaweed extracts, and fish emulsions. The success of these products in crop production appears dependent on a number of factors, including the crop fertilized, the rate of application, the composition of the product, and the existing soil fertility. As these products continue to grow in popularity among organic growers, the growers need to know the situations in which these fertilizers can be most beneficial and cost-effective. This study found that SBM applied at a moderate rate (2466 $kg \cdot ha^{-1}$) at least one week before transplanting was an effective fertilizer. Sea-based foliar fertilizers were not found to have any measurable benefit to crop yield.

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Table 1. Test 1: Soybean meal (SBM) soil fertilizer effects on pepper plant survival, fruit yield and grade, and end of season plant dry weight.

			Total Season Yield				
			Grade			Grade	
Soil Fertilizer SBM Rate[x]	Plant Survival (%)	Plant Dry wt (g)	Fancy ($Mg \cdot ha^{-1}$)	No. 1 ($Mg \cdot ha^{-1}$)	Marketable ($Mg \cdot ha^{-1}$)	Fancy (%)[z]	No. 1 (%)
None	100a	490a	8.1a	6.7a	16.4a	45a	39
Low	90b	151b	2.2b	2.5b	5.8b	25b	38
High	67c	89b	0.6b	0.9c	2.1c	20b	32

[x]SBM was applied at a low rate of 2466 $kg \cdot ha^{-1}$ and a high rate of 4932 $kg \cdot ha^{-1}$.

[y]Means followed by the same letter within a column are not significantly different, according to Fisher's Protected LSD (alpha = 0.05).

[z]Percent of total harvested fruit (fancy, No. 1, No. 2, and cull).

Table 2. End of season leaf and petiole analysis for peppers and broccoli grown in succession in Test 1 and peppers in Test 2.

		Test 1 - Successive Crops						Test 2		
		First crop: Pepper			Second crop: Broccoli			Pepper		
		Rate of Soybean Meal[y]								
Nutrient		None	Low	High	None	Low	High	None	Low	High
N	%	6.2[x] a	4.5 a	5.9 a	5.7 b	6.3 ab	7.0 a	3.9 b	4.9 a	5.3 a
P	%	0.4 a[z]	0.2 b	0.3 b	0.5 a	0.5 a	0.6 a	0.4 a	0.2 b	0.2 b
K	%	5.2 a	3.5 b	3.7 b	1.7 a	1.9 a	2.1 a	4.3 a	4.2 a	4.4 a
Ca	%	1.6 b	2.2 a	1.7 b	1.7 a	1.6 a	1.5 a	2.5 b	2.5 b	2.9 a
Mg	%	0.7 b	0.9 a	0.7 b	0.3 a	0.3 a	0.3 a	0.6 c	0.8 b	0.9 b
S	%	0.5 a	0.3 b	0.4 b	1.0 a	1.1 a	1.1 a	0.4 a	0.4 a	0.4 a
Fe	ppm	143.3 a	164.0 a	172.0 a	71.1 a	75.4 a	89.5 a	60.8 a	72.4 a	74.8 a
Mn	ppm	52.0 b	175.7 a	191.8 a	28.3 b	30.9 b	44.9 a	58.0 b	132.8 a	171.5 a
Zn	ppm	66.9 c	101.5 a	87.4 b	38.3 a	41.8 a	51.3 a	77.9 a	69.7 a	76.4 a
Cu	ppm	27.6 a	10.5 b	12.3 b	6.0 a	6.0 a	6.8 a	32.5 a	27.9 a	30.0 a
B	ppm	36.6 b	52.4 a	35.5 b	21.9 a	22.6 a	24.4 a	40.2 b	33.3 b	30.6 a

[x]All values are means of four replications.

[y]SBM was applied at a low rate of 2466 $kg \cdot ha^{-1}$ and a high rate of 4932 $kg \cdot ha^{-1}$.

[z]Means followed by the same letter within a row are not significantly different, according to Fisher's Protected LSD (alpha = 0.05).

Table 3. Test 1: Soybean meal (SBM) soil fertilizer effects on broccoli grown after peppers.

SBM Soil Fertilizer[x]	Harvest No. 1		Harvest No. 2		Harvest No. 3		Harvest No. 4		Total Harvest	
	% Cut[z]	$kg \cdot head^{-1}$	% Cut	$kg \cdot head^{-1}$	% Cut	$kg \cdot head^{-1}$	% Cut	$kg \cdot head^{-1}$	$kg \cdot head^{-1}$	($Mg \cdot ha^{-1}$)
None	17b	0.40b	32a	0.40a	26a	0.44b	25a	0.42a	0.41b	5.82b
Low Rate	36a	0.48a	24a	0.45a	19a	0.49ab	20a	0.39a	0.46a	6.55a
High Rate	35a	0.50a	26a	0.45a	21a	0.53a	17a	0.46a	0.49a	7.00a

[x]SBM was applied at a low rate of 2466 $kg \cdot ha^{-1}$ and a high rate of 4932 $kg \cdot ha^{-1}$.

[y]Means followed by the same letter within a column are not significantly different, according to Fisher's Protected LSD (alpha = 0.05).

[z]Percent is number harvested/total season harvest.

Table 4. Soil pH and nutrient levels from 0-15 cm deep for the three soybean meal (SBM) treatments in Tests 1 and 2.

Test 2 - Pepper crop, measured one month after transplanting and at last harvest

		pH	P	K	Ca
	SBM Rate		$mg \cdot dm^{-2}$	$meg \cdot 100\ cm^{-2}$	
6/13/03	None	5.9a	68.7a	0.5a	4.0 b
	Low	5.5a	71.0a	0.5a	4.0 b
	High	5.7a	78.1a	0.7a	4.4 a
9/25/03	None	5.8 a	65.3a	0.4 b	4.0a
	Low	5.3 b	67.4a	0.6 a	4.2a
	High	5.1 b	80.3a	0.7 a	4.4a

[y]SBM was applied at a low rate of 2466 $kg \cdot ha^{-1}$ and a high rate of 4932 $kg \cdot ha^{-1}$.
[z]Means followed by the same letter within a column are not significantly different, according to Fisher's Protected LSD (alpha = 0.05).

Table 5. Inorganic soil N measured at six depths between 0-90 cm at three rates of soybean meal (SBM) soil fertilizer.

Test 1 - Soil cores taken 27 Aug. 2003 after one SBM application 15 May 2002 and continous cropping with sweet pepper, broccoli, and lettuce.

	Soil Fertilizer SBM Rate[y]	depth (cm) 0-15	15-30	30-45	45-60	60-75	75-90
NH_4^+ - N	None	2.4a[z]	2.4a	2.3a	2.5a	2.0a	2.2a
($kg\ N{\cdot}ha^{-1}$)	Low	2.9a	2.2a	2.4a	2.4a	1.9a	2.0a
	High	3.2a	2.6a	2.7a	2.8a	2.3a	2.5a
NO_3^--N	None	12.8a	16.5a	17.4b	18.4b	16.7a	17.3a
($kg\ N{\cdot}ha^{-1}$)	Low	21.0a	16.9a	15.3b	20.1b	14.3a	14.0a
	High	45.8a	15.3a	27.7a	30.1a	20.2a	20.6a
(NH_4^+ + NO_3^-)-N	None	15.2a	18.9a	19.7b	20.9b	18.8a	19.5a
($kg\ N{\cdot}ha^{-1}$)	Low	24.0a	19.2a	17.7b	22.5b	16.1a	16.0a
	High	49.0a	18.0a	30.4a	33.3a	22.6a	23.1a

Test 2- Soil cores taken 27 Aug 2003 after last pepper harvest from 2003 pepper experiment.

	Soil Fertilizer SBM Rate	depth (cm) 0-15	15-30	30-45	45-60	60-75	75-90
NH_4^+ - N	None	4.2b	6.7a	7.7a	4.4a	4.3a	3.6a
($kg\ N{\cdot}ha^{-1}$)	Low	5.6b	10.3a	5.6a	4.8a	4.0a	3.4a
	High	51.9a	7.9a	6.0a	4.4a	4.3a	4.0a
NO_3^--N	None	96.4b	26.7a	15.6a	10.8a	14.3a	18.6a
($kg\ N{\cdot}ha^{-1}$)	Low	128.6b	39.5a	23.0a	13.6a	13.4a	14.6a
	High	444.1a	45.9a	17.7a	15.2a	24.2a	19.9a
(NH_4^+ + NO_3^-)-N	None	100.6b	33.5a	23.3a	15.1a	18.7a	22.2a
($kg\ N{\cdot}ha^{-1}$)	Low	134.1b	49.8a	28.6a	18.3a	17.4a	18.0a
	High	495.9a	53.7a	23.6a	19.6a	28.6a	23.8a

ySBM was applied at a low rate of 2466 kg.ha-1 and a high rate of 4932 $kg{\cdot}ha^{-1}$.

[z]Means followed by the same letter within a column are not significantly different, according to Fisher's Protected LSD (alpha = 0.05).

Table 6. Test 2: Soybean meal (SBM) soil fertilizer effects on pepper fruit yield and grade, Summer 2003.

	Soil Fertilizer SBM Rate[x]	Grade Fancy ($Mg\cdot ha^{-1}$)	No. 1 ($Mg\cdot ha^{-1}$)	Total Mkt. ($Mg\cdot ha^{-1}$)	Grade Fancy $g\cdot fruit^{-1}$	No. 1 $g\cdot fruit^{-1}$	Total Mkt. $g\cdot fruit^{-1}$	Grade Fancy %	No. 1 %
Harvest 1	None	0.9b	2.8a	3.7c	215b	160b	169b	20c	60a
	Low	3.8a	3.3a	7.1a	248a	178a	210a	44b	52a
	High	3.6a	1.9b	5.5b	246a	183a	220a	60a	37b
Harvest 2	None	3.7b	5.0a	8.5a	235b	199a	212b	38b	53a
	Low	5.2a	4.7a	9.9a	262a	212a	239a	53a	46a
	High	5.8a	4.8a	10.6a	256a	202a	233a	57a	41a
Harvest 3	None	4.6a	6.6a	11.2a	232b	186b	205b	40b	60a
	Low	6.3a	5.1a	11.4a	256a	198a	230a	55a	45b
	High	6.2a	4.6a	10.9a	251a	201a	229a	58a	39b
Total Season Yield	None	9.2b	14.4a	23.4a	228b	178b	194b	30b	60a
	Low	15.3a	13.1a	28.4a	255a	194a	224a	49ab	49b
	High	15.6a	11.3b	27.0a	247a	196a	226a	57a	40b

[y]SBM was applied at a low rate of 2466 $kg\cdot ha^{-1}$ and a high rate of 4932 $kg\cdot ha^{-1}$.

[z]Means followed by the same letter within a column are not significantly different, according to Fisher's Protected LSD (alpha = 0.05).

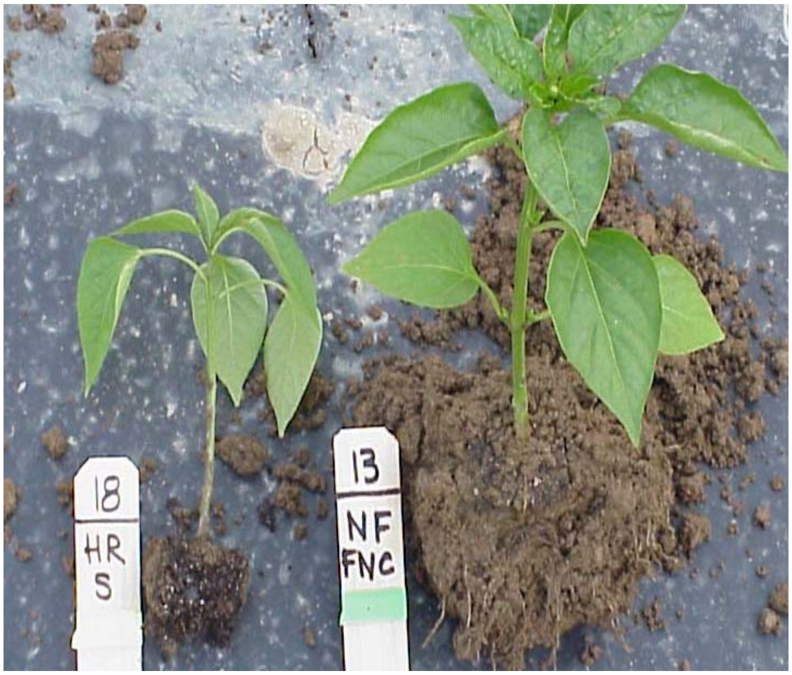
Table 7. Effects of five foliar fertilizers on yield of three crops.

	Test 1 - Continuous Cropping			Test 2	Organic On-farm
	Pepper - 2002	Broccoli - 2002	Lettuce - 2003	Pepper - 2003	Pepper - 2002
Foliar Treatment	Marketable ($Mg \cdot ha^{-1}$)	Marketable ($Mg \cdot ha^{-1}$)	Mean weight per head (g)	Marketable ($Mg \cdot ha^{-1}$)	Marketable ($Mg \cdot ha^{-1}$)
Water control	9.3	6.5	263	31.9	9.6
20-20-20	9.1	6.5	291	33.5	NA[y]
Fish/Seaweed	6.2	6.2	268	35.4	8.5
Fish	9.1	6.9	236	31.0	9.9
Seaweed	7.0	6.2	227	27.9	11.3
LSD (0.05)	NS[z]	NS	NS	NS	NS

[y]Treatment not applied due to organic standards.

[z]Not significant according to Fisher's Protected LSD (alpha = 0.05).

Figure 1. Test 1: Peppers. Soybean meal (SBM) applied at a high rate of 4932 $kg \cdot ha^{-1}$ (left) compared to the unfertilized control (right) two weeks after transplanting.



Chapter Two

Soybean Meal Inhibits Germination and Growth of Common Vegetable Seeds

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Soybean Meal Inhibits Germination and Growth of Common Vegetable Seeds

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Soybean Meal Inhibits Germination and Growth of Common Vegetable Seeds

Additional index words: organic soil amendment, fertilizer, crop production, natural products

Abstract. Soybean (*Glycine max*) meal (SBM) is an animal feed that is also used as an organic fertilizer by farmers interested in reducing inputs of inorganic fertilizers. Relatively little is known about the use of SBM as a fertilizer in horticultural crops. Greenhouse studies were conducted to investigate the effect of SBM on germination and growth of eight common vegetables. Treatments included five rates of SBM: 0, 975, 1950, 2925, and 3900 lb·acre^{-1} (0, 1093, 2186, 3279, and 4372 kg·ha^{-1}) representing a total N application of 0, 68, 137, 205, and 273 lb N·acre^{-1} (0, 76, 154, 230, and 306 kg N·ha^{-1}) and two application methods (surface applied (SA) and incorporated (IN) into the media). Percent germination and fresh clipped shoot weight were measured for each pot. Overall, at applications of 975 and 1950 lb·acre^{-1} (1093 and 2186 kg·ha^{-1}) IN SBM, shoot weight increased by 20% and 10%, respectively, compared to the unfertilized control. At the same rate of SA SBM, shoot weight was reduced by 6% and 18% respectively. At all rates of SA SMB, shoot weight was more reduced in small seeded vegetables (spinach, lettuce, carrot, and radish) than in large seeded vegetables (squash, cucumber, bean, and pea). At 2925 and 3900 lb·acre^{-1} (3279 and 4372 kg·ha^{-1}) of IN SBM, shoot weight of small seeded vegetables was reduced by 8% and 46%, respectively. The EC and pH of the

media increased with increased rates of SBM and were greater with SA SBM than with IN SBM. Levels above pH 6.5 and EC 1.0 $dS \cdot m^{-1}$ were measured on day 7 for media at all SBM rates. These levels could be inhibitory to germinating seeds. Because SBM reduced growth of small seeded vegetables (spinach, radish, lettuce, and carrot), it is not recommended that small seeded vegetables be surface fertilized with SBM or that they be sown directly into soil where SBM has been recently incorporated. SBM incorporated at low rates (<1950 $lb \cdot acre^{-1}$) could prove to be a useful fertilizer for large seeded crops (cucumber, squash, pea, and bean) where inhibition by SBM would not be a concern.

Soybean (*Glycine max*) is one of the most cultivated plants in the world today and is valued for both its oil and meal (Hasegawa et al., 2002). Soybean meal (SBM) is a byproduct of soybean oil extraction. SBM contains 44% to 47% protein and is a leading source of protein in livestock diets (Erickson, 1995). In the last century, SBM was used as a slow release N fertilizer (Kubo et al., 1994). With the advent of chemically synthesized fertilizers, the use of organic fertilizers declined (Rubins and Bear, 1942). Today there is renewed interest in SBM as a fertilizer in organic vegetable production systems.

SBM has an average analysis of 7N-1.2P-1.5K (Zublena et al., 1997) and has been found to increase biomass production in some plant species. Applied at rates of 1200 to 2400 $lb \cdot acre^{-1}$ (1345 and 2690 $kg \cdot ha^{-1}$), SBM increased the foliar fresh weight and dry weights of greenhouse tomatoes compared to the unfertilized control (Hafez and Sundararaj, 1999). There is evidence that higher rates of SBM can have phytotoxic effects on weeds and vegetables. However, at 4800 $lb \cdot acre^{-1}$ (5380 $kg \cdot ha^{-1}$) tomatoes suffered severe stunting, necrosis, and death (Hafez and Sundararaj, 1999). In another study, SBM inhibited perennial ryegrass growth at 3046 $lb \cdot acre^{-1}$ (3414 $kg \cdot ha^{-1}$) and completely stopped growth at higher levels (Liu, Christians, and Garbutt, 1994).

Corn (*Zea mays*) gluten meal, another grain byproduct, has also been found to inhibit vegetable and weed seed germination (Liu and Christians, 1997; McDade and Christians, 2000). Christians (1991) patented corn gluten meal as a natural preemergence herbicide and Christians, Garbutt, and Liu (1994) patented corn gluten hydrolysate as a preemergence weed control agent. Corn gluten contains approximately 10 percent N by weight (Gardner et al., 1997) and is also used as a fertilizer. To avoid germination inhibition of crop seeds, though, corn gluten is usually applied one to four months before direct seeding.

As SBM has been found to increase biomass production in some species, but also inhibit germination and growth of weed seeds at some application rates, greenhouse studies were conducted to determine whether SBM can be used safely as a fertilizer in direct seeded vegetable production systems.

Material and Methods

Germination

A greenhouse study was conducted in the fall of 2002 and repeated in the spring of 2003 to determine the effect of SBM on germination and growth of eight common vegetable species. Square plastic pots with a surface area of 16 in^2 (100 cm^2) and a depth of 3.5 in (9 cm) were filled with Scotts Metro-Mix 360 (The Scotts Company, Marysville, OH). Ten seeds of ‘Conquest’ cucumber [Cucumis sativus L.], ‘Provider’ snap beans [Phaseolus vulgaris L.], ‘Easter Egg’ radish [Raphanus sativus L.], ‘Sugarsnap’ peas [Pisum sativum L.], ‘Space’ spinach [Spinacea oleracea L.]; six seeds of ‘Yellow Crookneck’ summer squash [Cucurbita pepo L.]; and 20 seeds of ‘Bolero’ carrots [Daucus carota L.] (Johnny’s Selected Seeds, Winslow, ME) were planted 0.5 in (1 cm) below the medium surface in each pot. Preweighed amounts of 0.1 g ‘Black Seeded Simpson’ lettuce [Lactuca sativa L.] were sprinkled uniformly on the surface and covered with 0.5 cm of medium. Rates of 0, 975, 1950, 2925, and 3900 $lb \cdot acre^{-1}$ (0, 1093, 2186, 3279, and 4372 $kg \cdot ha^{-1}$) of SBM were then hand dusted on the medium surface (SA). Additional containers were filled with media mixed with 0, 975, 1950, 2925, and 3900 lb·acre^{-1} (0, 1093, 2186, 3279, and 4372 kg·ha^{-1}) of SBM and seeds were planted as above (IN). These treatments represent a total N application of 0, 68, 137, 205, and 273 lb N·acre^{-1} (0, 77, 153, 230, and 306 kg N·ha^{-1}), a P application of 0, 12, 24, 36, and 48 lb P_2O_5·acre^{-1} (0, 13, 26, 39, and 52 kg P_2O_5·ha^{-1}), and a K application of 0, 15, 30, 45, and 60 lb K_2O·acre^{-1} (0, 16, 32, 49, and 66 kg K_2O·ha^{-1}).

The containers were grouped by species and placed on a greenhouse bench in a randomized complete block design with one row of nine pots per block. There were four replications per treatment. The plants were grown under natural light in a greenhouse maintained between 18^{o} and 24^{o} C. The pots were misted with tap water three times daily to maintain adequate moisture for germination, and were watered once daily after germination. The duration of the study was 14 days. At harvest, the germinated plants were counted. All of the shoots were then cut at the soil surface and weighed.

EC and pH

A greenhouse study was conducted simultaneously to determine the EC and pH of the SBM amended media. The treatments were the same as those described in the germination study, except no seeds were planted. The pots were placed in a randomized complete block design with one row of nine pots per block. There were four replications of each treatment. Three sets of pots were started at the same time in this manner.

Pots were kept in the greenhouse and watered as described for the germination study. At days 1, 7 and 12 a set of pots was tested for pH and EC using the press extraction method (Scoggins et al., 2002). Pots were watered to maximum capacity and then allowed to equilibrate for one hour. The top 1 in (2.5 cm) of media was then removed from the pot and pressed to expel the liquid solution into a beaker. The extract pH and EC were measured (EXTECH 695 pH/Conductivity Meter; Waltham, Mass.).

Data Analysis

Germination and shoot weights for each pot were divided by the control for that replication to obtain percent of control. This allowed all crops to be compared at once. The data were then analyzed using analysis of variance (SAS PROC GLM, SAS Inst., Cary, N.C.). Run was not significant so the data from both runs were pooled. For further analysis, crops were placed into two categories according to their seed size. The large seeded vegetables included pea, squash, bean, and cucumber, while the small seeded vegetables included spinach, radish, lettuce, and carrot.

Results and Discussion

Overall response. The effects of the SBM treatments were not crop dependent (germ $p=0.608$, shoot weight $p=0.525$) (Table 1). Overall, germination and shoot weight decreased significantly with increased rates of SBM ($p=<0.0001$) (Figure 1). There was a linear response to SBM rate for both germination and shoot weight, but there was a larger range of response for shoot growth than there was for germination.

Surface applied (SA) SBM reduced both germination and shoot weight more than incorporated (IN) SBM at all SBM rates (p=<0.0001) (Figure 1). At 975 and 1950 $lb \cdot acre^{-1}$ (1093 and 2186 $kg \cdot ha^{-1}$) of SA SBM, germination was reduced by 7% and 14%, respectively, compared to the control (Figure 1A). At the same rates of IN SBM, germination was not affected. At higher SBM rates though, germination was reduced for both application methods. At 3900 $lb \cdot acre^{-1}$ (4372 $kg \cdot m^{-2}$) IN and SA SBM, germination was reduced by 9% and 29% respectively, compared to the control.

Similarly, shoot weight was reduced by 6% and 18% at 975 and 1950 $lb \cdot acre^{-1}$ (1093 and 2186 $kg \cdot ha^{-1}$) of SA SBM, respectively, compared to the control (Figure 1B). At the same rates of IN SBM, shoot weight increased by 20% and 10% respectively, compared to the control. This fertilization effect of the SBM was not present with higher rates of SBM. The highest rate of IN and SA SBM reduced shoot weight by 23% and 40% respectively, compared to the control.

There was no interaction of rate and application method of the SBM (germ p=0.309, shoot weight p=0.688).

Species response. Crop by rate and crop by application interactions were significant for both germination and shoot weight. This suggests the magnitude of the SBM effect was species dependent (Table 2 and 3). Radish germination and shoot weight were reduced by 44% compared to the control at 975 $lb \cdot acre^{-1}$ (1093 $kg \cdot ha^{-1}$) of SA SBM, while peas and beans at the same SBM rate were unaffected (Table 2). Radish, carrot, and lettuce germination and shoot growth were also highly sensitive to application method (Figure 2). At 1950 lb·acre^{-1} (2186 kg·ha^{-1}) of IN SBM, lettuce shoot weight increased by 31% compared to the control (Table 3). When the same rate was surface applied, shoot weight was decreased by 44%. It was observed that lettuce seed treated with SA SBM germinated but died soon after (Figure 3). The roots of these seedlings had no root hairs and appeared burned.

These findings are comparable to the effect corn gluten meal (CGM) had on various vegetable seeds (McDade and Christians, 2000). Onion, carrot, and lettuce growth were the most affected by CGM, while beet, radish, bean, pea, and corn growth were the least affected.

Seed size response. The effect of SBM on germination and shoot growth was dependent on seed size ($p<0.0001$) (Table 4). Small seeded vegetables (lettuce, spinach, radish, and carrot) were much more likely to be damaged by SBM than large seeded (cucumber, bean, pea, and squash) vegetables ($p=<0.0001$). Application method was not significant for large seeded vegetables and shoot weight was only reduced at rates above 2925 lb·acre^{-1} (3279 kg·ha^{-1}) (Table 5). For small seeded vegetables, application method was significant. Shoot weight was reduced at all rates of SA SBM and at rates above 1950 lb·acre^{-1} (2186 kg·ha^{-1}) IN SBM.

EC and pH. EC and pH increased with increased rates of SBM and were greater at each rate when the SBM was surface applied than when it was incorporated (Figures 4 and 5). EC and pH increased for all rates and application methods from day 1 to day 7. From day 7 to day 12, the EC at all rates and application methods declined while the pH remained at a similar level. All SBM treatments had a higher pH and EC than the control on all days.

Most germinating vegetable seeds prefer a pH between 5.8 and 6.5 and an EC below 1.0 $dS \cdot m^{-1}$ as measured by the press extraction method (Styer and Koranski, 1997). Because pH and EC are above these levels at 975 and 1950 $lb \cdot acre^{-1}$ (1093 and 2186 $kg \cdot ha^{-1}$) of SA SBM, germination and growth can be inhibited. In this study, pH was above optimal levels for all treatments on days 7 and 12 (Table 6). The highest pH levels were 7.45 and 7.28, attained on day 7 at 3900 $lb \cdot acre^{-1}$ (4372 $kg \cdot ha^{-1}$) of SBM, SA and IN, respectively. EC was above optimal levels for all treatments on day 7. By day 12, the EC levels had dropped for all treatments. The only treatments falling below optimal levels though were IN SBM at 975 and 1950 $lb \cdot acre^{-1}$ (1093 and 2186 $kg \cdot ha^{-1}$).

The above-optimal pH and EC levels observed in this study, especially values far above the optimal range, could have had inhibitory effects on the germinating seeds. The inhibitory pH and EC levels appeared to decrease over time as the SBM decomposed and the salts were diluted and leached out or taken up by the seedlings. A nitrification test of SBM determined that 61% of the added N was converted to nitrate after 20 days; 65% was converted after 40 days (Rubins and Bear, 1942). These data suggest that applications of SBM made 20 days or more before planting are less likely to inhibit germination and growth than those made less than 20 days before planting because the SBM may be more degraded.

Decomposing organic materials can injure plants by the accumulation of harmful by-products and the increased growth of harmful organisms (Fred, 1918). In this study, both chemical and biological factors could have hindered seed germination and growth. The generation of ammonia during SBM mineralization could have led to potentially harmful pH levels and the decomposing SBM could have been an energy source for potentially harmful organisms. The differences in germination and shoot weight due to application method were likely the result of very different biological and chemical environments for the seeds. Surface application of the SBM left a large concentration of SBM at the soil surface, in the region of seed growth. This led to increased contact of the SBM with the germinating seedlings. Incorporated SBM was more evenly distributed throughout the media, leading to a dilution of the potentially harmful effects.

Conclusions

In conclusion, because SBM reduced germination and growth of small seeded vegetables (spinach, radish, lettuce, and carrot), vegetables of similar seed size should not be sown directly into soil where SBM has been recently surface applied or incorporated. SBM incorporated at low rates (<1950 $lb \cdot acre^{-1}$), however, could prove to be a useful fertilizer for large seeded crops such as cucumber, squash, pea, and bean without concerns of SBM toxicity. Planting at least two weeks after SBM fertilization could further reduce the risk of SBM toxicity to both small and large seeded vegetables.

Future research with SBM should further explore management practices that would utilize SBM's phytotoxic properties for weed control while optimizing its nutrient value as a slow release fertilizer. Transplanting into fields broadcast with SBM may be one alternative practice. Research could also focus on development of fertilizer products derived from SBM. Hasegawa et al. (2002) found that SBM degraded with *Bacillus circulans* HA12 increased root hair density of Chinese cabbage (*Brassica campestris*) to three times that of the untreated SBM and increased yield of potato (*Solanum tuberosum* L.) by 37% compared with a synthetic chemical fertilizer. As the public's concern over the long-term ecological effects of synthetic agricultural chemicals continues to grow, there will be more interest in natural products, such as SBM, for weed control and fertilization.

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Table 1. ANOVA for two replicates of a soybean meal (SBM) greenhouse study with eight vegetable crops, four rates of SBM, and two application methods.

		Germination			Shoot Weight		
Source	df	Mean Square	F	P	Mean Square	F	P
Replicate (Rep)	1	0.218	1.37	0.2861	0.957	2.24	0.1854
Blk (Rep)	6	0.159	3.94	0.0008	0.428	2.99	0.0073
Crop	7	0.370	0.79	0.6081	1.420	0.95	0.5246
Rate	3	0.624	15.42	<0.0001	3.221	22.47	<0.0001
Application (App)	1	3.191	78.91	<0.0001	6.960	48.59	<0.0001
Rate*App	3	0.049	1.20	0.3088	0.071	0.49	0.6880
Crop*Rate	21	0.062	1.54	0.0750	0.260	1.82	0.0158
Crop*App	7	0.614	15.17	<0.0001	1.019	7.11	<0.0001
Crop*Rate*App	21	0.076	1.88	0.0167	0.117	0.82	0.6980
Rep*Rate	3	0.049	1.22	0.3030	0.328	2.29	0.0779
Rep*App	1	0.167	4.13	0.0423	1.549	10.8	0.0011
Rep*Crop	7	0.468	11.57	<0.0001	1.490	10.4	<0.0001
Rep*Crop*App	7	0.294	7.28	<0.0001	0.493	3.44	0.0014
Rep*Rate*App	3	0.037	0.92	0.4334	0.088	0.61	0.6085
Rep*Crop*Rate*App	42	0.032	0.79	0.7988	0.103	0.72	0.9066

Table 2. Germination, as percent of control, of eight vegetable seedlings at four rates of soybean meal (SBM) and two application methods (AM): surface applied (SA) and incorporated (IN).

	% of control germination[z]								
	Quantity of SBM								
	975 lb·acre^{-1} (1093 kg·ha^{-1})		1950 lb·acre^{-1} (2186 kg·ha^{-1})		2925 lb·acre^{-1} (3279 kg·ha^{-1})		3900 lb·acre^{-1} (4372 kg·ha^{-1})		
Vegetable	SA	IN	SA	IN	SA	IN	SA	IN	LSD(0.05)
Cucumber	95	97	102	93	88	99	82	97	15
Bean	102	101	95	103	94	99	89	94	12
Pea	105	98	83	102	93	103	97	86	18
Squash	98	98	100	100	96	92	92	90	9
Radish	56	116	66	96	52	98	51	75	31
Spinach	98	100	87	104	78	98	57	101	17
Carrot	95	120	68	114	59	106	26	96	23
LSD(0.05)	20	16	23	24	20	16	20	18	

[z]Data presented are means from two replications. Germination for each pot was divided by the control germination for that replication to obtain percent of control germination. The mean was then determined at each rate and AM for each vegetable (n=8). Lettuce germination was not measured.

Table 3. Shoot weight, as percent of control, of eight vegetable seedlings at four rates of soybean meal (SBM) and two application methods (AM): surface applied (SA) and incorporated (IN).

	% of control shoot weight[z]								
	Quantity of SBM								
	975 lb·acre^{-1} (1093 kg·ha^{-1})		1950 lb·acre^{-1} (2186 kg·ha^{-1})		2925 lb·acre^{-1} (3279 kg·ha^{-1})		3900 lb·acre^{-1} (4372 kg·ha^{-1})		
Vegetable	SA	IN	SA	IN	SA	IN	SA	IN	LSD(0.05)
Cucumber	114	129	130	118	103	114	81	105	25
Bean	102	107	98	105	94	108	71	91	19
Pea	100	97	88	105	91	94	96	75	29
Squash	99	119	103	107	108	101	101	92	17
Radish	56	111	58	85	62	71	48	38	35
Spinach	97	90	74	110	71	92	47	78	25
Carrot	100	171	43	116	37	96	13	57	60
Lettuce	82	126	56	131	32	108	26	83	33
LSD (0.05)	32	24	28	27	40	25	28	30	

[z]Data presented are means from two replications. The total shoot weight from each pot was divided by the control shoot weight for that replication to obtain percent of control shoot weight. The mean was then determined at each rate and AM for each vegetable (n=8).

Table 4. ANOVA for soybean meal greenhouse study by crop seed size.

		Germination			Shoot Weight		
Source	df	Mean Square	F	P	Mean Square	F	P
Replicate (Rep)	1	0.298	5.86	0.0159	0.957	5.62	0.0182
Blk (Rep)	6	0.159	3.14	0.0051	0.428	2.51	0.0211
Seed Size	1	1.501	29.60	<0.0001	7.659	44.95	<0.0001
Rate	3	0.721	14.21	<0.0001	3.221	18.91	<0.0001
Application (App)	1	4.073	80.29	<0.0001	6.966	40.88	<0.0001
Rate*App	1	0.057	1.13	0.3366	0.071	0.41	0.7431
Seed*Rate	3	0.224	4.41	0.0046	0.743	4.36	0.0048
Seed*App	3	3.064	60.41	<0.0001	4.125	24.21	<0.0001
Seed*Rate*App	3	0.044	0.86	0.4621	0.069	0.4	0.7511
Rep*Rate	1	0.065	1.29	0.2787	0.328	1.93	0.1243
Rep*App	1	0.276	5.44	0.0201	1.549	9.09	0.0027
Rep*Seed	3	0.337	6.65	0.0103	0.002	0.01	0.9233
Rep*Seed*App	1	0.716	14.15	0.0002	1.824	10.71	0.0011
Rep*Rate*App	3	0.038	0.76	0.5195	0.088	0.51	0.6731
Rep*Seed*Rate*App	6	0.041	0.80	0.5707	0.096	0.56	0.7608

Table 5. Mean shoot weights, relative to the control, for small and large seeded vegetables at four soybean meal rates (SBM) and two application (App) methods: incorporated (IN) and surface applied (SA) as harvested fourteen days after planting.

SBM rate $lb \cdot acre^{-1}$	Application Method	Relative Shoot Weight Small Seeded	Large seeded
975	IN	1.25	1.13
	SA	0.84	1.04
1950	IN	1.10	1.09
	SA	0.58	1.05
2925	IN	0.92	1.04
	SA	0.51	0.99
3900	IN	0.64	0.91
	SA	0.33	0.87
	rate	***	***
	app	***	NS
	rate*app	NS	NS

NS,*,**,*** - Nonsignificant or significant at P<0.05, 0.01, or 0.001, respectively.

Figure 1: Mean germination (A) and shoot weight (B) (± standard errors) at 14 days after seeding of eight vegetables relative to the control at four rates of soybean meal (SBM) and two application methods (AM) - incorporated (INC) and surface applied (SA). Data are combined from two replications (n=64).

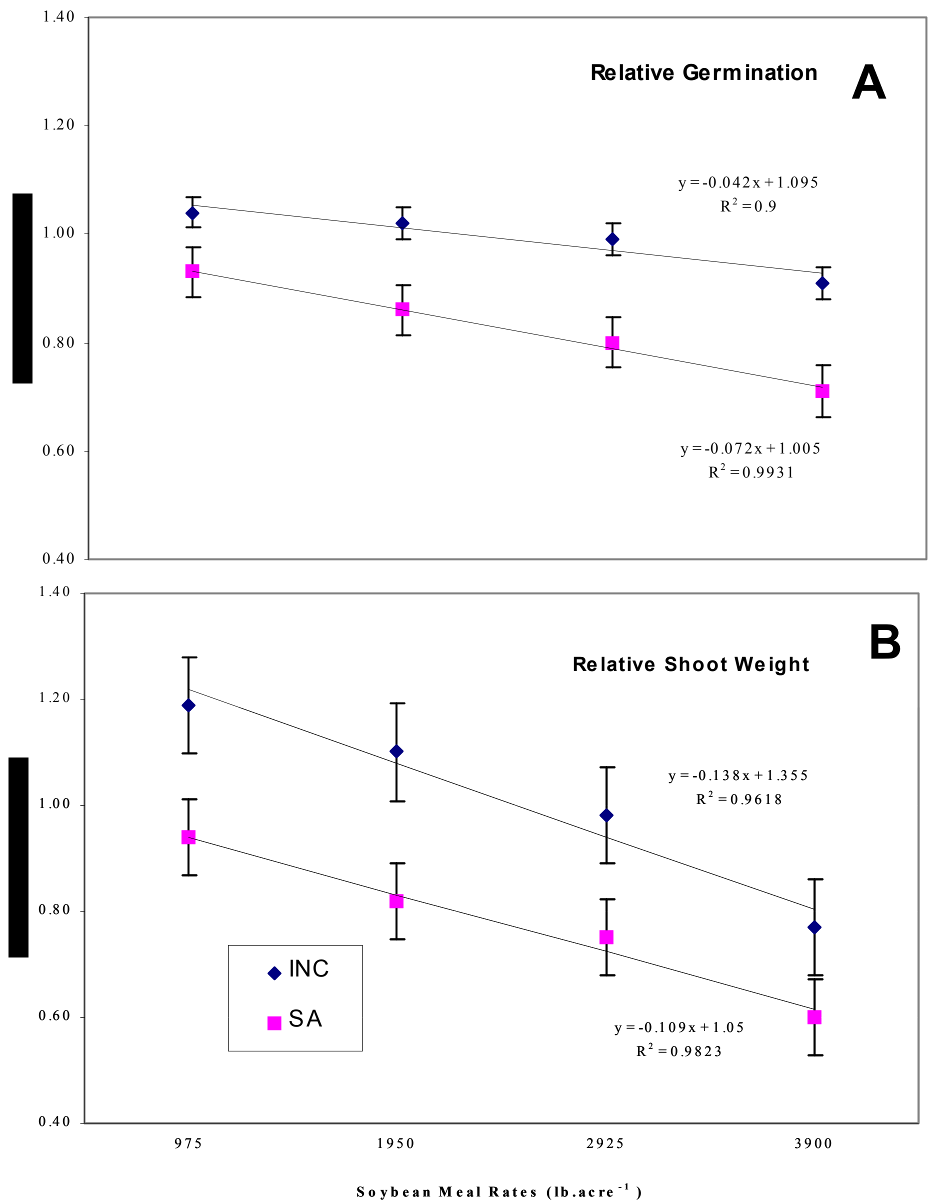
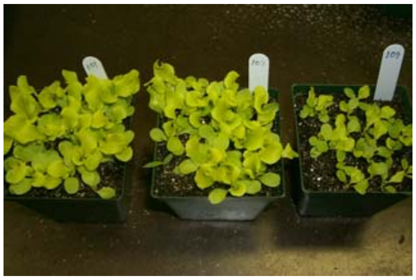
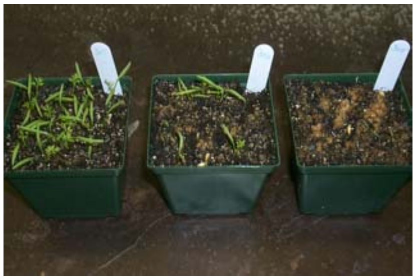


Figure 2: Carrot and lettuce seeds treated with three rates of incorporated and surface applied SBM.

Carrot - Incorporated SBM
L to R: 0, 1950, and 3900 $lb \cdot acre^{-1}$
(0, 2186, and 4372 $kg \cdot ha^{-1}$)



Lettuce - Incorporated SBM
L to R: 0, 1950, and 3900 $lb \cdot acre^{-1}$
(0, 2186, and 4372 $kg \cdot ha^{-1}$)



Carrot - Surface applied SBM
L to R: 0, 1950, and 3900 $lb \cdot acre^{-1}$
(0, 2186, and 4372 $kg \cdot ha^{-1}$)

Lettuce - Surface applied SBM
L to R: 0, 1950, and 3900 $lb \cdot acre^{-1}$
(0, 2186, and 4372 $kg \cdot ha^{-1}$)

Figure 3: Lettuce treated with 3900 $lb \cdot acre^{-1}$ (4372 $kg \cdot ha^{-1}$) of surface applied SBM. Seeds germinated and then died.

Figure 4: Mean electrical conductivity (dS m^{-1}) ($\pm$ standard errors) over twelve days in media amended with five rates of surface-applied (SA) and incorporated (IN) soybean meal (SBM) ($kg \cdot ha^{-1}$).

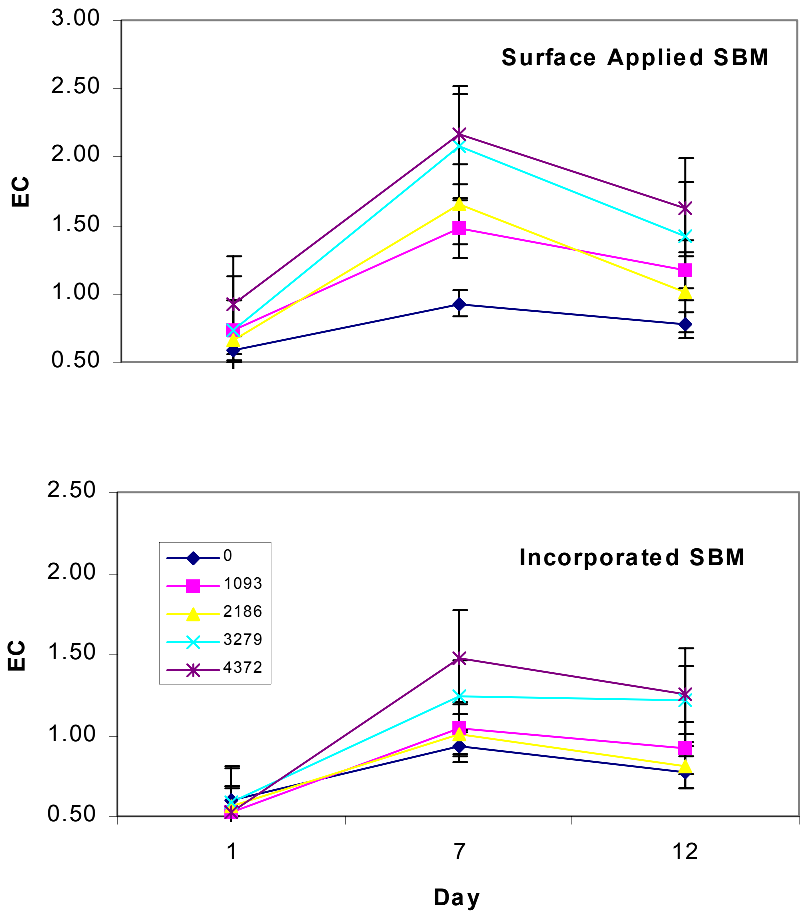
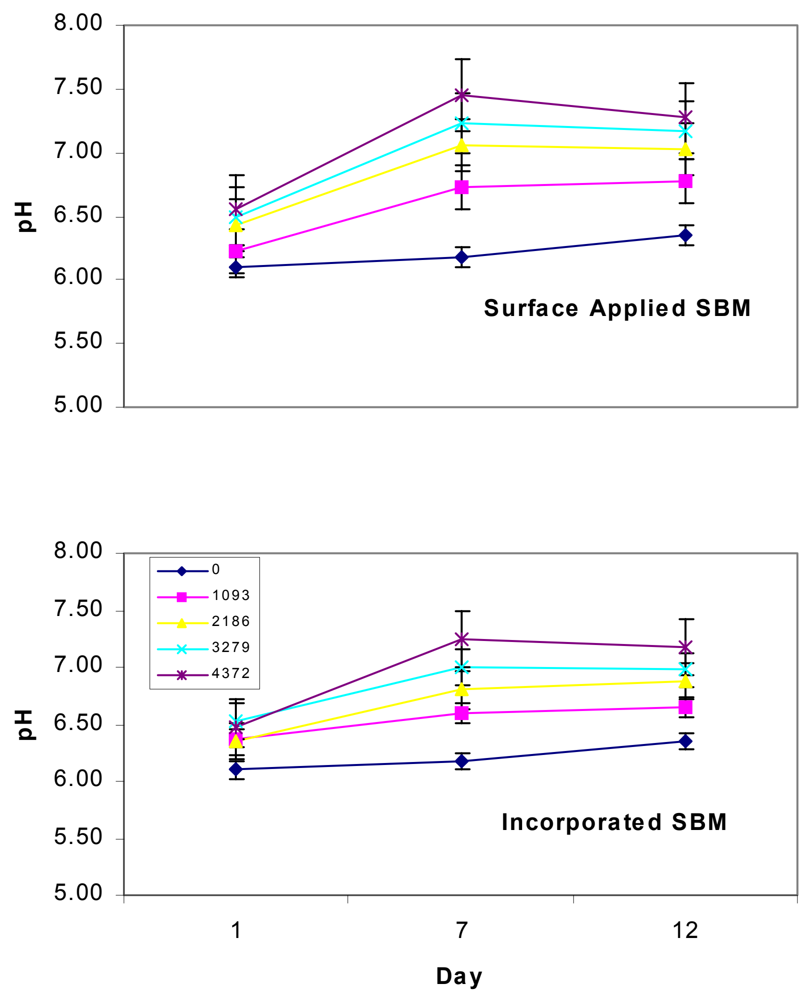


Figure 5: Mean pH (+ standard errors) over twelve days in media amended with five rates of surface-applied (SA) and incorporated (IN) soybean meal (SBM) (kg·ha^{-1}).



Chapter Three

Soybean Meal Fertilization of Plasticulture Sweet Peppers

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Soybean Meal Fertilization of Plasticulture Sweet Peppers

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Soybean Meal Fertilization of Plasticulture Sweet Peppers

Additional index words. organic fertilizer, fertilizer injury

Abstract. Field studies were conducted to investigate the optimal rate of soybean (*Glycine max*) meal (SBM) application and planting timing after SBM incorporation for plasticulture sweet bell pepper (*Capsicum annuum* L.) production. SBM was applied at three rates: 0, 2160, and 4320 $lb \cdot acre^{-1}$ (0, 2421, and 4842 $kg \cdot ha^{-1}$) representing a total N application of 0, 150, and 300 lb $N \cdot acre^{-1}$ (0, 168, and 336 kg $N \cdot ha^{-1}$), a P_2O_5 application of 0, 26, and 52 $lb \cdot acre^{-1}$ (0, 29, and 58 $kg \cdot ha^{-1}$), and a K_2O application of 0, 32, and 64 $lb \cdot acre^{-1}$ (0, 36, and 72 $kg \cdot ha^{-1}$). Sweet peppers were then transplanted at four intervals following SBM incorporation and black plastic application: at one day, three days, seven days, and fourteen days. Growth was delayed in peppers planted into the high rate of SBM less than one week after incorporation. By the end of the season, however, these peppers had recovered and had a greater biomass than the unfertilized control. Peppers fertilized with the low rate of SBM did not suffer an initial delay in growth and had the highest yield of marketable peppers at all planting times. This study suggests that SBM applied at 4320 $lb \cdot acre^{-1}$ (4842 $kg \cdot ha^{-1}$) can inhibit pepper plant growth and reduce fruit yield while an application of 2160 $lb \cdot acre^{-1}$ (2421 $kg \cdot ha^{-1}$) may produce good yields of peppers without early inhibition. SBM at any rate should be applied at least two weeks before the intended planting date to allow the dissipation of the inhibitory factors in SBM.

Soybean meal (SBM) is an animal feed that is also used as an organic fertilizer by farmers interested in reducing inputs of inorganic fertilizers. SBM has an average analysis of 7N-1.2P-1.5K (Zublena et al., 1997) and has been found to increase biomass production in some plant species. In a test of thirteen organic fertilizers for the production of greenhouse tomato (*Lycopersicon esculentum* Mill.) transplants, SBM mixed into the media increased tomato shoot dry weight 40% above the unfertilized control (Gagnon and Berrouard, 1994). Applied at rates of 1200 to 2400 lb·acre^{-1} (1345 and 2690 kg·ha^{-1}), SBM increased the foliar fresh weight and dry weights of greenhouse tomatoes compared to the unfertilized control (Hafez and Sundararaj, 1999). In a previous experiment, we found that SBM applied at least one week before transplanting at 2126 and 4252 lb·acre^{-1} (2383 and 4766 kg·acre^{-1}) increased the plant nutrient level and yield of broccoli (*Brassica oleracea* L.) and sweet peppers (*Capsicum annuum* L.) above that of the control (Chapter 1). Both rates of SBM application also contributed to an earlier broccoli harvest compared to the control.

There is evidence that high rates of SBM can have phytotoxic effects on weeds and vegetables both in the greenhouse and in plasticulture. SBM applied at 4800 lb·acre^{-1} (5380 kg·ha^{-1}) produced greenhouse tomatoes with severe stunting, necrosis, and death (Hafez and Sundararaj, 1999). In another study, SBM inhibited perennial ryegrass (*Lolium perenne* L.) growth when applied at 3046 lb·acre^{-1} (3414 kg·ha^{-1}) and completely stopped growth at higher application rates (Liu, Christians, and Garbutt, 1994). And in our preliminary field study in 2002, we found that plasticulture sweet bell peppers transplanted one day after application of 2126 and 4252 lb·acre^{-1} (2383 and 4766 kg·acre^{-1}) of SBM experienced 69% and 82% reduction in plant dry weight and 64% and 86% reduction in fruit yield, respectively, compared to the control (Chapter 1).

The precise inhibitory factor in SBM is unknown. Future research may decipher if the observed phytotoxicity is due to a particular compound such as was found in corn gluten meal (Unruh et al., 1997) or due to a more generic reaction such as ammonium toxicity. SBM, as a fertilizer source, has been found to increase biomass production in some vegetable species, but also inhibit plant growth at high rates. This field study was conducted to determine optimal rates of SBM application and planting timing after SBM incorporation for plasticulture sweet pepper production.

Materials and Methods

Field studies were conducted in the summer of 2003 at two locations at the Mountain Horticultural Crops Research Station in Fletcher, North Carolina. At each location, the experimental design was a split-plot, arranged in a randomized complete block with four replications. The soil series was a Comus sandy loam (course-loamy, mixed, mesic Fluventic Dystrochrepts). Main plots were SBM soil fertilizer treatments 52 ft (16 m) long and subplots were time treatments 13 ft (4 m) long.

Soybean meal, commercially available as an animal feed, was hand broadcast at a low rate of 2160 lb·acre^{-1} (2421 kg·ha^{-1}) equivalent to 150 lb N·acre^{-1} (168 kg N·ha^{-1}), 26 lb P_2O_5·acre^{-1} (29 kg P_2O_5·ha^{-1}), and 32 lb K_2O·acre^{-1} (36 lb K_2O·ha^{-1}) and a high rate of 4320 lb·acre^{-1} (4842 kg·ha^{-1}) equivalent to 300 lb N·acre^{-1} (336 kg N·ha^{-1}), 52 lb P_2O_5·acre^{-1} (58 kg P_2O_5·ha^{-1}), and 64 lb K_2O·acre^{-1} (72 lb K_2O·ha^{-1}). The control received no SBM. Beds, 3 ft (76 cm) wide on 5 ft (1.5 m) centers, were then machine formed and covered with black plastic mulch.

'X3R Camelot' sweet peppers (*Capsicum annuum* L.) (Twilley Seed Co., Hodges, SC) in 50 cell (cell size = 2.6 in^2 (16 cm^2)) flats (Winstrip, Inc., Fletcher, NC) were used as transplants. Staggered seed starting times were used so plants of the same age were always field set. Eight week-old plants were hand transplanted at four intervals following the initial SBM incorporation: one day, three days, seven days, and fourteen days. Planting holes, 12 in (30 cm) apart in a single row, were manually punched in the plastic the day of planting. The first transplants were set on June 2. All plots received equal irrigation through drip tape (Chapin Watermatics, Watertown, NY) laid in bed centers, 2 in (5 cm) below the soil surface.

At six weeks after planting, five of the ten plants in each plot were harvested to measure fresh and dry weights of the stems and leaves (fruit removed). At nine weeks after planting, the fruit from the remaining five plants in each plot was harvested. Peppers were harvested at maturity and graded according to USDA grading standards for sweet bell peppers. Number and weights were recorded for each grade from each subplot. The above ground plant parts (leaves and stems) were then harvested to determine final shoot weight.

Soil samples were collected from the uppermost 6 in (15 cm) of soil at six and fourteen weeks after SBM fertilization. Samples were collected between the middle two pepper plants in each subplot. Samples from all four planting times within each SBM rate were combined for one sample per main plot (n=12). The NCDA Soil Testing Lab analyzed the samples for P, K, Ca, Mg, Mn, Zn, Cu, and pH. All procedures were carried out on a volume basis of soil.

Data Analysis

Data were analyzed using the means and GLM procedures of the SAS statistical package (SAS Institute, Cary, NC). Location was not significant so data from the two experiments were combined. There were no interactions between rate and time. Time was significant for all of the measured variables so data were analyzed by planting time. Pairwise comparisons of means were performed using the Fisher's Protected LSD (alpha = 0.05).

Results and Discussion

Pepper growth

At six weeks after transplanting, plant growth at the high SBM rate was reduced by 17% to 25%, compared to the unfertilized control, in peppers transplanted seven days or less after the SBM was broadcast (Table 1). Peppers planted two weeks after SBM application were not affected by the high rate of SBM. At nine weeks after transplanting, the plant biomass of peppers fertilized at the high rate of SBM was greater than or equivalent to the biomass of the unfertilized control for all planting dates (Table 1). This suggests the unknown inhibitory factor from the SBM had dissipated and pepper root growth was no longer inhibited.

At the low SBM rate, early pepper growth was no different than the control for peppers planted a week or less after SBM application (Table 1). Peppers planted two weeks after the low rate of SBM application were significantly larger than the control, as measured six weeks after transplanting. This suggests by two weeks the inhibitory factor in the SBM had dissipated and the mineralized nutrients from the SBM were available for plant uptake. By the end of the season, peppers planted with the low rate of SBM had plant biomass significantly greater than the control for plants set one, seven, and fourteen days after SBM application (Table 1).

The growth delaying effects of SMB were not as apparent in the present study as in a preliminary study conducted in 2002 (Chapter 1). Identical rates of SBM were used in the 2002 study as in the 2003 study, but in 2002 all of the pepper transplants were set one day after SBM application. In that study (2002), three weeks after transplanting the SBM fertilized peppers showed signs of stress (wilting leaves and reduced root mass) compared to the more vigorous unfertilized controls (Figure 1). By the end of the season, plant biomass was reduced by 82% and 69% at the high and low rates of SBM, respectively, compared to the unfertilized control. In 2003, the high rate of SBM reduced the plant biomass by 17% compared to the control as measured six weeks after transplanting for peppers planted one day after SBM incorporation (Table 1, Figure 2). By nine weeks after transplanting plant biomass of peppers fertilized with the high rate of SBM at this timing was 19% greater than the control (Table 1).

The differences in rates of inhibition by SBM between the two years may have been, in part, due to much wetter field conditions in 2003 compared to 2002. 2002 was the fourth year of a drought in western N.C. In contrast, 2003 was one of the wettest seasons on record. The extra soil moisture in 2003 may have aided in pepper root regrowth following the initial SBM injury by providing a readily available water source to the injured root system. In 2002, pepper leaves wilted during the middle of the day; plants in 2003 did not show such symptoms of dehydration (Figures 1 and 2). The wetter soils in 2003 may also have diluted the fertilizer, creating a less toxic fertilizer solution and dispersing the fertilizer solution throughout the soil profile, reducing the potential injury to the pepper roots.

Yield

For plants set one day after SBM application, the high and low rates of SBM produced a greater yield of fancy grade peppers than the control (Table 2). For plants set three, seven, and fourteen days after SBM application, there were no differences in the yield of fancy peppers among the treatments. Peppers at the high SBM rate produced a higher percent of fancy grade peppers than the low rate and the control for plants set out at one and fourteen days after transplanting. In plants set out three days after SBM fertilization, both SBM treatments had a higher percent of fancy grade peppers than the unfertilized control.

With plants set one and seven days after SBM application, the high rate of SBM produced less number one grade peppers than the low and control applications (Table 2). The low rate and control yields were not different.

The highest total marketable yield was achieved with the low rate of SBM for plants set one day after SBM application (Table 2). For plants set three days and fourteen days after SBM application, there were no significant differences in marketable yield between the rates of SBM addition. For plants set seven days after SBM application, the low rate yield was significantly greater than the high rate yield, but not different than the control. The low rate may have produced equal to or greater yields than the high rate of SBM because the peppers at the high rate may have still been recovering from SBM burn.

Soil data

Study sites were analyzed separately for soil data due to differences in soil characteristics, even though the locations were only 200 feet apart. Both sites showed similar responses to the SBM treatments. The soil pH was lower than the control for both rates of SBM at mid-season and end of season sampling (Table 3). For both SBM treatments, the pH was lower at the end of the season than at the mid-season. This was likely due to the conversion of ammonium to nitrate, causing an acidification of the soil. Soil phosphorus was higher with the high SBM rate than the low SBM rate or control in study two at the end of the season. Soil potassium levels at the high rate of SBM additions were usually greater than the low rate of SBM and always greater than the unfertilized control both at mid-season and end of season. These levels of phosphorus and potassium represent the fertility that remained in the SBM fertilized plots after the first harvest. Calcium levels, ranging from 3.3 to 4.8 $meq \cdot 100cm^{-3}$, did not differ among treatments.

Conclusion

SBM has been found to be an effective organic fertilizer (Gagnon and Berrouard, 1994; Hafez and Sundararaj, 1999) and is a commonly used nutrient source among organic growers (Fernandez-Cornejo et al., 1998). When applied at high rates under black plastic, SBM can burn sweet pepper transplant roots, inhibiting growth, reducing yield, and/or leading to plant death. Based on these results, SBM should be applied to the soil at moderate rates (depending on the nutrient needs of the crop) at least two weeks before planting to allow the SBM to partially break down, and thus reduce the risk of transplant burn. Adequate soil moisture in the beds may help increase the rate of SBM decomposition.

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Table 1. Dry weights of pepper plants (leaves and stems) transplanted one, three, seven, and fourteen days after application of three rates of soybean meal (SBM), as measured six and nine weeks after transplanting.

	Days transplanted after SBM application			
	1 day	3 days	7 days	14 days
	-------------------- g/plant--------------------			
SBM Rate[y]	*Six weeks after transplanting*			
None	30 a[z]	30 a	36 a	33 b
Low	32 a	25 ab	38 a	42 a
High	25 b	21 b	27 b	36 ab
	Nine weeks after transplanting			
None	54 b	53	63 b	57 b
Low	62 a	54	79 a	78 a
High	64 a	59	69 ab	86 a

[y]SBM was applied at a low rate of 2160 $lb \cdot acre^{-1}$ (2421 $kg \cdot ha^{-1}$) equivalent to 150 $N \cdot acre^{-1}$ (168 $kg\ N \cdot ha^{-1}$) and a high rate of 4320 $lb \cdot acre^{-1}$ (4842 $kg \cdot ha^{-1}$) equivalent to 300 $lb\ N \cdot acre^{-1}$ (336 $kg\ N \cdot ha^{-1}$).

[z]Means followed by the same letter within a column are not significantly different, according to Fisher's Protected LSD (alpha = 0.05).

Table 2. Yield from peppers transplanted one, three, seven, and fourteen days after application of three rates of soybean meal (SBM).

	Days planted after SBM application			
SBM Rate[y]	1 day	3 days	7 days	14 days
Percent Fancy Grade Peppers				
	------------------------ % ------------------------			
None	12 c[z]	12 b	38	29 c
Low	35 b	37 a	40	41 b
High	58 a	41 a	54	55 a
	-------------------- cartons/acre --------------------			
Yield of Fancy Peppers				
None	22 b	28	131	86
Low	86 a	73	146	137
High	90 a	70	120	141
Yield of #1 Peppers				
None	127 a	150 a	142 ab	118
Low	126 a	100 ab	161 a	114
High	50 b	78 b	68 b	77
Yield of Marketable Peppers				
None	152 b	178	278 a	204
Low	212 a	173	316 a	252
High	140 b	148	188 b	218

[y]SBM was applied at a low rate of 2160 $lb\cdot acre^{-1}$ (2421 $kg\cdot ha^{-1}$) equivalent to 150 $N\cdot acre^{-1}$ (168 kg $N\cdot ha^{-1}$) and a high rate of 4320 $lb\cdot acre^{-1}$ (4842 $kg\cdot ha^{-1}$) equivalent to 336 lb $N\cdot acre^{-1}$ (154 kg $N\cdot ha^{-1}$).

[z]Means followed by the same letter within a column are not significantly different, according to Fisher's Protected LSD (alpha = 0.05).

Table 3. Soil properties as measured at two locations six and fourteen weeks after application of three rates of soybean meal (SBM).

STUDY 1

SBM Rate[y]	pH	P $mg\cdot dm^{-3}$	K $meq\cdot 100\ cm^{-3}$
Six weeks after SBM application			
None	5.7 a[z]	76.5	0.4 c
Low	5.3 b	80.3	0.5 b
High	5.3 b	91.4	0.7 a
Fourteen weeks after SBM application			
None	5.8 a	82.6	0.4 b
Low	5.2 b	84.8	0.4 b
High	4.8 c	94.4	0.6 a

STUDY 2

SBM Rate	pH	P $mg\cdot dm^{-3}$	K $meq\cdot 100\ cm^{-3}$
Six weeks after SBM application			
None	6.1 a	89.9	0.5 b
Low	5.6 b	91.4	0.6 b
High	5.6 b	97.2	0.8 a
Fourteen weeks after SBM application			
None	6.0 a	94.8 b	0.5 b
Low	5.4 b	96.8 b	0.6 a
High	5.2 b	103.2 a	0.7 a

[y]SBM was applied at a low rate of 2160 $lb.acre^{-1}$ (2421 $kg.ha^{-1}$) equivalent to 150 $N.acre^{-1}$ (168 kg $N.ha^{-1}$) and a high rate of 4320 $lb.acre^{-1}$ (4842 $kg.ha^{-1}$) equivalent to 300 lb $N.acre^{-1}$ (336 kg $N.ha^{-1}$).

[z]Means followed by the same letter within a column are not significantly different, according to Fisher's Protected LSD (alpha = 0.05).

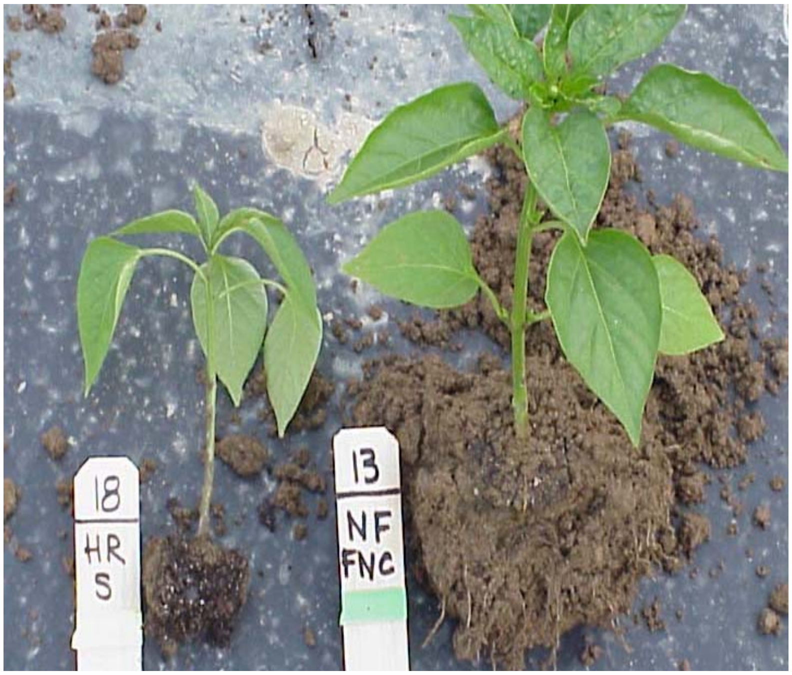

Figure 1. The effect of application of soybean meal at the high rate of 4320 lb·acre^{-1} (4842 kg·ha^{-1}) (left) compared to the unfertilized control (right) in a 2002 preliminary study. Peppers are shown three weeks after transplanting.

Figure 2. The effect of application of soybean meal at the high rate of 4320 lb·acre^{-1} (4842 kg·ha^{-1})(left) compared to the unfertilized control (right) in the 2003 study. Peppers are shown six weeks after transplanting.

Appendix

Figure 1. Test 1. Soil profile of inorganic N after lettuce harvest.

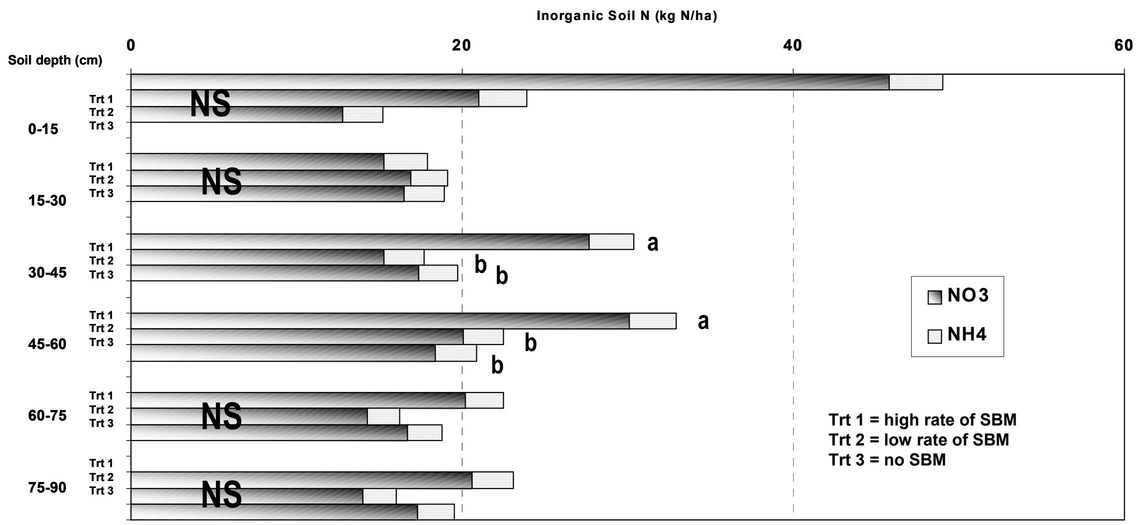

Figure 2. Test 2. Soil profile of inorganic N after pepper harvest.