STUDIES IN VEGETABLE AND HIGH TUNNEL PRODUCTION ON THE CENTRAL GREAT PLAINS

by

SHARON JOY BLANTON KNEWTSON

B.S. Agronomy, Missouri State University, 1997
M.S. Soil Science, Texas A&M University, 2000

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Horticulture, Forestry, and Recreation Resources
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2008

Abstract

A series of four investigations was conducted from 2005 to 2007 focusing on vegetable or high tunnel production. In the first study (chapters 1 & 2), the effect of high tunnels on soil quality was investigated. Grower perceptions of soil quality were assessed from 81 responses to a questionnaire. Indicators of soil quality were evaluated at two KSU research centers. Soil quality was then quantified in high tunnels and adjacent fields at 79 farms, where high tunnels ranged in age from two to fifteen years. Particulate organic carbon as a fraction of soil total carbon was used as an indicator of soil quality. At 80 % of locations, particulate organic matter carbon was greater under high tunnels than adjacent fields. Soil quality was not adversely affected by the continuous presence of high tunnel covering. Management and cropping history in high tunnels was also collected and reported as this information is of interest to growers and the universities and agricultural industries that serve them. Tomato was the most common high tunnel crop. It was grown by 86 % of survey respondents in the previous four year period. Organic soil amendments were applied by 89 % of growers; 35 % use organic soil amendments exclusively. In the second study (chapter 3), two microbial tea solutions were applied to collard green (*Brassica oleracea* L. var. *acephala* cv. Top Bunch) or spinach (*Spinacea oleracea* L. cv. Hellcat) crops at Olathe and Haysville, Kansas, without significant effects on crop yield or soil microbial biomass. Finally, preliminary results from two studies were formatted for reporting as extension publication (chapters 4 and 5). Autumn production, over-wintering, and spring bolting were assessed for 26 spinach cultivars in a 3-season multi-bay Haygrove high tunnel. Also, the effect of autumn planting date on harvest date and yield was observed for two spinach cultivars (cv. Avenger and PVO172) planted on six dates in October and November, under high tunnels at Olathe, Kansas. Spinach planted in the first half of October was harvested in the winter, without loss of spring yield for both cultivars.

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Major Professor
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Acknowledgements

I appreciate the contributions made by each of my committee members, Dr. Mary Beth Kirkham, Dr. Rhonda Janke, and Dr. Kimberly Williams, but especially Dr. Ted Carey. Their guidance in research planning, and advice in refining written reports, has been most valuable during my educational experience at Kansas State University.

To Maryanne and Monica Lillis I owe my gratitude. Maryanne was diligent, cheerful, and kept legible records - the perfect laboratory assistant. Monica loved and cared for my son, from three weeks after his birth until this dissertation was completed. The friendship of the Lillis ladies is a treasure.

Thank you to my husband, Jeremy, for your love and support through one more "educational endeavor".

Thank you to my parents, Rev. Jeffery and Judith Blanton, for our family.

> Jou kind kan sy geleerdheid nog by the skool agterlaat;
> sy opvoeding sal hom vergesel tot in die graf.
> C.J. Langenhoven

Dedication

To Nathan Jeremiah Knewtson

Preface

Each of the research projects presented in this dissertation was intended to integrate with activities of the Kansas State University Horticulture Research and Extension Service.

The use of high tunnels by growers of horticultural crops in Kansas continues to expand. A few high tunnel owners were vocally concerned about possible soil quality decline in their high tunnels. In response, we investigated soil quality in high tunnels in Kansas, Missouri, Nebraska, and Iowa. The growers who participated in the soil quality study were interested in the demographics of high tunnel management. We report some survey results in a paper that besides being sent to the journal HortTechnology will be sent to the survey participants.

A representative of a local company, SDC, based out of Kansas City, Mo., that manufactures microbial soil conditioners, approached Dr. Carey about testing their product, Efficient Microbes™. There were some published studies that indicated that Efficient Microbes™ could potentially improve soil productivity.

Trees for Life, a non-profit agriculture and educational organization, contacted Dr. Carey around the same time about testing a manure tea. Anecdotal evidence suggested that the manure tea could boost soil microbial populations to improve soil productivity. They wanted to have the manure tea tested before promoting it in developing countries with limited resources.

We did an experiment with the two teas with the hypothesis that microbial populations in the teas would boost the soil microbial population and be reflected in crop yield. Both teas were tested on a sandy loam soil that would be more similar to a nutrient poor soil, such as might be found in the Trees for Life target areas. We also tested the Efficient Microbes™ in a nutrient rich loam soil more typical for Kansas growers.

Market demand for fresh spinach continues to grow. Seed companies are introducing new spinach cultivars. Most of these are developed in cool northern climates and targeted at growers in California. We began studies that will help growers choose varieties that perform well in Kansas high tunnels. We also did a preliminary study investigating autumn planting date effect on harvest date and yield of spinach.

I have enjoyed the past few years working with growers and university extension personnel. I hope that my work will be of benefit to growers of horticultural crops in Kansas.

Sharon Knewtson
May 2008

CHAPTER 1 - Management Practices of Growers Using High Tunnels in the Central Great Plains

[Formatted for submission to HortTechnology]

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The authors wish to thank the growers who by completing this survey assisted with ongoing high tunnel research. Thanks also to Lewis Jett and Laurie Hodges for assistance in contacting growers, to Candice Shoemaker for reviewing the questionnaire and suggesting format improvements, to high tunnel growers Daniel Nagengast and Tom Circle for reviewing question clarity, and to John Bauer, for creating the map. Funding for this study was provided in part through a Sustainable Agriculture Research and Education graduate student grant to the senior author (project no. GNC05-048, Soil and Crop Quality under High Tunnels).

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Subject Category: Technology Transfer

Management Practices of Growers Using High Tunnels in the Central Great Plains

Additional index words. survey, vegetable, flower, organic, fertilizer, Kansas, Missouri, protected agriculture

Summary. Eighty-one growers managing 185 high tunnels in Missouri, Kansas, Nebraska, and Iowa participated in a survey about their high tunnel management practices, with emphasis on soil management. The survey of growers was administered from 2005 to 2007 using both internet-based and written forms. The average respondent had four years of high tunnel experience. The oldest tunnel still in use was fifteen years old. Twenty-five percent of respondents grew crops in their high tunnels year round. Tomato, lettuce, spinach, cucumber, pepper, and flowers were the most common crops. Organic soil amendments were used by 85 % of growers, and multi-element conventional fertilizers by 56 %. The summary of management practices should be of interest to growers and the industries and university research and extension scientists who serve them.

High tunnels are walk-in plastic-film-covered structures used to improve the crop environment. They are used by growers to provide season extension and to enhance crop quality and yield (Lamont, 2005). High tunnels provide a barrier to wind and rain and to some extent may exclude animal and insect pests (Lamont, 2005). Rainfall protection results in reduction in foliar diseases reported in high tunnels (Orzolek et al., 2004). Air temperatures in a high tunnel from late autumn to early spring typically reach minimum daily temperatures only 1 to 4 ºC higher than adjacent fields (Akinci et al., 1999; Both et al. 2007; Rader and Karlsson, 2006; Reiss et al., 2004; Waterer and Bantle, 2000), but the minimum soil (upper 10 cm) temperature may be 1 to 7 ºC warmer (Both et al., 2007; Rader and Karlsson, 2006; Reiss et al., 2004). The average minimum strawberry (*Fragaria x Ananassa* Duchesne) crown temperature was 5 ºC higher under high tunnels than in adjacent fields in December to February in Kansas (Kadir, et al., 2006). Winter production in unheated high tunnels may be limited by air temperature in some climates, but increased soil temperature may allow over wintering and early planting. Warmer air temperatures in high tunnels allow faster accumulation of growing degree days, which brings high tunnel crops to faster maturity (Waterer and Bantels, 2000; Both et al., 2007). In Kansas, harvest of strawberries over wintered in a high tunnel began five weeks before field harvest (Kadir et al., 2006).

Increased yield and crop quality are reported in many high tunnel crops (Lamont, 2005). The benefits are seen internationally. Yield and quality were improved in high tunnel grown strawberries in Croatia (Voca et al., 2006), India (Nevkar et al., 1998) and Kansas (Kadir et al., 2006).

Protected agriculture in plastic film structures began in the 1950s. Vegetable, flower, and small fruit producers use high tunnels. In Asia and Europe high tunnel use took off rapidly, especially in Japan where 93 km^2 of vegetable production were reportedly under plastic film by 1970. In 1999, Greenhouse or plastic house production was reported to be 800 000 ha world wide. Most of this was under simple plastic houses, with the exception of the glass greenhouses of northern Europe. China, Japan, and the Mediterranean region lead in high tunnel crop production (Enoch and Enoch, 1999). High tunnel use continues to expand. Around the Mediterranean there was a 50 % increase in plastic tunnels between 1985 and 1995 (Baudoin, 1999). It was also during this time that interest in high tunnels surged in the USA. Interest in high tunnels research has spread from the northeastern U.S. (Lamont et al., 2002) and in 2007, high tunnels were reported from 45 states, with ongoing research and demonstration projects underway in 37 states (Carey et al., 2008).

A survey targeting high tunnel growers in Iowa, Kansas, Missouri and Nebraska was conducted in 2006 and 2007. The survey was part of a larger study to examine the effects of cropping and management practices on soil quality in high tunnels. The objective of this paper is to report the more general information collected about high tunnel use and management practices of growers of horticultural crops in Iowa, Kansas, Missouri and Nebraska as of 2007. Such information would be of interest to growers, as well as the research and extension specialists and industries that serve them.

Materials and Methods

The target population for the questionnaire was growers in Kansas, Missouri, Iowa, and Nebraska, who had used high tunnels for in-ground crop production for more than two years. The survey did not include container production under high tunnels.

The questionnaire consisted of thirty multiple choice questions and six open ended questions (Table 1.1). The questions covered physical description of tunnels, crop history, nutrient management (including organic matter additions), tillage management, irrigation methods, and perceptions of soil quality. The survey did not cover pest and disease incident and management, nor economic profitability.

The questionnaire was offered online from June 2005 to October 2007 as a link from www.hightunnels.org, a website maintained by Kansas State University. Twenty-one surveys were collected from this website. Five of the respondents were from the four state target region, and are included in this report.

The questionnaire was also offered in booklet format at the Great Plains Vegetable Growers Conference held in St Joseph, Mo., in January 2006. Contact information of vegetable producers possibly using high tunnels was provided by research and extension agents in Kans., Mo., Nebr., and Iowa and by other growers. Growers who had used high tunnels for more than two years were visited and given the questionnaire, if they had not already completed one. Growers who did not complete the questionnaire during a farm visit were given an addressed and stamped envelope for survey return. Only four growers did not return the questionnaire after a farm visit for a 95 % return rate. Seventy-six questionnaires were collected in booklet format from growers in the four state region.

Questionnaire responses were compiled in November 2007. In this report we include only results from growers producing crops in soil under high tunnels in Kans., Mo., Iowa and Nebr. Not all participants responded to all questions. Survey responses are presented in the results section based on the number of respondents to a question. Survey questions and response counts are presented in Table 1.1.

During visits to eighty farms, the senior author had informal discussions with many of the growers who participated in the survey presented in this report about crop production in high tunnels. Growers were asked how university research and extension personnel could serve them and also about topics they would find interesting at future workshop or conference events.

Results and Discussion

Eighty-one growers from Missouri, Kansas, Nebraska and Iowa completed questionnaires. Locations of survey participants in these states are indicated on the map (Fig. 1.1). States were represented as follows: 53 % Missouri, 25 % Kansas, 14 % Nebraska, and 8 % Iowa. The oldest high tunnel still in use was built in 1991, in Elm Creek, Nebr. The median and mode of production experience with high tunnels was four years at the time growers completed the survey (Fig. 1.2). The year 2002 saw the largest number of survey respondents construct an initial high tunnel in a single year. Thirteen percent of the participants had used high tunnels for under three seasons. Growers with less than three years of high tunnel experience are under represented in this survey because they were not actively sought. Given our effort to identify and survey most experienced high tunnel producers in the target region, data reported here provide a comprehensive picture for Missouri, Kansas, Nebraska and Iowa.

The growers surveyed managed a total of 185 tunnels. Thirty-seven percent of respondents had one high tunnel, and 35 % had two. The maximum number of tunnels per grower was ten.

A variety of high tunnel widths and lengths were reported. The most common high tunnel size was 30 ft by 96 ft (268 m^2). Only seven high tunnels were more than 100 ft (30.5 m) in length. One grower had a 400-ft-long tunnel.

One of the main advantages of high tunnel use is an extended growing season for crop production. Growers extended their crop season by planting earlier in the spring and some crops extended into the autumn. On average high tunnels had a crop for nine months of the year. January was the least utilized month with only 33 % of high tunnels in use (Fig. 1.3). Twenty-five percent of growers surveyed grew a crop or cover crop in their high tunnel year round.

The most common crop in high tunnels was tomato (*Lycopersicon esculentum* Mill.). Eighty-six percent of growers surveyed produced tomatoes in their high tunnel within the past four years (Table 1.1; Fig. 1.4). Growers who considered tomato to be their main crop may have used high tunnel space for a different crop for at least some portion of the past four years. During visits the author observed that a bed of shorter crops, like strawberries or leafy greens, were sometimes grown along the curved outer edges of quonset-shaped tunnels while tomato was grown in the higher center. Also, some growers produced crops for personal use when tomato crops were not in the high tunnels.

The majority of growers produced several vegetables in their high tunnels. Salad crops like lettuce (*Lactuca sativa* L.), spinach (*Spinacia oleracea* L.), other leafy greens, cucumber (*Cucumis sativus* L.), and pepper (*Capsicum* sp.) were favored for high tunnel production (Fig. 1.4). Bean (*Phaseolus* sp.), onion (*Allium cepa* L.), broccoli (*Brassica oleracea* var. *italica* Plenck), eggplant (*Solanum melongena* var. *esculentum* Nees), squash (*Cucurbita* sp.), and melons (*Cucumis melo* L. and *Citrullus lanatus* (Thunb.) Matsum & Nakai) were commonly grown with a medley of crops. More vegetables not represented in Fig. 1.4 were grown, but by less than 5 % of those surveyed.

Thirty-one percent of the growers surveyed produced flowers in their high tunnel. Growers collectively listed 43 flower crops that they had grown. Lisianthus (*Eustoma grandiflorum* (Raf.) Shinn.) was the most commonly grown flower, reportedly grown by ten of the twenty-five respondents who grew flowers. Delphinium (*Delphinium nuttallianum* Pritz. ex Walp), dianthus (*Dianthus armeria* L.), geranium (*Pelargonium* x *domesticum* L.H.Bailey), petunia (*Petunia hybrida* Hort. Vilm.-Andr.), sweet pea (*Lathyrus odoratus* L.), zinnia (*Zinnia elegans* Jacq.), and tulip (*Tulipa* sp.) cut flowers were each grown by four growers. Other flowers were grown by fewer than four growers.

Single crop growers did exist. Tomato was the sole crop for 26 % of growers surveyed. Three percent of growers produced only salad greens, 1 % only flowers, and 1 % only strawberries.

Organic soil amendments were used in high tunnels by 85 % of growers surveyed. Thirty-five percent of the growers surveyed reported using organic soil amendments exclusively. Organic additions were made on an annual basis by 66 % of the growers and more frequently by 14 %. Animal manure and homemade compost were the most commonly used organic amendments, applied by 55 and 48 % of growers respectively. Other organic fertilizers used by growers were: seaweed (29 %), commercial compost (29 %), fish emulsion (29 %), worm castings (23 %), and bone meal (17 %). Other organic fertilizer options were used by less than ten percent of respondents (Table 1.1).

Multi-element conventional fertilizer use was reported by 56 % of growers surveyed, or 73 % of the sixty growers who responded to questions about use of conventional fertilizers. Calcium nitrate use was reported by 35 % of total survey respondents. Ten percent of growers reported use of slow release fertilizers and 8 % use of micronutrient fertilizers.

Calcium and magnesium supplements were commonly used. Gypsum ($CaSO_4$) and epsom salts ($MgSO_4$) application was reported by 25 and 24 % of growers, respectively. Lime application was reported by 39 % of growers. Half of those who applied lime had done a soil nutrient analysis.

Growers tend to till prior to planting a new crop; therefore, tillage frequency is mostly determined by crop turnover. Forty-seven percent of respondents reported tilling their high tunnel soil once annually, 32 % twice annually, and 14 % more often than that. Tillage depth was eight inches or less for 82 % of growers. Annual or more frequent subtilling was reported by 16 % of growers.

Drip irrigation was the primary form of irrigation for 89 % of respondents. Hand watering is the primary method for 11 %. Some growers noted that they use secondary irrigation methods such as hand watering, sprinklers or misters and flood irrigation.

Fifty-nine percent of growers did not irrigate in the high tunnel when not growing a crop. Fourteen percent irrigated weekly or more often even when not growing a crop. Four percent of growers removed the plastic cover from the tunnel when not growing a crop.

Cover crops had been used by 41 % of growers. Occasional use of cover crops was reported by 21 % of growers. On a regular basis, cover crops were grown in the winter by 13 %, in the summer by 2.5 %, and in both summer and winter by 5 % of growers.

Fifty percent of growers practiced some form of crop rotation. Crop rotation systems were described as growing different crops in successive years or rotating crops to different areas of the high tunnel. Moving the high tunnel to cover a different soil location was part of crop rotation for two growers, and two moved their tunnels at infrequent intervals.

Soil quality was perceived as problematic by 14 % of respondents. Fifty-four percent of respondents were of the opinion that they did not have soil quality problems in their high tunnels compared to adjacent fields. The remainder were uncertain if they had experienced soil quality problems. Respondents were also asked to report soil observations. Hardpans were reported by 32 % of respondents. Mineral surface deposits were seen in 30 % of high tunnels. Clod formation was reported to be worse in high tunnel soil compared to outside by 12 % of respondents, and surface crusting by 13 %. Water infiltration was a concern for 13 % of growers.

Four survey questions were open ended, with participants invited to describe possible causes of success or problems with crop productivity and soil quality, to compare high tunnel and open field production, or simply to request information of research and extension personnel. Questionnaire information was supplemented with informal discussions with growers during farm visits. High tunnels were used by hobby horticulturists, growers who supplement income with produce sales, and farmers whose sole income was from produce sales. Growers typically reported satisfaction with their high tunnels. Growers with more than one high tunnel had often added subsequent tunnels following the success of crop production in an initial tunnel. The author saw many new tunnels, often on neighboring farms. Labor for crop maintenance was the main limiting factor verbally reported by growers as preventing expanded high tunnel production on a farm. Growers with more than two tunnels usually spoke of the need to hire help.

Growers showed interest during discussions and survey responses in testing crop management improvements. Information was requested about research station variety trials and trials with crops that might follow a spring tomato crop. Growers were interested in tomato cultivars with good harvest quality and yield, disease resistance, and early harvest. There was also interest in the possibilities for autumn tomato production.

During farm visits the senior author was asked about services offered through agriculture extension offices and universities, including how to get soil analyzed for nutrient requirements or tissue samples analyzed to identify disease. Common themes among growers for continued management improvement are disease and pest control, nutrient management, and water management.

Growers in all four states requested information about tomato ripening disorders – especially yellow shoulder and hard core. These problems were reported in high tunnel and field tomatoes. It was not an ongoing problem for any grower. It could affect one crop, but not the next, or one grower, but not his neighbor.

Growers indicated an interest in information about nutrient management. Soil nutrient analysis had been done by 55 % of growers. Considering survey responses and soil analysis conducted during parallel research (Chapter 2), it is advisable that growers planning to apply lime have a soil test done. Only half of those who applied lime had done a soil nutrient analysis. Growers expressed awareness of the connection between calcium deficiency and blossom end rot in tomatoes. Lime applications were made by some growers as a calcium addition. However, lime increases soil pH. Of soil samples analyzed from over sixty of the farms included in the survey, only four had a soil pH of less than six. Micronutrient uptake is optimal between pH 6 and 6.5, so it would usually not be desirable to increase pH beyond this range. If soil analysis indicates low calcium, calcium sources other than lime are a better option for non-acidic soils.

It may be that because location selection favored good soils, and organic soil amendments have followed, micronutrient deficiencies were rare, or not severe enough to be visible. Only 8 % felt the need to apply a fertilizer specifically for micronutrient amendment. Few growers were of the opinion that their crops had shown nutrient deficiency symptoms.

Survey participants expressed the opinion that their success with high tunnel crop production was due to good site selection and regular organic matter additions.

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Table 1.1. Questions, response options (if included), and selected responses to a survey of high tunnel growers in Missouri, Kansas, Nebraska and Iowa. Questions for which response options were not provided in the survey are indicated by footnotes.

Question	Response options and selected responses (number of respondents); n= total number of responses.
1) How many high tunnels (hoophouses) do you use?[y]	None (not counted), one (30), two (28), three, (11) other (12); n = 81
2) When did you begin production in high tunnels? Month and year.[z]	n = 79
3) Which of the following crops have you grown in your high tunnels in the past four years? Select all that apply.[y]	Flowers (25), tomato (73), pepper (33), cucumber (34), melon (11), bean (23), pea (12), squash (20), onion (15), asparagus (0), spinach (36), lettuce (39), other leafy greens (29), strawberry (17), brambles (1), other (19); n = 80
4) If you grow flowers, please list your top five flower crops based on volume produced, with most produced listed first then in decreasing order.[z]	n = 25
5) What are the approximate dimensions of each of your high tunnels (e.g., 14 x 20 ft)? If various sizes, indicate all sizes.[z]	n = 76
6) Are you experiencing soil quality problems in any of your high tunnels?	Yes (11), no (41), not sure (24); n = 76
For the following questions, consider one of your high tunnels in which you are experiencing soil quality problems. If you do not have soil quality problems, consider the high tunnel that has been in production the longest.	
7) Please, indicate the category that applies to your high tunnel.	Soil quality problem (12), longest production time (59); n= 71

Question	Response options and selected responses (number of respondents); n= total number of responses.
8) Which of the following crops have you grown in your high tunnel in the past four years? Select all that apply.[y]	Flowers (21), tomato (69), pepper (24), cucumber (26), melon (9), beans (22), pea (10), squash (16), onion (10), asparagus (0), spinach (32), lettuce (32), other leafy greens (21), strawberry (14), brambles (1), other (14); n = 77
9) Do you use only organic amendments?	Yes(28), no(51), do not know (0); n = 79
10) Which of the following organic amendments have you used in the past four years? Select all that apply.[y]	Homemade compost (33), commercial compost (20), urban waste compost (1), animal manure (37), worm castings (16), mushroom compost (3), seaweed/kelp (20), fish emulsion (20), bone meal (12), lime (26), gypsum ($CaSO_4$) (18), epsom salt ($MgSO_4$) (14), other(21); n = 69
11) How often do you apply organic amendments? Select one best answer.	Never(8), once each 4 years (2), once each 2 years (10), annually(48), twice a year (7), more frequently (3); n = 73
12) Approximately how much organic amendment do you add on an annual basis? Please indicate the amendment and rate; for example, 400 lb mushroom compost per 1000 square foot, and 50 kg bone meal per 5 foot x 20 ft bed.[z]	n = 55
13) Which fertilizers do you use in your high tunnel? Select all that apply.[y]	Commercial multi-element combination (44), commercial slow release fertilizer (8), micronutrient mix (6), urea (3), calcium nitrate $Ca(NO_3)_2$ (28), potassium nitrate KNO_3 (8), sodium nitrate $NaNO_3$ (0), ammonium nitrate NH_4NO_3 (5), triple superphosphate (0), lime (21), gypsum $CaSO_4$ (15), epsom salt $MgSO_4$ (16), other (12); n = 60
14) How frequently do you till the soil under your high tunnel? Select one best answer.	Never (2), once every two years (3), annually (37), twice a year (25), four times a year (8), more than four times a year (3); n = 78
15) To what depth do you usually till? Select one best answer.	Four inch or less (18), 8 inch or less (47), 12 inch or less (12), 18 inch or less (2), more than 18 inch (0); n = 79

Question	Response options and selected responses (number of respondents); n= total number of responses.
16) How often do you till the subsoil (i.e. with a subsoiler or ground fork)?	Never(45), rarely(10), once in two years (6), annually (11), more often than once a year (1); n = 73
17) What type of irrigation do you use? Select the options that best describe your primary method of irrigation.	None (0), hand watering (14), drip (66), bubblers (0), sprinklers (5), flood (2); n = 77
18) Do you occasionally soak the soil to result in deep leaching?	Yes(36), no(39); n = 75
19) Some high tunnels are designed to be stationary and some to be moveable. How often is this high tunnel moved? Select the one best answer.[y]	Never (72), rarely (2), once a year (1), after each crop (0), other (1); n = 76
20) Is the plastic cover of this high tunnel removed during the year. If so, for how long? Select the one best answer.[y]	Never (59), rarely (8), one month (0), two months (0), three months (1), other (8); n = 76
21) How often do you irrigate the soil when no crops are being produced in your tunnels? Select the one best answer.[y]	Never (42), monthly (12), twice a month (3), weekly (4), more than once a week (3), other (9); n = 73
22) During which months do you typically have a crop (commercial or cover crop) in your high tunnel? Select all that apply.	All year (20), January (26), February (48), March (70), April (76), May (77), June (74), July (71), August (63), September (59), October (57), November (44), December (32); n = 79
23) Do you use a cover crop when commercial crops are not being produced in this high tunnel? Select all that apply.	Never (47), summer (6), winter (14), occasionally (17); n = 80
24) Do you use a crop rotation? If yes, describe briefly.[y]	Yes (37), no (37); n = 74
25) How would you describe the soil texture in your high tunnel? Select the one best answer.[y]	Clayey (10), loam (34), sandy loam (13), loamy sand (2), sandy (2), do not know (9), other (3); n = 73
26) What is the pH of your soil? Select the one best answer.	Do not know (32), alkaline (greater than pH 7.5) (4), neutral (between approximately pH 6-7.5) (37), acidic (less than pH 6) (3); n = 76
27) How would you describe water infiltration in the soil under your high tunnel? Select one.	Rapid (15), normal (43), slow (11), do not know (7); n = 76

Question	Response options and selected responses (number of respondents); n= total number of responses.
28) Do you seem to have increased clod formation in the high tunnel compared to outside fields?	Yes (10), no (67); n = 77
29) Do you seem to have increased surface crust formation in the high tunnel compared to outside fields?	Yes (12), no (64); n = 76
30) Do you seem to have a salty surface or visible mineral buildup in the high tunnel compared to outside fields?	Yes (25), no (51); n = 76
31) Do you seem to have a hard pan developing in the high tunnel compared to outside fields? If so at what depth? [z]	None (54), 4 inch (5), 6 inch (7), other (10); n = 76
32) Have you had your high tunnel soil tested for nutritive quality?	Yes (41), no (34); n = 75
33) If you have soil quality problems in your high tunnels compared to open field production, please describe these problems. [z]	n = 24
34) Are there any other problems that you've experienced in your tunnels that might be related to soil quality and management? Please describe. [z]	n = 31
35) If you have had no soil problems in your high tunnel, why do you think that is the case? [z]	n = 31
36) What factors in your opinion have attributed to the soil quality or crop productivity in your high tunnel? For example: compaction by a bulldozer, alkaline water source, addition of four tons horse manure in the first year of site preparation, excellent soil from the start, etc. [z]	n = 50

[z]Response options not provided. Respondent provides answer.

[y]Response options partially provided. Respondent fills in blank to provide additional information such as listing "other" crops or amendments.

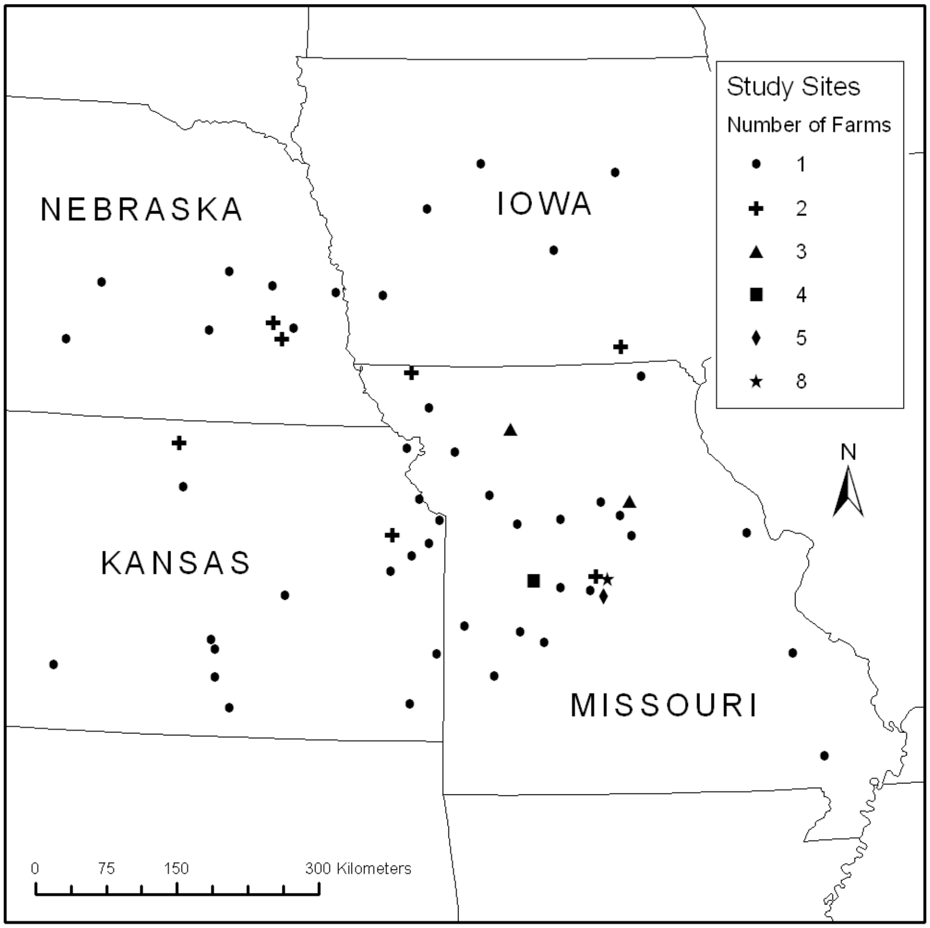

Figure 1.1. Locations of 81 high tunnel producers surveyed from Iowa, Kansas, Missouri, and Nebraska.

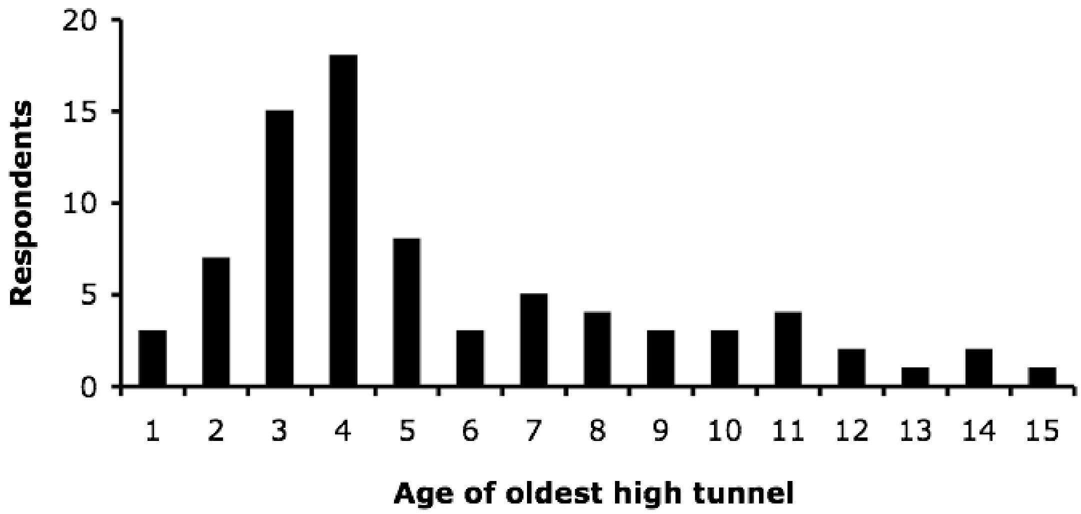

Figure 1.2. Years of high tunnel crop production experience reported by growers in a survey of producers from Iowa, Kansas, Missouri, and Nebraska (n = 79).

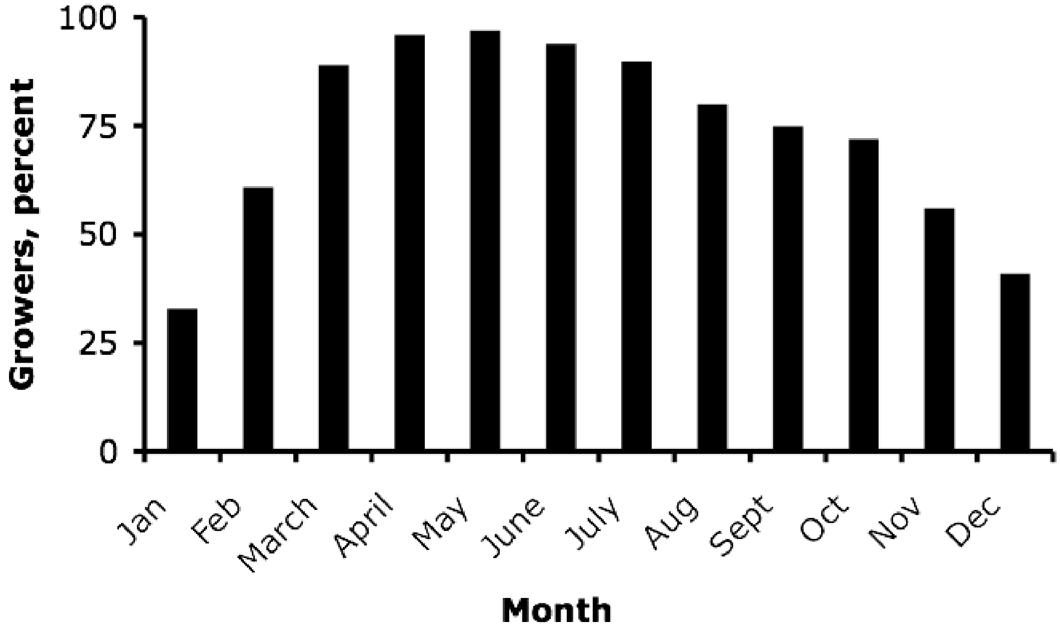

Figure 1.3. Proportion of producers reporting growing crops in high tunnels during each month of the year. Results of a survey of 81 growers from Iowa, Kansas, Missouri, and Nebraska conducted from 2005 to 2007.

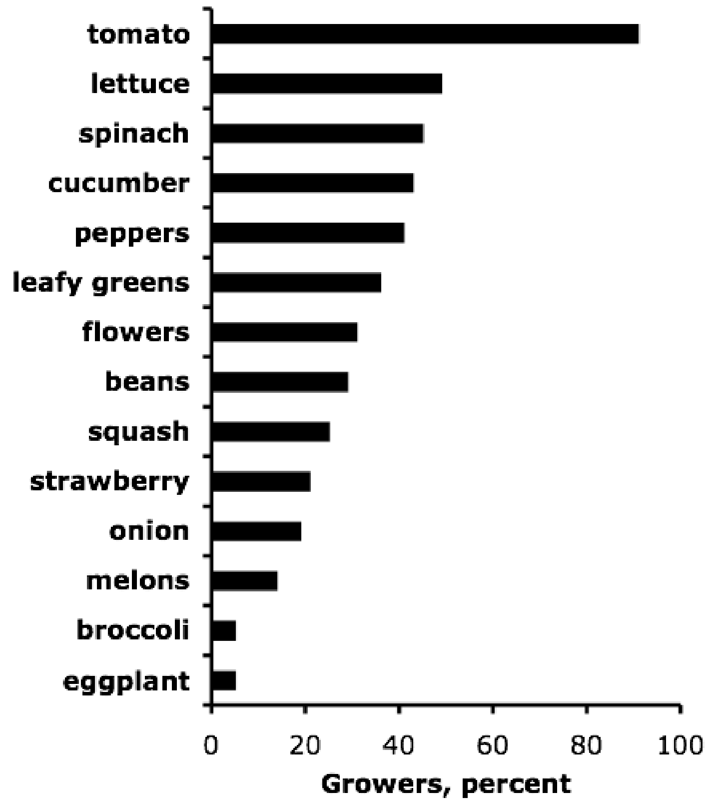

Figure 1.4. Percent of growers that reported producing various vegetable crops in high tunnels during the previous four years. Results of a survey of 81 growers from Iowa, Kansas, Missouri, and Nebraska conducted from 2005 to 2007.

CHAPTER 2 - Soil Quality in High Tunnels in the Central Great Plains

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The senior author wishes to thank the growers who allowed her to sample soils on their farms, and who shared so generously their interests and insights about high tunnels. We also thank John T. Bauer, geographer at the University of Nebraska – Kearney, who created the map of participating farms. Funding for this study was provided in part through a Sustainable Agriculture Research and Education graduate student grant to the senior author (project nr. GNC05-048, Soil and Crop Quality under High Tunnels).

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Soil Quality in High Tunnels in the Central Great Plains

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Abstract. Soil quality under high tunnels in the central Great Plains was assessed by a survey of grower experience and comparison of soil quality indicators measured in soil under high tunnels of varying ages and the adjacent fields at 79 farms. Soil quality indicators were initially assessed for usefulness by comparing high tunnel and adjacent field soils at two research stations in Kansas. Particulate organic matter carbon as a fraction of total carbon was found to be a good indicator of soil quality. Water stable aggregate analysis was a potentially good indicator. Particulate organic matter carbon made up 10 to 67 % of the total carbon under high tunnels sampled. The particulate organic matter carbon fraction was higher in high tunnels than adjacent fields at 80 % of locations sampled. Water stable aggregate mean weight diameter was greater under 65 % of high tunnels than fields in the subset of locations where it was measured. Salinity in the soil upper 15-cm was less than 2 dS m^{-1} in 95 % of high tunnels sampled. In the soil upper 5-cm, salinity was less than 2 dS m^{-1} under 74% of high tunnels, and less than 4 dS m^{-1} in 97 % of high tunnels. Soil surface salinity was elevated in some high tunnels compared to the adjacent field, but this was not related to time under the high tunnel. Soil pH, salinity, particulate organic matter carbon, and water stable aggregates were not correlated to age of high tunnel. Soil quality as measured in this study was not negatively impacted by high tunnel structures over time.

Additional index words. particulate organic matter carbon, water stable aggregates, total carbon, salinity, penetrometer

Introduction

In its simplest form a high tunnel is clear plastic covering a frame high enough to walk inside, heated by solar radiation and cooled by passive ventilation (Wells and Loy, 1993). Construction designs, materials, and other features vary. Producers use high tunnels to modify crop environment. The primary function is to elevate temperatures to allow earlier planting in the spring, early ripening and extended fall harvests. Other benefits include wind and rain protection, reduction of some diseases and insects compared to open field, and typically, enhanced crop quality and yield (Lamont et al., 2005; Wells and Loy, 1993).

Much of the research and published high tunnel experience in the US has been from the northeastern states (Lamont et al., 2002). University researchers in Kansas, Missouri, and Nebraska began doing variety and fertility trials in high tunnels in 2002 (Jett, 2004, Kadir et al., 2006, Zhao et al., 2007). The number of growers using high tunnels in the central Great Plains has increased steadily in the past decade. Midwest vegetable, fruit, and flower growers expressed favorable high tunnel experiences and with each passing year the number of high tunnels in use has increased (Chapter 1).

The effect over time of cropping on soil quality in high tunnels is uncertain. High tunnel crops and soils are often more intensively managed than field crops, and the growing season is longer. Intensified production may increase soil nutrient removal, tillage, and traffic. Some growers are concerned that covering soil year round will result in a buildup of insect pests, soil pathogens, and excess nutrient salt levels (Coleman, 1999). Soil revitalizing options have included soil sterilization, soil removal and replacement, removal of plastic covering for part of the year, pesticide applications and flushing irrigation (Coleman, 1999). Methods and frequency for physically moving high tunnels were discussed by Coleman (1999). However, the necessity of moving the high tunnel because of declining soil quality has not been confirmed by research.

Soil quality comparisons require appropriate indicators to quantify quality. Indicators may include measures of crop productivity or of physical, chemical, or biological soil qualities (Lal, 1994). The use of crop production indicators requires years of data (Dumanski and Pieri, 2000) and so may not be useful as a survey tool. To determine if high tunnels alter soil quality, paired comparisons can be made of soils from individual high tunnels and adjacent fields. Comparison using high tunnels of varying age would allow evaluation of possible relationships between soil quality and time of soil covering.

Possible physical indicators to be considered include: water infiltration, penetration resistance, bulk density, modulus of rupture, and analysis of water stable aggregates. Penetration resistance measures the mechanical impedance plant roots may experience in soil. Quantitative measurements of resistance have been correlated to crop yields and tilth (Davidson, 1965). Modulus of rupture is a measurement used to evaluate the cohesion of dry soil. Cohesion forces relate to soil surface crusting and clod formation (Reeve, 1965). The stability of soil aggregates will determine the existence of soil macropores. Large pores in the soil generally favor good infiltration rates, aeration, and tilth (Kemper and Rosenau, 1986). A combination of soil drying, wetting, and sieving can be used to measure aggregate stability.

Chemical indicators to be considered include: pH and salinization. Nutrient analysis would not be useful because of potential fertilizer application differences between high tunnel and field. pH is closely correlated to base saturation and may be used as an indication of nutritive quality (Singh and Goma, 1995). A combination of excessive fertilizer applications, irrigation and poor drainage can induce salinity (Brady, 1999), so in some high tunnels it may be advisable to monitor salinity.

Soil organic matter (SOM) is a commonly used biological indicator of soil quality. Organic matter influences soil structure, nutrient storage, water holding capacity, biological activity, tilth, water and air infiltration, erosion, and even efficacy of chemical amendments made to soil (Dumanski and Pieri, 2000). Soil organic carbon is used to estimate organic matter (Nelson and Sommers, 1996). In non-calcareous soils total carbon is equivalent to organic carbon (Loeppert and Suarez, 1996). Particulate organic matter (POM) is labile organic matter of size fraction 53 microm – 2 mm, and has the advantage as an indicator of soil quality of faster response to environmental change than SOM (Elliott et al., 1994; Wander, 2004). Changes in POM can be used to predict trends in SOM. Gregorich and Janzen (1996) cited four studies that showed greater resolution and sensitivity in measurements of POM change compared to SOM change. Particulate organic matter has been correlated to microbial biomass (Wander and Bidart, 2000), C and N mineralization (Bremer et al., 1994; Janzen et al., 1992), and soil aggregate formation and stability (Waters and Oades, 1991) demonstrating that increased POM indicates improved soil quality. The ratio of POM C : total C can be used for comparison of locations or for comparison of changes over time.

The overall objective of the current study was to evaluate soil quality in high tunnels in the central Great Plains. Soil quality was assessed by grower perception and measures of soil quality indicators. To assess grower perception we conducted a survey of producers, asking them about their soil conditions and management practices. We complemented the written questionnaire by assessing and comparing quality attributes of soils from established high tunnels and adjacent fields at the farms of survey respondents in four states. To determine suitable quality indicators to be used, we conducted a preliminary study of soil quality factors using soils from established high tunnels and adjacent field plots at two research stations in Kansas.

Therefore, the specific objectives of this research were to

1) determine useful indicators of soil quality;
2) collect information about grower management practices and perception of soil quality;
3) determine if measures of soil quality relate to grower management practices or perception of soil quality;
4) assess whether soil quality is affected by time under a high tunnel.

Materials and Methods

Locations for testing soil quality indicators

Soil quality indicators were tested on soil under high tunnels and adjacent fields at the Kansas State University Horticulture Research and Extension Center, Olathe, and at the John C Pair Horticultural Center at Haysville, 8 km south of Wichita, Kansas.

The high tunnels at the Olathe research center were established in 2002, on a Kennebec silt loam soil (fine-silty, mixed, superactive, mesic Cumulic Hapludolls) that was formerly pasture. There were six high tunnels and six plots in the adjacent field. The tunnels and field plots had been largely managed with matching crops. Half of the high tunnels and field plots have been managed with organic amendments and half with conventional amendments. Researcher perception of increased clod formation under the Olathe high tunnels indicated the possibility of declining soil quality.

At Haysville, Kansas, four high tunnels and four matching plots in the adjacent field were established in 2002, on a Canadian-Waldeck sandy loam (coarse-loamy, mixed, superactive thermic Udic Haplustolls, and Fluvaquentic Haplustolls) that was formerly used for vegetable production. The tunnels and field plots have been managed with matching crops and conventional amendments.

Soil quality indicator data were analyzed using a mixed analysis of variance procedure (SAS 9.1, Statistical Analysis System Institute, Cary, N.C.) with a location (high tunnel or field) variable for Haysville data, and location and management variables for Olathe data.

Indicators of soil quality

Soil samples were bulked after at least five random collections within crop rows. Soil pH, texture, POM and total carbon were determined in soil collected to 15-cm depth with a soil probe. Soil was collected with a trowel from the surface 5-cm for salinity analysis. Soil samples collected with a trowel to a 15-cm depth and held in an 8 mm sieve were used for WSA analysis.

Soil texture was determined using the Bouyoucos style hydrometer method (Gee and Bauder, 1986) for soil characterization. Soil pH was measured in a 1:1 soil and water slurry. Salinity was measured as electrical conductivity in water extracted from a 1:2 soil and water slurry (Rhoades, 1996).

Soil penetration resistance was measured using a cone penetrometer (Soiltest, Inc., 1978). Water infiltration was measured as rate of a volume of water (440 ml) receding in metal rings pushed into the soil (interior diameter 147 mm, depth below surface 60 mm).

Modulus of rupture was measured using the method and apparatus described by Reeve (1965). Soil was oven dried and ground to pass a 2 mm sieve prior to making briquettes. Laboratory analysis of modulus of rupture was replicated four times for each sample.

Soil for water stable aggregate (WSA) analysis was air dried before being passed through an 8 mm sieve and caught on a 4.76 mm sieve. A sample of this sieved soil was placed on a nest of four sieves (4.76, 2, 1, and 0.2 mm mesh) in a Yoder (1936) type sieving machine. Samples were submerged for 10 min before being sieved – and then were raised and lowered 3.8 cm about 30 times per minute for 10 minutes while submerged. Mean weight diameter was calculated as the sum of products of (1) the mean diameter of each sieve size fraction (6.38, 3.38, 1.5, and 0.6 mm) and (2) the portion of the total dried sample weight in that corresponding size fraction (Kemper and Rosenau, 1986).

Soil carbon was measured by combustion with a TruSpec CN 2000 (Leco Corp, St. Joseph, Mich.). The particulate organic matter fraction (POM) was separated by moist sieving soil samples dispersed in 0.5 % sodium hexametaphosphate through a 53 um sieve (Gregorich and Ellert, 1993). Sieves were rinsed with distilled water so clay and silt size particles drained out. Sand and POM were retained on the sieve. The collected POM was dried at 55 °C and ground with a mortar and pestle. Carbon was measured in POM by combustion with a TruSpec CN 2000.

Survey of high tunnel management and grower perception of soil quality

Growers with more than two years of experience with high tunnels were sought out in Kansas, Missouri, Nebraska, and Iowa to gather information about high tunnel management and grower perceptions of soil quality. A thirty-six question survey was offered online beginning June 2005 as a link from www.hightunnels.org, a website maintained by Kansas State University. It was also offered in booklet format at the Great Plains Vegetable Growers Conference held in St Joseph, Mo., in January 2006. Contact information of vegetable producers possibly using a high tunnel was provided by research and extension agents in Kansas, Missouri, Nebraska, and Iowa and by other growers. These growers were contacted by telephone and those who had used high tunnels for more than two years were asked to participate in the study by completing the questionnaire and allowing soil samples to be collected from their high tunnels and adjacent field. Because of the objective to investigate the effect of high tunnels on soil quality, high tunnels that had been in use for at least three years within the region, were of more interest.

The questionnaire was used to collect information about high tunnel age, size, and number, crop history, nutrient management, organic additions, tillage, irrigation, and perception of soil quality and soil observations such a as surface deposits, crusts, or clods, hardpan formations, and water infiltration. Respondents could skip questions or respond to a query as uncertain. An expanded report on survey questions, responses, and high tunnel management trends, without correlation to soil quality, is presented in Chapter 1.

The first five survey questions addressed demographics. The sixth question asked, “Are you experiencing soil quality problems in any of your high tunnels?” Growers were classified as those who self identified as having a soil quality problem and those who did not based on this question. The growers opinion about high tunnel soil quality was thus gauged in general before being asked about specific soil observations. Questions numbered 7 through 26 addressed soil and crop management. Questions numbered 27 through 36 asked about specific soil quality observations. A response of “not sure” or left blank were not included in statistical analysis.

Growers estimated the amount and frequency of organic matter additions made to high tunnels. Responses were in units preferred by the grower. These estimates were converted to uniform units using conversion factors from Parnes (1990). Organic additions were divided into four categories based on annual application rates. Categories were less than 5 000, 25 000, 97 500 and excess of 97 500 kg ha^{-1} (100, 500, 2 000 lb/1000 ft^2).

Soil sample collection from farms

Based on the standard deviation of POM measurements at the research stations we calculated (Ott and Longnecker, 2001) that a sample size of 25 high tunnel and adjacent field pairs would be needed to measure a 5 % mean difference in POM (α and $\beta = 0.025$). Because farm sample variability would potentially be higher than at the research stations with matching plots, our goal was to collect soil from double the estimated sample size. This was surpassed as soil was collected from high tunnels and adjacent fields on 79 farms in Kansas, Missouri, Nebraska, and Iowa in the autumn of 2006 (Fig. 2.1).

Soil collection was focused on high tunnels that had been in place at least three years. A few high tunnels in use for less than three years were included in the soil collection (Fig. 2.2). These were mainly from farms with high tunnels erected over a series of years. Soil was collected adjacent to the high tunnel for quality comparison. Management of the adjacent fields varied. Fields were cultivated with horticultural crops, pasture or ornamental turf. If there was a similarly managed area (e.g. vegetable crops) near the high tunnel this was sampled rather than a grassy area. Locations where soil under the high tunnel was not that of the adjacent field (e.g. a creek bottom soil had been brought in) were not included in the data set.

Statistical analysis of soil quality and management factors

Results were analyzed using SAS 9.1 (Statistical Analysis System Institute, Cary, N.C.) program for correlations between the ratio of quantified quality indicators for soil samples from under high tunnels and adjacent fields, soil characteristics (pH and texture), information about management practices and observations of soil conditions as reported for that location in the grower questionnaire, and tunnel age. Statistical analysis was done using t-tests with binomial data, Chi-Square test of independence with categorical data, and correlations with numeric data.

Results and Discussion

Determination of useful quality indicators for comparing high tunnel and field soils

Preliminary evaluation was conducted at university research plots at Olathe and Haysville, Kansas. Results from testing soil quality indicators at the KSU research stations showed that many of the quantification methods were not practical for our purpose.

Soil penetrometer measurements in two high tunnels constructed on-farm in 2001 near Lawrence, Kans., one with rows of mixed flowers and one with mixed vegetables and with rows irrigated on different schedules, demonstrated the non-uniform vertical resistance within a high tunnel (Table 2.1a.). Variability was greatest below 15-cm depth. In the adjacent field variability was high even in surface measurements (Table 2.1b.).

Water infiltration in field vegetable rows was similarly variable, and proceeded at rates varying from 10 to 100 ml min^{-1} (data not shown). Complicating factors such as crop, tillage and soil moisture could not be controlled for this study.

Though statistically significant at Olathe, soil pH was not affected in practical terms by the presence of a high tunnel at Olathe or Haysville (Table 2.2). A measured soil pH difference of 0.3 is not meaningful.

Electrical conductivity was significantly affected by the presence of high tunnels at Olathe ($p = 0.0028$) and Haysville ($p = 0.0001$). Salinity was less than 1 dS m^{-1} in all plots but it was an average of 0.4 dS m^{-1} higher under high tunnels compared to the adjacent field (Table 2.2). Organic management did not significantly affect salinity ($p = 0.82$) at Olathe.

Analysis of modulus of rupture results did not identify significant differences between high tunnel and field locations ($p = 0.71$) at Olathe (Table 2.2). Management systems (organic vs. conventional) also did not have a significant effect on modulus of rupture ($p = 0.80$). The Canadian-Waldeck soil from near Haysville is sandier than the Kennebec soil from Olathe. The briquettes from this soil were very fragile and results of analysis were so variable as to be meaningless.

At Olathe, significant differences in WSA mean aggregate diameter were not found between high tunnel and field locations ($p = 0.81$), nor between conventional and organic management ($p = 0.76$) (Table 2.2). At Haysville, WSA mean aggregate diameter was significantly higher in high tunnels than in the adjacent field ($p = 0.001$) (Table 2.2). Unfortunately the high tunnel soils had not been irrigated in weeks and not tilled for months while the field plots had been tilled only the week before sampling, potentially weakening aggregate stability. Thus the high tunnel covering may not have been the strongest influence on Haysville WSA differences. We decided to measure WSA in a subset of the farm soil samples rather than draw conclusions about the potential value of WSA as a soil quality indicator on the basis of those results.

In the organic management system at Olathe, the POM C fraction was significantly larger in high tunnels, while total C did not differ, so that mathematically the

POM C : total C ratio was significantly higher in high tunnels than in the adjacent field (Table 2.3). In the conventional management system, both POM C and total C were lower in the high tunnels, so that POM C : total C was not significantly different in soils under high tunnels compared to adjacent fields. At Haysville, POM C and total C were greater in the high tunnels compared to the adjacent field. The POM C : total C ratio was significantly higher in Haysville high tunnels.

Total C may not necessarily differ between organically and conventionally managed high tunnels on farms. At Olathe the conventionally managed plots are not purposely given organic amendments. However, the survey of growers in this study revealed that over 80 % of growers that used conventional fertilizers also applied organic amendments (Chapter 1, Table 1.1).

Comparison of total C and POM C quantity under high tunnels and in fields was meaningful at the university research centers because identical amounts of fertilizer and compost were applied. This comparison would not be possible elsewhere. Analyzing POM as a portion of total soil carbon has an equalizing effect that allows comparison of soils at different locations and at different times.

The particulate organic matter C : total C ratio was significantly affected by both high tunnel presence and management (organic vs. conventional) at Olathe ($p < 0.0001$). High tunnel presence significantly ($p = 0.012$) affected the POM C : total C ratio at the Haysville location as well. The POM C : total C ratio was higher under high tunnels than in the adjacent fields at Haysville and in the organic management system at Olathe, (Table 2.3). From these initial tests we considered the POM C : total C ratio to have good potential as a quantifier of soil quality.

Results of preliminary assessment of soil quality attributes are summarized in Table 2.4. Management is not uniform across a high tunnel as several crops may be grown in a season. Areas with different crops may be irrigated on different schedules and tilled at different times. Tillage differences were not an issue when sampling research station plots that had matching crops, but soil water content under the high tunnels and in the adjacent fields may differ depending on irrigation schedules or precipitation in the fields. Comparison of indicators strongly influenced by moisture and tillage is practically impossible on farms where little attempt is made at identical management for high tunnels and adjacent fields. Penetration resistance, water infiltration, and soil density would be more dependent on current soil moisture and tillage history (Kirkham, 2005) than on how long a high tunnel has been in place. Particulate organic matter C : total C was chosen to compare high tunnel and field soil quality in the survey of regional high tunnels. Water stable aggregate analysis was also done on a limited basis to assess its potential usefulness. Electrical conductivity was also measured to address grower concerns about salinization.

Soil quality and high tunnel management on farms in the central Great Plains

Details of cropping and management practices used by growers in their high tunnels were obtained through a written survey at each farm, and results were examined in relation to analyses of soil attributes measured in high tunnels and adjacent fields at each location. The ages of high tunnels sampled on farms ranged from one to fifteen years. The median age of high tunnels was five years. Growers were asked in the survey about their production experience in their high tunnels compared to outside in the adjacent field.

Fifty-four percent of respondents were of the opinion that they did not have soil quality problems in their high tunnels compared to adjacent fields. Fourteen percent perceived problems. The remainder were uncertain if they had experienced soil quality problems. Hardpans were reported by 32 % of respondents. Mineral surface deposits were seen in 30 % of high tunnels. Clod formation was reported to be worse in high tunnels compared to outside by 12 % of respondents, and surface crusting by 13 %. Water infiltration was a concern for 13 % of growers. Growers who did and did not perceive general soil quality problems reported observation of increased mineral deposition, clod, crust and hardpan formation in high tunnels. A larger proportion of growers who considered that they had soil quality problems also reported specific adverse soil observations (Table 2.5). Growers who self identified as having decreased soil quality in high tunnels also reported significantly more surface crusting ($p = 0.0001$), surface mineral deposits ($p = 0.031$) and clod formation ($p = 0.0001$) (Table 2.6). Perception of soil quality was less strongly correlated to hardpan formation ($p = 0.12$).

Management of tunnels by growers who self identified as having soil quality problems was not significantly different from those who did not report problems for the following practices: tillage depth ($p = 0.49$), tillage frequency ($p = 0.34$), crop rotation ($p = 0.11$), organic input amount ($p = 0.48$), and application frequency ($p = 0.12$) (Table 2.7). Identification as an organic or conventional producer was not related to perception of soil quality problems ($p = 0.13$) (Table 2.7).

Soil textures were in the fine loamy and coarse loamy families with maxima of 34 % clay and 66 % sand. Soil texture was not related to grower perception of general soil quality (Table 2.7).

Soil pH in high tunnels and adjacent fields ranged from 5.3 to 7.9. Four high tunnels had soil pH less than six, with one below pH 5.5. Soil pH was greater than 7 in 10 % of the high tunnels. Of those high tunnels with pH greater than 7, only two had a pH greater than the adjacent field. On average, high tunnel pH was a half point below the pH of the adjacent field (data not shown). Thus high tunnels did not affect soil pH.

Hardpan formation was reported by 32 % of growers, making it the most common soil quality concern of growers. In some cases compaction may have occurred during high tunnel construction. Pan formation may also be related to restricted traffic patterns in high tunnels. Hardpan formation can affect water infiltration and rooting depth. Growers need to be aware of potential hardpans and manage so that intervention is done in a timely fashion. Growers can test for hardpan formation by pushing a homemade penetrometer (i.e., a sturdy stick) into beds irrigated to about field capacity (Kirkham, 2005). Hardpans can be broken up with pitchfork action or a deep tined ripper.

Mineral surface deposits reported by growers may indicate salt accumulation near the soil surface. To verify this we measured electrical conductivity (EC) in the upper 5 cm of soil in 93 high tunnels at 63 farms. Soil with EC greater than 4 dS m^{-1} is considered saline (Brady and Weil, 1999). The highest EC measured in field soil was 2 dS m^{-1} (Fig. 2.3a). From this it can be concluded that soils at the farms evaluated were not inherently saline.

Analysis did show salt accumulation in the surface 5 cm of some high tunnels; 26 % had an EC greater than 2 dS m^{-1}, and 3 % had an EC greater than 4 dS m^{-1} in the upper 5 cm (Fig. 2.3b). A second set of salinity measurements was done on soil collected to a 15-cm depth in high tunnels with EC of 2 dS m^{-1} or more (Fig. 2.3c). None of the high tunnel soils were saline in the upper 15 cm. All but five had an EC less than 2 dS m^{-1} in the upper 15 cm (Fig. 2.3c).

Salinity in the high tunnels was found to be slight and mostly superficial. This surface accumulation could potentially have deleterious affects on seed germination or transplanted seedlings. A 10 % yield reduction may occur in tomato crops with soil EC 4 dS m^{-1} and in lettuce at 2 dS m^{-1} (Bernstein, 1964). Most growers can avoid yield reduction by leaching salts deeper into the soil profile with heavy irrigation before planting.

The surface mineral deposit reported by 30 % of the survey respondents was not a cause for alarm. Electrical conductivity was not different ($p = 0.34$) in high tunnels with and without reported visible surface minerals (Table 2.6). The mineral deposition at the surface could be carbonates, or salts, but as both pH and salinity were within acceptable limits at nearly all locations the presence of a surface mineral deposit may not be of concern.

High tunnel salinity was correlated to soil clay ($p = 0.039$) and total carbon ($p = 0.047$) content (Table 2.7). These soil components are responsible for most cation exchange, so this is reasonable. Fertility management significantly affected salinity ($p = 0.011$) (Table 2.7). Growers who self identified as using only organic soil amendments had a mean EC of 1.16 dS m^{-1} in the soil upper 5 cm, compared to conventional fertilizer utilization with a mean EC of 1.85 dS m^{-1}. The higher salinity of conventional fertility management is acceptable for vegetable production. It is interesting to note that the chance of having increased salinity was lower with organic nutrient amendments.

Increased clod formation, surface crusting, and water infiltration problems reported by survey participants were hypothesized to be related to declining soil quality, probably due to soil structure changes, possibly related to weakened soil aggregation. Organic matter binds mineral soil particles together into the granules that make up soil structure (Brady and Weil, 1999). To quantify soil quality with special emphasis on changes that would reflect soil structure we considered indicators previously tested at the Olathe and Haysville research stations: water stable aggregates and particulate organic matter analysis.

Analysis of water stable aggregates (WSA) was done on soil from nineteen high tunnels ranging in age from 2 to 12 years, from twelve farms (Table 2.8). Five of the growers (representing eight high tunnels) self identified as experiencing soil quality problems.

An increase in the unit mean weight diameter (MWD) indicates increased aggregate stability. Aggregate stability was similar between high tunnel and adjacent field for four high tunnels (giving a HT:Field ratio close to 1), declined under two high tunnels and was greater under the remaining thirteen high tunnels (Table 2.8).

The average MWD of water stable soil aggregates was higher in high tunnels and fields of growers who self identified soil quality problems. However, it is interesting that the MWD ratio of high tunnel to adjacent field (WSA HT:Field) was higher ($p = 0.059$) for the group that did not identify with soil quality problems. Grower perception of soil quality was based on comparison of high tunnels and adjacent fields, so analysis of this subsample of 12 growers may indicate a correlation between WSA HT:Field and grower perception of soil quality. But the MWD HT:Field was not significantly related to reports of specific quality problems like clod formation ($p = 0.32$), surface crusting ($p = 0.51$), or hardpan formation ($p = 0.35$) (Table 2.6).

Total C measured under high tunnels and in adjacent fields ranged from 10.7 to 125 g C kg^{-1} soil. Eighty percent of high tunnels were found to have higher total C, with 16 % having double the amount of C, compared to adjacent fields. Many growers give high tunnels priority when applying organic soil amendments, so this was not surprising. This was supported by statistical analysis that showed significant correlation between total C in high tunnels to total C in the adjacent field ($p = 0.001$) and the amount of organic matter growers estimated as having added in the high tunnel ($p = 0.005$). Total C in the high tunnel is a function of both the original base level of soil C - thus the correlation to C in the adjacent field - and the amount of organic matter added during high tunnel production. Comparison of the ratio of total C in high tunnels and fields, with sets of varying high tunnel age, would not indicate a high tunnel effect over time, but would rather reflect grower management. Rate of organic decomposition could be affected by the presence of a high tunnel and be less dependant on grower management. This may be indicated by POM C : total C ratio comparison.

Particulate organic matter carbon as a fraction of total carbon (POM C) in high tunnels significantly exceeded that in adjacent fields ($p = 0.0005$). Particulate organic matter made up 10 to 67 % of the total C under high tunnels (Fig. 2.4). In 78 % of the high tunnels it made up more than a quarter of the total C. In the fields, the POM C was 10 to 89 % of the total C. Particulate organic matter made up 25 % or more of the total C in 48 % of the fields (Fig. 2.4). Particulate organic matter was observed to make up 10 % of total soil C in long-term arable soil and 40 % under grassland (Christensen, 1996).

The high percent of POM C in many of the locations we sampled may indicate recent additions of organic matter not yet decomposed. Soil C and organic amendments added to soil were correlated to high tunnel POM C (Table 2.7). Particulate organic matter in the high tunnel was significantly correlated to total C in the high tunnel ($p=0.0001$), as well as to POM C ($p = 0.0039$) and total C ($p = 0.040$) in the field. The amount of organic matter added to the high tunnel (estimated by the grower) affected POM C in high tunnels ($p = 0.0003$) (Table 2.7) (Pearson correlation coefficient 0.53). Observations of soil clods, and surface crusting or deposits were not well correlated to POM C in high tunnels (Table 2.6). There is possibly a connection between POM C and hardpan formation in high tunnels ($p = 0.044$). Growers reporting hard pan formation had a higher mean POM C (39% of total C) compared to those not reporting hard pans (31 % of total C).

The ratio of high tunnel to field was used to compare locations. The high tunnel : adjacent field ratio of the POM C fraction (POM HT:Field) ranged from 0.38 to 3.2. This is (POM C : total C in the high tunnel) : (POM C : total C in the field) – a unitless ratio of a ratio. At 80 % of locations sampled, the POM C fraction was higher in the high tunnel than the adjacent field. As representative of labile organic matter, increased POM C is usually considered an indication of improved soil quality. There thus seems to be a general trend toward improved soil quality in high tunnels.

This POM trend in high tunnels was not limited by soil texture. The POM C fraction in high tunnel compared to field was not correlated to soil sand percent ($p = 0.33$) or clay percent ($p = 0.75$) (Table 2.7).

The high tunnel : field ratio of POM fraction did not differ between growers who did and did not consider their high tunnel to have declining soil quality ($p = 0.45$). It was also not correlated to observations of soil clods, surface crusts, surface mineral deposits or hardpan formation (Table 2.6).

Organic matter addition increased POM in the high tunnel ($p = 0.0003$), but was not correlated to POM HT:Field ($p = 0.72$) (Table 2.7). Besides the relationship to increased organic matter addition in high tunnels relative to adjacent fields, the increase in POM C fraction in high tunnels may be related to a reduced rate of organic decomposition in high tunnels compared to adjacent fields. Organic decomposition could be retarded by environmental factors that adversely affect the soil microbial population. A high tunnel fallow period without irrigation would be such an example. However, most fallow coincided with the cold winter months, so the effect of fallow time was not strong. Fallow time (months high tunnel was not used annually) were not well correlated with POM HT:Field ($p = 0.79$), nor the high tunnel POM fraction ($p = 0.46$) (Table 2.7). Comparisons were made with the soil quality indicator POM HT:Field and various high tunnel management practices (Fig. 2.5). Management practices as single factors did not significantly affect POM HT:Field (Table 2.7).

Management practices were poorly correlated to measures of soil quality (Table 2.7) and observations of adverse soil characteristics (Table 2.9). It seems that cultural practices of the high tunnel system are so interrelated that the effects of single management practices were diluted. The only correlation of significance was possible relationship between tillage frequency Also, observations of adverse soil conditions influenced grower perception of soil quality, but were not correlated with measures of soil quality (Table 2.9).

Only the frequency of organic matter application was possibly correlated to adverse soil characteristics (Table 2.9). Observation of adverse soil characteristics increased with more frequent organic amendment applications. However, frequency categories were skewed toward annual application, and combined with the low number of adverse soil reports, statistical results were mathematically suspect. With six categories of organic application frequency (never, once in four years, once in two years, annually, twice a year, more frequently) and binomial soil observations (observed: yes or no) there is a total of twelve categories for this statistical computation. Half the growers were in the category with annual organic matter application and no adverse soil observation and eight categories had five or fewer growers.

Additional categorization of high tunnel management revealed a few effects of management on total soil carbon. There were twenty-one growers that grew only tomato crops in their high tunnels. They tended to have lower mean total soil carbon (28.0 vs. 37.4 g kg $^{-1}$ soil, $p = 0.023$), but POM did not differ compared to other high tunnels (Table 2.10). This may be related to reduced organic matter applications in the tomato only high tunnels (Table 2.10).

Nine growers applied animal manure as their only organic amendment. This included six growers who also applied conventional fertilizers. Soil salinity did not differ between high tunnels of the nine growers and others ($p = 0.72$) (Table 2.10). Soil total C was lower in high tunnels with animal manure applied without other organic additives (29.3 vs. 35.4 g kg^{-1} soil). Where animal manure was the only organic amendment, total soil C in the high tunnel was similar to the adjacent field (mean HT:Field ratio was 1.07). In other management systems, total C was higher in high tunnels compared to fields (mean HT:Field ratio is 1.47). Manure management was significantly correlated to HT:Field total C ($p = 0.0008$) (Table 2.10). Particulate organic matter did not differ for growers using only animal manure as an organic additive.

Some of the soil quality discussion was based on comparison of soil from high tunnels and adjacent fields. The adjacent fields were not identically managed compared to high tunnels, but in some cases field management was more similar than others. This variability in management may have obscured some of the relation between high tunnel management and measures of soil quality.

High tunnel age effect on soil quality

Perception of soil quality did not differ with age of high tunnel ($p = 0.26$) (Table 2.7). Growers with tunnels in situ for up to 15 years reported good soil quality. Growers reported soil quality problems in tunnels with age ranging from three to eleven years.

Measured indicators of soil quality were also not correlated to the age of high tunnels (Table 2.7). Salinity was not significantly correlated to high tunnel age ($p = 0.96$). Soil aggregate stability differed between high tunnel and field, but this difference was due to factors more complex than just the duration of high tunnel use (Table 2.8). The high tunnel mean weight diameter (MWD) and MWD high tunnel : adjacent field were not significantly correlated to the age of the high tunnel structure ($p = 0.92$ and 0.71, respectively). Particulate organic matter carbon fraction size differed between high tunnel and adjacent field, but this difference was not because of the length of time a high tunnel covered the soil. The high tunnel : adjacent field POM ratio was also poorly correlated to high tunnel age (p = 0.33). This was still true when the data was separated into two categories based on POM C fraction in the high tunnel being higher or lower than in the field (Table 2.11). Age of high tunnel did not affect POM HT:Field in either category.

Although we could not account for the effect of single management practices, with whole farm variability age did not cause a decline in measured soil quality. This was true for older high tunnels and newer high tunnels (in use less than seven years), and with organic and conventional management (Table 2.12). The possible exception to this was in the measure of salinity. However, salinity was generally found to be manageable in high tunnels.

Because high tunnel use is relatively new to our region of study, there were few high tunnels available that had been in place more than ten years. It would be interesting to repeat this study in five or ten years with older tunnels. Comparison of growers' perception of soil quality and measured quality indicators may have been affected by uncertainty among survey respondents. For example, 24 of 76 respondents were "not sure" if they were experiencing soil quality problems in their high tunnel. Quality indicators may be adapted in future studies. This research was conducted with a select number of soil quality indicators. It may be found that high tunnel age influences soil quality as measured by some other indicator. Pathologic or pest problems may also become factors that influence high tunnel management in the future.

Conclusions

Particulate organic matter carbon was a good indicator of soil quality for comparison of high tunnel and field soils based on literature and our analysis of soils in high tunnels and adjacent fields at research locations. Measures of particulate organic matter carbon and salinity indicated soil differences between four-year old high tunnels and adjacent fields with matched management at research locations near Haysville and Olathe, Kansas.

Fourteen percent of growers surveyed were of the opinion they experience soil quality problems in their high tunnels. This opinion was not related to single management practices (i.e. nutrient management, organic matter application amount or frequency, tillage depth or frequency, use of cover crops, crop rotation or fallow months). Opinion of soil quality was related to observations of increased soil clods, surface crusting and surface mineral deposition. Other measures of soil quality (analysis of salinity, water stable aggregates and particulate organic matter carbon) were not correlated to observations of soil clods, surface crusting and surface mineral deposition. Measures of soil quality were poorly related to single high tunnel management factors.

Soil carbon in farm high tunnels was related to C in field soil and organic amendments. Particulate organic matter carbon made up more than a quarter of the total soil C in 78 % of high tunnels. This is high for cultivated soil (Christensen, 1996). At 80 % of the locations sampled high tunnel POM exceeded field POM. Particulate organic matter C : total C in a high tunnel was not correlated to soil type, organic input quantity, or fallow time.

Soil quality as measured by grower perception, salinity, water stable aggregates, and particulate organic matter carbon as a fraction of total carbon were not effected by age of a high tunnel in comparisons between high tunnel and adjacent field. Soil pH was not negatively affected by high tunnel structures. Salinity can be a problem in high tunnels, but in the geographic region of our study it is manageable, and not correlated to tunnel age.

Soil quality as measured in this study was not negatively impacted by high tunnel structures over time. High tunnels in fixed locations for up to fifteen years continued to maintain acceptable soil quality. We conclude that soil quality can be successfully managed in stationary high tunnels on the central Great Plains.

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Figure Captions

Fig. 1. Location of farms from which soil was collected in 2006, for comparison of soil quality indicators in high tunnels and adjacent fields.

Fig. 2. Age of high tunnels at the date of soil collection in 2006, in the states of Kansas, Missouri, Nebraska and Iowa.

Fig. 3a. Salinity in the surface upper 5-cm at sixty-three field locations adjacent to high tunnels in the central Great Plains.

Fig. 3b. Salinity in the soil surface upper 5-cm in ninety-three high tunnels in the central Great Plains.

Fig. 3c. Salinity in the soil upper 15-cm in high tunnels with salinity more than 2 dS m^{-1} in the upper 5-cm.

Fig. 4. Particulate organic matter carbon as a fraction of total soil carbon in high tunnel and field, and the age of the high tunnel, at locations (x-axis) sampled in 2006.

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Table 7. Observed significance levels (P-values) of correlation^{z} between high tunnel soil quality and management practices or soil characteristics. Soil quality was measured in the high tunnel (HT) by grower perception, salinity, particulate organic matter carbon (POM HT) or by the ratio of particulate organic matter carbon in the high tunnel compared to the adjacent field (POM HT:Field).

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Table 11. Observed significance level (indicated by P-values) of correlations between the high tunnel and field particulate organic matter carbon ratio (POM HT:Field) and high tunnel age, factors of soil characterization, organic addition or grower perception of soil quality in the high tunnel (HT), after sorting data into groups based on high tunnel and field particulate organic matter carbon as a fraction of total soil carbon.

Table 12. Soil quality indicator means and the observed significance level (indicated by P-values) of indicator correlation with high tunnel age, after sorting data into two categories based on high tunnel age or conventional (Conv) and organic (Org) management of high tunnels.

Table 2.1a. Soil penetration resistance in relation to crop and soil moisture status as measured by a penetrometer in high tunnels (HT) near Lawrence, Kansas, on 1 September 2006.

Soil depth	Penetration resistance in high tunnels constructed in 2001 [z]						
	HT1, Flowers			HT2, Vegetables			
	Moist row 1	Moist row 2	Dry row 3	Dry row 1	Moist row 2	Dry row 3	Dry row 4
cm	MPa						
2.5	0	0	0.034	0.138	0	0.069	0.069
7.5	0.034	0.069	0.207	0.207	0.276	0.276	0.276
15	0.138	0.138	0.345	0.345	0.276	0.552	0.276
23	0.552	0.276	0.828	0.690	0.414	0.965	0.552
30	0.759	0.690	- [y]	0.828	0.414	1.103	0.690

[z] n=1, one measurement per row
[y] resistance exceeds penetrometer force

Table 2.1b. Soil penetration resistance in relation to crop and soil moisture status in a field, adjacent to the high tunnels referenced in Table 1a, on 1 September 2006. There had been precipitation one week prior to sampling .

Soil depth	Penetration resistance in field adjacent to high tunnel [z]					
	Flowers				Turf	Asparagus
	row 1	row 2	row 3	row 4	row 5	row 6
cm	MPa					
2.5	0.138	0.276	0.552	0.552	0.138	0.138
7.5	0.414	0.552	0.828	0.965	0.414	0.414
15	0.690	1.103	- [y]	-	-	0.690
23	0.690	1.241	-	-	-	0.690
30	0.552	1.103	-	-	-	0.552

[z] n=1, one measurement per row
[y] resistance exceeds penetrometer force

Table 2.2. Soil pH, salinity, modulus of rupture, and water stable aggregates measured in high tunnels (HT) and adjacent fields with conventional (conv) or organic management at Olathe and Haysville, Kansas, in 2006.

	Olathe, organic	Olathe, conv	Haysville, conv [z]
	Soil pH		
HT	6.3	6.1	6.0
Field	6.0	6.2	6.1
LSD[y]	0.09		0.24
	Salinity dS m^{-1} in the surface 5-cm		
HT	0.68	0.67	0.57
Field	0.22	0.28	0.10
LSD	0.23		0.066
	Modulus of rupture MPa		
HT	5.593	5.458	-
Field	5.445	5.530	-
LSD[z]	0.204		
	Water stable aggregates mean weight diameter		
HT	2.03	2.15	3.21
Field	2.52	1.99	0.78
LSD	1.54		1.0

[z] Values are the mean of samples from three replicated plots at Olathe or three at Haysville

[y] Least significant difference (p = 0.05), Olathe LSD compares across management and location effects

Table 2.3. Total carbon (C) and particulate organic matter (POM) carbon measured in soils from high tunnels (HT) and adjacent fields with conventional (conv) or organic management at Olathe and Haysville, Kansas, in 2006.

	Olathe, organic	Olathe, conv	Haysville, conv[z]
	Particulate organic matter carbon g POM C kg^{-1} dry soil		
HT	3.05	0.89	0.83
Field	1.85	1.07	0.47
LSD[y]	1.0		0.16
	Total carbon g total C kg^{-1} soil		
HT	21.4	17.8	4.91
Field	21.4	19.8	3.97
LSD	1.6		0.91
	POM C : total C		
HT	0.14	0.05	0.17
Field	0.09	0.05	0.12
LSD	0.01		0.03

[z] Values are the mean of samples from three replicated plots at Olathe or three at Haysville

[y] Least significant difference (p = 0.05), Olathe LSD compares across management and location effects

Table 2.4. Summary of preliminary studies in quantification of soil quality indicators used to compare high tunnels and field soils.

Soil Quality Indicator	Experience
pH	Effect significant statistically, but not for practical purposes
Electrical conductivity	Significantly affected by HT at Olathe and Haysville
Penetration resistance	Dependent on soil moisture and tillage
Water infiltration	Dependent on soil moisture and tillage
Modulus of rupture	Not significantly affected by HT or organic management at Olathe Not reliable in sandy soils at Haysville
Water stable aggregates	Not significantly affected by HT or organic management at Olathe Significantly at Haysville (possibly due to tillage)
Particulate organic matter carbon (POM C)	Significantly affected by HT at Olathe and Haysville and by management (organic vs. conventional) at Olathe
Particulate organic matter carbon as a fraction of total carbon (POM C : Total C)	Significantly affected by HT at Olathe and Haysville and by management (organic vs. conventional) at Olathe

Table 2.5. Grower perception of soil quality and specific soil characteristics observed by growers as reported in a survey of 81 high tunnel producers from Iowa, Kansas, Missouri, and Nebraska.

	Measure of soil quality					
	Quality problem n= 11		No quality problem n =41		Uncertain of problem n= 24	
	Number of growers that observed soil characteristic [z]					
Characteristic [y]	Observed	Not observed	Observed	Not observed	Observed	Not observed
Clod formation	6	7	0	51	4	19
Surface crust	6	7	1	49	5	17
Mineral deposition	8	5	15	36	4	19
Hardpan	5	7	9	40	4	18

[z] Some questionnaire participants responded as uncertain of soil observation or may not have responded to all questions

[y] Grower may have responded “no” to soil quality problem query, but later indicate observation of a problematic soil characteristic

Table 2.6. Observed significance level (indicated by P-values) of correlations between soil quality indicators and grower observations of soil in high tunnels (HT). Soil quality was measured in the high tunnel by grower perception, salinity, water stable aggregates (WSA), particulate organic matter carbon (POM HT) or the ratio of particulate organic matter carbon in the high tunnel compared to the adjacent field (POM HT:Field).

	Measure of soil quality				
	Perception of soil quality [zy]	Salinity	WSA	POM HT	POM HT:Field
Soil observation [z]	P-value [x]				
Clod formation	0.0001	0.1050	0.3174	0.6425	0.1572
Surface crust	0.0001	0.1761	0.5078	0.3025	0.3376
Mineral deposition	0.0312	0.3415	0.4795	0.4594	0.6938
Hardpan	0.1167	0.7079	0.3494	0.0441	0.2093

[z] Indicated by grower in a questionnaire
[y] Chi-square test may not be valid because of low counts (< 5) in a category
[x] Statistical procedures: Chi-square test for categorical data (perception), t-tests for numeric data (measured quality indicators) and a binomial factor (observation)

Table 2.7. Observed significance levels (P-values) of correlation between indicators of high tunnel soil quality and management practices or soil characteristics. Soil quality was measured in the high tunnel (HT) by grower perception, salinity, particulate organic matter carbon (POM HT) or by the ratio of particulate organic matter carbon in the high tunnel compared to the adjacent field (POM HT:Field).

	Soil quality			
	Grower perception of soil quality [z]	Salinity	POM HT	POM HT:Field
Management practice [z]		P-value [y]		
Age of HT	0.2578	0.9567	0.6069	0.3346
Months HT used annually	0.9808	0.4198	0.4631	0.7910
Organic management	0.1274	0.0112	0.0532	0.4744
Organic amendment amount	0.4856	0.3724	0.0003	0.7159
Organic amount class	0.4797	0.2120	0.0028	0.7148
Organic amendment frequency[x]	0.1204	0.3601	0.4331	0.2509
Tillage depth [x]	0.4907	0.3559	0.1900	0.5508
Tillage frequency [x]	0.3398	0.9161	0.7570	0.9939
Crop rotation [x]	0.1080	0.0441	0.7305	0.3248
Cover crop [x]	0.0695	0.7673	0.6439	0.4212
Irrigation leaching	--	0.4321	0.1732	--
Soil characterization				
Clay %	0.6740	0.0385	0.5601	0.7487
Sand %	0.6482	0.9814	0.2389	0.3315
Total C	0.0014	0.0466	0.0001	0.9771

[z] Indicted by grower in a questionnaire
[y] Statistical procedures: Chi-square test for categorical factors, t-tests for a binomial factor with numeric factor, correlation for two numeric factors
[x] Chi-square test may not be valid because of low counts (< 5) in a category

Table 2.8. Water stable aggregate (WSA) in soils from high tunnels and adjacent fields at twelve farms in Iowa, Kansas, Missouri or Nebraska, including nineteen high tunnels (HT) of 2 to 12-year age, compared to grower perception of a general soil quality problem.

			WSA		
			mean weight diameter (g·mm)		
Farm	Age of HT	problem	HT	Field	HT : Field
A	2	no	1.07	3.42	0.31
B	3	yes	3.55	2.69	1.32
C	3	no	1.62	0.63	2.58
D	3	no	2.57	0.79	3.26
E	4	yes	4.07	3.30	1.23
F	5	no	1.00	0.44	2.26
F	5	no	0.86	0.44	1.95
G	6	no	1.07	0.95	1.13
H	7	no	2.59	1.25	2.07
H	7	no	4.57	1.37	3.33
C	7	yes	2.89	0.63	4.60
D	7	yes	3.78	0.79	4.80
I	7	yes	3.52	3.09	1.14
E	8	yes	1.61	1.78	0.90
C	9	no	2.04	0.63	3.24
J	9	no	4.05	1.98	2.05
B	10	yes	3.81	2.69	1.42
K	10	no	1.81	1.88	0.97
L	12	yes	0.64	1.55	0.41

Table 2.9. Observed significance level (indicated by P-values) between grower observations of soil in high tunnels (HT) and reported management practices or soil characterization.

	Grower observations [z]			
	Clod	Crust	Mineral	Hardpan
Management practice [z]	P-values			
Age of HT [y]	0.8991	0.5897	0.5230	0.8671
Months HT used annually [y]	0.1648	0.5719	0.2233	0.3722
Organic management [x]	0.9772	0.9539	0.9531	0.2771
Organic amendment amount [y]	0.1510	0.3303	0.5046	0.3592
Organic amount class [xw]	0.8554	0.5191	0.1520	0.1509
Organic amendment frequency [xw]	0.0002	0.0003	0.0095	0.0178
Tillage depth [xw]	0.1392	0.1294	0.1785	0.3576
Tillage frequency [xw]	0.7937	0.3627	0.3726	0.0001
Crop rotation [xw]	0.3744	0.9366	0.1717	0.2142
Cover crop [xw]	0.3542	0.8800	0.1011	0.2539
Soil characterization				
Clay % [y]	0.0501	0.3618	0.4666	0.1919
Sand % [y]	0.4305	0.6722	0.7916	0.3714
Total C [y]	0.3252	0.0407	0.0711	0.1848

[z] Reported by growers in a questionnaire
[y] Statistical procedure: t-tests for a binomial factor with numeric factor
[x] Statistical procedure: chi-square test for categorical factors
[w] Chi-square test may not be valid because of low counts (< 5) in a category
[v] Data skewed toward annual application with few counts in all other categories

Table 2.10. Observed significance level (P-values) of correlations between selected management practices - tomato as sole crop (n = 21) vs. other cropping systems (n = 45), and manure application only (n = 9) vs. other organic soil amendment strategies (n = 57) - and soil quality indicators or high tunnel management practices.

	Management [z]	
	Continuous tomato	Manure only organic
Soil quality indicator	P-value	
Grower perception of soil quality	0.9064	0.9671
Salinity	0.9077	0.7215
Total carbon HT [y]	0.0225	0.4019
Total carbon HT:Field [x]	0.5048	0.0008
POM HT [w]	0.2194	0.8403
POM HT:Field	0.0660	0.9932
Management practice [z]		
Organic management	0.0845	0.7459
Organic amount class	0.0236	0.7843
Tillage depth	0.5311	0.8604
Tillage frequency	0.1802	0.2614
Crop rotation	0.0308	0.5329
Cover crop	0.2313	0.1550

[z] Reported by growers in a questionnaire
[y] HT = high tunnel
[x] HT:Field = ratio comparing high tunnel and the adjacent field
[w] POM = particulate organic matter carbon as a fraction of total carbon

Table 2.11. Observed significance level (indicated by P-values) of correlations between the high tunnel and field particulate organic matter carbon ratio (POM HT:Field) and high tunnel age, factors of soil characterization, organic addition or grower perception of soil quality in the high tunnel (HT), after sorting data into groups based on high tunnel and field particulate organic matter carbon as a fraction of total soil carbon.

	POM HT:Field	
	HT < Field[z]	HT > Field[y]
Factor	P-value	
Age of HT [w]	0.9289	0.7309
Clay %	0.4105	0.6058
Sand %	0.7643	0.4320
Organic amendment amount [w]	0.2759	0.7592
Grower perception of soil quality [w]	60.8810	0.8301

[z] n=19
[y] n= 56
[w] Reported by growers in a questionnaire

Table 2.12. Soil quality indicator means and the observed significance level (indicated by P-values) of indicator correlation with high tunnel age, after sorting data into two categories based on high tunnel age or conventional (Conv) and organic (Org) management of high tunnels.

	Age category					
	< 7 yr [z]	≥ 7yr [y]	< 7 yr	≥ 7yr	< 7 yr	≥ 7yr
	Soil quality indicator					
	Grower perception problem count		POM HT:Field		Salinity dS m-1	
Quality measure	6	5	1.37	1.55	1.55	1.93
P-value	0.5726	0.2254	0.5800	0.8435	0.0403	0.4445
	Management category					
	Conv [x]	Org [w]	Conv	Org	Conv	Org
	Soil quality indicator					
	Grower perception problem count		POM HT:Field		Salinity dS m-1	
Quality measure	7	4	1.41	1.28	1.85	1.16
P-value	0.1140	0.7978	0.4498	0.6645	0.9273	0.3336

[z] Age less than 7 year, subsample size n = 55, mean age, mean 3.9 yr
[y] Age greater than or equal to 7 year, subsample size n = 20, mean 8.9 yr
[x] Conventional management, subsample size n = 49, mean age 5.1 yr
[w] Organic management, subsample size n = 19, mean age 5.2 yr

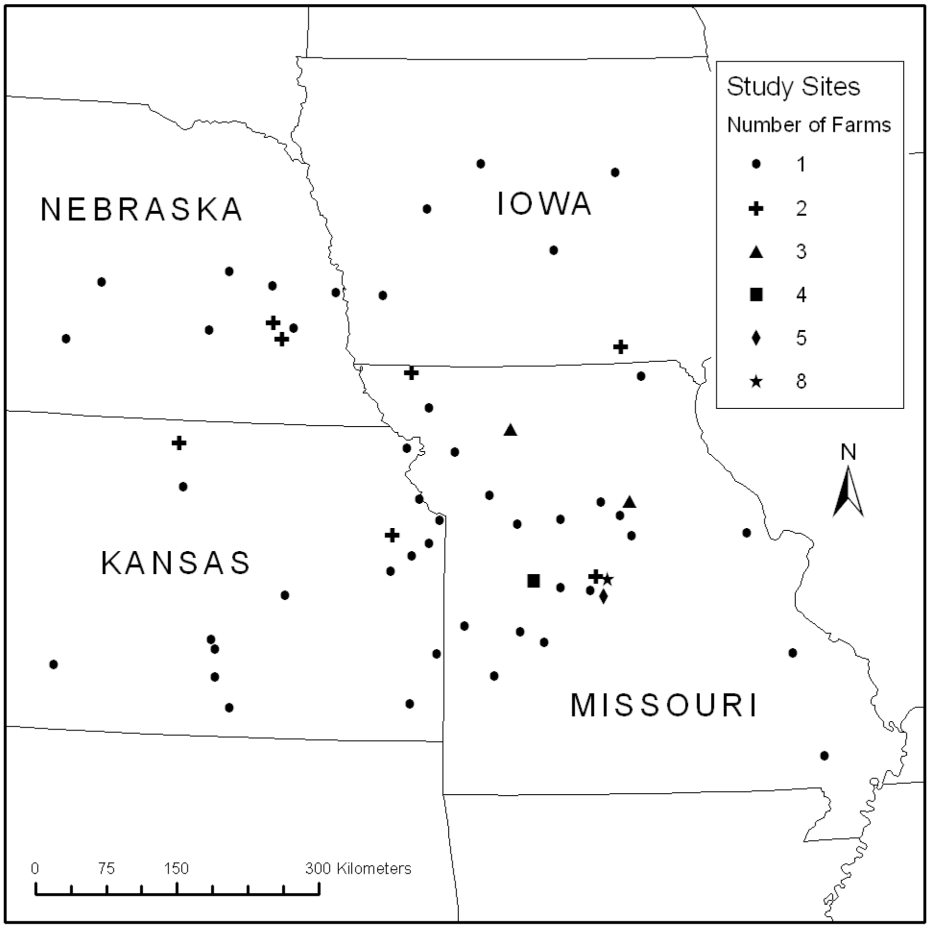


Figure 2.1. Location of farms from which soil was collected in 2006, for comparison of soil quality indicators in high tunnels and adjacent fields.

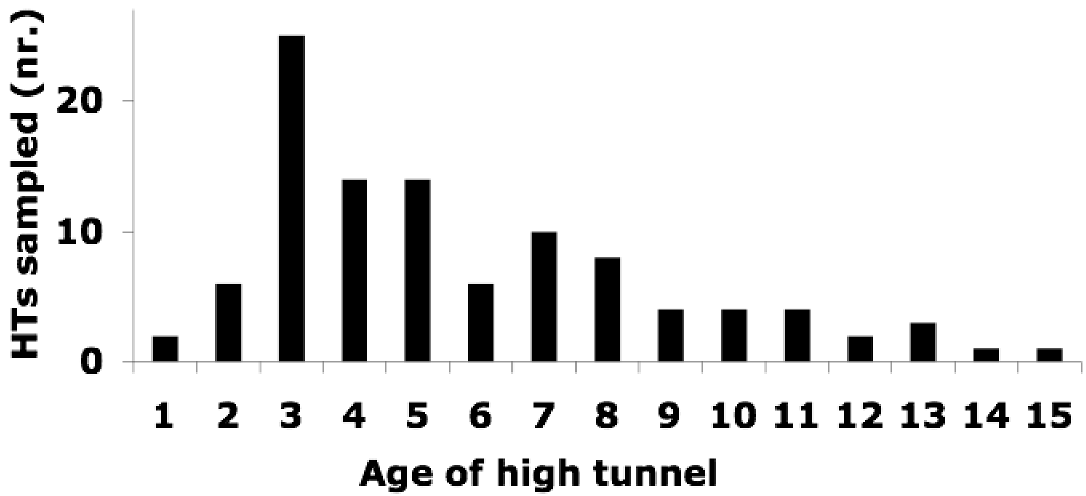


Figure 2.2. Age of high tunnels at the date of soil collection in 2006, in the states of Kansas, Missouri, Nebraska and Iowa.

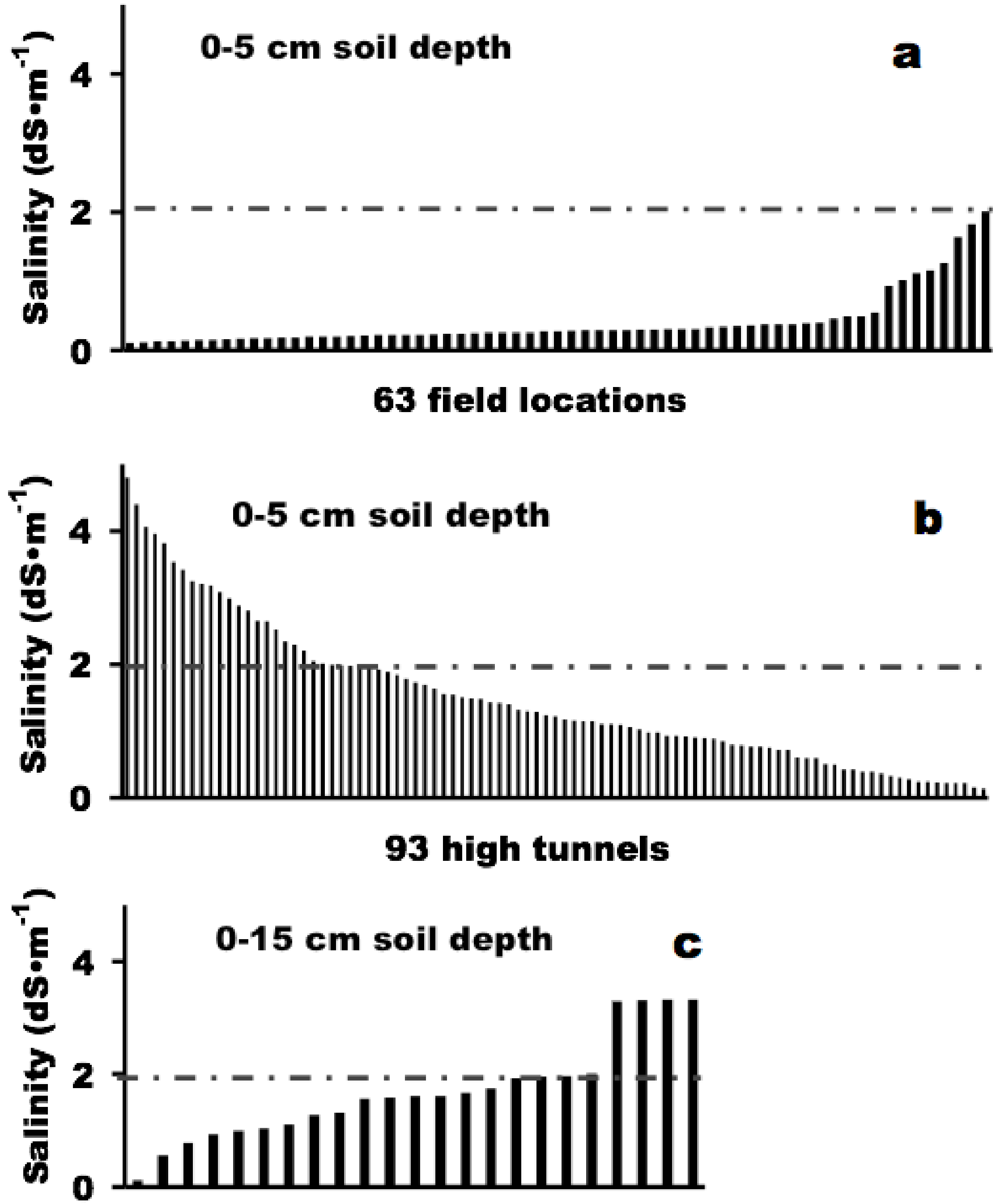


Figure 2.3. Salinity in the surface upper 5-cm at (a) sixty-three field locations adjacent to high tunnels and (b) ninety-three high tunnels in the central Great Plains, and (c) salinity in the soil upper 15-cm in the high tunnels with salinity exceeding 2 dS m^{-1} in the upper 5-cm.

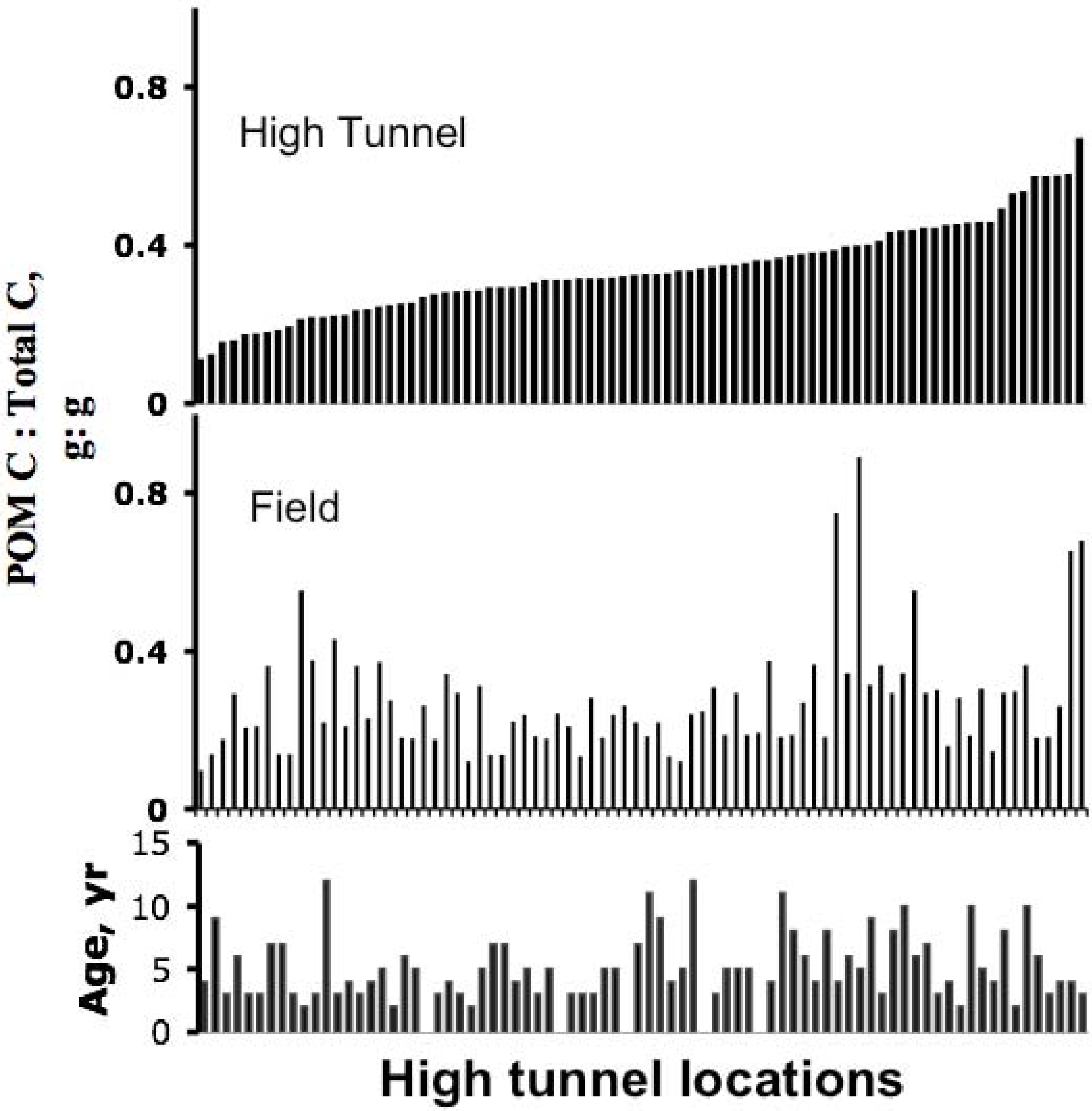


Figure 2.4. Particulate organic matter carbon as a fraction of total soil carbon in high tunnel and field, and the age of the high tunnel, with matching x-axis indicating 93 high tunnels sampled in 2006.

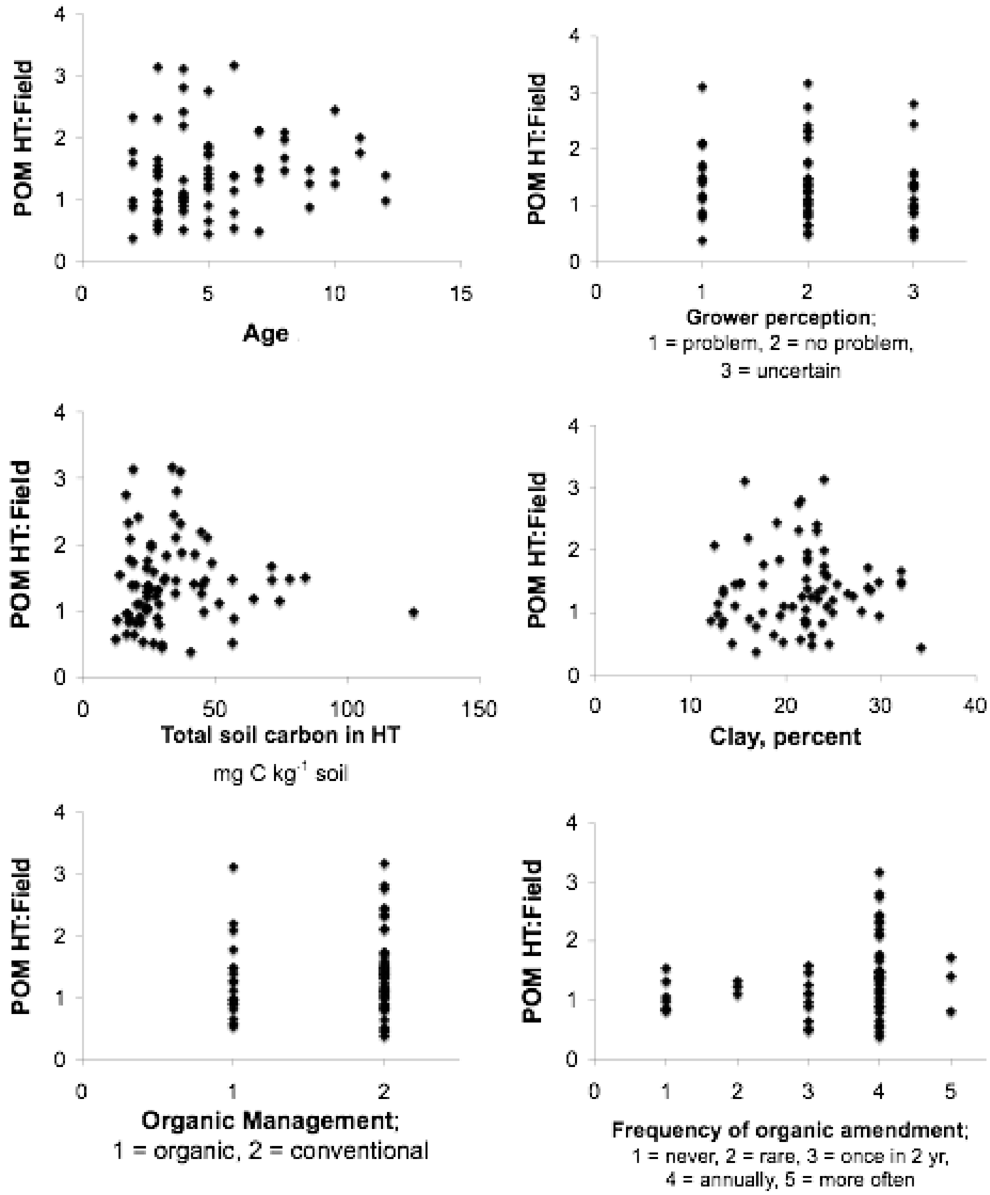
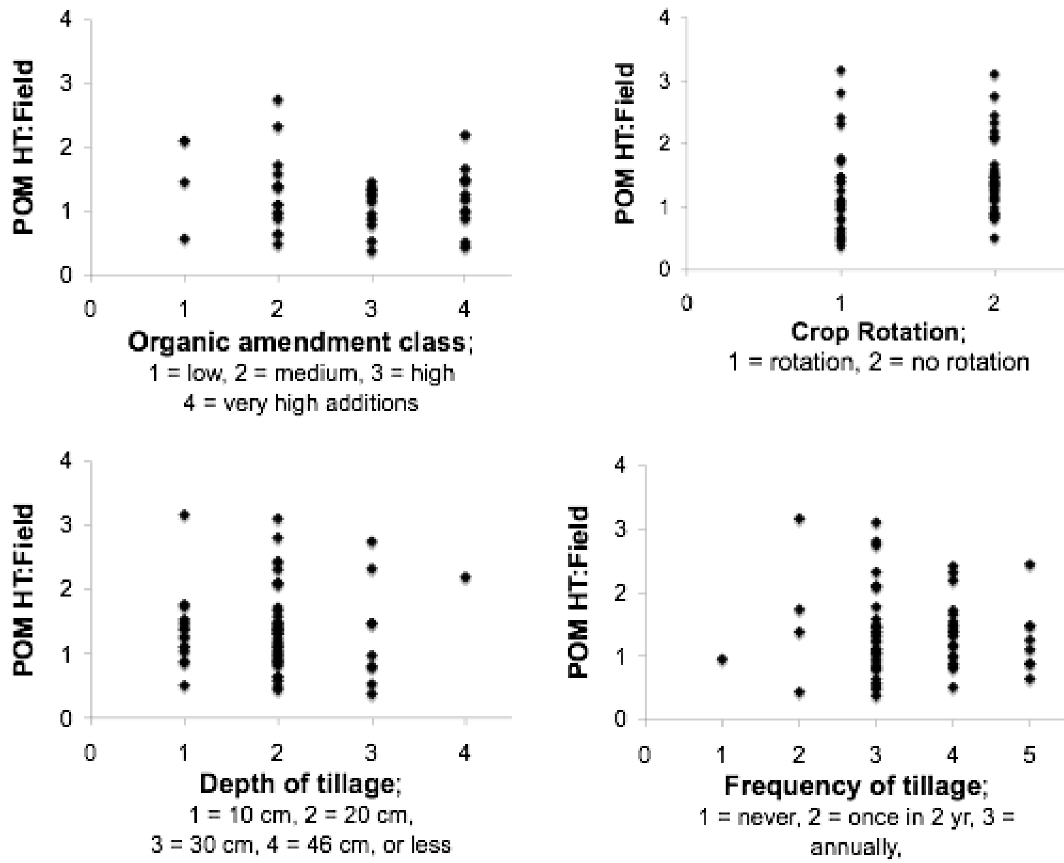


Figure 2.5. Relationship between high tunnel soil quality measured by POM HT:Field and soil characteristics or management practices.


POM HT:Field
Organic amendment class;
1 = low, 2 = medium, 3 = high
4 = very high additions
POM HT:Field
Crop Rotation;
1 = rotation, 2 = no rotation
POM HT:Field
Depth of tillage;
1 = 10 cm, 2 = 20 cm,
3 = 30 cm, 4 = 46 cm, or less
POM HT:Field
Frequency of tillage;
1 = never, 2 = once in 2 yr, 3 =
annually,

Cont. Fig.2.5.

CHAPTER 3 - Microbial teas did not affect collard or spinach yield

[Formatted for submission to HortSci]

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Thank you to Paul White (USDA soil scientist, former manager of Kansas State University soil microbiology laboratory) for instruction in analysis of microbial biomass and allowing use of laboratory facilities. Efficient Microbes (EM)™ Original solution was donated for this study by Sustainable Community Development, L.L.C. (Kansas City, Mo.). Trees for Life (Wichita, Kans.), a non-profit agriculture and educational organization, aerated the cow manure slurry with fresh bakers yeast donated by the American Institute of Baking, Manhattan, Kans. The J.C. Pair Horticultural Center of Kansas State University staff (Tami Roesch, Richard Ryer and Mike Shelton) is greatly appreciated for assisting with the planting and maintenance of the collard crops. We are grateful to the Trees for Life staff volunteers who harvested collards.

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Subject Category: Crop Production

Microbial teas did not affect collard or spinach yield

Additional index words. Efficient Microbes, effective microbes, manure tea, compost tea

Abstract. Microbial tea from a commercially available source, and a homemade manure tea, were evaluated for two years under organic and conventional fertility regimes at two locations. Collard green (*Brassica oleracea* L. var. *acephala* cv. Top Bunch) yield and soil microbial activity were measured after microbial tea applications were made in three fertility treatments (conventional, organic, or no fertilizer amendment) on a previously unfertilized sandy loam soil. Spinach (*Spinacia oleracea* L. cv. Hellcat) and collard green yields were determined after commercial microbial tea application to a silt loam soil previously managed with organic or conventional vegetable crops in open fields and under high tunnels. Results indicated that nutrient additions influenced crop yields at both locations. However, microbial tea applications did not affect crop yield. These results do not support the hypothesis that microbial tea improves plant nutrient uptake. Additionally, soil microbial respiration and biomass was unaffected after two or three tea applications.

Introduction

Compost tea is a term used to refer to any solution produced using composted animal or vegetative matter. Over 10 000 customers have purchased equipment for home production of compost tea in the US (Carpenter-Boggs, 2005). Interest was fostered mostly by anecdotal evidence shared in newsletters and specialty publications targeting home and smaller market fruit and vegetable producers. Compost tea may or may not be actively aerated during production. Amendments to tea, such as molasses, cane syrup or fruit are intended to facilitate multiplication of microbes beneficial to crops (Ingham, 2000).

Most compost teas are filtered, to remove the compost, but retain the microbes that were grown in the composting and brewing (Ingham, 2000). Compost tea is thought to act more as a microbial inoculant that stimulates soil or foliar microbial population effectiveness, than as a nutrient source (Carpenter-Boggs, 2005).

Claims of benefit from compost steeped microbial tea are broad and include improved crop yield, vigor, quality and resistance to diseases and pests (Carpenter-Boggs, 2005; Grobe, 1997). However, variable effects from a variety of tea production and application methods have been reported. Several foliar pathogens are reported to be suppressed by aerated and non-aerated microbial teas (Scheuerell and Mahaffee, 2002). Early blight (*Alternaria solani* (Ell. & Mart) L.R. Jones & Grout) of tomato (*Lycopersicon esculentum* Mill.), purple blight (*Alternaria porri* (Ellis) Cif.) of onion (*Allium cepa* L.) were suppressed by a non-aerated compost tea (Haggag and Saber, 2007). Compost tea application may not be consistently beneficial. Compost tea applied to potato (*Solanum tuberosum* L.) increased incidence of silver scurf (*Helminthosporium* *solani* Dur. & Mont.) and black scurf (*Rhizoctonia solani* Kuhn), but did not affect incidence of dry rot (*Fusarium* sp.), common scab (*Streptomyces scabies* (Thaxter) Waksman & Henrici), early blight, bacterial soft rot (*Erwinia carotovora* var. *carotovora* (Jones) Dye) (Al-Mughrabi, 2006), or late blight (*Phytophthora infestans* (Mont.) deBary) (Sturz et al., 2006). Some compost tea formulas increased yield of broccoli (*Brassica oleracea* var. *italica* Plenck) (Sanwal, et al., 2006), onion, and tomato crops (Haggag and Saber, 2007). Compost teas prepared with chicken manure consistently reduced disease and increased yield of onion and tomato crops (Haggag and Saber, 2007). However, not all tea formulas increased yield (Al-Mughrabi, 2006; Haggag and Saber, 2007).

Commercially available microbial sources may replace compost as an inoculant and may simplify compost tea production. These may also decrease variability (Scheuerell and Mahaffee, 2002) between batches and alleviate human health concerns about pathogens (Kannangara et al., 2006) in compost tea. A class of microbial teas was developed by Teruo Higa, Professor of Horticulture at the University of the Ryukyus, Okinawa, Japan, and contains what he has called "effective microorganisms". These commercial products contain selected species of microorganisms, which are predominantly lactic acid bacteria and yeasts, and smaller numbers of photosynthetic bacteria, actinomycetes and other organisms (Higa and Parr, 1994). Higa hypothesized that by increasing the microbial diversity of soils, effective microorganisms improve soil quality, enhance crop production and quality, and create a more sustainable environment.

The benefits of effective microbes have been demonstrated in crop systems in Japan, China, Sri Lanka, India, Bangladesh and Brazil. Research showed yield increased by soil application of effective microbes in combination with organic and conventional fertilizers in tomato (cv. Momotaro T96) (Wang et al., 1999), sweet orange (*Citrus sinensis* Osbeck cv. Pera) grafted to lemon rootstock (*Citrus limonia* Osbeck cv. Cravo) (Paschoal et al., 1998), onion (cv. Taherpur) bulbs and string beans (*Vigna sesquipedalis* L. cv. Topgreen) (Chowdhury et al., 1996). Yield increase was related to increased fruit set (Wang et al., 1999) and increased total chlorophyll content (Chowdhurry, 1996).

The reported effects of effective microbes on soil include increased nutrient availability (Sangakkar and Weerasakera, 2001); increased aggregation, porosity and water infiltration (Tokeshi et al, 1996); increased organic matter, pH and cation exchange capacity (Paschoal et al., 1998). Effective microbes in a rice bran carrier (EM^{TM} Bokashi) was reported to increase rice (*Oryza sativa* L.) grain yield by increasing soil organic matter content, microbial biomass and available nutrients, as well as improving soil porosity and permeability compared to organic and chemical fertilizer treatments without effective microbes (Shao et al., 2003).

Manure teas are another variant on the concept of compost tea. The product may serve only as a dilute liquid fertilizer (Diver, 2005), but it is hypothesized by some to be a potential stimulant of indigenous soil microbial populations (Jim Barlow, California agronomist and commercial producer of microbial products, personal communication). A tea is made from a solution that contains animal manure. Multiplication of microbes from the manure is encouraged by aeration and additives, which may include a sucrose source and yeast to help diversify the microbial population. However, the soil environment is not optimal for many of the microbial organisms in the manure tea, which are consumed by the indigenous microbes. Manure tea is hypothesized to be beneficial not because of individual ingredients, but like compost tea, because of the microbial population grown in the tea. The term microbial tea is used in this report as a descriptive term that also encompasses tea from microbe sources other than compost.

Variability in microbial tea effects is probably due, in part, to variation in tea production methods. Ingredients, brew conditions (aeration, temperature, and time), application rate, frequency, and mechanism may all vary (Scheuerell and Mahaffee, 2002). It is also hypothesized that microbial tea effects may vary by crop, season and soil condition (Carpenter-Boggs, 2005). This variability discourages scientific investigation and publication despite positive anecdotal reports. Improved yield is an important consideration for the growers waiting to review credible evidence of microbial tea benefit.

This study evaluated the effect of two microbial teas made from: 1) a homemade manure tea recipe and 2) a commercially available microbial source. The commercial product was an effective microbe culture, produced in our region by a former student of Teruo Higo, with the trade name Efficient Microbes™. The manure tea recipe was chosen at the request of Trees for Life, a non-profit agriculture and educational organization, with home office in Wichita, Kans. It was considered to be a potential low cost agriculture input for impoverished tropical regions (Calovich, 2005). A scientific study was desirable before promoting it within their network.

It was hypothesized that microbial tea applications improve the soil microbial environment and this would be reflected in improved plant growth. It was also hypothesized that the microbial tea benefit may be affected by nutrient source (organic or conventional fertilizer). The objective of this study was to evaluate the effect of microbial teas, made from manure and from Efficient Microbes™, on crop yield and microbial biomass in a sandy loam soil. The effect of Efficient Microbes™ on crop yield was also evaluated on a loam soil.

Materials and Methods

Sandy loam soil site

Experiments were conducted at the John C. Pair Horticultural Center, Haysville, Kansas, in autumn of 2005 and 2006. The soil is a Canadian-Waldeck sandy loam (coarse-loamy, mixed, superactive thermic Udic Haplustolls, and Fluvaquentic Haplustolls). Previously the crop at this location was unfertilized brome (*Bromus inermis* Leyss.) pasture since 1991.

The experiment was a randomized complete block design with a split-plot arrangement of treatments, replicated four times. Fertilizer treatment represented the whole plot factor and microbial tea application was the subplot factor. Whole plots consisted of an incorporated conventional fertilizer, an incorporated organic fertilizer, or an unamended control. Subplot treatments were an animal manure tea (MT), a commercial microbial tea (EM), or a non-treated control (N). Individual subplots were 10.5 m^2 in size. Treatments were repeated in the same plots the second year.

The commercial microorganism culture (EM) was prepared according to the manufacturer's directions (Sustainable Community Development, L.L.C., Kansas City, Mo.). To make 10 L of tea, 0.47 L Efficient Microbes™ and 0.47 L unsulfurated molasses were added to 10 L deionized water. Brer Rabbit or Grandma's molasses was used. The solution was incubated at 32 °C for 4 to 7 days in a sealed plastic container with little headspace.

Homemade animal manure tea (MT) was made according to directions provided by Trees for Life, Wichita, Kans. To make 10 L of tea, 480 g air dried chipped dairy cow manure, 37 g bakers yeast and 0.5 L molasses were added to 10 L tap water. Two five-gallon buckets of dry dairy cow manure was collected at the Kansas State University research farm holding pens. The manure was chopped with a machete to chips size 3 cm or smaller, then spread on tarp to further dry, before being well mixed. Bakers' yeast was provided by the American Institute of Baking, Manhattan, Kans. The slurry was aerated with an aquarium pump for at least five days in an open plastic container.

Microbial tea was applied from a watering can at rates of 375 L ha^{-1} EM (17 L EM™ concentrate ha^{-1}) and 187 L ha^{-1} MT during irrigation. Microbial tea applications were made at planting, one week after planting and five weeks after planting. In addition, in 2006, tea applications were also made six and three weeks before planting.

Conventional fertilizer as pelletized 13-13-13 (13N-5.7P-10.8K) (Propell, Farmland Industries, Kansas City, Mo.) was soil incorporated to supply N at a rate of 90 kg ha^{-1} a week before planting, and side dressed at 34 kg N ha^{-1} three and six weeks after planting. Organic fertilizer was soil incorporated a week before planting to supply N at a rate of 280 kg ha^{-1}. Hu-more compost (1N-0.4P-0.8K) was used in 2005. Hu-more is produced by Humalfa, LLC (Stattuck, Okla.), from aerobically composted cow manure and alfalfa. Bradfield organic fertilizer (3N-0.4P-4.1K) was used in 2006. Bradfield Organics (Springfield, Mo.) fertilizers contain alfalfa, molasses, sulfate of potash, poultry by product meal and humates.

The crop used was collard greens (*Brassica oleracea* L. var. acephala cv. Top Bunch, obtained from Johnny's Selected Seeds, Albion Maine). Seeds were sown in a greenhouse a month before transplant to the field. Collard seedlings were transplanted 0.4 m apart in rows spaced 0.9 m. Each plot included three rows of seven plants. Rows had three buffer plants between plots and at row ends. Transplant dates were 25 August 2005 and 14 September 2006.

The crop was drip irrigated and weeds controlled by hoeing. Caterpillar damage was controlled with *Bacillus thuringiensis* (Dipel, Valient BioSciences Corporation, Libertyville, Ill.) applications as required. Pest incidence was low. Disease was not observed.

A cover crop of sorghum sudangrass [(*Sorghum bicolor* (L.) Moench) x (*S. sudanense* (Pipe) Stapf.)] was grown in the summer before the second experiment. Sorghum sudangrass seed was obtained from Albert Lea Seed House (Albert Lea, Minn.) and planted 24 May 2006. It was mowed to about 30 cm height through the summer. Mowed clippings were not removed. In late August the sorghum sudangrass was mowed to the ground.

Soil microbial respiration and nitrogen mineralization were measured in 2005. Soil samples were collected from each plot one week after the second microbial tea application and again at harvest. Soil was fumigated and incubated according to methods described by Horwath and Paul (1994). Biomass measured by fumigation is well correlated to that measured by microscopy and soil ATP analysis methods (Vance and Brooks, 1987). Soil (25 g) moistened to approximately field capacity was preincubated at 35 °C for three days and then 25 °C for four days before fumigation. Samples were fumigated overnight with ethanol-free chloroform. Chloroform was evacuated the next day. Chloroformed samples and non-chloroformed controls were incubated for eleven days at 25 °C. Evolved CO_2 was measured using a Shimadzu GC-8A gas chromatograph (xShimadzu Scientific Instruments, Columbia, Md.). Inorganic soil nitrogen was extracted with a 1:4 ratio of 1M KCL and measured with an autoanalyzer RFA-300 (Alpkem Corp., Clackamas, Or.). Soil microbial biomass C and N were compared between treatments. Nitrogen mineralization was measured as the difference between initial soil inorganic N and that measured in non-fumigated soil after 11-day incubation.

Collard tops were harvested eight weeks after transplanting by cutting the stem at the soil surface and obtaining a fresh weight in the field. Mean yield differences were analyzed between microbial tea treatments within fertility treatments. Analysis of variance was calculated using SAS 9.1 (Statistical Analysis System Institute, Cary, N.C.) mixed procedure holding block and block by fertilizer as random effects.

Silt loam soil site

Experiments with application of the commercially available microorganism culture (EM) were conducted at the Kansas State University Research and Extension Center - Olathe, Kans., in 2005 and 2006. The experiment was conducted in high tunnels and adjacent field plots. The soil is a Kennebec silt loam soil (fine-silty, mixed, superactive, mesic Cumulic Hapludolls). Plots had been divided for either conventional or organic vegetable production since 2002. They were previously unfertilized brome pasture.

Spinach (*Spinacia oleracea* L. cv. Hellcat, obtained from Seminis, Inc., St. Louis, Mo.) was direct seeded in high tunnels on 11 October 2005 and harvested 22 November by cutting leaves just above the surface, then over wintered and harvested again on 3 February 2006. Collard greens (cv. Top Bunch) were grown in 2006 in high tunnels and adjacent fields. Collards were transplanted on 12 May 2006. Lower collard leaves were harvested on five occasions; 6, 7, 9, 11, and 14 weeks after planting.

Preparation and application methods for EM were the same as for the Haysville experiments. Microbial tea was applied to the spinach crop at planting, then reapplied two weeks after planting and following each harvest. In 2006, EM was applied to the collard crop at planting, two and five weeks post-planting, and after each of the leaf harvests.

Fertilizer was pre-plant soil incorporated to supply N at a rate of 224 kg ha^{-1}. Organic fertilizer Hu-more compost (1N-0.4P-0.8K) was used in 2005 and Bradfield (3N-0.4P-4.1K) in 2006. Conventional fertilizer (16N-3.5P-6.6K) was pelletized (Loveland Golf Course Starter, Howard Johnson's Enterprises, Inc., Milwaukee, Wis.). In 2006, an additional 33.6 kg N ha^{-1} conventional fertilizer was side dressed after the third collard leaf harvest. Crops were drip irrigated and weeds were manually controlled. Pest and disease incidence were low.

Within the conventional and organic production systems the experiment was 2 x 2 factorial with fertilizer and microbial tea treatments. Treatment plots were 1 m^2 and replicated in open field and under high tunnels three times.

Analysis of variance of harvest means was done using SAS 9.1(Statistical Analysis System Institute, Cary, N.C.). The mixed procedure was used considering five main factors and their interactions with fresh harvest weights. Statistical factors were:

EM application, fertilizer application, nutrient management (conventional vs. organic), location (high tunnel and field), and harvest date.

Results

Microbial tea application did not affect collard yield at Haysville, Kansas, in 2005 or 2006 (Table 1). Neither EM nor MT improved fresh plant mass compared to collard plants that did not receive microbial tea in any nutrient management system, in 2005 and 2006, as seen in Fig. 1. Additionally, microbial tea treatment did not significantly affect yield on an oven dried mass basis (data not shown). Visual observations suggested leaf size was affected by fertility treatments, but treatment differences were not obvious for tea treatments. Fertilizer treatment did affect yield (Table 1).

Soil microbial response to tea applications was not detected by analysis of N mineralization, soil respiration, or microbial biomass C or N. Mineralized N (Fig. 2) and evolved CO_2 (Fig. 3) were not significantly affected by microbial tea treatments within conventional, organic or unamended fertility management systems in soil collected one week after the second inoculation and soil collected at harvest from Haysville, in 2005. Variability of carbon dioxide measurements between replicates was as great as that between treatments (Fig 3). Soil microbial activity, as indicated by changes in microbial biomass C and N, was not significantly affected by microbial tea applications (Table 2).

The addition of EM did not significantly improve yield on either conventional or organically managed plots at Olathe, Kansas. Yield of spinach grown in high tunnels in 2005 was not significantly improved by EM application regardless of fertilizer or management regime (Fig. 4). Spinach planted in the field in 2005 germinated poorly and was not harvested. Nutrient amendment and EM applications were repeated in the same plots in 2006, but with a collard green crop (Fig. 5). The application of EM did not significantly improve collard yield under high tunnels or in adjacent fields in the second season (Table 3).

Neither tea application nor management (conventional vs. organic amendments) affected yield in 2005 or 2006 (Table 3). There were differences in yield between harvest dates, but there was not an interaction effect between date and tea application. Fertilizer application affected yields in 2006, but not 2005. A fertilizer effect may have been masked in 2005 by residual soil nutrients from previous crops. The interaction effect of tea and fertilizer application was not significant (Table 3).

Discussion

The two soils used in these experiments represented nutrient poor (previously unfertilized sandy loam soil) and nutrient rich (fertilized loam) soil conditions. Microbial tea treatment did not produce significant ($p = 0.05$) yield improvement in either situation. Like Al-Mughrabi (2006), we did not find yield increases due to microbial tea application.

The two microbial teas that we tested did not result in improved crop yields. This was not due to hindrance by fertilizer source. Treatments included no fertilizer, standard conventional fertilizers, and two organic fertilizers – one a composted product and one an alfalfa base with additives to hasten mineralization. Fertilizer was applied at rates that took into account soil texture and former management. The sandy loam soil was not previously fertilized and so received organic fertilizer at a higher rater than the fertilized loam soil. Conventional fertilizer applications were split on the sandier soil to prevent deficiency later in the season. It is doubtful that a change in fertilizer rate or timing would alter results.

Improvement in crop yield due to increased nutrient uptake was possible, as demonstrated by improved yield of collard crops associated with nutrient amendment (Table 1 and 3). Yield results analyzed within management systems (conventional and organic) at Olathe, Kans., also did not demonstrate microbial tea affecting an improvement in yield (Table 3). If nutrient availability had been improved by EM microbial tea application in the current study, as previously reported by Shao et al. (2003) and Sangakkar and Weerasakera (2001), it should have been reflected in yield differences between plots with and without microbial tea application. Our study could also not repeat the results of Shao et al. (2003) with increased microbial biomass. We could not demonstrate a link between microbial tea application and soil microbial activity.

In 2006, there was a significant tea by fertilizer interaction effect (Table 1) at the Haysville location. Single degree of freedom contrasts of collard yield means showed differences in the responses to MT versus no tea (N) under organic and no fertilization treatments, and in the responses to EM versus N under conventional and no fertilization treatments (Fig. 1). Within fertilizer treatments, the only difference of statistical significance was a yield decline accompanying MT application with organic fertilizer. Interaction effects were not seen between tea and fertilizer at Haysville in 2005. Data pointing to a possible negative tea x fertilizer interaction was inconclusive, because it was not seen across combinations of fertilizer and tea and only appeared in one season.

There was a significant tea by management interaction in the Olathe high tunnels in 2006 (Table 3). While total collard green yield was similar in EM treated plots for organic and conventionally managed high tunnels, plots with no EM application had comparatively lower yields in conventionally managed than in organically managed high tunnels, particularly in the absence of fertilizer (Fig. 5). Paired comparison of collard yield within management systems did not indicate significant differences with and without tea application. The tea by management interaction effect was seen in only one year, was not repeated in the field, and did not produce tea treatment differences of statistical significance, so may not be meaningful.

Results with MT did not justify the conversion of manure to tea. The addition of organic matter is well established as beneficial to poor soils. Farmers with nutrient poor tropical soils that have an available manure source are unlikely to gain an advantage by brewing tea rather than simply applying manure to fields.

Growers may choose to apply microbial tea for benefits suggested in other studies (for example protection from diseases). Our study, however, did not show EM or MT improving short term yield or microbial biomass. Our studies were limited to two species and locations. Future studies may show microbial tea benefits on yield at other locations or with different crops, for example a crop with known mycorrhizal associations. Continuation of the study with the same crops and locations may show benefit if trials were continued for a longer period. It is also possible that other tea recipes could be more effective than those that we used.

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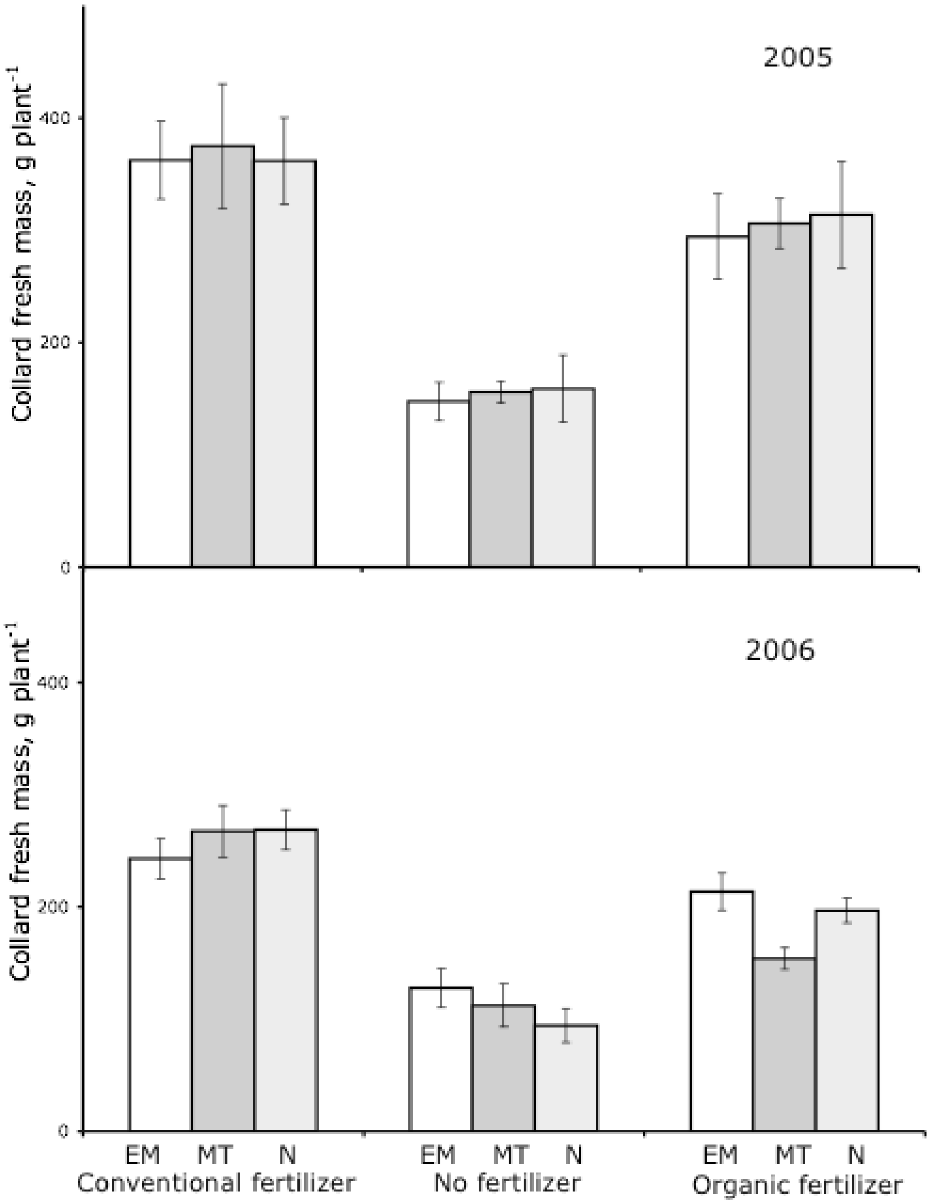

Figure 3.1. Fresh yield of whole collard plants with applications of commercially available microbial tea (EM), animal manure tea (MT), or no tea (N) in three nutrient management systems (conventional, organic or no fertilizer applied), grown at Haysville, Kansas, in 2005 and 2006. Error bars represent standard errors of means of four replicates.

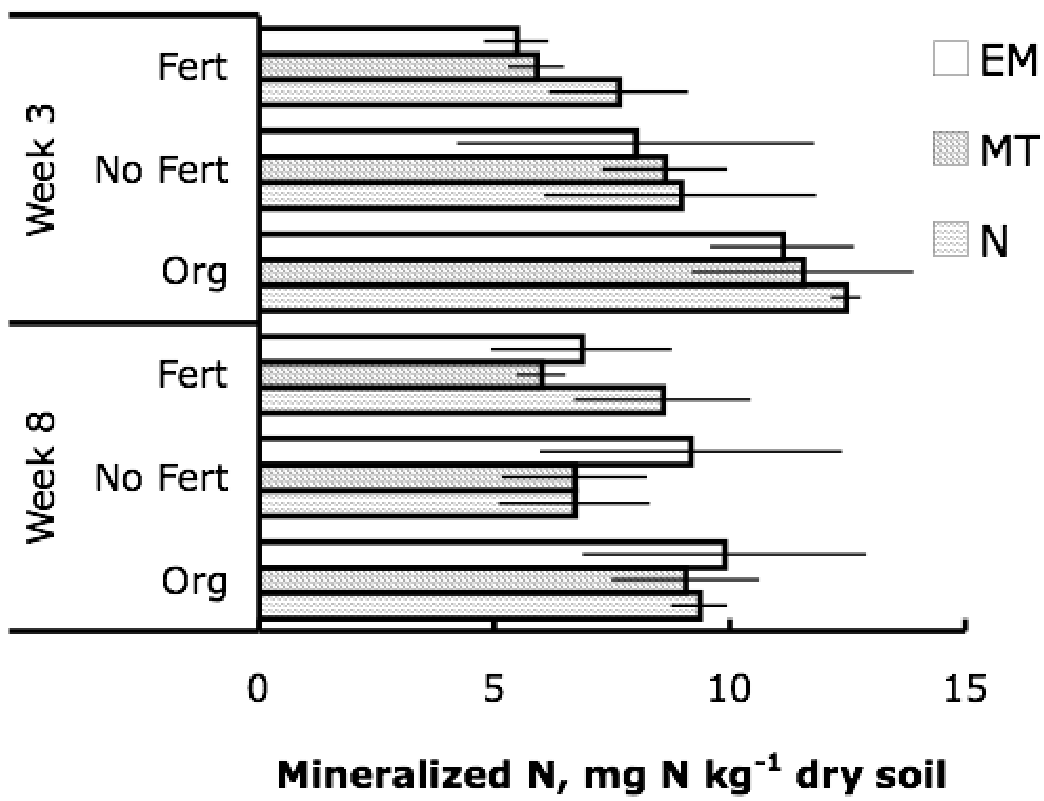

Figure 3.2. Nitrogen mineralized during 11 d incubation from soil treated with applications of commercially available microbial tea (EM), animal manure tea (MT), or no tea (N) in three nutrient management systems (conventional, organic or no fertilizer applied), at Haysville, Kansas, 2005. Soil was collected at week 2 and 8 of the experiment and tea applications were made on week 0, 1, and 5. Error bars indicate standard errors of means of four replicates.

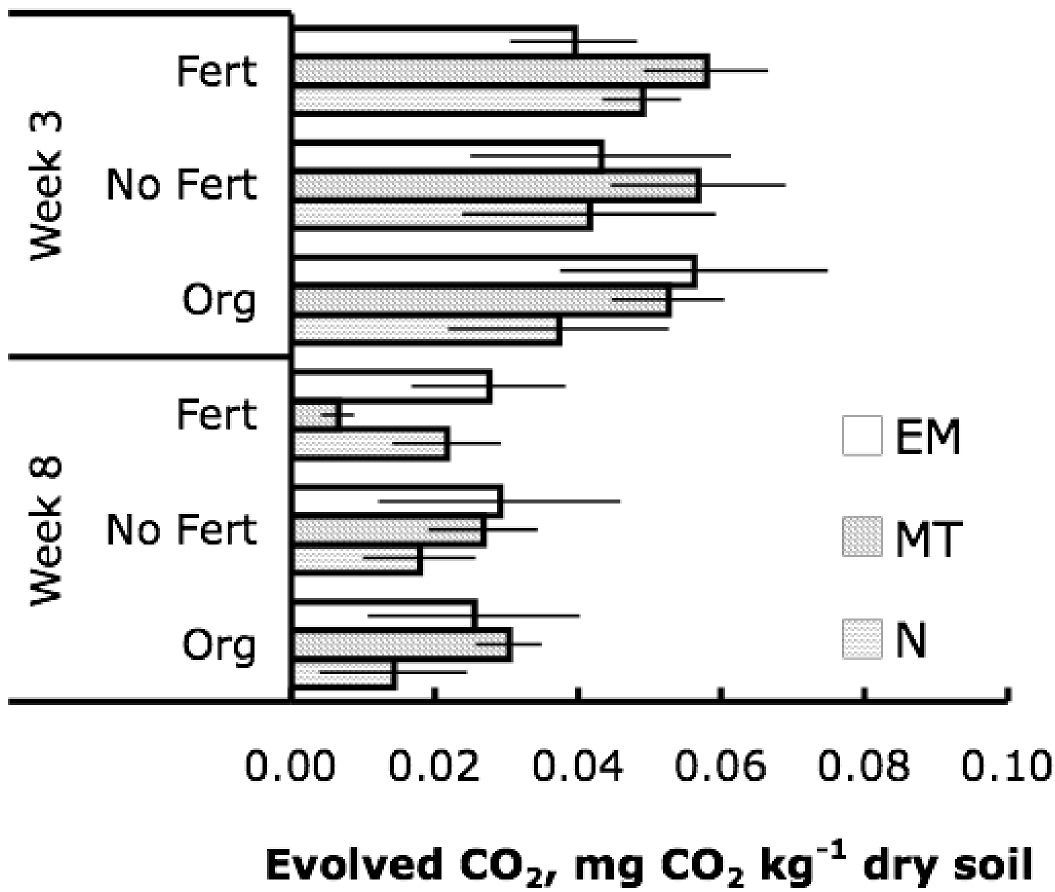

Figure 3.3. Carbon dioxide evolved during 11 d incubation from soil treated with applications of commercially available microbial tea (EM), animal manure tea (MT), or no tea (N) in three nutrient management systems (conventional, organic or no fertilizer applied), at Haysville, Kansas, 2005. Soil was collected at week 3 and 8 of the experiment and tea applications were made on week 0, 2, and 5. Error bars indicate standard errors of means of four replicates.

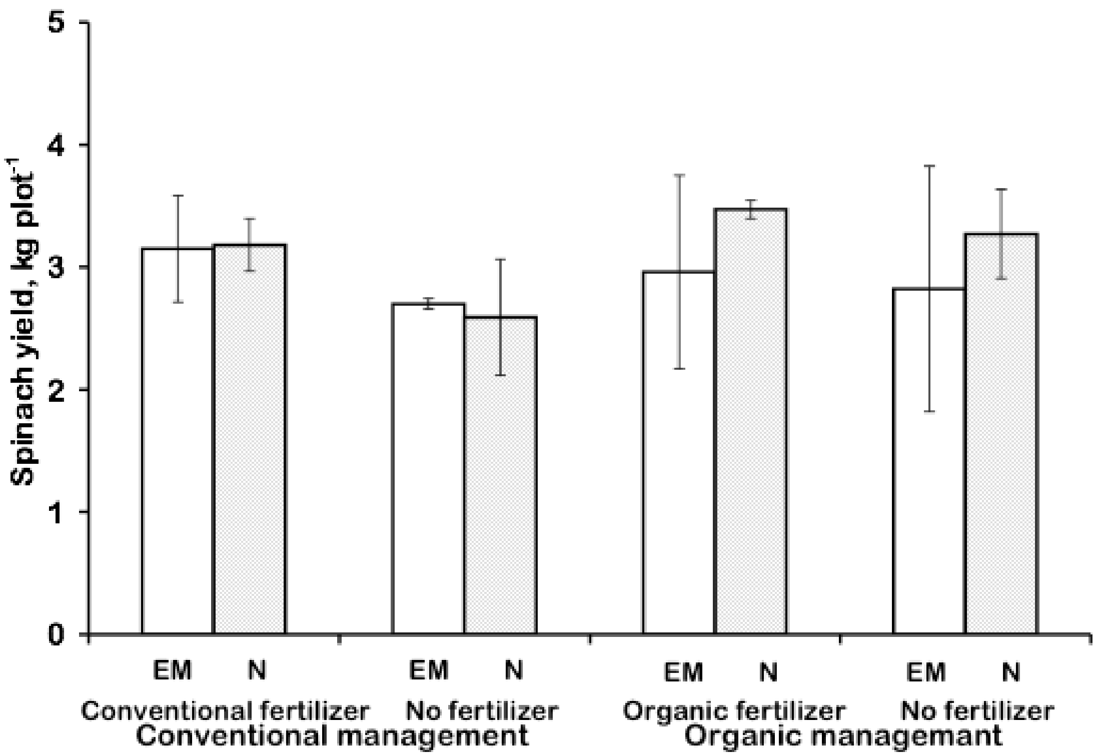

Figure 3.4. Spinach yield as affected by fertilizer and microbial tea (EM = commercially available microbial tea, N = no tea) in conventional and organic management systems on a loamy soil under high tunnels near Olathe, Kansas, in 2005. Error bars indicate standard errors of means of three replicates.

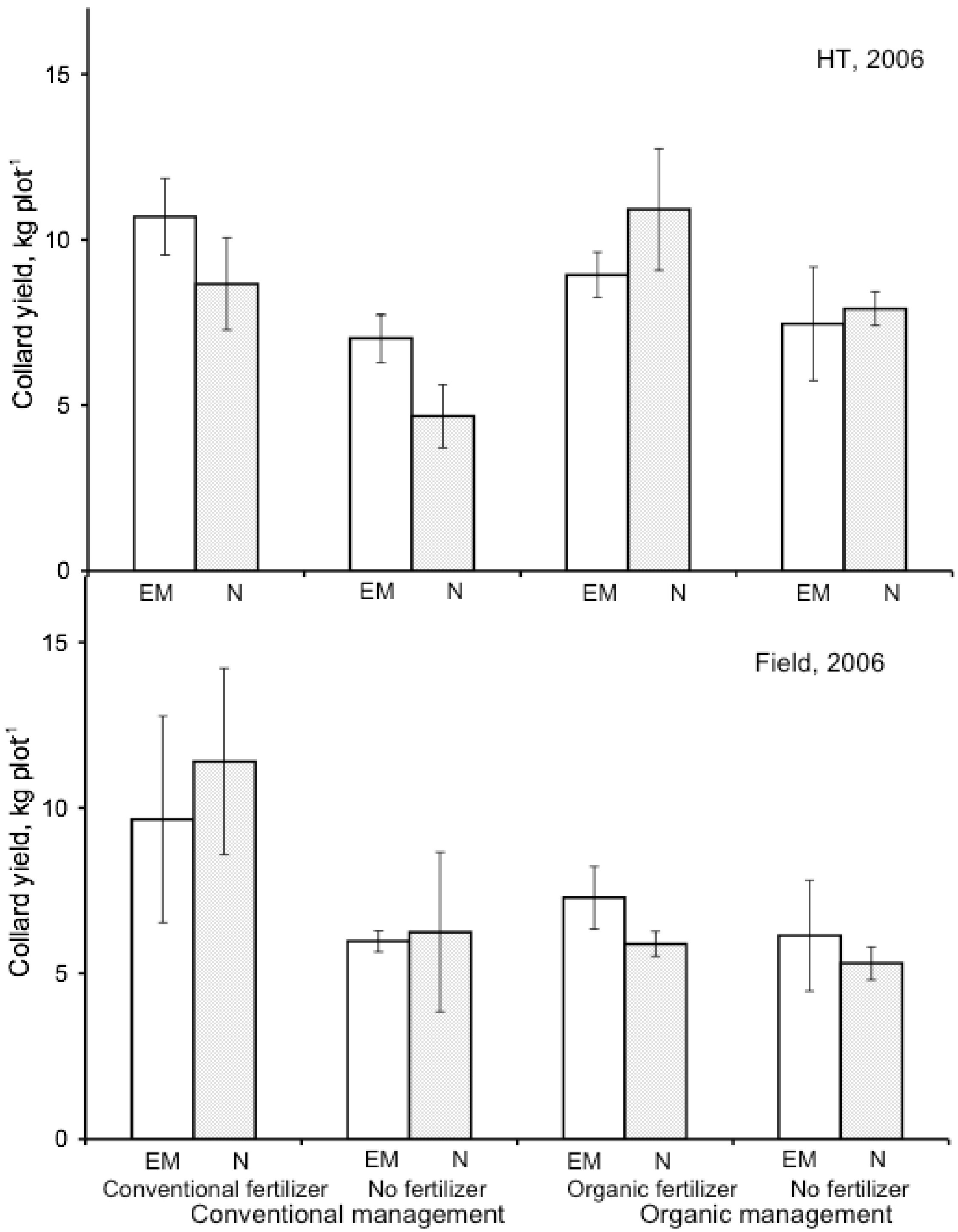

Figure 3.5. Collard yield as affected by fertilizer and microbial tea (EM = commercially available microbial tea, N = no tea) in conventional and organic management systems on a loamy soil under high tunnels and in adjacent fields near

Olathe, Kansas, in 2005. Error bars indicate standard errors of means of three replicates.

Table 3.1. Analysis of variance of effects of microbial teas and fertilizers on collard (*Brassica oleracea* L. var. *acephala* cv. Top Bunch) crop yield in an open field at Haysville, Kansas, in 2005 and 2006.

Source	df	p value	
		2005	2006
Tea [z]	2	0.8270	0.3716
Fertilizer [y]	2	0.0018	0.0001
Tea x Fertilizer	4	0.9912	0.0283

[z] Manure tea, Efficient Microbes (EM), or no tea application

[y] Organic, conventional, or no fertilizer application

Table 3.2. Analysis of variance of effects of microbial teas and fertilizers on microbial biomass carbon and microbial biomass nitrogen two and eight weeks after initial microbial tea applications to soil at Haysville, Kansas, in 2005.

Source	df	P value			
		week 3		week 8	
		MBC[z]	MBN[y]	MBC	MBN
Tea [x]	2	0.267	0.472	0.441	0.191
Fertilizer [w]	2	0.137	0.579	0.133	0.728
Tea x Fertilizer	4	0.150	0.483	0.164	0.699

[z] MBC = microbial biomass carbon

[y] MBN = microbial biomass nitrogen

[x] Manure tea, Efficient Microbes (EM), or no tea application

[w] Organic, conventional, or no fertilizer application

Table 3.3. Analysis of variance of effects of microbial tea, fertilizer (seasonal application made or withheld), management system (conventional or organic) and harvest dates on crop yield under high tunnels (HT) and in open field plots at Olathe, Kansas, in 2005 and 2006.

Source [z]	df	P value		
		2005, HT[y]	2006, HT[y]	2006, field[x]
Tea	1	0.4850	0.4504	0.8871
Fertilizer	1	0.2807	0.0014	0.0155
Management	1	0.6923	0.4364	0.2834
Harvest date	1,4 [w]	0.0433	0.0001	0.0001
Tea x Fertilizer	1	0.8618	0.4731	0.8915
Tea x Management	1	0.4019	0.0365	0.3336
Tea x Date	1,4	0.7776	0.1170	0.3875

[z] Interactions not presented in the table are not significant, except for fertilizer x date

[y] Spinach tops (*Spinacia oleracea* L. cv. Hellcat)

[x] Collard leaves (*Brassica oleracea* L. var. *acephala* cv. Top Bunch)

[w] Two leaf harvests in 2005 and five in 2006

CHAPTER 4 - Spinach Harvest Date and Yield in High Tunnels as Affected by Autumn Planting Date

[Formatted to post as a KSU research and extension publication on the website www.hightunnels.org]

Introduction

Spinach (*Spinacia oleracea* L.) can be harvested as baby spinach (soupspoon sized leaves) with repeated cuttings from the same planting. Spinach planted in the autumn can be harvested with repeated cuttings through the winter and into the spring. Autumn planting date is critical to winter harvests. Through the short cold days of winter spinach continues to grow, but at a much reduced rate. This growth reduction takes effect around 16 November at the 39 °N latitude (Coleman, 2001). Autumn crops must grow vegetatively before this time to carry the crop through the winter. Coleman (2001) presents his high tunnel autumn planting dates as a frame of reference for other regions. In Maine, he plants in an unheated high tunnel through September to harvest through the winter.

Planting date affects yield and growing days before harvest based on the accumulation of heat units (growing degree days) by the crop and on light intensity. To begin to assess the effects of autumn planting date on spinach harvest in Kansas high tunnels, we planted spinach on six dates in the autumn of 2005 at the Kansas State University Horticulture Research and Extension Center, Olathe [latitude 38°53'N, elevation 1056 ft (322 m)]. Growers may be able to use information from this study when choosing autumn planting dates for spinach. Planting date choice would differ based on need for autumn, midwinter or spring harvests.

Materials and Methods

The experiment was conducted with two cultivars – Avenger (from Seminis, Inc., St. Louis, Mo.) and PVO172 (from Santa Clara Seeds, Greenfield, Calif.). Each cultivar was replicated with plantings in three organically managed high tunnels and three conventionally managed high tunnels. The spinach was harvested when the leaves reached soupspoon size. Yield was measured as fresh mass. Harvest dates differed between planting dates and cultivars. Statistical significance is reported with possible 5 percent error ($p = 0.05$).

Seed beds were 30 ft long and 2 ft wide, divided into six plots of 5-ft length. Fertilizer was applied at a rate to provide the equivalent of 200 lb N per acre. Organic fertilizer Hu-more compost (1-1-1) from Humalfa, LLC. (Shattuck, Okla.), and a conventional pelletized fertilizer (16-8-8), were used. Planting dates were 6, 11, and 25 October, and 3, 8, and 17 November. Planting dates were randomly assigned to plots within a bed. Sprinkler irrigation was used during seed germination in the autumn, and drip irrigation through the winter and spring. Spinach was seeded with two passes of a 4-row pinpoint seeder that distributes 1 seed per inch in a row, with 2.25 inches between rows. From December through February spinach was protected in the unheated high tunnels under a sheet of spunbonded polyester fabric (Typar 580, Ken-Bar, Peabody, Mass.).

Results and Discussion

Shortened day length and cooling night temperatures affected spinach growth so that days between planting and first harvest were vastly different for spinach planted in early October compared to November (Fig. 1 and Fig. 2). Autumn and winter harvests were possible with spinach planted in early October. March harvest was possible with spinach planted at all dates in October and November. Harvest dates for each high tunnel planting are indicated in Table 4.1.

Table 4.1. Harvest dates of spinach planted in high tunnels in autumn 2005.

Planting date	Harvest dates – Avenger cultivar			
6 October	17 Nov	1 Dec	31 Jan	27 Mar
11 October	1 Dec	19 Jan	7 Feb	27 Mar
25 October	24 Jan	16 Feb	27 Mar	
3 November	8 Feb	27 Mar		
8 November	16 Feb	27 Mar		
17 November	16 Feb	27 Mar		
Planting date	**Harvest dates – PVO172 cultivar**			
6 October	24 Nov	19 Jan	16 Feb	27 Mar
11 October	24 Nov	24 Jan	16 Feb	27 Mar
25 October	24 Jan	16 Feb	27 Mar	
3 November	8 Feb	27 Mar		
8 November	16 Feb	27 Mar		
17 November	16 Feb	27 Mar		

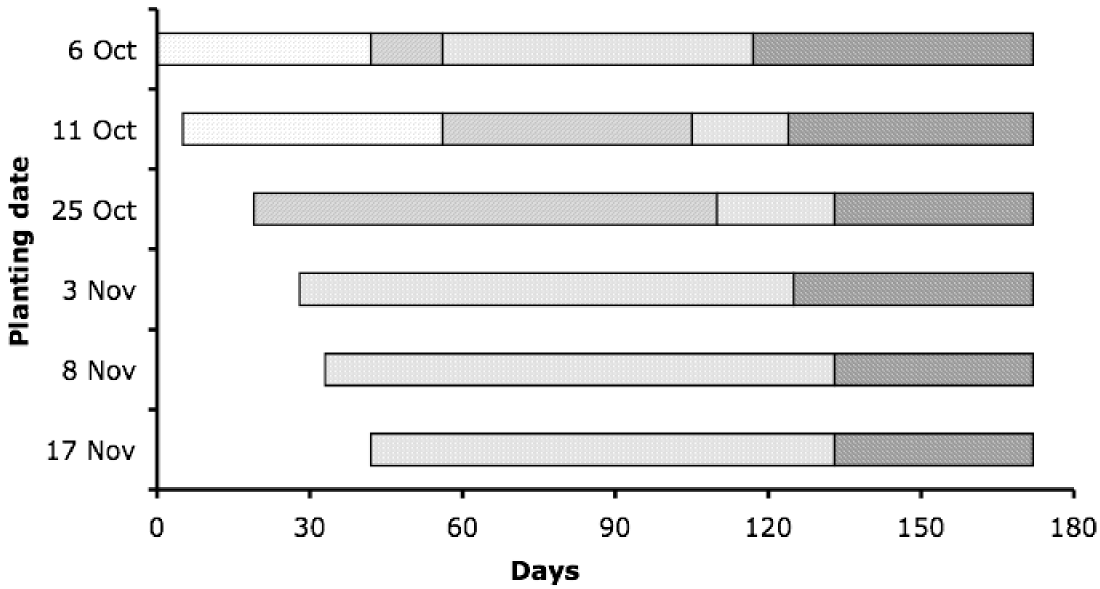

Figure 4.1. Intervals from planting until harvest of Avenger spinach. Successive harvests are indicated by change in crosshatch patterns, with final harvest on 27 March 2006.

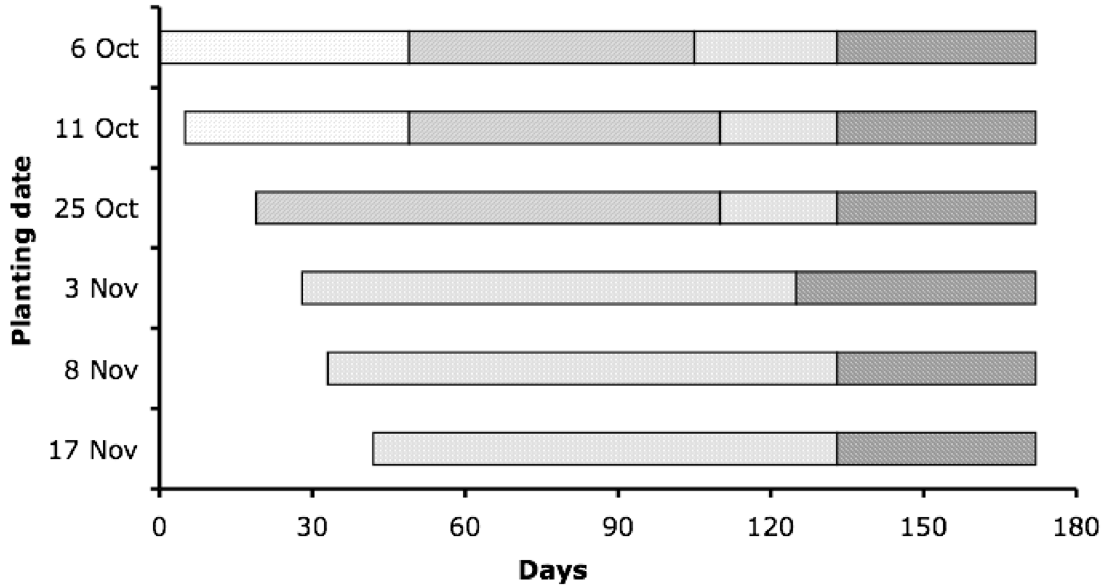

Figure 4.2. Intervals from planting until harvest of PVO172 spinach. Successive harvests are indicated by change in crosshatch patterns, with final harvest on 27 March 2006.

Table 4.2. Analysis of variance of the effects of planting date and management (conventional or organic) on total spinach yield in trials at Olathe, Kansas, planted in autumn 2005.

Effect	df	P-value Cultivar	
		Avenger	PVO172
Planting date	5	0.0001	0.0001
Management	1	0.8760	0.6898
Planting date x Management	5	0.1949	0.6586

Planting date affected total harvest yield mainly because of differences in autumn harvests. It can probably be assumed that the crops with reduced spring yield were less established or had fewer reserves, going into winter. Spinach planted in November was not harvestable until February. Yield data are presented for Avenger (Fig. 3) and PVO172 (Fig. 4) in organic and conventionally managed plots. Yield in organic and conventional high tunnels differed somewhat in individual harvests, but there was not an overall statistically significant difference between spinach yield in organic and conventionally managed high tunnels (Table 2). Harvest trends due to planting date were similar in organic and conventionally managed high tunnels (i.e. no interaction between planting date and management).

Early planting of Avenger spinach increased the cumulative harvest. Avenger spinach planted on 6 and 11 October had significantly greater total yield than spinach planted on 17 November in organically managed high tunnels, and greater than that planted on 8 and 17 November in conventionally managed high tunnels (Table 3).

Spring harvest may be reduced spinach planted after the first week of November. Delayed planting in the month of November did not significantly reduce the February-March yield in organic high tunnels, but in conventional high tunnels 17 November planting resulted in significant yield reduction compared to 3 and 8 November plantings (Table 4). October planting date did not affect spring harvest (February-March) in organic high tunnels. In conventionally managed high tunnels, spinach planted on 11 and 25 October did not have a reduced total yield (Table 3), but because of differences in harvest dates the spring yield was statistically similar to the low yields of the 17 November planting, and less than the 3 and 6 November plantings (Table 4).

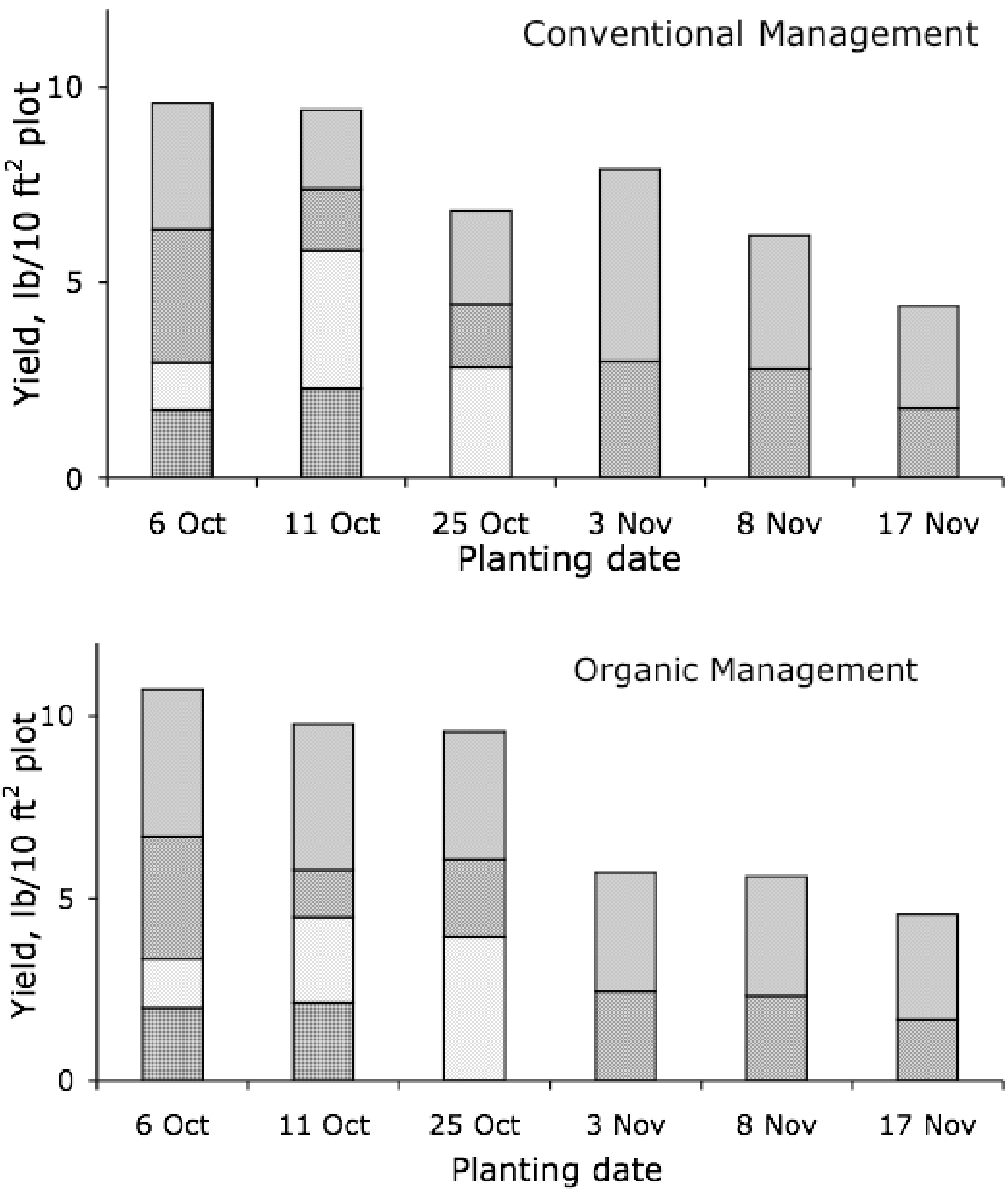

Figure 4.3. Fresh weight yield of successive harvests of Avenger spinach from plantings in autumn 2005, in organic or conventionally managed high tunnels, stacked with final harvest on top.

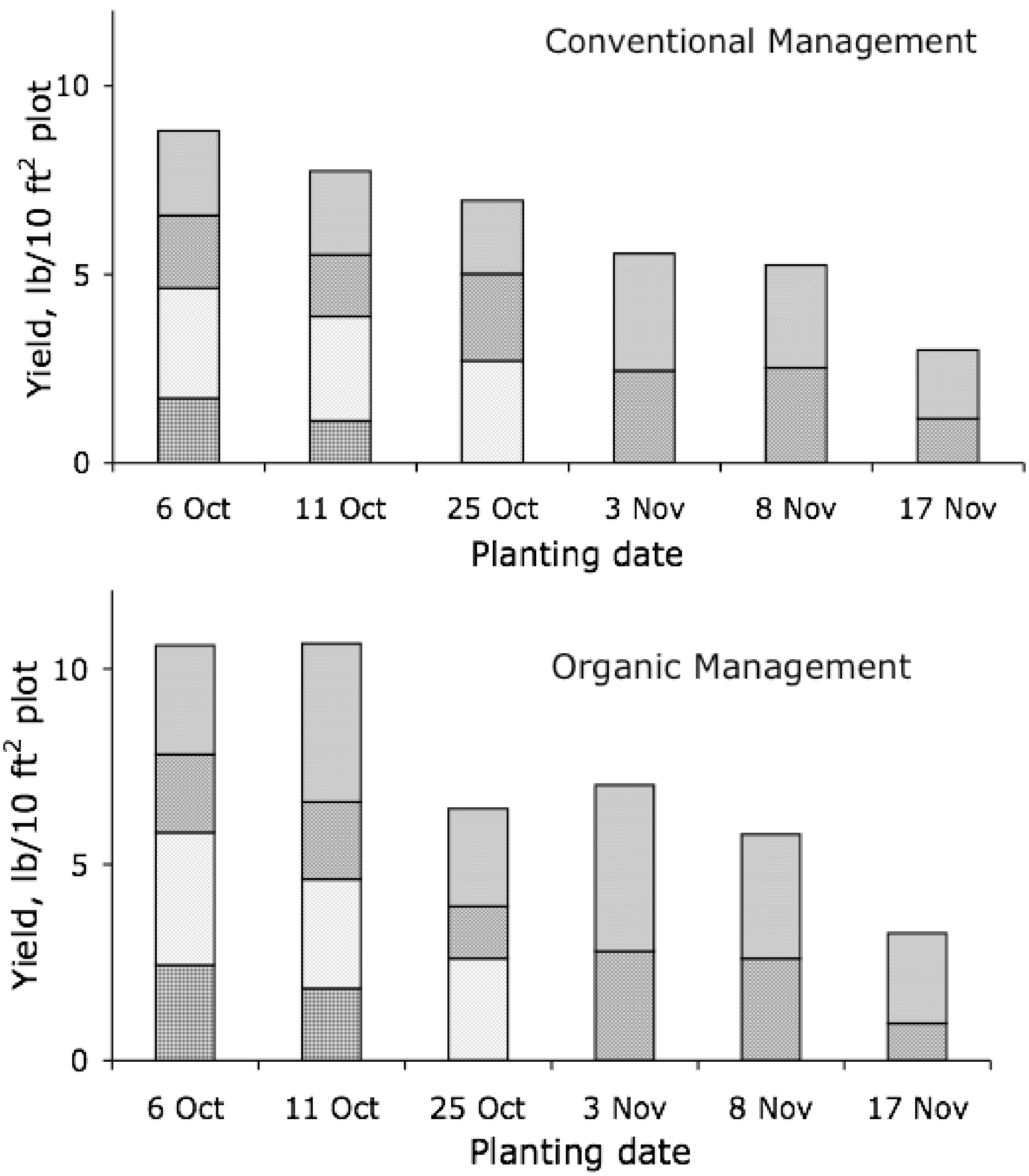

Figure 4.4. Fresh weight yield of successive harvests of PVO172 spinach from plantings in autumn 2005, in organic or conventionally managed high tunnels, stacked with final harvest on top.

Table 4.3. Total fresh weight yield of spinach cultivars Avenger and PVO172 planted on six dates in the autumn of 2005 and harvested through March 2006, in conventional and organically managed high tunnels at Olathe, Kansas. Values in a column followed by the same letter are not significantly different (α = 0.05).

Planting date	Total yield [z] lb / 10 ft^2							
	Avenger				PVO172			
	Conventional		Organic		Conventional		Organic	
6 Oct	8.52	a	9.38	a	9.36	a	9.49	a
11 Oct	8.74	a	9.78	a	8.74	a	8.39	ab
25 Oct	6.85	ab	8.40	ab	7.33	ab	6.87	abc
3 Nov	7.90	ab	5.70	ab	5.80	b	6.60	bcd
8 Nov	5.07	bc	5.60	ab	5.42	b	5.77	cd
17 Nov	3.53	c	4.57	b	3.00	c	3.35	d

[z] Mean of three replicates

Table 4.4. Fresh weight yield from the final two cuttings of spinach cultivars Avenger and PVO172 planted on six dates in the autumn of 2005 and harvested through March 2006, in conventional and organically managed high tunnels at Olathe, Kansas. Values in a column followed by the same letter are not significantly different (α = 0.05).

Planting date	Spring yield [z] lb / 10 ft^2							
	Avenger				PVO172			
	Conventional		Organic		Conventional		Organic	
6 Oct	6.70	a	7.38	a	4.95	a	5.50	a
11 Oct	3.68	b	5.30	b	4.92	a	6.40	a
25 Oct	4.02	b	5.63	ab	4.63	ab	5.23	a
3 Nov	7.90	a	5.70	ab	5.80	a	6.60	a
8 Nov	5.07	a	5.60	ab	5.42	a	5.77	a
17 Nov	3.53	b	4.57	b	3.00	b	3.35	b

[z] Mean of three replicates

Early planting of PVO172 spinach resulted in greater yields. PVO172 spinach planted on 6 October had a significantly greater total yield than that planted in November in organic and conventionally managed high tunnels (Table 3). Plantings on 11 November resulted in significantly greater yield than the 3 and 17 November plantings in organic high tunnels, and in conventional high tunnels greater yield than all November plantings (Table 3). Each week of planting delay in November reduced yield. Spinach planted on 17 November produced significantly less spinach for spring harvest (February-March) than earlier plantings (Table 4). All other plantings in organic and conventionally managed high tunnels had statistically similar spring spinach yields.

Conclusions

Over wintering of spinach in unheated high tunnels was successfully demonstrated with two cultivars, Avenger and PVO172. Planting date affected harvest dates and total yield. October planted spinach can be harvested in the winter without significant loss of spring yield. Harvest trends of the two cultivars were similarly affected by planting date. There was a point in mid-November where late planting significantly reduced spring yield for both cultivars. Spinach planted at staggered dates through October in unheated high tunnels at Olathe, Kansas, produced spinach for harvest from November through March. Future studies should evaluate both earlier and later planting date effect on winter and spring production. Temperatures should be monitored so that results can be interpreted with respect to heat unit accumulation and day length.

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CHAPTER 5 - Spinach Over-Winter Cultivar Trial in a 3-Season Multi-bay High Tunnel (2005 – 2006)

[Formatted to post as a KSU research and extension publication on the website www.hightunnels.org]

Introduction

Annual spinach consumption increased in the US from an estimated 0.3 lb/capita in 1970 to 0.9 in 1998 (Heacox, 2000) and 2.5 lb/capita in 2003 (Boriss and Kreith, 2006). The increase is mostly due to consumption of fresh "baby" leaf spinach (Boriss and Kreith, 2003; Heacox, 2000). Fresh, clean, salad ready spinach brings premium revenues (Heacox, 2000). Growers using high tunnels are able to supply some of the market demand for spinach. A survey of growers in the central Great Plains found that leafy greens are a favorite crop for high tunnel vegetable production.

Kansas growers are interested in recommended spinach cultivars for spring or autumn crops. Spinach production is mainly concentrated in the southwest US, California, Texas and Arkansas. Because of this seed cultivar selections are often based on production in those climatic zones. It was our intention to grow and record observations for spinach (*Spinacia oleracea* L.) cultivars planted in the autumn in northeast Kansas.

Methods and Materials

Several seed companies provided seed that they either currently market, or are considering for market, in our region. Twenty-six spinach cultivars were planted in autumn 2005 in a 3-season multi-bay Haygrove™ high tunnel and in adjacent field plots at the Kansas State University Horticulture Research and Extension Center, Olathe [latitude 38°53'N, elevation 1056 ft (322 m)]. The high tunnel cover was removed for the winter on 10 December 2005 and replaced on 15 April 2006. From December through February the spinach was protected under a sheet of spun-bonded polypropylene fabric (Typar 580 floating row cover; Ken-Bar, Peabody, Mass.) held in place with sand bags. The spinach grew slowly during the cold winter with little freeze damage. Spinach was harvested twice, once in the autumn and once in the spring, with yield reported as fresh mass.

Six raised beds of 96 ft length and approximately 2 ft width were prepared in the north half of one bay of our 4-bay, half-acre Haygrove high tunnel. The distance between beds was 3 ft. Cultivars were randomized within pairs of beds, giving three replicates.

Irrigation was from overhead sprinklers. Raised seedbeds were prepared with a wheel hoe equipped with a furrower attachment. Bradfield Organic fertilizer 3-1-5 (Bradfield Industries, Springfield, Mo.) was applied to supply nitrogen at a rate of 136 lb/acre on 2 September 2005. Plots were about 5 x 2 ft, with about six inches of buffer zone between plots within rows. We seeded the beds with two passes of a 4-row pinpoint seeder giving eight rows of spinach per bed. The seeder delivers a seed per inch of row.

Results and Discussion

Beds were seeded the first week of September. Germination was very poor. The field plots were a total failure. Under the high tunnel fewer than twenty plants survived in the majority of plots. Only the cultivars Hellcat and Highpack had 50-75 plants in one plot each. The weather was hot and this may have been a factor in the poor germination that followed. We had used a roller to press the seeds into the bed. It is possible that some of the seed was pushed too deep. We determined that with the second planting we would sprinkler irrigate for short periods throughout the day to cool the soil and not use the roller.

Spinach was seeded a second time under the high tunnel on 27 September 2005. Germination was much improved, but not excellent in any plot. Based on observation, germination within a plot of less than 50 seedlings was rated as poor, 50 to 70 was fair, 70 to 100 was moderate, and 100 to 125 was rated as a good germination. Cultivar PVO172 had the best overall germination with an average of 104 plants per plot. Interceptor, PVO170, Space, Lombardia, Bloomsdale, Emilia, and Hellcat cultivars had moderate germination (Table 1).

Table 5.1. Germination and seed source of spinach seeded on 27 September 2005.

Cultivar	Source	Germination				
		three replicates			average[1]	average
		plants per 10 ft^2 plot				%
Avenger	Seminis	62	62	62	62	13
Baker	Alf Christianson	35	62	62	53	11
Blackhawk	Seminis	62	62	62	62	13
Bloomsdale	Chesmore Seed Co.	62	87	62	70	15
C1-601	Alf Christianson	35	62	62	53	11
C1-608	Alf Christianson	62	62	62	62	13
C2-605	Alf Christianson	35	35	35	35	7
C2-606	Alf Christianson	62	62	62	62	13
C2-607	Alf Christianson	35	35	35	35	7
Emilia	Santa Clara Seed	62	87	62	70	15
Falcon	Seminis	35	62	62	53	11
Hellcat	Seminis	62	87	62	70	15
Highpack	Chesmore Seed Co.	35	62	62	53	11
Interceptor	Seminis	87	112	87	95	20
Lombardia	Santa Clara Seed	62	87	87	79	16
Melody	Chesmore Seed Co.	35	87	62	61	13
Olympia	Alf Christianson	62	62	62	62	13
PVO170	Santa Clara Seed	62	112	87	87	18
PVO172	Santa Clara Seed	87	112	112	104	22
Samish	Alf Christianson	35	62	62	53	11
Space	Johnny's Selected Seeds	87	87	87	87	18
Spinner	Johnny's Selected Seeds	35	62	62	53	11
Springer	Johnny's Selected Seeds	35	62	35	44	9
Tigercat	Seminis	62	62	62	62	13
Tyee	Chesmore Seed Co.	35	62	62	53	11
Umbria	Santa Clara Seed	62	62	62	62	13
LSD[2]					22	4.5

[1] Possible 480 seeds

[2] Least significant difference – values in the column above that differ by this amount are significantly different ($p = 0.05$).

Besides the effect on harvest yield, germination rate was also important because of the relationship to weed encroachment. Plots with poor spinach germination had more weeds later. Henbit (*Lamium amplexicaule* L.) was the main weed. Our only method of weed control was pulling by hand. Denser seeding would reduce weed pressure. This could be done by overlapping an increased number of passes with a wheel planter, using a closer spaced planter, or broadcasting seed. The cost in extra seed would likely be worth the reduced time spent pulling weeds.

We harvested the spinach as “baby spinach”. The ideal harvest size and shape is that of a soupspoon. All cultivars conformed to the spoon shape. Leaf texture is described as smooth or savoy (rippled). Some markets have a preference for smooth leaves. Growth habit and leaf texture are noted in Table 2. Upright petiole growth allows easier harvest, especially if using a leafy greens harvester (consists of a serrated blade on a frame with a bag on the back of the frame to hold the cut greens). It is possible that some cultivars that seemed to have more prostrate growth habit could be forced to have upright petioles if more densely seeded.

We harvested the spinach in the autumn on 10 November 2005. Spinach was harvested a second time on 11 March 2008. Average fresh mass yield per 10 ft^2 plot is presented for each cultivar in Table 3. The following cultivars were among the ten with highest yield in both harvests: Interceptor, Highpack, Lombardia, Olympia, PVO170, and Tigercat. However, it should be noted that the cultivar with the highest combined yield, Interceptor, had a statistically significantly higher yield than only Spinner, Samish, C2-606, C2-605 and Tyee.

Table 5.2. Leaf texture and growth habit of baby spinach planted 27 September 2005 under a high tunnel at Olathe, Kansas.

Spinach variety	Leaf surface texture	Growth habit
~~Avenger~~	~~smooth mostly, youngest leaves savoy~~	~~prostrate~~
Baker	mixed savoy and smooth	mixed
Blackhawk	smooth, mostly	mixed
Bloomsdale	savoy	upright
C1-601	savoy	mixed
C1-608	savoy	upright
C2-605	mixed savoy and smooth	upright
C2-606	smooth mostly	upright
C2-607	mixed savoy and smooth	upright
Emilia	mixed savoy and smooth	upright
Falcon	mixed savoy and smooth	mixed
Hellcat	mixed savoy and smooth	upright
Highpack	smooth, mostly	upright
Interceptor	smooth	upright
Lombardia	mixed savoy and smooth	upright
Melody	savoy	upright
Olympia	savoy, mostly	upright
PVO170	smooth	upright
PVO172	smooth, mostly	upright
Samish	savoy	prostrate
Space	smooth, mostly	upright
Spinner	savoy, few arrow shaped	upright
Springer	smooth mostly, youngest leaves savoy	mixed
Tigercat	smooth	upright
Tyee	savoy	upright
Umbria	smooth, mostly	upright

Table 5.3. Fresh mass harvest yield of spinach planted on 27 September 2005 under a high tunnel at Olathe, Kansas. Yield is average of three replicated plots.

Variety	Harvest 10 Nov 2005	Harvest 11 March 2006	Total yield	Total yield
		lb per 10 ft^2 plot		lb / plant
Avenger	1.35	7.06	8.42	0.14
Baker	1.40	6.45	7.85	0.15
Blackhawk	1.45	5.98	7.43	0.12
Bloomsdale	1.52	6.73	8.26	0.12
C1-601	1.47	5.93	7.40	0.14
C1-608	1.41	7.15	8.56	0.14
C2-605	1.05	5.12	6.17	0.18
C2-606	1.08	5.28	6.37	0.10
C2-607	0.86	6.87	7.73	0.22
Emilia	1.58	6.72	8.30	0.12
Falcon	2.20	6.48	8.68	0.16
Hellcat	1.52	6.02	7.54	0.11
Highpack	1.76	7.27	9.03	0.17
Interceptor	1.86	7.52	9.38	0.10
Lombardia	1.66	7.58	9.24	0.12
Melody	1.65	6.47	8.11	0.13
Olympia	1.62	7.13	8.75	0.14
PVO170	1.63	6.52	8.14	0.09
PVO172	1.94	5.86	7.81	0.08
Samish	1.21	5.50	6.71	0.13
Space	1.96	5.82	7.78	0.09
Spinner	1.68	5.05	6.73	0.13
Springer	1.30	6.34	7.64	0.17
Tigercat	1.65	7.96	9.61	0.16
Tyee	1.37	4.42	5.79	0.11
Umbria	1.37	6.11	7.49	0.12
LSD[z]	0.72	2.19	2.39	0.073

[z] Least Significant Difference – values in the column above that differ by this amount are significantly different (p = 0.05).

Spinach with prostrate growth was harvested by holding bunches in the hand and cutting with a knife. Plots with upright growth were harvested with a leafy greens harvester from Johnny's Selected Seeds (Winslow, Maine).

The second harvest was of greater mass, but the leaf size not much larger than the first harvest. The plantlets seemed to have put on more leaves.

After the second harvest the weed population took over. We were not able to devote the time it would have required to hand pull all of the spring weeds. We continued to water the spinach and let it grow long enough to observe how the cultivars responded to warm weather.

On 2 May 2006, observations of spinach bolting were recorded (Table 4). The least objectionable warm weather effect was petiole lengthening. This might make harvest easier and did not detract from the leaf form. At the time of evaluation, some cultivars had developed elongated internodes that are typical of bolting, but had not yet flowered. Some cultivars had developed flowers or gone to seed. Leaves on the cultivar Springer elongated and became arrow shaped. Spinach cultivars that had the best appearance and least bolting effects in warm weather were: Blackhawk, C1-601, C2-606, Interceptor, PVO170, PVO172, Space and Umbria.

Table 5.4. Spring bolting of spinach as observed on 2 May 2006. Spinach was planted on 27 September 2005 and over wintered in a high tunnel. (n = no bolting effects, e = elongated internodes, p = petioles long, f = flowers, s = seed formation)

Cultivar		Bolting	
	replicate 1	replicate 2	replicate 3
Avenger	e	pe	e
Baker	efs	efs	efs
Blackhawk	p	p	n
Bloomsdale	e	ef	ef
C1-601	p	p	p
C1-608	efs	efs	ef
C2-605	e	e	n
C2-606	p	p	n
C2-607	efs	ef	pe
Emilia	e	pe	n
Falcon	ef	ef	ef
Hellcat	e	e	e
Highpack	efs	efs	efs
Interceptor	n	e	p
Lombardia	n	pe	e
Melody	p	e	e
Olympia	n	pe	e
PVO170	n	p	n
PVO172	p	p	n
Samish	efs	efs	efs
Space	n	pe	p
Spinner	n	e	e
Springer	arrow shape	e	arrow shape
Tigercat	e	n	e
Tyee	pe	e	p
Umbria	p	p	n

Information presented in this report such as germination, leaf appearance and spring bolting may be of current interest for growers in our climatic zone [Plant hardiness zone 5 (USDA, 1990)]. Harvest yield data will be of more value when added to additional years of cultivar trials. Cultivar trial data are more reliable when results are collected over a few years. Performance of autumn planted spinach may vary from year to year depending on weather (cloud cover, temperature, and early and late frost).

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Appendix A - High tunnel grower survey and soil quality

The alphabetic letters assigned to identify growers in Table A.1 coincide with the farms sharing the same identification in the other tables in appendix A. Data not included in previous chapters appears in the appendix, i.e. surveys outside the central Great Plains.

Table A.1. Demographics of growers who participated in the 2006 soil quality study.

Grower	Survey	Visit	Location State	HT count	Initial HT year	HT Size ft x ft
A	N	Y	MO	1	.	
B	N	Y	.	2	.	
C	N	Y	NE	6	.	
D	N	Y	.	7	.	
E	N	Y	MO	8	.	
F	N	Y	MO	9	.	
G	N	Y	MO	13	.	
H	Y	N	NM	1	1	10x50
I	Y	N	WV	1	1	48x20
J	Y	N	KS	1	1	8x80
K	Y	N	MO	1	1	20X96
L	Y	N	OH	4	1	20 x 50, three 14 x 50
M	Y	N	NY	4	.	two 26X96, one 20X48, one 17X96, one 30X96 (under construction will begin using in 2007)
N	Y	N	NY	2	2	two 20x96x 11 height
O	Y	N	MI	8	6	four 30 x 96; two 28 x 72; and two 12 x 72
P	Y	N	GA	2	2	30 x 96 and 26 x 80
Q	Y	N	KS	2	2	31x48 & 12x60
R	Y	N	KS	.	.	
S	Y	N	IN	1	1	10 x 33
T	Y	N	KS	2	.	16x60 14 x 36
U	Y	N	OR	1	3	12x25
V	Y	Y	MO	1	4	26x70
W	Y	Y	NE	1	4	30x96
X	Y	Y	MO	1	2	26x96
Y	Y	Y	KS	2	5	20x96
Z	Y	Y	MO	1	5	

Table A.1. Continued

Grower	Survey	Visit	Location State	HTs count	Initial HT year	HT Size ft x ft
AA	Y	Y	NE	1	4	20x60
AB	Y	Y	NE	1	3	
AC	Y	Y	KS	3	2	one 20X56, two 24X56
AD	Y	Y	KS	4	10	20x10
AE	Y	Y	MO	1	4	18x45
AF	Y	Y	KS	2	13	12x96, 12x28
AG	Y	Y	IA	2	.	
AH	Y	Y	MO	3	4	30x96, 20x144
AI	Y	Y	KS	2	5	21X30 28X96
AJ	Y	Y	IA	2	7	20x100,20x80,20x40
AK	Y	Y	MO	3	11	60x18, 60x18, 56x22
AL	Y	Y	MO	1	4	20x96
AM	Y	Y	MO	1	9	12x20
AN	Y	Y	NE	6	1	20 x 45
AO	Y	Y	MO	4	8	two 18x72, one 12x24
AP	Y	Y	KS	4	5	19 x 60, 19 x 30, 12x60, 20x40
AQ	Y	Y	MO	1	3	26x96
AR	Y	Y	MO	1	3	
AS	Y	Y	KS	10	9	seven 16x96, one 20x96, two 30x96
AT	Y	Y	NE	4	15	40x100, 22x48, 20x48, 20x48
AU	Y	Y	KS	1	2	30x96
AV	Y	Y	MO	2	11	30x96, 26x96
AW	Y	Y	MO	4	4	20X96, three 10X100
AX	Y	Y	NE	3	8	20x192, 30x96
AY	Y	Y	KS	3	14	16x48, 30x40, 20x60
AZ	Y	Y	NE	1	2	18x28

Table A.1. Continued

Grower	Survey	Visit	Location State	HT count	Initial HT year	HT Size ft x ft
BA	Y	Y	MO	3	12	two 30x96, 26x50
BB	Y	Y	MO	2	8	26x160, 32x96
BC	Y	Y	MO	4	3	four 26x96
BD	Y	Y	MO	2	4	20x96
BE	Y	Y	MO	2	**6**	30x96, 26x96
BF	Y	Y	IA	2	4	30x96
BG	Y	Y	NE	3	7	27x84, 29x84, 40x96
BH	Y	Y	KS	3	4	20 X 96
BI	Y	Y	MO	1	3	30x96
BJ	Y	Y	KS	2	4	30x98, 21x30
BK	Y	Y	MO	8	5	20x36
BL	Y	Y	MO	1	4	30x96
BM	Y	Y	NE	1	3	20x100
BN	Y	Y	KS	2	6	30x30, 30x60
BO	Y	Y	MO	2	3	30x96
BP	Y	Y	MO	3	3	30x96
BQ	Y	Y	MO	2	10	24x96, 30x96
BR	Y	Y	MO	1	12	30 x 96
BS	Y	Y	MO	2	5	30x96, 25x120
BT	Y	Y	MO	1	8	30x96
BU	Y	Y	MO	2	5	30x96, 40x96
BV	Y	Y	MO	1	6	36x96
BW	Y	Y	NE	1	5	30x96
BX	Y	Y	IA	8	9	five 20x96, two 20x200, one 36x60
BY	Y	Y	MO	1	3	26x96
BY	Y	Y	IA	1	4	30x60
BZ	Y	Y	MO	1	4	20x50

Table A.1. Continued

Grower	Survey	Visited	Location State	HT count	Initial HT year	HT Size ft x ft
CA	Y	Y	KS	2	11	20x96, 12.5x40
CB	Y	Y	KS	6	11	20x96
CC	Y	Y	MO	3	7	30x96,30x200
CD	Y	Y	MO	2	10	N - 30x200, S - 30x96
CE	Y	Y	KS	2	4	14x20
CF	Y	Y	MO	2	7	16x96, 20x96
CG	Y	Y	IA	2	2	20x96
CH	N	Y	MO			
CI	Y	Y	.	2	3	26x48, 26x96
CJ	Y	Y	MO	2	4	22x96,30x96
CK	Y	Y	MO	1	3	30x96
CL	Y	Y	MO	4	7	39x96, 29x96, 29x96, 28x96
CM	Y	Y	MO	2	3	30x96
DA	Y	.	.	3	.	2-14x96 and one 20x48
DB	Y	.	.	2	.	30x96
DC	Y	.	.	1	14	12x36
DE	Y	.	.	1	10	18x90
DF	Y	.	.	2	4	20x90
DG	Y	.	.	2	3	34x96,20x96
DH	Y	.	.	1	2	26x96
DI	Y	.	.	1	2	20 x 96
DJ	Y	.	.	1	2	30x96
DK	Y	.	.	1	2	96x20
DL	Y	.	.	1	4	30X96
DM	Y	.	.	5	11	two 21x60, three 20x96
DN	Y	.	.	2	.	12 x 24 x 7(height)

Table A.2. Soil characterization for high tunnels and adjacent fields at farms visited in autumn 2006.

Farm	HT	sand	clay	pH		Total C	
				HT	Field	HT	Field
		%	%			mg C kg^{-1} soil	
A	1	.	.	6.5	6.2	.	.
B	2	.	.	6.8	7.2	.	.
C	3	29	24	.	.	18.9	29.1
C	4	29	24	.	.	25.6	29.1
C	5	29	24	.	.	24.0	30.7
C	6	29	24	.	.	24.4	30.7
D	7	28	27	.	.	23.9	14.6
E	8	36	29	7.1	6.5	24.1	19.9
F	9	27	19	6.3	6.8	42.1	19.3
F	10	.	.	.	.	.	.
F	11	.	.	.	.	.	.
G	12	34	25	6.6	6.7	23.8	25.2
G	13	34	25	6.6	.	24.2	25.2
H	14	.	.	.	.	.	.
I	15	.	.	.	.	.	.
J	16	.	.	.	.	.	.
K	17	.	.	.	.	.	.
L	18	.	.	.	.	.	.
M	19	.	.	.	.	.	.
N	20	.	.	.	.	.	.
O	21	.	.	.	.	.	.
P	22	.	.	.	.	.	.
Q	23	.	.	.	.	.	.
R	24	.	.	.	.	.	.
S	25	.	.	.	.	.	.
T	26	.	.	.	.	.	.
U	27	.	.	.	.	.	.
V	28	48	14	6.8	6.6	56.5	56.4
W	29	33	13	6.7	7.3	19.9	14.6
X	30	32	18	6.6	7.0	17.5	14.6
Y	31	36	34	6.6	7.2	29.8	14.3
Z	32	31	30	6.9	7.3	31.0	20.9

Table A.2. Continued

Farm	HT	sand	clay	pH		Total C	
				HT	Field	HT	Field
		%	%			mg C kg^{-1} soil	
AA	33	.	.	.	.	.	.
AB	34	28	30	6.8	6.5	16.4	16.5
AC	35	.	.	.	.	125.0	95.7
AD	36	31	23	.	.	44.7	39.4
AE	37	32	28	.	.	24.3	24.8
AF	38	31	23	6.7	7.3	25.3	20.4
AF	39	31	23	6.3	6.9	27.4	20.4
AG	40	.	.	.	.	.	.
AH	41	.	.	6.6	7.7	.	.
AI	42	.	.	6.5	6.8	.	.
AJ	43	31	23	6.9	7.2	.	.
AK	44	.	.	.	.	.	.
AK	45	43	15	6.7	.	56.5	55.1
AK	46	43	15	6.7	7.2	78.0	55.1
AK	47	.	.	6.8	.	.	.
AL	48	35	16	7.0	7.0	44.6	11.3
AM	49	31	22	6.4	7.1	34.8	33.5
AN	50	.	.	7.0	7.3	.	.
AO	51	.	.	5.3	7.2	18.8	13.0
AO	52	.	.	5.7	.	18.3	13.0
AO	53	.	.	6.0	.	33.6	13.0
AP	54	.	.	.	.	.	.
AQ	55	17	24	6.8	7.4	17.2	13.9
AR	56	33	25	6.2	7.1	35.0	24.9
AS	57	33	32	6.9	7.1	84.0	29.7
AS	58	33	32	6.5	.	71.2	29.7
AS	59	33	32	6.8	.	71.5	29.7
AS	60	.	.	6.8	.	64.4	29.7
AT	61	.	.	6.7	7.3	.	.
AU	62	.	.	.	.	.	.
AV	63	30	20	6.4	6.9	22.7	24.7
AW	64	32	12	7.3	6.7	57.0	17.2
AX	65	25	22	7.2	7.7	25.7	23.7
AX	66	25	22	7.2	.	31.4	23.7
AX	67	25	22	.	.	37.2	23.7
AY	68	.	.	6.6	7.3	.	.
AZ	69	.	.	.	.	.	.
AZ	70	.	.	.	.	.	.

Table A.2. Continued

Farm	HT	sand	clay	pH		Total C	
				HT	Field	HT	Field
		%	%			mg C kg^{-1} soil	
BA	71	26	24	6.1	6.4	19.9	10.7
BB	72	33	16	6.5	6.9	36.8	23.1
BB	73	47	12	6.4	6.9	17.7	20.1
BC	74	.	.	6.5	6.6	.	.
BC	75	.	.	7.0	.	.	.
BC	76	.	.	7.2	.	.	.
BC	77	.	.	.	.	.	.
BD	78	26	22	7.2	7.6	21.9	22.9
BD	79	26	22	6.5	.	23.6	22.9
BE	80	42	13	5.7	5.3	74.4	43.9
BF	81	41	21	5.9	.	20.2	19.0
BG	82	28	23	6.8	6.4	29.8	13.4
BG	83	28	23	.	.	19.3	13.4
BH	84	33	29	.	.	41.8	36.5
BH	85	33	29	.	.	48.6	36.5
BI	86	25	25	7.0	6.8	26.6	33.3
BJ	87	.	.	.	.	.	.
BK	88	.	.	.	.	.	.
BL	89	29	27	6.9	7.4	28.3	19.6
BM	90	.	.	7.1	7.1	.	.
BN	91	59	17	6.7	6.5	28.7	27.2
BN	92	59	17	6.5	.	40.7	27.2
BO	93	20	22	6.3	6.8	12.8	12.8
BO	94	20	22	6.2	.	13.7	12.8
BP	95	.	.	6.0	6.1	.	.
BQ	96	24	19	6.6	7.1	34.4	19.3
BR	97	40	13	6.3	6.7	45.5	38.2
BS	98	35	21	6.7	6.9	17.0	32.9
BS	99	35	21	6.8	.	16.1	32.9
BT	100	.	.	.	.	.	.
BT	101	.	.	.	.	.	.
BU	102	38	20	6.8	6.8	21.3	18.0
BU	103	29	19	7.5	7.1	16.4	22.1
BV	104	48	22	7.5	7.6	44.9	31.4
BW	105	51	16	6.4	6.2	21.5	26.2
BX	106	65	13	6.9	6.9	24.6	22.0
BX	107	65	13	6.4	.	28.1	22.0
BX	108	65	13	.	.	17.7	22.0
BY	109	.	.	6.8	7.3	.	.
BY	110	40	22	6.8	7.3	35.3	20.2
BZ	111	42	18	7.0	7.2	23.8	19.9

Table A.2. Continued

Farm	HT	sand	clay	pH		Total C	
				HT	Field	HT	Field
		%	%			mg C kg^{-1} soil	
CA	112	.	.	.	.	.	.
CB	113	.	.	.	.	.	.
CB	114	.	.	.	.	.	.
CB	115	.	.	.	.	.	.
CB	116	.	.	.	.	.	.
CB	117	.	.	.	.	.	.
CC	118	.	.	6.7	6.8	.	.
CD	119	28	15	6.4	6.9	51.3	21.8
CD	120	28	15	6.0	.	46.1	21.8
CE	121	35	19	8.0	7.4	16.9	30.2
CF	122	.	.	.	.	.	.
CG	123	.	.	.	.	.	.
CH	124	29	22	6.2	5.9	28.1	31.8
CI	125	36	22	6.6	7.1	12.2	33.7
CJ	126	38	23	6.8	6.4	36.7	14.6
CJ	127	38	23	6.0	.	20.8	14.6
CK	128	35	18	6.6	6.8	30.4	30.5
CL	129	.	.	7.0	6.9	35.0	26.4
CL	130	.	.	6.9	.	46.9	26.4
CM	131	33	24	.	.	26.5	26.8
CM	132	33	24	.	.	28.8	26.8
CN	133	.	.	6.8	7.1	.	.
CN	134	.	.	7.2	.	.	.
CN	135	.	.	6.9	.	.	.
CN	136	.	.	6.0	.	.	.
CN	137	.	.	6.4	.	.	.
CN	138	.	.	7.3	.	.	.
CO	139	.	.	6.8	7.3	.	.

Table A.3. Soil quality indicted by salinity, particulate organic matter carbon (POM C) and water stable aggregates in high tunnels (HT) and adjacent fields on farms visited in 2006.

Farm	HT	Age	Salinity		POM C			Water stable aggregates		
			HT	Field	HT	Field	HT : Field	HT	Field	HT : Field
			dS m^{-1}		g POM C : g total C			mean weight diameter		
A	1	.	0.78	1.25	.	.	.	.	.	.
B	2	.	2.66	0.21	.	.	.	.	.	.
C	3	3	.	.	0.57	0.18	3.14	.	.	.
C	4	11	.	.	0.37	0.18	2.00	.	.	.
C	5	3	.	.	0.30	0.18	1.64	.	.	.
C	6	11	.	.	0.32	0.18	1.75	.	.	.
D	7	.	.	.	0.31	0.24	1.27	.	.	.
E	8	.	0.86	0.36	0.34	0.25	1.37	.	.	.
F	9	11	0.25	0.16	0.36	0.19	1.85	.	.	.
F	10	3	.	.	.	.	.	.	.	.
F	11	3	.	.	.	.	.	.	.	.
G	12	.	1.93	0.25	0.27	0.26	1.01	.	.	.
G	13	.	2.05	.	0.32	0.26	1.20	.	.	.
H	14	1	.	.	.	.	.	.	.	.
I	15	1	.	.	.	.	.	.	.	.
J	16	1	.	.	.	.	.	.	.	.
K	17	1	.	.	.	.	.	.	.	.
L	18	11	.	.	.	.	.	.	.	.
M	19	1	.	.	.	.	.	.	.	.
N	20	2	.	.	.	.	.	.	.	.
O	21	6	.	.	.	.	.	.	.	.
P	22	2	.	.	.	.	.	.	.	.
Q	23	2	.	.	.	.	.	.	.	.
R	24	.	.	.	.	.	.	.	.	.
S	25	1	.	.	.	.	.	.	.	.
T	26	1	.	.	.	.	.	.	.	.
U	27	3	.	.	.	.	.	.	.	.
V	28	4	4.81	0.91	0.38	0.75	0.51	.	.	.
W	29	4	0.76	0.28	0.28	0.34	0.81	.	.	.
X	30	2	1.43	0.24	0.53	0.30	1.78	.	.	.
Y	31	5	3.82	0.20	0.40	0.89	0.45	.	.	.
Z	32	5	2.02	0.27	0.46	0.31	1.49	.	.	.

Table A.3. Continued

Farm	HT	Age	Salinity		POM C			Water stable aggregates		
			HT	Field	HT	Field	HT : Field	HT	Field	HT : Field
			dS m^{-1}		g POM C : g total C			mean weight diameter		
AA	33	4	.	.	.	.	.	.	.	.
AB	34	3	2.99	0.27	0.28	0.29	0.96	.	.	.
AC	35	2	.	.	0.67	0.68	0.98	.	.	.
AD	36	10	.	.	0.43	0.35	1.26	.	.	.
AE	37	4	.	.	0.38	0.37	1.03	.	.	.
AF	38	5	2.89	0.18	0.32	0.24	1.33	0.86	0.44	1.95
AF	39	5	2.53	0.31	0.29	0.24	1.23	1.00	0.44	2.26
AG	40	.	.	.	.	.	.	.	.	.
AH	41	4	3.19	0.12	.	.	.	.	.	.
AI	42	5	0.60	0.33	.	.	.	.	.	.
AJ	43	7	0.25	0.29	.	.	.	3.52	3.09	1.14
AK	44	11	.	.	.	.	.	.	.	.
AK	45	7	1.98	.	0.32	0.22	1.47	.	.	.
AK	46	9	0.80	0.21	0.32	0.22	1.48	.	.	.
AK	47	4	0.73	.	.	.	.	.	.	.
AL	48	4	0.73	0.28	0.57	0.26	2.19	.	.	.
AM	49	9	1.25	0.14	0.40	0.32	1.26	4.05	1.98	2.05
AN	50	4	1.70	0.29	.	.	.	.	.	.
AO	51	5	1.15	0.13	0.31	0.18	1.73	.	.	.
AO	52	6	0.80	.	0.25	0.18	1.38	.	.	.
AO	53	6	0.40	.	0.57	0.18	3.17	.	.	.
AP	54	5	.	.	.	.	.	.	.	.
AQ	55	3	0.98	0.16	0.17	0.21	0.83	.	.	.
AR	56	3	4.40	0.29	0.44	0.30	1.46	.	.	.
AS	57	7	3.54	0.10	0.44	0.29	1.50	.	.	.
AS	58	8	1.98	.	0.49	0.29	1.67	.	.	.
AS	59	8	3.09	.	0.43	0.29	1.47	.	.	.
AS	60	5	0.77	.	0.35	0.29	1.18	.	.	.
AT	61	15	1.50	0.21	.	.	.	.	.	.
AU	62	2	.	.	.	.	.	.	.	.
AV	63	6	0.28	0.48	0.16	0.29	0.53	1.07	0.95	1.13
AW	64	4	1.79	0.44	0.58	0.65	0.88	.	.	.
AX	65	8	1.16	0.18	0.37	0.19	1.96	.	.	.
AX	66	5	1.07	.	0.35	0.19	1.83	.	.	.
AX	67	5	.	.	0.35	0.19	1.87	.	.	.
AY	68	14	2.30	0.13	.	.	.	.	.	.
AZ	69	8	.	.	.	.	.	.	.	.
AZ	70	2	.	.	.	.	.	.	.	.

Table A.3. Continued

Farm	HT	Age	Salinity		POM C			Water stable aggregates		
			HT	Field	HT	Field	HT : Field	HT	Field	HT : Field
			dS m^{-1}		g POM C : g total C			mean weight diameter		
BA	71	12	1.18	0.22	0.33	0.24	1.39	0.64	1.55	0.41
BB	72	4	1.98	0.24	0.46	0.15	3.11	4.07	3.30	1.23
BB	73	8	0.89	0.23	0.38	0.18	2.08	1.61	1.78	0.90
BC	74	3	0.90	0.47	.	.	.	.	.	.
BC	75	3	0.40	.	.	.	.	.	.	.
BC	76	1	0.23	.	.	.	.	.	.	.
BC	77	1	.	.	.	.	.	.	.	.
BD	78	3	0.37	0.09	0.17	0.21	0.82	.	.	.
BD	79	4	1.22	.	0.22	0.21	1.05	.	.	.
BE	80	6	1.03	0.26	0.39	0.34	1.15	.	.	.
BF	81	4	1.32	.	0.11	0.10	1.10	.	.	.
BG	82	7	1.11	1.10	0.18	0.36	0.49	3.78	0.79	4.80
BG	83	3	.	.	0.23	0.36	0.64	2.57	0.79	3.26
BH	84	5	.	.	0.25	0.18	1.40	.	.	.
BH	85	5	.	.	0.31	0.18	1.72	.	.	.
BI	86	3	0.91	0.33	0.22	0.43	0.51	.	.	.
BJ	87	4	.	.	.	.	.	.	.	.
BK	88	5	.	.	.	.	.	.	.	.
BL	89	4	1.99	0.15	0.29	0.22	1.31	.	.	.
BM	90	3	0.93	0.23	.	.	.	.	.	.
BN	91	6	0.23	0.24	0.44	0.55	0.79	.	.	.
BN	92	2	3.96	.	0.21	0.55	0.38	.	.	.
BO	93	3	3.21	0.53	0.15	0.18	0.86	.	.	.
BO	94	3	2.81	.	0.27	0.18	1.54	.	.	.
BP	95	3	1.73	0.36	.	.	.	.	.	.
BQ	96	10	2.00	0.20	0.45	0.19	2.45	1.81	1.88	0.97
BR	97	12	1.16	0.28	0.22	0.22	0.98	.	.	.
BS	98	2	0.60	0.24	0.28	0.12	2.33	1.07	3.42	0.31
BS	99	5	0.51	.	0.33	0.12	2.75	.	.	.
BT	100	8	.	.	.	.	.	.	.	.
BT	101	8	.	.	.	.	.	.	.	.
BU	102	3	0.98	0.26	0.34	0.31	1.11	.	.	.
BU	103	5	0.43	1.00	0.24	0.37	0.65	.	.	.
BV	104	6	0.60	0.34	0.37	0.27	1.39	.	.	.

Table A.3. Continued

Farm	HT	Age	Salinity		POM C			Water stable aggregates		
			HT	Field	HT	Field	HT : Field	HT	Field	HT : Field
			dS m^{-1}		g POM C : g total C			mean weight diameter		
BW	105	5	1.11	1.14	0.28	0.31	0.90	.	.	.
BX	106	3	2.21	0.17	0.19	0.14	1.38	.	.	.
BX	107	7	1.51	.	0.18	0.14	1.32	.	.	.
BX	108	9	.	.	0.12	0.14	0.88	2.04	0.63	3.24
BY	109	3	1.29	0.18	.	.	.	2.89	0.63	4.6
BY	110	4	1.64	0.13	0.45	0.16	2.81	1.62	0.63	2.58
BZ	111	4	0.23	0.12	0.23	0.23	1.01	.	.	.
CA	112	11	.	.	.	.	.	.	.	.
CB	113	11	.	.	.	.	.	.	.	.
CB	114	8	.	.	.	.	.	.	.	.
CB	115	8	.	.	.	.	.	.	.	.
CB	116	7	.	.	.	.	.	.	.	.
CB	117	3	.	.	.	.	.	.	.	.
CC	118	7	0.50	0.28	.	.	.	.	.	.
CD	119	3	1.10	0.36	0.41	0.37	1.11	3.55	2.69	1.32
CD	120	10	4.07	.	0.53	0.37	1.46	3.81	2.69	1.42
CE	121	4	0.44	0.19	0.36	0.38	0.96	.	.	.
CF	122	7	.	.	.	.	.	.	.	.
CG	123	2	.	.	.	.	.	.	.	.
CH	124	2	1.55	1.81	0.25	0.28	0.89	.	.	.
CI	125	3	1.31	0.27	0.22	0.38	0.57	.	.	.
CJ	126	3	0.92	1.63	0.31	0.14	2.31	.	.	.
CJ	127	4	1.56	.	0.33	0.14	2.41	.	.	.
CK	128	3	1.49	0.21	0.31	0.21	1.46	.	.	.
CL	129	7	2.35	0.38	0.29	0.14	2.11	2.59	1.25	2.07
CL	130	7	1.75	.	0.29	0.14	2.11	4.57	1.37	3.33
CM	131	2	.	.	0.45	0.28	1.59	.	.	.
CM	132	3	.	.	0.31	0.28	1.10	.	.	.
CN	133	.	0.34	0.16	.	.	.	.	.	.
CN	134	.	0.31	.	.	.	.	.	.	.
CN	135	.	0.16	.	.	.	.	.	.	.
CN	136	.	3.25	.	.	.	.	.	.	.
CN	137	.	1.89	.	.	.	.	.	.	.
CN	138	.	0.24	.	.	.	.	.	.	.
CO	139	.	1.44	0.29	.	.	.	.	.	.

Table A.4. Grower perception of general soil quality problems and observation of soil characteristics in the high tunnel compared to adjacent fields as measured by questionnaire response.

Farm	HT	Age	Problem	Clod	Crust	Mineral	Pan
A	1	.	.	.	.	.	.
B	2	.	.	.	.	.	.
C	3	3	.	.	.	.	.
C	4	11	.	.	.	.	.
C	5	3	.	.	.	.	.
C	6	11	.	.	.	.	.
D	7	.	.	.	.	.	.
E	8	.	No	.	.	.	.
F	9	11	.	.	.	.	.
F	10	3	.	.	.	.	.
F	11	3	.	.	.	.	.
G	12	.	.	.	.	.	.
G	13	.	.	.	.	.	.
H	14	1	.	No	No	No	No
I	15	1	Yes	No	No	No	other, not specified
J	16	1	.	No	No	No	No
K	17	1	not sure	No	Yes	.	No
L	18	11	No	No	No	No	No
M	19	1	not sure	.	No	No	other, not specified
N	20	2	No	No	No	No	other, not specified
O	21	6	No	Yes	No	Yes	No
P	22	2	No	No	No	No	other, not specified
Q	23	2	No	No	No	No	No
R	24	.	.	.	.	.	.
S	25	1	not sure	No	No	No	No
T	26	1	not sure	Yes	Yes	No	No
U	27	3	Yes	No	No	No	other, not specified
V	28	4	No	No	No	No	No
W	29	4	No	No	No	No	No
X	30	2	No	No	No	No	No
Y	31	5	not sure	No	Yes	Yes	8 inch
Z	32	5	.	.	.	.	.

Table A.4. Continued

Farm	HT	Age	Problem	Clod	Crust	Mineral	Pan
AA	33	4	.	No	Yes	No	No
AB	34	3	.	.	.	.	.
AC	35	2	not sure	No	No	No	other, not specified
AD	36	10	No	No	No	No	No
AE	37	4	No	No	No	Yes	No
AF	38	5	No	No	No	Yes	No
AF	39	5	No	No	No	Yes	No
AG	40	.	.	.	.	.	.
AH	41	4	.	Yes	No	Yes	No
AI	42	5	No	No	No	No	other, not specified
AJ	43	7	not sure	Yes	No	No	6 inch
AK	44	11	No	No	No	Yes	No
AK	45	7	No	No	No	Yes	No
AK	46	9	No	No	No	Yes	No
AK	47	4	No	.	.	.	.
AL	48	4	No	No	No	Yes	No
AM	49	9	No	No	No	No	4 inch
AN	50	4	Yes	No	No	Yes	18 inch
AO	51	5	No	No	No	No	6" also Field
AO	52	6	No	No	No	No	6" also Field
AO	53	6	No	No	No	No	6" also Field
AP	54	5	.	No	No	Yes	No
AQ	55	3	Yes	Yes	No	No	.
AR	56	3	.	Yes	No	.	No
AS	57	7	Yes	Yes	Yes	Yes	6 inch
AS	58	8	Yes	.	.	.	.
AS	59	8	Yes	.	.	.	.
AS	60	5	Yes	.	.	.	.
AT	61	15	.	.	.	.	8 inch
AU	62	2	.	No	No	No	No
AV	63	6	not sure	No	No	No	No
AW	64	4	Yes	No	No	Yes	6 inch
AX	65	8	.	No	No	Yes	.
AX	66	5	.	No	No	Yes	.
AX	67	5	.	No	No	Yes	.
AY	68	14	.	.	.	.	.
AZ	69	8	.	.	.	.	.
AZ	70	2	No	Yes	No	Yes	Pan

Table A.4. Continued

Farm	HT	Age	Problem	Clod	Crust	Mineral	Pan
BA	71	12	not sure	No	No	.	No
BB	72	4	Yes	Yes	Yes	Yes	4 inch
BB	73	8	Yes	Yes	Yes	Yes	4 inch
BC	74	3	No	.	.	.	.
BC	75	3	No	.	.	.	.
BC	76	1	No	.	.	.	.
BC	77	1	No	.	.	.	.
BD	78	3	No	No	No	No	No
BD	79	4	No	No	No	No	No
BE	80	6	Yes	No	Yes	Yes	No
BF	81	4	No	No	No	Yes	4 inch
BG	82	7	No	No	No	Yes	No
BG	83	3	No	No	No	Yes	No
BH	84	5	Yes	Yes	Yes	Yes	4 inch
BH	85	5	Yes	Yes	Yes	Yes	4 inch
BI	86	3	No	No	No	No	No
BJ	87	4	.	.	.	.	.
BK	88	5	.	No	No	Yes	No
BL	89	4	not sure	.	.	No	4 inch
BM	90	3	No	No	No	Yes	other, not specified
BN	91	6	Yes	No	No	Yes	No
BN	92	2	Yes	No	No	Yes	No
BO	93	3	not sure	No	No	No	No
BO	94	3	not sure	No	No	No	No
BP	95	3	.	.	.	.	.
BQ	96	10	not sure	No	No	No	No
BR	97	12	No	No	No	No	No
BS	98	2	No	No	No	No	No
BS	99	5	No	No	No	No	No
BT	100	8	.	.	.	.	.
BT	101	8	.	No	Yes	No	No
BU	102	3	No	No	No	No	No
BU	103	5	No	No	No	No	No
BV	104	6	not sure	No	No	No	No
BW	105	5	No	No	No	No	No
BX	106	3	not sure	No	No	No	No
BX	107	7	not sure	No	No	No	No
BX	108	9	not sure	No	No	No	No
BY	109	3	.	.	.	.	.
BY	110	4	not sure	No	No	No	No
BZ	111	4	3	No	.	Yes	Yes

Table A.4. Continued

Farm	HT	Age	Problem	Clod	Crust	Mineral	Pan
CA	112	11	.	No	No	Yes	No
CB	113	11	No	No	No	No	No
CB	114	8	No	No	No	No	No
CB	115	8	No	No	No	No	No
CB	116	7	No	No	No	No	No
CB	117	3	No	No	No	No	No
CC	118	7	.	No	No	No	No
CD	119	3	Yes	No	No	No	No
CD	120	10	Yes	No	No	No	No
CE	121	4	not sure	No	No	No	No
CF	122	7	.	Yes	No	No	No
CG	123	2	.	No	No	No	No
CH	124	2	No	No	No	No	No
CI	125	3	not sure	No	No	No	No
CJ	126	3	No	No	No	No	No
CJ	127	4	No	No	No	No	No
CK	128	3	No	No	No	No	No
CL	129	7	Yes	No	No	No	No
CL	130	7	Yes	No	No	No	No
CM	131	2	not sure	No	No	No	No
CM	132	3	not sure	No	No	No	No
CN	133	.	.	.	.	.	.
CN	134	.	.	.	.	.	.
CN	135	.	.	.	.	.	.
CN	136	.	.	.	.	.	.
CN	137	.	.	.	.	.	.
CN	138	.	.	.	.	.	.
CO	139	.	.	.	.	.	.

Appendix B - Spinach Experiments

Autumn planting date experiments

Table B.1. Harvest of spinach cultivar Avenger in autumn planting date study conducted in conventionally managed high tunnels at Olathe Kansas, in 2005-2006.

Planting date	Harvest date	Harvest day	Plot	Rep	Yield g	Leaf size inch	Observations
6-Oct-05	17-Nov-05	42	HC1	1	825		
6-Oct-05	17-Nov-05	42	HC2	2	750		
6-Oct-05	17-Nov-05	42	HC3	3	800		
6-Oct-05	1-Dec-05	56	HC1	1	550		
6-Oct-05	1-Dec-05	56	HC2	2	500		
6-Oct-05	1-Dec-05	56	HC3	3	600		
6-Oct-05	31-Jan-06	117	HC1	1	1497	5.5	
6-Oct-05	31-Jan-06	117	HC2	2	1610	5.5	
6-Oct-05	31-Jan-06	117	HC3	3	1520	6	
6-Oct-05	27-Mar-06	172	HC1	1	.		
6-Oct-05	27-Mar-06	172	HC2	2	1860		aphids
6-Oct-05	27-Mar-06	172	HC3	3	1089	4.5	aphids
11-Oct-05	1-Dec-05	51	HC1	1	825		
11-Oct-05	1-Dec-05	51	HC2	2	1050		
11-Oct-05	1-Dec-05	51	HC3	3	1250		
11-Oct-05	19-Jan-06	100	HC1	1	1338	7.25	
11-Oct-05	19-Jan-06	100	HC2	2	1792	7	
11-Oct-05	19-Jan-06	100	HC3	3	1656	6.75	
11-Oct-05	7-Feb-06	119	HC1	1	658	4.5	
11-Oct-05	7-Feb-06	119	HC2	2	680	3.75	
11-Oct-05	7-Feb-06	119	HC3	3	816	4.25	
11-Oct-05	27-Mar-06	167	HC1	1	.		
11-Oct-05	27-Mar-06	167	HC2	2	771		aphids
11-Oct-05	27-Mar-06	167	HC3	3	1066		aphids

Table B.1. Continued

Planting date	Harvest date	Harvest day	Plot	Rep	Yield g	Leaf size inch	Observations
25-Oct-05	24-Jan-06	91	HC1	1	1542	5.25	
25-Oct-05	24-Jan-06	91	HC2	2	1270	5.25	
25-Oct-05	24-Jan-06	91	HC3	3	1043	5	
25-Oct-05	16-Feb-06	114	HC1	1	1043	5	yellow, frost damage
25-Oct-05	16-Feb-06	114	HC2	2	544	5.25	frost damage
25-Oct-05	16-Feb-06	114	HC3	3	612	4	
25-Oct-05	27-Mar-06	153	HC1	1	885		aphids
25-Oct-05	27-Mar-06	153	HC2	2	1202		aphids
25-Oct-05	27-Mar-06	153	HC3	3	1179		aphids
3-Nov-05	8-Feb-06	97	HC1	1	1270	3.75	yellow leaves
3-Nov-05	8-Feb-06	97	HC2	2	1338	4	
3-Nov-05	8-Feb-06	97	HC3	3	1452	4.5	
3-Nov-05	27-Mar-06	144	HC1	1	1996	4	aphids
3-Nov-05	27-Mar-06	144	HC2	2	2132		aphids
3-Nov-05	27-Mar-06	144	HC3	3	2563	6	aphids
8-Nov-05	16-Feb-06	100	HC1	1	998	4.25	yellow, frost damage
8-Nov-05	16-Feb-06	100	HC2	2	1452	4.75	frost damage
8-Nov-05	16-Feb-06	100	HC3	3	1338	4.5	frost damage
8-Nov-05	27-Mar-06	139	HC1	1	.	6	aphids
8-Nov-05	27-Mar-06	139	HC2	2	1429		aphids
8-Nov-05	27-Mar-06	139	HC3	3	1678	4	aphids
17-Nov-05	16-Feb-06	91	HC1	1	1066	4.5	frost damage
17-Nov-05	16-Feb-06	91	HC2	2	363	4.5	heavy aphids
17-Nov-05	16-Feb-06	91	HC3	3	1021	5.25	
17-Nov-05	27-Mar-06	130	HC1	1	1066	4.5	aphids
17-Nov-05	27-Mar-06	130	HC2	2	1293	5	aphids
17-Nov-05	27-Mar-06	130	HC3	3	.		

Table B.2. Harvest of spinach cultivar Avenger in autumn planting date study conducted in organically managed high tunnels at Olathe Kansas, in 2005-2006.

Planting date	Harvest date	Harvest day	Plot	Rep	Yield g	Leaf size inch	Observations
6-Oct-05	17-Nov-05	42	HO1	1	700		
6-Oct-05	17-Nov-05	42	HO2	2	850		
6-Oct-05	17-Nov-05	42	HO3	3	1175		
6-Oct-05	1-Dec-05	56	HO1	1	475		
6-Oct-05	1-Dec-05	56	HO2	2	600		
6-Oct-05	1-Dec-05	56	HO3	3	750		
6-Oct-05	31-Jan-06	117	HO1	1	703	5.5	
6-Oct-05	31-Jan-06	117	HO2	2	1996	6	
6-Oct-05	31-Jan-06	117	HO3	3	1860	5.5	
6-Oct-05	27-Mar-06	172	HO1	1	.		
6-Oct-05	27-Mar-06	172	HO2	2	2381	6	aphids
6-Oct-05	27-Mar-06	172	HO3	3	1270		aphids
11-Oct-05	1-Dec-05	51	HO1	1	800		
11-Oct-05	1-Dec-05	51	HO2	2	900		
11-Oct-05	1-Dec-05	51	HO3	3	1225		
11-Oct-05	19-Jan-06	100	HO1	1	862	6.5	
11-Oct-05	19-Jan-06	100	HO2	2	1043	7	
11-Oct-05	19-Jan-06	100	HO3	3	1270	5.75	
11-Oct-05	7-Feb-06	119	HO1	1	204	3.5	
11-Oct-05	7-Feb-06	119	HO2	2	862	4.5	
11-Oct-05	7-Feb-06	119	HO3	3	680	4	
11-Oct-05	27-Mar-06	167	HO1	1	1746	4.5	aphids
11-Oct-05	27-Mar-06	167	HO2	2	1293	5	aphids
11-Oct-05	27-Mar-06	167	HO3	3	2427	4.5	aphids

Table B.2. Continued

Planting date	Harvest date	Harvest day	Plot	Rep	Yield g	Leaf size inch	Observations
25-Oct-05	24-Jan-06	91	HO1	1	1973	5.25	
25-Oct-05	24-Jan-06	91	HO2	2	1678	6	
25-Oct-05	24-Jan-06	91	HO3	3	1701	5	
25-Oct-05	16-Feb-06	114	HO1	1	1293	5.5	
25-Oct-05	16-Feb-06	114	HO2	2	862	4.75	frost damage
25-Oct-05	16-Feb-06	114	HO3	3	748	4.5	yellow
25-Oct-05	27-Mar-06	153	HO1	1	1520	4.5	aphids
25-Oct-05	27-Mar-06	153	HO2	2	1656	5.5	aphids
25-Oct-05	27-Mar-06	153	HO3	3	.		
3-Nov-05	8-Feb-06	97	HO1	1	340	4.5	aphids, yellow leaves
3-Nov-05	8-Feb-06	97	HO2	2	1406	3.75	yellow leaves
3-Nov-05	8-Feb-06	97	HO3	3	1588	4	yellow leaves
3-Nov-05	27-Mar-06	144	HO1	1	.		
3-Nov-05	27-Mar-06	144	HO2	2	1882	5.5	aphids
3-Nov-05	27-Mar-06	144	HO3	3	1066	4	aphids
8-Nov-05	16-Feb-06	100	HO1	1	771	4.75	yellow
8-Nov-05	16-Feb-06	100	HO2	2	1338	4	frost damage
8-Nov-05	16-Feb-06	100	HO3	3	1066	5	
8-Nov-05	27-Mar-06	139	HO1	1	1179	4.5	aphids
8-Nov-05	27-Mar-06	139	HO2	2	1814	4	aphids
8-Nov-05	27-Mar-06	139	HO3	3	1452	4.5	aphids
17-Nov-05	16-Feb-06	91	HO1	1	885	5	
17-Nov-05	16-Feb-06	91	HO2	2	816	4.25	
17-Nov-05	16-Feb-06	91	HO3	3	567	4.75	
17-Nov-05	27-Mar-06	130	HO1	1	885		aphids
17-Nov-05	27-Mar-06	130	HO2	2	1746	5	aphids
17-Nov-05	27-Mar-06	130	HO3	3	.		

Table B.3. Harvest of spinach cultivar PVO172 in autumn planting date study conducted in conventionally managed high tunnels at Olathe Kansas, in 2005-2006.

Planting date	Harvest date	Harvest day	Plot	Rep	Yield g	Leaf size inch	Observations
6-Oct-05	23-Nov-05	48	HC1	1	675		
6-Oct-05	24-Nov-05	49	HC2	2	825		
6-Oct-05	24-Nov-05	49	HC3	3	825		
6-Oct-05	19-Jan-06	105	HC1	1	1520	6.5	
6-Oct-05	19-Jan-06	105	HC2	2	1270	6.25	
6-Oct-05	19-Jan-06	105	HC3	3	885	5	
6-Oct-05	16-Feb-06	133	HC1	1	1520	4	
6-Oct-05	16-Feb-06	133	HC2	2	1270	4.25	
6-Oct-05	16-Feb-06	133	HC3	3	885	3.75	
6-Oct-05	27-Mar-06	172	HC1	1	1089	3.5	aphids
6-Oct-05	27-Mar-06	172	HC2	2	1520	3	aphids
6-Oct-05	27-Mar-06	172	HC3	3	454	4	aphids
11-Oct-05	24-Nov-05	44	HC1	1	525		
11-Oct-05	24-Nov-05	44	HC2	2	475		
11-Oct-05	24-Nov-05	44	HC3	3	525		
11-Oct-05	24-Jan-06	105	HC1	1	1520	5.5	
11-Oct-05	24-Jan-06	105	HC2	2	1270	5.5	
11-Oct-05	24-Jan-06	105	HC3	3	885	4.75	
11-Oct-05	16-Feb-06	128	HC1	1	1520	5.5	
11-Oct-05	16-Feb-06	128	HC2	2	1270	5.5	
11-Oct-05	16-Feb-06	128	HC3	3	885	4.75	
11-Oct-05	27-Mar-06	167	HC1	1	839	3	aphids
11-Oct-05	27-Mar-06	167	HC2	2	839	2	aphids
11-Oct-05	27-Mar-06	167	HC3	3	1338	4.5	aphids

Table B.3. Continued

Planting date	Harvest date	Harvest day	Plot	Rep	Yield g	Leaf size inch	Observations
25-Oct-05	24-Jan-06	91	HC1	1	1520	6	
25-Oct-05	24-Jan-06	91	HC2	2	1270	5.25	
25-Oct-05	24-Jan-06	91	HC3	3	885	4.5	
25-Oct-05	16-Feb-06	114	HC1	1	1520	4.25	yellow
25-Oct-05	16-Feb-06	114	HC2	2	1270	3.25	
25-Oct-05	16-Feb-06	114	HC3	3	885	4.25	
25-Oct-05	27-Mar-06	153	HC1	1	816	3.5	aphids
25-Oct-05	27-Mar-06	153	HC2	2	1089	3	aphids
25-Oct-05	27-Mar-06	153	HC3	3	726	4	aphids
3-Nov-05	8-Feb-06	97	HC1	1	1520	3.75	
3-Nov-05	8-Feb-06	97	HC2	2	1270	4.25	
3-Nov-05	8-Feb-06	97	HC3	3	885	4.75	light aphids
3-Nov-05	27-Mar-06	144	HC1	1	1066	3.5	aphids
3-Nov-05	27-Mar-06	144	HC2	2	1429	3	aphids
3-Nov-05	27-Mar-06	144	HC3	3	1724	4	aphids
8-Nov-05	16-Feb-06	100	HC1	1	1520	4	
8-Nov-05	16-Feb-06	100	HC2	2	1270	4	
8-Nov-05	16-Feb-06	100	HC3	3	885	4	
8-Nov-05	27-Mar-06	139	HC1	1	1179	4.5	aphids
8-Nov-05	27-Mar-06	139	HC2	2	1610	3	aphids
8-Nov-05	27-Mar-06	139	HC3	3	907	4	aphids
17-Nov-05	16-Feb-06	91	HC1	1	590	4	
17-Nov-05	16-Feb-06	91	HC2	2	181	4	sparse growth
17-Nov-05	16-Feb-06	91	HC3	3	839	4	
17-Nov-05	27-Mar-06	130	HC1	1	726	3	aphids
17-Nov-05	27-Mar-06	130	HC2	2	862	3	aphids
17-Nov-05	27-Mar-06	130	HC3	3	885	5	aphids

Table B.4. Harvest of spinach cultivar PVO172 in autumn planting date study conducted in organically managed high tunnels at Olathe Kansas, in 2005-2006.

Planting date	Harvest date	Harvest day	Plot	Rep	Yield g	Leaf size inch	Observations
6-Oct-05	24-Nov-05	49	HO1	1	1075		
6-Oct-05	24-Nov-05	49	HO2	2	975		
6-Oct-05	24-Nov-05	49	HO3	3	1275		
6-Oct-05	19-Jan-06	105	HO1	1	1066	5.75	
6-Oct-05	19-Jan-06	105	HO2	2	1066	6	
6-Oct-05	19-Jan-06	105	HO3	3	1406	7	
6-Oct-05	16-Feb-06	133	HO1	1	1066	3.75	heavy aphids
6-Oct-05	16-Feb-06	133	HO2	2	1066	5	
6-Oct-05	16-Feb-06	133	HO3	3	1406	4	yellow
6-Oct-05	27-Mar-06	172	HO1	1	.		
6-Oct-05	27-Mar-06	172	HO2	2	1565	4.5	aphids
6-Oct-05	27-Mar-06	172	HO3	3	953	4	aphids
11-Oct-05	24-Nov-05	44	HO1	1	950		
11-Oct-05	24-Nov-05	44	HO2	2	925		
11-Oct-05	24-Nov-05	44	HO3	3	625		
11-Oct-05	24-Jan-06	105	HO1	1	1066	5.75	
11-Oct-05	24-Jan-06	105	HO2	2	1066	5	
11-Oct-05	24-Jan-06	105	HO3	3	1406	4.5	
11-Oct-05	16-Feb-06	128	HO1	1	1066	5.75	
11-Oct-05	16-Feb-06	128	HO2	2	1066	5	
11-Oct-05	16-Feb-06	128	HO3	3	1406	4.5	sparse
11-Oct-05	27-Mar-06	167	HO1	1	.		
11-Oct-05	27-Mar-06	167	HO2	2	1837	5	aphids
11-Oct-05	27-Mar-06	167	HO3	3	.		

Table B.4. Continued

Planting date	Harvest date	Harvest day	Plot	Rep	Yield g	Leaf size inch	Observations
25-Oct-05	24-Jan-06	91	HO1	1	1066	4.75	
25-Oct-05	24-Jan-06	91	HO2	2	1066	4.25	
25-Oct-05	24-Jan-06	91	HO3	3	1406	5	
25-Oct-05	16-Feb-06	114	HO1	1	1066	4	aphids, sparse
25-Oct-05	16-Feb-06	114	HO2	2	1066	4	
25-Oct-05	16-Feb-06	114	HO3	3	1406	3.75	heavy aphids
25-Oct-05	27-Mar-06	153	HO1	1	.		
25-Oct-05	27-Mar-06	153	HO2	2	1520	4.5	aphids
25-Oct-05	27-Mar-06	153	HO3	3	748	4	aphids
3-Nov-05	8-Feb-06	97	HO1	1	1066	4.75	light aphids
3-Nov-05	8-Feb-06	97	HO2	2	1066	4.75	
3-Nov-05	8-Feb-06	97	HO3	3	1406	4.25	heavy aphids
3-Nov-05	27-Mar-06	144	HO1	1	.		
3-Nov-05	27-Mar-06	144	HO2	2	1928	5	aphids
3-Nov-05	27-Mar-06	144	HO3	3	.		
8-Nov-05	16-Feb-06	100	HO1	1	1066	4.25	
8-Nov-05	16-Feb-06	100	HO2	2	1066	4	
8-Nov-05	16-Feb-06	100	HO3	3	1406	3.5	
8-Nov-05	27-Mar-06	139	HO1	1	1338	4	aphids
8-Nov-05	27-Mar-06	139	HO2	2	1905	5	aphids
8-Nov-05	27-Mar-06	139	HO3	3	1066	3	aphids
17-Nov-05	16-Feb-06	91	HO1	1	340	3.75	aphids, sparse growth
17-Nov-05	16-Feb-06	91	HO2	2	363	3.75	
17-Nov-05	16-Feb-06	91	HO3	3	590	3.75	
17-Nov-05	27-Mar-06	130	HO1	1	.		
17-Nov-05	27-Mar-06	130	HO2	2	975	5	aphids
17-Nov-05	27-Mar-06	130	HO3	3	1111	2.5	aphids

Spinach cultivar comparison

Table B.1. Germination of spinach cultivars in a Haygrove high tunnel in 2005. The left column is the first row on the west edge of the bay.

(North side of Haygrove, second bay from the west)

Samish	62	Interceptor	112	Tigercat	62	C2-606	62	Hellcat	62	Umbria	62
Space	87	C2-606	62	C1-601	35	Highpack	62	Samish	62	Tyee	62
Lombardia	87	Umbria	62	Falcon	62	C1-608	62	C2-607	35	Springer	62
Falcon	62	C2-605	35	Springer	35	Spinner	35	Melody	62	PVO172	112
Spinner	62	Tyee	62	PVO170	62	Blackhawk	62	PVO170	87	Avenger	62
Tigercat	62	Emilia	87	C2-605	35	Space	87	Lombardia	87	Blackhawk	62
PVO170	112	PVO172	112	Samish	35	Baker	35	Space	87	Interceptor	87
Olympia	62	Baker	62	PVO172	87	Hellcat	87	Spinner	62	Emilia	62
Melody	87	Blackhawk	62	Bloomsdale	62	Emilia	62	Falcon	35	Baker	62
Highpack	62	Springer	35	Umbria	62	Lombardia	62	Olympia	62	C2-606	62
Hellcat	62	C1-601	62	Olympia	62	Interceptor	87	Tigercat	62	C1-601	62
Bloomsdale	87	C1-608	62	Avenger	62	C2-607	35	Bloomsdale	62	C1-608	62
C2-607	35	Avenger	62	Melody	35	Tyee	35	Highpack	35	C2-605	35
Hungnong	87	Hector		--		Hector	35	--		Hector	5

Spinach was planted in a 10 ft^2 plot with a seeder potentially supplying a seed per inch of row, with eight rows per bed. Ordering in columns indicates plot layout in to six beds.