Soil Quality Factors Affecting Garlic Production – Progress Report
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Sustane 4-6-4 organic fertilizer applied at 1.88 tons* per acre produced garlic yields comparable or better than U of M composted cow manure applied at 32 tons* per acre. Sustane 4-6-4 also produced garlic yields comparable or better than the inorganic fertilizer treatment.

*Sustane 4-6-4 x 1.88 tons per acre = 135 lb N – 203 lb P_2O_5 – 135 lb K_2O vs.
*U of M compost x 32 tons per acre = 780 lb N – 320 lb P_2O_5 - 64 lb K_2O vs.
*Inorganic fertilizer applied = 120 lb N – 25 lb P_2O_5 – 120 lb K_2O

The recent increased demand for high quality garlic has prompted an interest in growing garlic as an alternative crop in Minnesota. Prior to 1990, less than 1000 lbs. were produced in Minnesota. In 1994, over 25,000 lbs. were produced. A garlic yield of 7,000 to 10,000 lbs. Per acre is achievable depending on spacing and management. Most market gardeners in Minnesota currently plant up to ½ acre. With wholesale prices pf $2.00 to $4.00 per lb. Of garlic, the potential for improving farm profitability is enormous. Garlic in Minnesota and the upper Midwest can be grown with minimal chemical inputs. Because of few insect and disease related problems, garlic is a crop that is especially suited for organic production. Insecticides are rarely if ever needed and diseases can be controlled by using clean seed stock and proper rotation. The two most important problems associated with organic garlic production are weed control and soil fertility. Weeds can be controlled mechanically and by using appropriate cover crops. More questions exist regarding optimum soil requirements for garlic.

In Preliminary trials conducted at the Staples Irrigation Center in central Minnesota on a low organic matter soil, garlic production was poor, even with fertilizer additions. This circumstantial evidence suggests that soil organic matter plays an important role in producing marketable garlic. The importance of organic matter may be due to improving soil biological, chemical and physical properties.

Sustainable crop production requires knowledge of soil nutrient supplying capacity and nutrient requirements of the crop. For many nutrients, the supplying capacity of the soil can be estimated by using appropriate soil test procedures and is the basis for deciding on what fertilizer nutrients need to be applied. Various practices such as green manuring can be used to increase soil organic matter, nutrient availability, and soil nutrient cycling. Amending soils with composted manure can also be used to increase nutrient availability and replace nutrients removed with sale of the crop.

Release of nutrients from the soil organic component, particularly nitrogen, is dependent on microbial activity and difficult to measure with routine soil tests. More recent tests developed to measure microbial activity and microbial biomass nitrogen and carbon may provide further insights into the productivity of a soil for sustainable crop production. An estimate of the availability of nutrients from organic amendments and soil organic matter is essential to meet crop needs and avoid environmental problems due to over fertilization. Even though this project is specifically related to garlic production, the effects of organic amendments on microbial activity and nutrient release will be applicable to other cropping systems.

The overall objectives of this project are to: 1.) Characterize garlic growth in two contrasting soil types – one with low native soil organic matter and one with high soil organic matter. 2.) Determine the effects of various amendments on soil chemical and biochemical properties and garlic growth in these two contrasting soils. 3.) Identify management strategies that optimize garlic production in Minnesota.

Based on soil characterization, we hope to determine what, if any, soil inputs are needed for sustainable garlic production. An overall accomplishment will be to obtain better precision in defining the rate of input requires.

Materials and Methods

<u>Site Selection and description:</u> Two sites were selected based on initial soil characterization and willingness of the growers to participate in the study. The same locations will be used to repeat the study for the 1996/7 growing season. Garlic will not be planted in the exact same area, but will be rotated to an area adjacent to the plots used in 1995/6.

One site is located in Gutches Grove, Minnesota and the soil is mapped as a Kandota sandy loam (46 % sand, 47 % silt, and 7 % clay). Initial soil tests indicate a high organic matter content of 5 to 6% and relatively high level of available nutrients (Table 1). This site is owned and operated by Phil Arnold, an organic grower, and has been in a grass-legume cover of the past five years. During the summer of 1995, buckwheat was planted as a green manure and 2.68 dry tons/A were plowed in at the end of August.

The other site selected for the study is located in Cannon Falls, Minnesota and the soil is mapped as Spartan loamy fine sand (84 % sand, 11 % silt, and 5 % clay). Initial soil tests indicate a low organic matter content of 1 to 2 % and relatively low levels of available nutrients (Table 1). This site is owned and operated by Joel Girardin, a part-time grower of grapes and vegetables. This site has been in a grass cover for the past five years. During the summer of 1995, snap beans were planted and harvested, followed by a green manure of buckwheat. The buckwheat was plowed in (0.61 dry tons/A in the middle of September.

Treatments: Three treatments were tested at the Gutches Grove site and four Treatments were tested at the Cannon Falls site. Three treatments common to each site were: 1) nonamended control, 2) application of composted animal manure based on its nitrogen content and estimated availability and 3) application of inorganic fertilizer based on a soil test.

The composted manure was produced at the University of Minnesota (UM) animal operations and is a mixture of cow, sheep, and hog manure. The bedding consisted of woodchips and straw. The manure and bedding was composted for 12-14 months before use. A complete elemental analysis of the manure is provided in Table 2. The C/N ratio of the compost just before application was 15 indicating relatively stable compost. The nitrogen content was about 1.2% lb. a dry weight basis.

Application of the compost was based on an assumed N availability of 30% the first year after application.

At the Gutches Grove site, soil levels of P and K were in the high range so that no further additions of these nutrients were made for the inorganic fertilizer treatment. Only fertilizer N was applied at the rate of 80 lb. N/A. The N fertilizer was split applied as described below (Table 3).

At the Cannon Falls site, an additional manure compost treatment was evaluated. The compost used was Suståne locally available aerobically composted turkey litter compost, Certified for organic production called Sustane (4-6-4). The compost is dried and has a much higher N content than the animal manure compost produced by the University of Minnesota. The compost was applied based on its N content and an assumption of 80 % availability the first year. The rate applied was 1.88 dry tons/A. While Sustane is considered an organic fertilizer, it will not increase soil organic matter content to the extent the UM manure compost will because of lower application rates. For the inorganic fertilizer treatment, P (25 lb. P_2O_5/A), K (125 lb. K_2O/A), and B (1 lb./A) fertilizer were broadcast applied in the fall according to soil test recommendations. The total N rate, 120 lb. N/A, was split applied (Table 3).

Planting and cultural procedures: In cold climates, garlic should be planted in the fall for optimum production. Garlic was planted 27 September 1995 at Gutches Grove and 11 October 1995 at Cannon Falls. Each plot was 10 feet wide and 20 feet in length. Spacing within rows was 6 inches and 30 inches

between rows. This spacing was somewhat wider than conventionally grown garlic, but this spacing allowed for easier mechanical weed control. Thus, each plot consisted of four 20 ft. rows. The middle two rows were the harvest rows. Treatments were applied by hand at each site just prior to planting and incorporated to a depth of 6" with a rototiller. All the Um compost was applied before planting. Only a portion of the inorganic N and the Sustane was applied before planting (see Table 3). The inorganic N source used in the fall was ammonium sulfate.
The variety of garlic grown was a Rocambole purchased from Merrifield Farms in New York. This variety was selected based on grower input. For each plot, the garlic cloves were weighed to that the final yield could be related to the weight of the garlic planted. Garlic cloves were planted by hand and then mulched with straw. The straw mulch is needed for winter protection and was removed in the spring – 10 April at Cannon Falls and 18 April at Gutches Grove. The mulch was completely removed from the plots, soil was allowed to warm for one month and then mulch was placed between each row for weed control. Weeds were controlled by hand at each site.

The remainder of the inorganic N and Sustane was applied immediately after mulch removal in the spring. The inorganic N source in the spring was ammonium nitrate.

<u>Sample Collection and Measurements:</u> Fall 1995 – Soil samples were collected to initially characterize each site. The following determinations were made: pH, organic matter, extractable nitrate and ammonium, extractable P, K, Ca, Mg, S, B, Fe, Cu, Mn and Zn (Table 1). Moist soil samples were incubated and microbial biomass carbon and nitrogen were determined (fumigation/incubation method following procedures of Jenkinson and Powlson, 1976, Soil Biol. Biochem. 8:209-213). Green manure was sampled before plowing to estimate the quantity of nutrients recycled to the soil surface.

Spring 1996 – In mid-May, soil samples were collected to the 6-inch depth from each plot. Microbial biomass N and C were determined.

Summer 1996 – The youngest fully elongated leaf was sampled for nutrient analysis at initial bulbing, before scape removal – 7 June at Cannon Falls and 18 June at Gutches Grove. Samples were dried and then ground. The following nutrient determinations were made using ICP procedures: P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, B, and Mo. Total N was determined using Kjeldahl procedures.

An additional treatment was imposed to determine the effect of scape removal. One of the harvest rows was selected for scape removal and in the other harvest row, scapes were allowed to grow until harvest. Scapes were removed 27 June at Cannon Falls and 10 July at Gutches Grove. Scapes were dried, weighed and then ground for N determination.

On 29 July 1996 at Cannon Falls and 30 July at Gutches Grove, garlic was harvested by hand from the middle two, 10 feet row from each plot. The garlic was bunched and allowed to dry for 3 to 4 weeks. Remaining scapes were harvested, dried, weighed and then ground for N determination. After drying, roots were trimmed and shoot mass and bulb yield and graded quality were recorded. Subsamples of shoots and bulbs were collected for dry matter determination and total N analysis.

Statistical Design: At each site, a split plot design was used with three replications. Main plots were amendment treatment and subplots were scape treatment. These same treatments will be repeated in 1996/7 season.

Results

Green Manure Nutrient Content: The total content of nutrients in the green manure plowed down in the fall of 1995 at each site is presented in Table 4. Because crop at Cannon Falls was immature, the green manure contained relatively low amounts of nutrients. In contrast, at Gutches Grove the buckwheat was past flowering stage and significant amounts of nutrients were cycled into top six inches of soil.

Soil biochemical characterization: Initial levels of microbial biomass nitrogen and carbon are presented in Table 5. The Gutches Grove site had much higher levels of microbial biomass N and C compared to the Cannon Falls site. These results were somewhat predictable since the Gutches Grove site had 4 to 5 times the level of organic matter and had also been part of a significant soil building program over the last 5 years. Microbial biomass C and N as affected by treatments are presented in Table 6. As with the initial readings, the Gutches Grove site had greater levels of microbial biomass C and N compared to Cannon Falls. Treatment effects were inconsistent between sites and did not appear to change in a predictable manner.

Garlic Yield and quality – Cannon Falls: Rainfall was minimal during July 1996. Because of the lack of rain, the sandy nature of the soil at the Cannon Falls location, and lack of irrigation capabilities, the garlic crop was stressed during the bulbing stage. Bulb yields ranged from a low of 34 cwt/A to a high of 50 cwt/A (Table 7). Overall treatments tested did not significantly affect yield, although total bulb yield and bulb size tended to be higher with the Sustane compost treatment. Bulb yield increased by about 600 lbs/A when scapes were removed about 4 weeks before harvest compared to leaving the scapes on until harvest. In the control treatment, the difference was more dramatic with a yield loss of 1200 lbs/A when scapes were not removed. The decision to remove the scapes must be made in terms of a marketing context. If there is a market for the bulbils from mature scapes, then it may be beneficial to sacrifice bulb yield. On the other hand, if the scapes are discarded, then removal would be recommended, especially on soils with low fertility. The ratio of lbs garlic produced to lbs garlic planted ranged from 4 to 6, with higher ratios obtained when scapes were removed.

Dry mass production of scapes, shoots and bulbs are presented in Table 8. Soil treatments did not significantly affect dry mass production except for the fertilizer treatment which tended to decrease scape dry mass. The effect of scape removal was significant, with higher bulb dry mass when scapes were removed. Of interest is the fact that total dry mass was not affected by scape removal. The decrease in bulb dry mass when scapes were removed was offset by an increase in shoot and scape dry mass when scapes were not removed.

<u>Garlic yield and quality – Gutches Grove:</u> Rainfall was also limiting at Gutches Grove, but since the soil has a higher water holding capacity compared to the Cannon Falls soil, water stress was not apparent. Total bulb yield ranged from 63 cwt/A to 71 cwt/A (Table 9). The additional fertilizer tended to increase bulb size, but not total bulb yield. Scape removal tended to increase total bulb yield by 350 lb/A; however, when only the larger bulb size is considered, scape removal depended on soil amendment. The effect of scape removal was most dramatic in the nonamended soil, where leaving the scape on resulted in a 11% total bulb yield reduction and a 33% reduction in the large size bulbs. In contrast, the scape removal had minimal effects on total bulb yield or bulb size when compost or fertilizer was added. Coupled with the Cannon Falls findings where plants were water stressed, the results at Gutches Grove suggest that scape removal is important if the crop is stressed in some manner. If nutrients/water are limiting, then the effect of leaving the scape on will be to act as a sink at the expense of the bulb. The ratio of lbs garlic produced to lbs garlic planted ranged from 7 to 8, with higher ratios obtained when scapes were removed.

Dry mass production of scapes, shoots, and bulbs are presented in Table 10. Soil treatments did not significantly affect dry mass production. The effect of scape removal was significant, with higher bulb dry mass when scapes were removed. Similar to the results at Cannon Falls, total plant dry mass was not affected by scape removal. The increase in bulb dry mass when scapes were removed was offset by an increase in scape dry mass when scapes were not removed.

<u>Garlic yield in relation to soil quality factors:</u> Even though the soil amendments used in this study within each site has minimal effects on garlic yield, the differences in yield between soil types/location was dramatic. Yields at Gutches Grove were about 35% higher than those at Cannon Falls. While climatic factors are confounded with soil factors in this study, some of the differences in yield between the two sites can likely be attributed to soil. The higher water holding capacity of the Gutches Grove soil enabled the crop to withstand drought conditions. In a preliminary sense, microbial biomass carbon and nitrogen seem to be good indicators of soil quality as they were

both at higher levels at the Gutches Grove site. Plans in 1997 are to provide irrigation at the Cannon Falls site to eliminate differences due to water availability.

Table 1. Initial Soil Test Results – means of 3 samples (0-6" depth)

Site	NO3-N	NH4 -N	OM	pH	P ppm	K ppm	Ca ppm	Mg ppm	S ppm	Fe ppm	Mn ppm	Cu ppm	Zn ppm	B ppm
Gutches Grove	8	3	5.0	7.0	180	210	2100	260	5	99	8	0.9	9	1
Cannon Falls	10	1	1.4	6.9	50	85	790	119	4	19	7	0.3	3	0.4

Table 2. Initial UM Compost Analysis – means of 3 samples.

Property	
Total Organic Carbon (%)	18.8
Total N (%)	1.22
C/N ratio	15.4
Nitrate-N (ppm)	260
Ammonium-N (ppm)	193
P (ppm)	5198
K (ppm)	9476
Ca (%)	4.92
Mg (%)	2.15
Na (ppm)	1048
Fe (ppm)	3301
Mn (ppm)	367
Zn (ppm)	100
Cu (ppm)	20
B (ppm)	15
pH	7.7
EC mmhos.cm	8.6
Moisture (%)	43.2

Table 3. Summary of treatments and rates applied (acre equivalent) at each Location.

	Location	
	Gutches Grove	Cannon Falls
Treatment	--------------------rate applied[z]----------------	
Nonamended	----	----
UM Compost[y] 34 tons per acre	22 T/A	34 T/A = 64,000 lb. = 780 lb N/A 320 lb P_2O_5/A 64 lb K_2O /A
Inorganic Fertilizer	50 lb N/A (fall applied) 30 lb N/A (spring applied)	50 lb N/A (fall applied) 70 lb N/A (spring applied) 25 lb P_2O_5/A (fall applied) 125 lb K_2O/A (fall applied) 1 lb B/A (spring applied)
Sustane[x] 1.88 tons per acre	na[w]	0.63 T/A (fall applied) 1.25 T/A (spring applied) = 2,376 lb total per acre Total applied Sustane = 135 lb N/A 203 lb P_2O_5/A 135 lb K_2O/A

[z]The lower amendment rates applied to the Gutches Grove site reflect anticipated release of nitrogen and other nutrients from the soil organic matter.
[y]UM compost application rates were based on wet tons (56% moisture content)
[x]Sustane application rate was based on dry tons.
[w]na=not applied at this site.

Table 4. Nutrient content of buckwheat green manure plowed into each site prior to planting. Dry matter yield at Cannon Falls was 0.61 T/A and 2.68 T/A at Gutches Grove.

Site	N lb/A	P_2O_5 lb/A	K_2O lb/A	Ca lb/A	Mg lb/A	S lb/A	Fe oz/A	MN Oz/A	Cu Oz/A	Zn Oz/A	B Oz/A
Cannon Falls	39	12	47	24	15	3	3	1	0.1	0.9	0.3
Gutches Grove	102	84	228	69	30	10	9	11	0.5	3	2

Table 5. Initial microbial biomass carbon and nitrogen at each site. Samples were collected prior to planting. Means of 3 samples.

Site	Biomass Carbon ppm	Biomass Nitrogen ppm
Gutches Grove	702	39
Cannon Falls	227	4

Table 6. Microbial biomass carbon and nitrogen as affected by treatment. Samples were collected in May 1996. Means of 3 samples.

Treatment	Cannon Falls		Gutches Grove	
	Biomass C	Biomass N	Biomass C	Biomass N
	-------ppm--------		-------ppm--------	
Control	261	35	726	41
U of M Compost	270	29	583	41
Inorganic Fertilizer	278	23	820	49
Sustane	329	17	----	--

Table 7. Effect of soil amendments and scape removal on garlic yield and quality, scape yield, and ratio of bulb yield to seed input – Cannon Falls.

			Garlic Fresh Yield					
Treatment	Scape	Culls	<1.5"	1.5-2"	2-2.5"	>2.5	Total Bulb	lb yield / lb used
	--------------------------			cwt/A			--------------------------	
Control-S	7.2	1.5	0.2	13.0	22.0	9.5	46.2	5.4
Control+S	14.2	2.8	0.5	12.0	16.4	2.0	33.7	4.0
34 tons compost-S	6.3	2.0	0.0	8.6	28.1	7.3	46.0	5.3
34 tons compost+S	14.3	0.7	2.0	6.2	27.1	6.8	42.8	4.9
Fertilizer-S	4.4	2.2	0.0	4.5	33.9	4.6	45.2	5.4
Fertilizer+S	12.0	7.4	0.0	7.6	23.9	1.2	40.1	4.8
1.88 ton Sustane-S	7.8	5.4	0.2	4.3	22.8	17.5	50.2	5.9
1.88 ton Sustane+S	15.8	1.5	0.0	8.6	28.2	8.6	46.9	5.5
Pr>F	**	NS	NS	*	NS	++	**	**
Main Effects by Treatment								
Control	10.6	2.1	0.3	12.5	19.2	5.8	39.9	4.7
U of M compost	10.3	1.4	1.0	7.4	27.6	7.1	44.5	5.1
Fertilizer	8.2	4.8	0.0	6.1	28.9	2.9	42.7	5.1
Sustane	11.8	3.5	0.1	6.5	25.5	13.0	48.6	5.7
Significance	*	NS	NS	NS	NS	NS	NS	NS
Scape								
Removed	6.4	2.8	0.1	7.6	26.7	9.7	46.9	5.5
Not removed	14.1	3.1	0.6	8.6	23.9	4.7	40.9	4.8
Significance	**	NS	NS	NS	NS	+	*	NS
Interaction								
Treatment * Scape	NS	+	NS	NS	NS	NS	NS	NS

NS = nonsignificant, **,*,++,+=significant at 1%, 5%, 10%, and 20% respectively.

Table 8. Effect of soil amendments and scape removal on garlic dry matter production- Cannon Falls.

Garlic Dry Yield	Scape	Shoots	Bulbs	Total
	-----------------------cwt/A----------------------------			
control-S	1.92	2.66	24.3	28.9
control+S	4.58	2.86	18.4	25.8
34 tons / A compost-S	1.73	2.76	24.0	28.5
34 tons / A compost+S	4.55	2.99	23.3	30.8
Fertilizer-S	1.15	2.61	23.8	27.6
Fertilizer+S	3.79	2.82	21.7	28.3
1.88 ton / A Sustane-S	1.98	2.89	25.5	30.4
1.88 ton / A Sustane+S	4.72	2.92	24.0	31.6
Pr>F	**	*	*	*
Main Effects by Treatment				
Control	3.25	2.76	21.4	27.4
U of M compost	3.14	2.88	23.6	29.6
Fertilizer	2.47	2.72	22.8	28.0
Sustane	3.35	2.90	24.7	31.0
Significance	**	NS	NS	NS
Scape				
Removed	1.70	2.73	24.4	28.8
Not removed	4.41	2.90	21.8	29.1
Significance	**	++	*	NS
Interaction				
Treatment * Scape	NS	NS	NS	NS

NS= nonsignificant, **,*,++,+=significant at 1%, 5%, 10%, and 20% respectively.

Table 9. Effect of soil amendments and scape removal on garlic yield and quality, scape yield, and ratio of bulb yield to seed input – Gutches Grove.

		Garlic Fresh Yield						
Treatment	Scape	Culls	<1.5”	1.5-2”	2-2.5”	>2.5	Total Bulb	lb yield / lb used
	---------------------------------cwt/A---------------------------------							
Control-S	14.7	10.3	-	0.0	17.4	43.0	70.7	8.2
Control+S	23.5	4.7	-	1.3	27.4	29.3	62.7	7.3
U of M compost-S	11.8	3.4	-	0.5	26.4	37.4	67.7	7.3
U of M compost+S	23.8	4.9	-	0.0	26.3	36.5	67.7	7.3
Fertilizer-S	14.3	7.5	-	0.0	20.4	40.6	68.5	7.8
Fertilizer+S	24.7	3.2	-	0.7	13.9	48.4	66.2	7.5
Pr>F	**	NS	-	NS	NS	+	NS	+
Main Effects								
Treatment								
Control	19.1	7.5	-	0.7	22.4	36.1	66.7	7.7
compost	17.8	4.1	-	0.3	26.4	37.0	67.8	7.3
Fertilizer	19.5	5.3	-	0.4	17.1	44.4	67.2	7.6
Significance	NS	NS	-	NS	++	+	NS	NS
Scape								
Removed	13.6	7.1	-	0.2	21.4	40.3	69.0	7.7
Not removed	24.0	4.2	-	0.7	22.5	38.1	65.5	7.4
Significance	**	NS	-	NS	NS	NS	++	+
Interaction								
Treatment * Scape	NS	NS	-	NS	+	++	NS	+

NS = nonsignificant, **,*,++,+=significant at 1%, 5%, 10%, and 20% respectively.

Table 10. Effect of soil amendments and scape removal on garlic dry matter production- Gutches Grove.

	Garlic Dry Yield			
	Scape	Shoots	Bulbs	Total
	-----------------------cwt/A---------------------------			
control-S	3.51	3.94	35.1	42.6
control+S	5.81	3.65	31.4	40.9
compost-S	2.71	3.63	33.2	39.5
compost+S	5.81	3.80	32.4	42.1
Fertilizer-S	3.30	3.75	33.7	40.8
Fertilizer+S	5.89	3.66	31.2	40.8
Pr>F	**	+	+	+
Main Effects				
Treatment				
Control	4.66	3.79	33.2	41.7
Compost	4.26	3.72	32.8	40.8
Fertilizer	4.59	3.70	32.5	40.8
Significance	NS	NS	NS	NS
Scape				
Removed	3.17	3.77	34.0	40.9
Not removed	5.83	3.70	31.7	41.2
Significance	**	NS	*	NS
Interaction				
Treatment * Scape	+	+	NS	NS

NS= nonsignificant, **,*,++,+=significant at 1%, 5%, 10%, and 20% respectively