Bulb size can be larger than 2 inches following a mild winter. Because of their weak necks, the plants will lay down (lodge) about one week before harvest (Figure 6). Bulb size can sometimes be improved by planting early in the spring as soon as the ground thaws. Clove skins are somewhat tight making peeling difficult. Bulbs typically can be stored for up to one year.

- Typical named selections include: Silver White, Nookota Rose, Mild French, S&H Silver, Idaho Silver

Note: Elephant garlic is not a true garlic, but is actually a type of leek, *Allium ampeloprasum*. It can grow much larger than true garlic with each bulb of five to six cloves weighing as much as one pound. The taste of elephant garlic is much milder than true garlic, and in cold climates can develop a sharp or bitter taste.

Soils

Site selection and organic matter

Garlic grows best on well-drained soils high in organic matter. Sandy loam or loam soils have the most ideal texture for garlic. Drought or excessively wet conditions (i.e. low spots) will reduce yields and marketable bulbs. Planting site should be located in an area with well drained soils. Garlic can be planted on gentle slopes along the contour. Raised beds can be used to facilitate good drainage as well particularly on clay or heavy soils.

Use of a green manure crop such as buckwheat, oats, and field peas or other legumes tilled in a few weeks before planting is recommended to improve soil physical properties. There are many options for cover crops, for further information see: https://extension.umn.edu/cover-crops/planting-cover-crops. Well-composted manure applied and incorporated at a rate of 20-30 tons/acre (1000-1500 lb per 1000 sq. ft.) has also been shown to be ideal as a soil amendment, especially on low organic matter soils. Care should be taken not to over-apply compost as phosphorus in particular can build up to excessive levels.

pH requirements

The optimum soil pH for garlic is between 6 and 7, though a wider range can be tolerated, between 5.5-7.8 pH. Liming is recommended if the pH is less than 5.8. Rates to apply and incorporate should be based on soil test recommendations. There are resources available through Extension to adjust soil pH.

Fertilizer requirements

Nitrogen

Garlic has a moderate to high demand for nitrogen. Recommendations for nitrogen are based on previous crop and organic matter content (Table 1). Reduce recommended rates of nitrogen by: 70 lb N/acre if the previous crop is alfalfa, 40 lb N/acre if the previous crop is clover, and 20 lb N/acre if the previous crop is soybean or peas.

For quick release nitrogen sources like urea, ammonium sulfate, chilean nitrate, or blood meal, about one-third to one-half of the recommended N should be broadcast and incorporated in the fall before planting. The remainder of the N should be top-dressed and watered in one to two weeks after emergence in the spring. Bulbing may be delayed if high rates of nitrogen are applied late in the spring. For slow release sources like manure, composted manure or polymer-coated urea, most of the nitrogen can be applied in the fall before planting. If manure or compost has been applied, be sure to take credit for the nutrient value of these amendments. Obtaining a nutrient analysis of these organic amendments before application is strongly recommended. Additional N may not be needed in the spring if adequate amounts of compost or other slow release sources have been applied in the fall. Benefits of spring nitrogen application depend on the type of soil. Sandy low organic matter soils will benefit from a spring application more than clayey high organic matter soils.

Symptoms of nitrogen deficiency include a yellowing of older leaves and leaf tips, general yellowing of the plant, poor vigor, and low yields. Comparison of nitrogen deficient and nitrogen sufficient plants is shown in Figures 7 and 8. See note below about yellow tips.

Figure 7. Garlic plants with sufficient nitrogen.

Figure 8. Garlic plants with insufficient nitrogen. Note yellowing.

Table 1. Nitrogen recommendations for garlic.

Soil Organic Matter Level (% O.M.)	Nitrogen to apply (lb/acre)
Low (<3.1%)	120
Medium (3.1-4.5%)	100
High (4.6-19%)	80
Organic soil (>19%)	50

Phosphorus and potassium

Soil tests should be taken before planting to determine phosphorus and potassium needs. Recommendations for phosphorus based on a soil test are provided in Table 2. Use the Bray P1 test if soil pH is 7.4 or less and use the Olsen test if soil pH is greater than 7.4. Recommendations for potassium based on a soil test are provided in Table 3. All P and K fertilizers should be incorporated before planting. Symptoms of P deficiency include dark green to purple leaves and stunted growth. Symptoms of K deficiency include marginal scorching of the older leaves.

Table 2. Phosphate fertilizer guidelines for garlic based on either the Bray-P1 or Olsen soil methods test.

Bray-P1 (soil pH is 7.4 or less)	0-10 ppm	11-20 ppm	21-30 ppm	31-40 ppm	41-50 ppm	51+ ppm
Olsen (soil pH is 7.5 or more)	0-7 ppm	8-15 ppm	16-25 ppm	26-33 ppm	34-41 ppm	42+ ppm
Suggested lb of P_2O_5 per acre	200	150	100	75	50	0

Table 3. Potassium recommendations for garlic based on soil test.

Soil test K level	0-40 ppm	41-80 ppm	81-120 ppm	121-160 ppm	161-200 ppm	200+ ppm
Suggested lb of K_2O per acre	200	150	100	75	50	0

Calcium, Magnesium, and Sulfur

Calcium and magnesium may be low in acid soils. The need for these elements usually can be met by following lime recommendations. Sulfur is a major constituent of compounds believed to be involved with the medicinal qualities of garlic. Yield responses to sulfur additions are not common in garlic, but sulfur fertilizers may affect garlic flavor and medicinal compounds.

Micronutrients

Garlic response to micronutrients has not been reported in Minnesota. Addition of compost or other types of organic amendments will help to ensure that micronutrient supplies are adequate.

Tissue analysis

Use tissue analysis to help diagnose any suspected nutrient deficiencies and fine-tune a fertilizer program. Sufficiency ranges of the most recently matured leaf sampled at initial bulbing from high yielding garlic plants are presented in Table 4. Tissue samples can be sent in for analysis to the UMN Soil Testing Lab.

Table 4. Nutrient sufficiency ranges in the most recently matured leaf of garlic sampled at initial bulbing.

N	P	K	Ca	Mg	S	Mn	Fe	Zn	Cu	B	Mo
%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm
3.0-4.5	0.3-0.6	3.0-4.5	1.0-1.8	0.25-0.4	0.3-0.7	30-60	50-70	13-20	3-5	20-30	0.5-2

Many garlic varieties are susceptible to yellow tips. This disorder can occur even in the presence of adequate fertility. Unless the yellow tips occur early in the season (before bulbing) or the yellowing covers more than one third of the leaf, the disorder does not appear to have a drastic effect on yield. Yellow tips early in the season are usually a sign of water, cold or nutrient stress or disease (see below).

Planting

Prior to planting, soils should be tilled to provide a loose growing bed for optimal bulb growth. Since true seeds are not easily produced by the garlic plant, cloves of the bulb are used for clonal propagation. First time garlic growers should purchase bulbs for seed cloves from reputable regional garlic growers who test for major diseases of concern. Established growers usually save about 15-25 percent of their crop, depending on variety, for planting the subsequent year.

Porcelain varieties require a higher percentage of the crop saved for seed than all other varieties. Depending on quantity ordered and variety, the price of garlic seed cloves can range from $12-30 per pound. Planting cloves from garlic purchased at the grocery store is not recommended; this garlic is mainly adapted to milder climates and is usually treated or stored at temperatures not conducive for proper bulb formation.

Time of planting is critical since both optimum shoot and bulb development require a cold treatment (vernalization). However, field trials have shown that the planting window is much greater than previously thought. Garlic in Minnesota should be planted in the fall, usually within one to two weeks after the first killing frost (32˚ F). In northern Minnesota, planting during the third to fourth week of September is recommended, while in southern Minnesota planting around the first or second week of October is recommended. Ideally, roots should be developing and shoots should be emerging from the clove but not above the soil at the time of the first hard freeze (28˚ F). However, field trials have shown that the planting window can be wider than those two-week periods. Planting windows across Minnesota can last from mid-September until the ground freezes. There are risks to planting too early or two late that may outweigh the advantages. Freeze damage to top growth before winter is wasted energy. Planting too late will be difficult due to frozen soils. Planting can be done in phases to reduce risks of planting too early or late. Garlic shoots will emerge from the ground in late March or early April. Earlier emergence and growth in the spring can be accomplished by planting cloves stored in the refrigerator for three to four weeks prior to planting. This practice can also result in increased bulb size at harvest.

Spring planting is not recommended unless the cloves can be given a proper cold treatment like a few weeks in a refrigerator prior to planting. The home freezer is not a proper cold treatment and will kill the cloves. Garlic planted in the spring without a cold treatment will often produce weak shoots and poorly-developed bulbs. Lack of scape development in hardneck garlic and bulbing in all garlic is usually due to an inadequate cold treatment.

Spacing depends on a number of factors and there are many spacing arrangements that will yield a productive crop. Close spacing results in higher yield on an area basis but smaller bulbs, while spacing farther apart will result in lower total yields but larger bulbs. A common practice is 6-8 inch spacing between bulbs, and there is a lot of variation in between row spacing recommendations, which range from 12-40 inches. The best row spacing will depend on the cultivation method. Growers who use mechanical cultivation methods will need wider row spacing, but for those who cultivate by hand, narrower row spacing will leave less room for weeds.

One example of successful spacing is to plant cloves in two foot beds with four rows and 8" spacing within and between rows and a 2' walkway between beds (Figures 9 and 10). Other options include single rows spaced 30" inches apart and cloves spaced 6" apart within the row. This wide spacing between rows allows for mechanical cultivation for weed control. Typically, yields of garlic planted in double rows 30 inches apart will range from 3-5 tons per acre (138-230 lb/1000 sq. ft).

Higher yields can be attained with closer spacing. The amount of garlic to purchase will depend on the area to be planted, spacing, and variety. Some varieties have more plantable cloves per bulb than others. Generally, there are about 30-50 cloves per pound of garlic bulbs. Therefore, garlic spaced at 6" within a row 100' in length will require approximately 4 pounds of cloves or 4-5 pounds of bulbs. Generally, seed cloves from one pound of garlic bulbs will yield between 4-8 pounds of harvestable bulbs. This will also vary, of course, with growing conditions and variety.

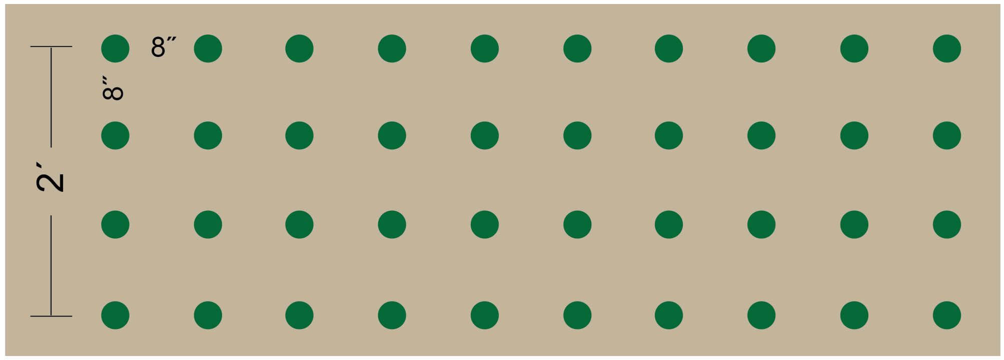

Figure 9. An example of garlic spacing in beds. Allow for a 2' walkway between beds. A 50' bed would require 300 seedcloves.

Individual cloves should be separated from the bulb the day of or up to one week before planting. Cloves separated for longer than that may dry out. Generally, larger cloves from larger bulbs will produce the largest bulbs. In some varieties, large cloves may be actually two cloves fused together, known as a "double". These doubles will produce two bulbs that become flattened as they grow together (Figure 3).

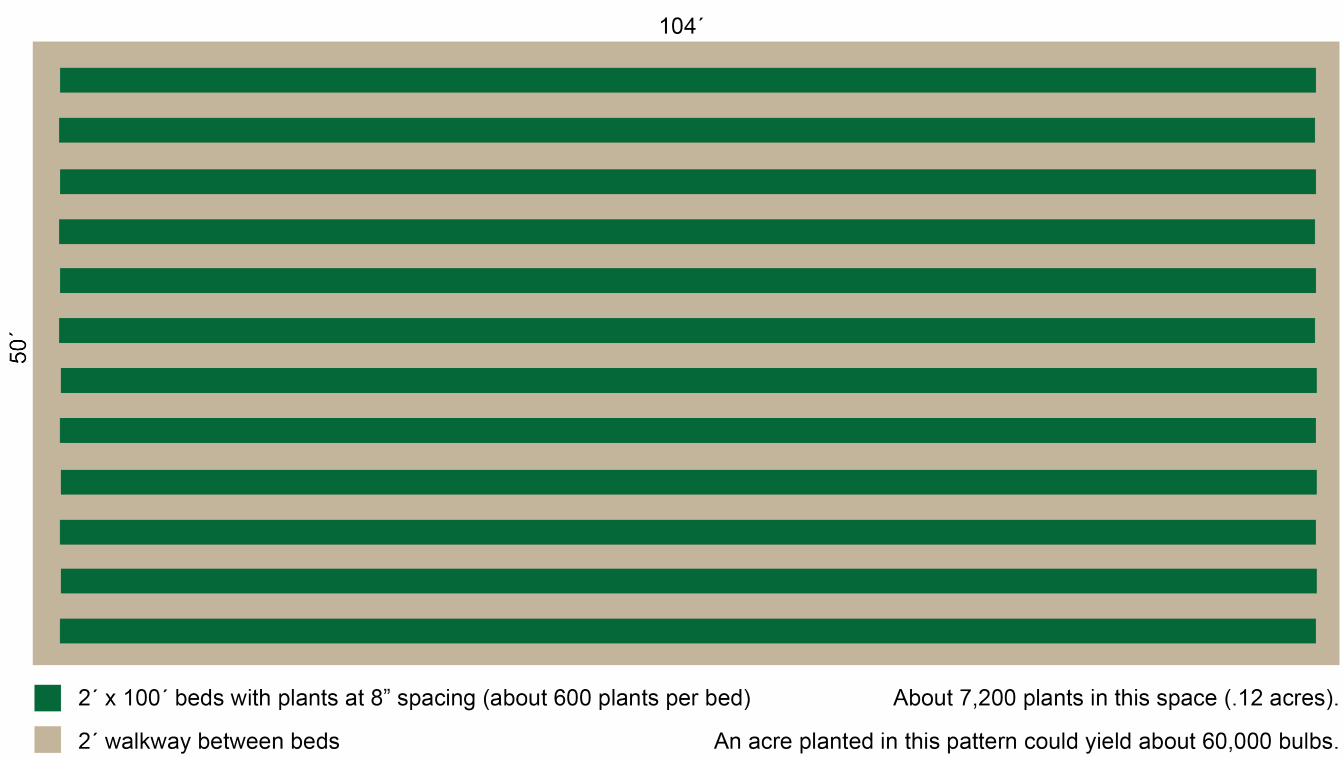

Figure 10. An example of a planting configuration for garlic.

The result is less marketable, poorly shaped bulbs. Double cloves are more prevalent in certain hardneck varieties, such as German Red and other Rocambole types, compared to Porcelain and softneck varieties.

Cloves should be planted with the pointed side up. Cloves planted upside down will develop a curved shoot that results in misshapen bulbs (Figure 11). The base of the clove should be planted two to three inches below the soil surface. As garlic grows, tractile roots pull cloves deeper into the ground. For small acreage, cloves are generally planted by hand. Large commercial growers use a mechanical planter.

Figure 11. Cloves planted upside down will develop a curved shoot.

Mulching

Use of mulch is recommended for several reasons: to protect garlic from frost damage, to help control weeds, moderate fluctuations in soil temperature in winter and early spring, and to preserve moisture in the soil. Garlic roots and shoots tolerate freezing conditions provided that sudden drops in temperature do not occur. Mulch can be applied any time after planting.
In general, mulching within five weeks after planting is suggested. Rows should be covered with a 3-4” layer of seed-free straw. If straw is not available, chopped corn stalks, soybean straw, or fall tree leaves can also be used as mulch.

Garlic shoots can tolerate air temperatures as low as 20˚ F without damage. Plant death, multiple shoots, and poor bulb development may occur if bulbs and shoots are exposed to temperatures below 10˚ F (Figures 12 and 13). In general, mulch should only be removed in spring if plants are having trouble pushing through it, which can occur for some softneck varieties. Mulch removal is not necessary for most hardneck varieties and weed control will be much easier if mulch is left on. There may be a few instances when some growers in the more northern latitudes of the state will remove the mulch completely in the spring to allow the soil to warm faster, then return the mulch

Figure 12. Garlic shoots damaged by cold weather.

Figure 13. Garlic plant damaged by cold weather.

after the shoots are about 6" tall. However, this practice is labor intensive and not recommended in most situations.

Plastic mulch may be a good option on farms that already use it for other crops. Caution is advised when using drip tape under plastic mulch because excessive moisture can lead to fusarium problems. Use of plastic is regulated for organic production, so check with your certifier before using.

Irrigation

Garlic has a relatively shallow root system and is sensitive to dry soil conditions. The amount of water to apply will depend on soil type. Irrigation is essential on sandy soils and may be beneficial in some years on finer-textured soils depending on rainfall amounts. Enough irrigation should be provided so that the available water holding capacity does not drop below about 50 percent.

The most critical stage for irrigation is during bulbing (end of May to early July). Lack of irrigation or rainfall during this stage will result in smaller bulbs and earlier maturity. Irrigation should be stopped about two weeks before harvest to avoid stained bulb wrappers and diseases. Standing water can be the worst enemy of garlic, so care should be taken not to overwater.

A soil's available water holding capacity (AWHC) can be obtained from the local Soil and Water Conservation District office or county soil survey. Table 5 shows AWHC estimations for some typical soil textures in Minnesota. Find out more about soil surveys at https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

Table 5. Available water holding capacities for several Minnesota soils.

Soil texture	Available water holding capacity	
	Inches per inch of soil	Inches per foot of soil
Loamy fine sand	0.08-0.12	0.96-1.44
Sandy loam	0.10-0.18	1.20-2.16
Loam	0.14-0.22	1.68-2.64
Silt loam	0.18-0.23	2.16-2.76
Clay loam	0.16-0.18	1.92-2.16

Soil Water Monitoring

Two common ways of estimating soil water deficit to help schedule irrigation are: 1) using soil moisture sensors and, (2) estimating soil moisture using the feel and appearance method with a soil probe. Soil moisture sensors are divided into two categories depending on the technology they use: 1) Sensors that measure volumetric water content and 2) Sensors that measure soil tension when placed in the soil profile.

Volumetric water content is the volume of water per volume of soil. It is usually expressed as a percentage. For example, 25% volumetric water content (VWC) means 0.25 cubic inch of water per cubic inch of soil. When compared with the maximum amount of water that the soil can hold (AWHC) or field capacity, volumetric water content (VWC) measurements can be used to measure soil water deficit for irrigation scheduling:

Soil water depletion/deficit (inches) = soil water content at field capacity (inches) – current soil water content (inches)

A better understanding of the basic principles, definitions, and terms behind the soil-water-plant relationship is essential to effectively utilize soil moisture sensors. For more information, visit: https://extension.umn.edu/irrigation/basics-irrigation-scheduling.

Soil water tension can be monitored at a given point in the active root zone by electrical resistant moisture blocks or tensiometers. Soil tension or suction is a measurement usually expressed in centibars, and describes how tightly water is held to the soil particles.

If the soil texture is known, the amount of soil water deficit for a given tension reading can be estimated by referring to tables in the following website: https://extension.umn.edu/irrigation/soil-moisture-sensors-irrigation-scheduling

Tensiometers directly read soil tension between 0 and 80 centibars, and work best in sandy loam or lighter textured soils. Resistance blocks, although slightly less accurate than tensiometers, work in a wider range of soil textures. Some types are as accurate in coarse textured soils as tensiometers.

To obtain representative soil moisture readings with any sensor type, it should be installed and left throughout the irrigation season, preferably at two or more locations in the field. If using portable sensors, access tubes should be installed and left throughout the irrigation season.Two depths are generally desired at each location. These depths should be about one-third and two-thirds of the active root zone, or at around six-inch and 12-inch depths.

The feel/appearance method involves collecting soil samples in the root zone with a probe or a spade. The soil water depletion of each sample can be estimated by feeling the soil and comparing its appearance to data in the NRCS bulletin. Soil samples should be taken from the top six inches to 12 inches in the root zone and at several locations in the field. Sum up the estimations from various depths for one location to estimate the total soil water depletion in the root zone. This method requires frequent use for an operator to develop the art of estimating soil water consistently.

For more information on in-field soil moisture monitoring tools refer to these two websites:

https://extension.umn.edu/irrigation/estimating-soil-moisture-feel-and-appearance-method

https://nrcspad.sc.egov.usda.gov/distributioncenter/product.aspx?ProductID=199.