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High Tunnel Winter Spinach Production

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Introduction

Spinach is a valuable fresh-market vegetable due to its high levels of vitamins, folic acid, potassium and antioxidants. These qualities, along with good cold tolerance, make spinach an excellent crop to complement other high tunnel vegetables. Spinach can be produced nearly all year in high tunnels, creating new marketing opportunities. Growing spinach during winter months allows for the use of idle facilities, thus meeting local demand for fresh produce at a time when production options are limited.

High tunnels are temporary structures, constructed of steel or PVC frames, and covered with greenhouse grade plastic. They are relatively inexpensive to build and are passively heated by solar radiation. High tunnels are used to extend growing seasons for a variety of crops by protecting them against extreme temperatures that would cause injury. A list of construction details and photographs for a low-cost PVC-framed high tunnel can be found on the Utah State University website (http://tunnel.usu.edu) along with information on other high tunnel crop options (Black et al., 2008).

Cultivar Selection

Several factors to consider in choosing a spinach cultivar for use in high tunnels are diseases resistance, cold tolerance, bolting tendency, and the number of days to harvest. The more cold tolerant cultivars, such as '*Space,*' are best for high tunnel winter production. Other varieties that grow well in high tunnels in the winter include '*Melody*' and '*Olympia*' (Knewtson, 2010). Consult reputable seed catalogs or talk to your seed company representative for other spinach cultivars suitable for high tunnel production.

Spinach can be distinguished by leaf type and seed coat. Smooth (flat) leaf types have oblong leaves that are light to dark green in color (NGB, 2011). Savoy (wrinkled) leaf plants produce larger, thicker leaves that are rounder and darker in color. They also ship better than smooth-leaf varieties. Savoy plants are currently grown for fresh production, while smooth leaf varieties are often used for processing (Swiader and Ware, 2002). Semi-savoy hybrids are becoming more popular, and can be both processed and sold fresh. Seed coats can be smooth or prickly. If direct seeding spinach, smooth seeds are easier to use and disperse more accurately from the planter. Seed coat and leaf type are unrelated, smooth seeds can produce both smooth and savoy leaves.

When selecting a cultivar, bolting (flowering) tendency is important. The combination of long days and warm temperatures initiates flower development and is cultivar dependent. Spinach plants are also dioecious (separate male and female plants). Female plants, and some male plants, produce more leaves throughout a growing season and bolt slower (Swiader and Ware, 2002). While bolting is not a big issue for late fall to early spring (winter) production, for spinach grown into April and May or when seeded in the late summer in high tunnels, slow bolting cultivars should be selected.

Site Selection

Well-drained, fertile sandy loam soils with a pH of 6.0 to 7.5 are ideal for spinach production. If the pH is too high, spinach may show manganese deficiency (often confused with nitrogen deficiency) which causes leaves to turn a yellowish color. Winter spinach requires infrequent watering, but high tunnels should be located near a year-round water supply to simplify watering when it is needed.

Site Preparation and Fertility

Spinach is a shallow rooted, annual vegetable, which prefers high amounts of nutrients and organic matter. Have the soil tested prior to planting to determine nutrient deficiencies, and apply fertilizer and organic matter based on test recommendations. Apply 20-25 lbs of high quality compost per 100 sq ft of tunnel space to help enrich the soil. Because winter-grown spinach is watered infrequently it is not feasible to supply fertilizer with the irrigation water. Therefore, compost and fertilizers should be incorporated 4 to 8 inches into the soil before planting with a tractor mounted or hand operated tiller. High tunnels can be designed to accommodate small machinery for tilling and other operations.

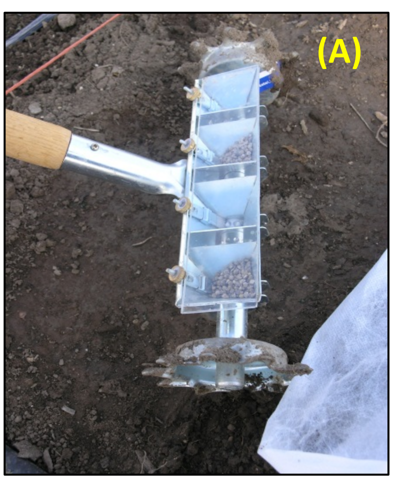
Due to the fast growth and shallow root system of spinach, high amounts of fertilizer are required. Generally 3 pounds of 10-10-10 fertilizer per 100 square feet is sufficient (Swiader and Ware, 2002). For more exact nutrient levels, the soil should be tested to determine deficiencies. In the early fall and spring when plants have high transpiration rates, liquid soluble fertilizer injected into the irrigation system can be an effective way to apply additional fertilizer to established plants.

Irrigation Management

Spinach plants prefer moist soils. Drip irrigation is suitable and convenient for winter spinach production. Drip lines should be place 2 to 4 inches from a spinach row with emitters every 4 inches. Watering frequency varies during the winter but should occur often enough to prevent plants from wilting. Water stress can stunt plant growth and cause bitter tasting leaves. Condensation forms in tunnels due to temperature differences between outside and inside air which helps keep soils moist. Even during the winter, monitoring soil moisture is necessary, and watering intervals will have to be determined based on high tunnel conditions, soil type and production periods. Commercially available resistance block sensors are a simple and reliable method for quantifying soil moisture and determining when to irrigate.

Transplants or Direct Seeding

Spinach can be direct seeded in a high tunnel, and with a precision seeder, planting is quick and accurate (Image 1a). Direct seeded rows are often narrow, ranging from 5 to 20 inches apart, with in-row spacing of 4 to 20 plants per foot of row (Swiader and Ware, 2002). Soil temperatures between 45 and 75°F are optimal for seed germination while higher or lower temperatures may decrease the percent germination and create non-uniform germination times. There are additional costs for greenhouse-grown transplants, but problems with delayed or asynchronous germination are avoided. Thus plants reach harvestable size in less time. To raise greenhouse transplants, sow seeds into 128-cell flats 4-5 weeks before transplanting them into a high tunnel (Image 1b). Seeds should be planted ¼ inch deep and watered gently to ensure seeds are not displaced, or washed away. Water the plants daily, fertilize 3 to 4 times a week with a soluble fertilizer (20-20-20 N-P-K) diluted to 100 ppm nitrogen, and keep temperatures between 70 and 75°F during the day and around 65°F at night. Avoid re-using flats or media to prevent the transmission of root diseases. Root disease can be expressed in a variety of ways including decreased germination, damping off, and stunted seedling growth.



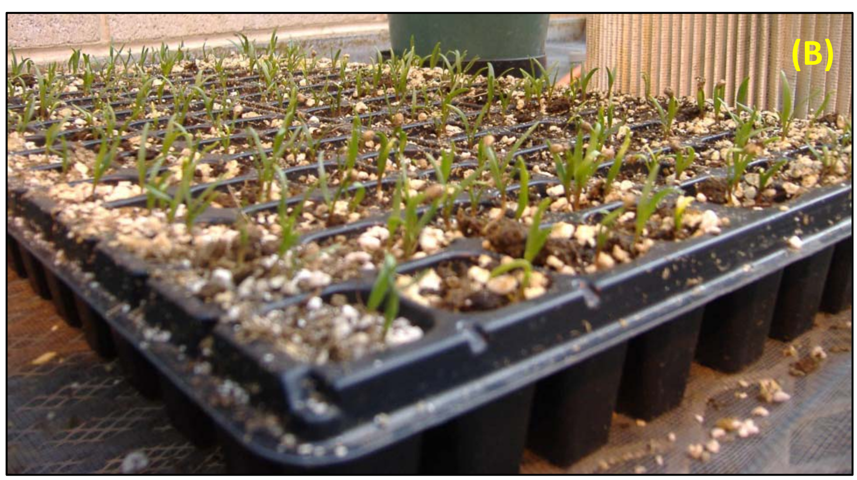


Image 1. Hand held four row planter (A) used to direct seed high tunnel spinach. Spinach transplants growing in a greenhouse prior to planting a high tunnel (B).

Harden plants for several days prior to transplanting them to increase transplant survival rate. Moving plants to a cool (40-45°F), bright location for 2 to 3 days before transplanting, helps harden plants. Plants should be moved back into the greenhouse at night. This allows spinach to acclimate to the cooler temperatures they will experience in the high tunnel.

Planting Dates

Whether direct seeding or using transplants, planting time is important in determining when the first harvest will occur, how many harvests can be taken, and total yield. Planting date is dependent on fall weather conditions and should be done when soil temperatures range between 45 and 75°F. For areas in northern Utah such as Cache Valley, direct seeding from mid-September to mid-October allows sufficient time for seed germination and plant establishment before soil and air temperatures drop below the optimal range. These plantings can be harvested in the fall and early winter, without reducing spring yields (Knewtson, 2008). Transplants should be seeded in the greenhouse at the same time and transplanted 4 to 5 weeks after seeding. Transplanting too late and not giving sufficient establishment time results in lower yields throughout the fall, winter, and spring (Knewtson, 2008). Mid-winter (January) transplanting is possible when combined with the use of secondary plant covers. Secondary covers are an additional layer of plastic or fabric that covers plants in a high tunnel to provide additional frost protection and assist in temperature management.

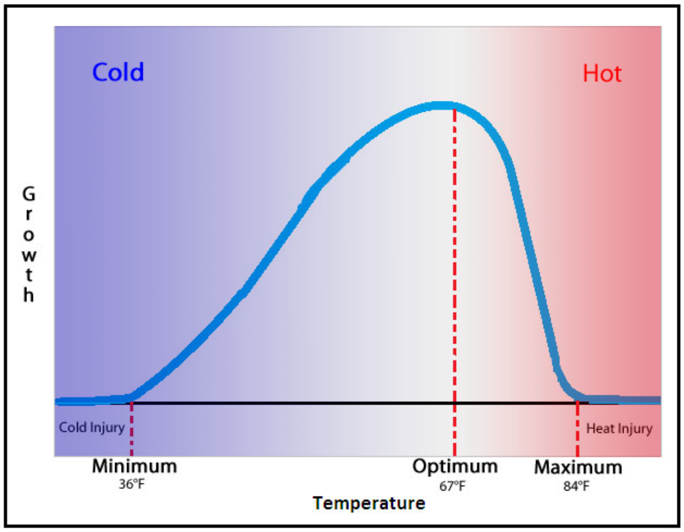


Figure 1. Relationship between plant growth rates and temperature. Critical values for spinach are shown.

Temperature Management

Plant growth has a predicable response to temperature. Figure 1 illustrates this typical growth/temperature relationship for spinach. Maximum growth rate occurs when temperatures are near the plants optimum (67°F) and spinach has an optimal temperature range for growth of 60-75°F. As temperatures decrease, growth slows until the minimum (coldest) temperature for growth is reached (36°F), at which growth ceases. If temperatures continue to decline, plant injury or death could occur, particularly if plants are not conditioned to the cold. Spinach is quite cold hardy when conditioned to low temperatures and can withstand hard frosts and survive temperature as low as 0°F. However, since growth is impeded at these temperatures, plant yield is low and physiological damage often occurs. Plants may recover from this damage, but only if environmental conditions improve. When temperatures increase above the optimum, growth progressively slows until the maximum temperature is reached (84°F), at which growth ceases. If temperatures rise further, spinach could experience damage or death (Black and Drost 2010; Swiader and Ware. 2002). Soil temperature is also important for spinach growth as it affects seed germination rate as well as nutrient and water uptake. Cool soils delay seedling emergence by several days but increases plant stands, whereas seeds sown in warm to hot soils emerge sooner but fewer plants may be established. The optimal soil temperature for spinach germination and root growth is between 45 and 75°F.

Although temperatures within a high tunnel during the winter are often above the outside air temperature, growth rate depends on the magnitude of temperature difference between day and night. In the Intermountain West, extreme temperature differences between day and night in the winter are common. Temperatures within a high tunnel can reach lows of 5°F at night with day temperatures above 85°F. Although spinach has the ability to survive these freezing temperatures and wide fluctuations, growth may be stunted and damage may occur to photosynthetic systems in the leaf. Therefore, it may be necessary to use secondary covers (low tunnels or row covers) within the tunnel to increase plant protection (Image 2). Secondary covers are often applied at seeding or transplanting to protect plants. Temperatures under low tunnels and row covers should be monitored as ventilation may be needed when temperatures exceed the optimal range for spinach.

A low tunnel is like a high tunnel only smaller and consists of a layer of plastic or fabric held up by wire hoops 1 to 2 feet above the ground. A row cover is a cloth or fabric material of various thicknesses that is applied like a blanket directly on top of the plants (Image 2). The extra layer of protection provided by the low tunnel or row cover reduces the effects of cold and fluctuating temperatures and decreases the occurrence of frost damage. Night temperatures under low tunnels or row covers are not as cold, and day temperatures are higher, thus providing plants better growth conditions.

Image 2. Secondary covers used for plant protection in a high tunnel: Plastic covered low tunnel (foreground), fabric row cover (background) and uncovered control (middle).

Pest Problems

The presence of pests in high tunnels can reduce both yield and quality. Cold temperatures are a good deterrent for most pests, simplifying winter production, but pests can be present in the fall and spring when temperatures are warmer. Pests can be controlled by integrated pest management (IPM) practices. IPM is a combination of pest management options to control pest infestations and spread, and thus minimizes control costs. For detailed information on IPM practices for greenhouse go to http://pested.osu.edu/documents/CommStudy/6d%20Greenhouse%20Pest%20Control2007.pdf. If you encounter trouble diagnosing a particular pest problem contact your local county Extension educator.

Aphids: Aphids (Image 3a) are small insects (varied in color) which cluster on the underside of leaves and stems, and feed by sucking sap out of cells. Symptoms include a decrease in plant vigor, a sticky sap on leaves or leaf spotting, and in some severe cases, loss of foliage and even plant death. Aphids can transmit viruses and other diseases, and these insects are spread by wind, water, and people. Aphid-free transplants and weed control in and around the high tunnel are effective control methods. Insecticidal soaps are also effective and are safe to use in high tunnels (Decoteau, 2002).

Slugs: Slugs (Image 3b) are common high tunnel pests but become less of a problem in the colder conditions of winter production. In the early fall, right after planting, and again in the spring as temperatures rise, slugs can be present. Slugs feed by chewing holes on the interior portions of leaves and seedlings. If infestation is extreme, whole leaves or entire plants could be eaten. Pellets and baits are effective in controlling slugs and are suitable for high tunnels use.

Disease Control

Most hybrid spinach cultivars have some level of disease resistance. Using resistant cultivars reduces the need for expensive chemical disease control. Cold winter temperatures slow the growth and spread of disease, making disease incident rare in winter production. For other cultural methods that reduce the occurrence of disease see http://www.ipm.ucdavis.edu/.

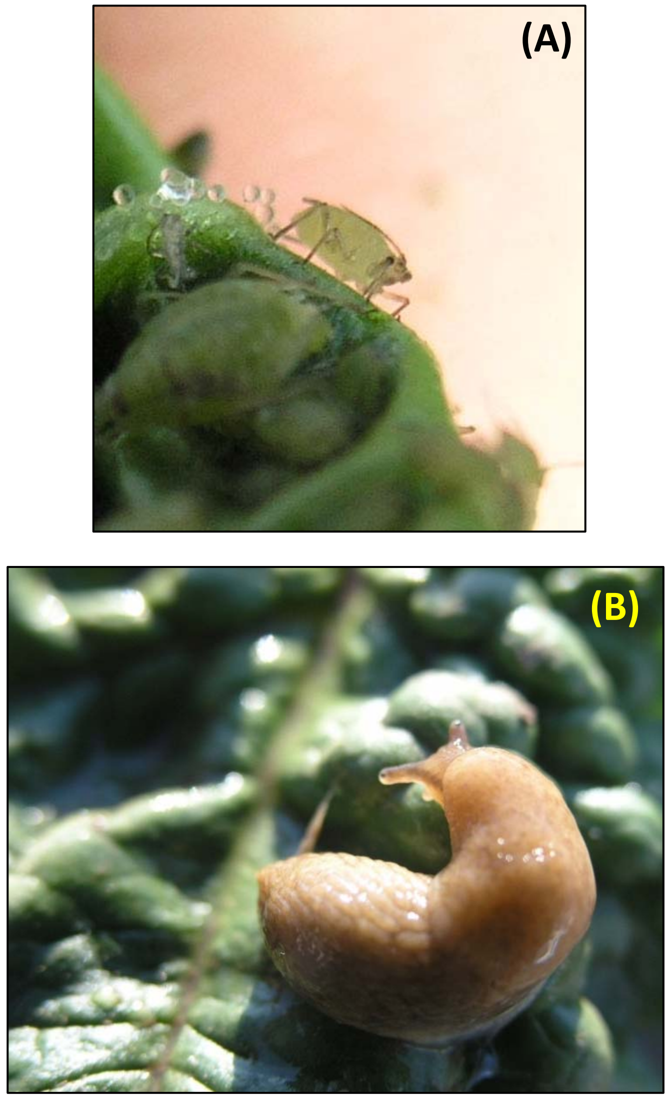


Image 3. Aphids (A) and slugs (B) are common insects that affect winter spinach production**.**

Rodents

Rodents have the potential of being the worst pest for winter spinach production. High tunnels provide rodents with a warm winter home with an abundant food supply. Once established, rodents can become difficult to eliminate, and have the capacity to eat large portions of produce. They can do significant damage when young plants are trying to get established.

Voles are small burrowing rodents measuring 4 to 5 inches (including tail) with short legs and tails and coarse black to brown fur. Control methods vary in effectiveness and require a combination of traps, baits and poisons to control the population. Because voles survive winters by burrowing into leaf piles and other debris, keeping the high tunnel a minimum of 50 feet from compost or garbage piles minimizes damage.

Physiological Disorders

Winter spinach is susceptible to a few physiological and environmental disorders that can reduce crop quantity and value. Most of the disorders are caused by cold temperatures and low light conditions, which are prevalent in winter months and difficult to avoid. Row covers or low cost heating inputs can reduce or eliminate these disorders.

Frost Injury: Frost injury results when ice crystals form between cells in the leaves, causing them to rupture. Symptoms include dark water-soaked leaves, or leaf tips may turn white (Image 4a). Spinach can withstand cold temperatures because of their high salt content, making winter production possible; however, the use of secondary covers will further reduce the amount of frost injury. Properly hardened plants or earlier planting dates can also reduce frost damage.

Oedema: Winter high tunnel environments provide perfect conditions for oedema to occur (Image 4b). When soils are warm and moist and the surrounding air is cold, roots absorb water faster than leaves transpire. This builds pressure within cells causing them to enlarge and sometimes burst. These cells then form corky blisters on the underside of leaves that harden, forming white to brown wart-like bumps on the leaf surface (Cornell University, 2011). Avoiding these conditions in winter high tunnels is impossible, but monitoring soil water levels and irrigating carefully can minimize the occurrence of oedema.

Guttation: Guttation is the excretion of liquid water from a leaf. It appears as tear drops on leaf tips or edges in the early morning (Image 4c). Roots continue absorbing water at night, when plants no longer transpire water, causing pressure to build and water to be forced out openings on leaf edges. These droplets dry during the day leaving a white salty residue on the leaf. Guttation does not harm plants but it provides openings for bacteria and other diseases to enter the leaf. It is not possible to avoid guttation in winter production; however, monitoring soil water levels and irrigating carefully may reduce its occurrence.

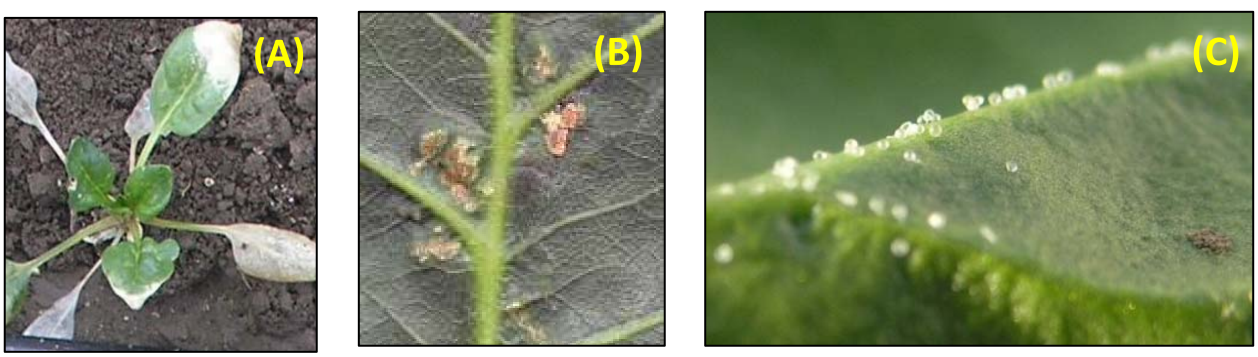


Image 4. Physiological disorders in spinach; frost injury (A), oedema (B), and guttation (C).


Image 5. Spinach growth phases; vegetative (left) and reproductive (bolting) growth (right).

Bolting: Spinach has two distinct growth phases. In the vegetative stage, plants have a rosette growth form made up of a single stem with exceptionally short internodes with leaves clustered around the stem (Image 5). Plants are generally harvested when they are growing vegetatively. The reproductive phase begins as temperatures rise and day length increases. During this phase, the stem elongates and branches to form flower stalks (Image 5), and production of marketable leaves ceases. Warmer temperatures initiate stem elongation, and once the proper photoperiod requirements are reached (12 to 15 hour day length, depending on cultivar), plants flower (bolt) quickly. Bolting can be minimized by careful variety selection, but it cannot be eliminated completely.

Weed Management

Cold temperatures limit weed seed germination and growth during the bulk of winter production. Weeds become a problem in the spring as temperatures rise. Weeds compete with spinach for nutrients, light, and water, which affects germination, slows crop growth and lowers yields. Weeds also harbor aphids, slugs and diseases. The best weed management for high tunnel spinach is to remove weeds when they are small to avoid disrupting the spinach root system.

Harvesting and Handling

When leaves reach the desired size and before flower stalks form, spinach is ready to harvest. Spinach can be harvested two ways, the quickest being clipping the entire plant (or row) 1/2 to 1 inch above the apical meristem, which allows the plant to produce more leaves and be harvested repeatedly. Harvest then occurs every 3 to 4 weeks depending on plant growth rate and weather conditions. A second method is to selectively remove only older leaves of the desired size, which allows the plant to continue to grow. After harvest, leaves should be washed thoroughly to remove any adhering soil .At the end of the growing season, whole plants can be harvested before the tunnel is prepared for the next crop.

Spinach can be stored fresh for 10 to 14 days in a refrigerated environment where high humidity is maintained. Because it is sensitive to ethylene, don't store spinach near bananas, apples or other ethylene producing fruit.

Utah State Winter Spinach Trials

Since the fall of 2010, Utah State University has conducted various spinach trials using the cold-tolerant, smooth leaf cultivar *'Space'*. Transplants were grown in a heated greenhouse for 4 to 5 weeks before planting into a high tunnel. A four-row pinpoint seeder was also used to directly seed high tunnel beds. Tunnels received 1.1 pounds per 100 ft^2 of ammonium sulfate which was incorporated into the soil prior to planting. Trials evaluated the effect of secondary internal covers (low tunnel and floating row cover) combined with low-cost soil heating cables on production levels. Transplants were spaced 5 inches apart in the row with 6 inch row spacing. Drip irrigation (4 inches emitters) was installed between every other row and plants were watered as needed.

Soil Heating and Secondary Covers Case Study

Prior to planting, soil heating cables were installed in half of each tunnel between every other spinach row. Cables were buried 1 inch below the soil surface and connected to a thermostat programmed to add heat only when soil temperatures dropped below 60°F. Secondary covers were installed over the plants after transplanting. Low tunnels were made with U-shaped conduit pipe, 8 inches high, and covered with 4-mil construction grade clear plastic. The fabric row cover used was a double layer of light weight Agribon - AG-19 row cover (rated at 0.55 oz/yd^2; J&M Industries Inc., Ponchatoula LA). The high tunnel and various secondary covers were equipped with air and soil temperature sensors. Plants were seeded in a greenhouse on October 1 and December 22, 2010, and transplanted into the high tunnels on November 1, 2010, and January 19, 2011, respectively. Production levels were determined by harvesting sections in each plot every 10 days. Final harvest occurred 60 days after transplanting. Harvested plants were weighed, the leaves counted and the leaf area measured.

Secondary covers (low tunnels and row covers) had a significant positive effect on day and night temperatures, when compared to the uncovered controls (Figure 2). Plants growing under the two secondary covers reached the optimal growing temperature for spinach for a longer time each day. Air temperature warmed up faster in the morning, reached a higher temperature throughout the day, and remained warmer at night when plants were covered than when uncovered. This allowed increased plant growth, leading to a significant increase in final plant weight for both covers during the fall 2010 and spring 2011 production periods (Table 1). Low production levels in the fall 2010 were due to planting too late in the year (November 1). This trial was repeated in fall of 2011 and plants were seeded and transplanted a month earlier than in 2010. The earlier planting date, combined with warmer fall temperatures in 2011, significantly improved fall production levels in all treatments.

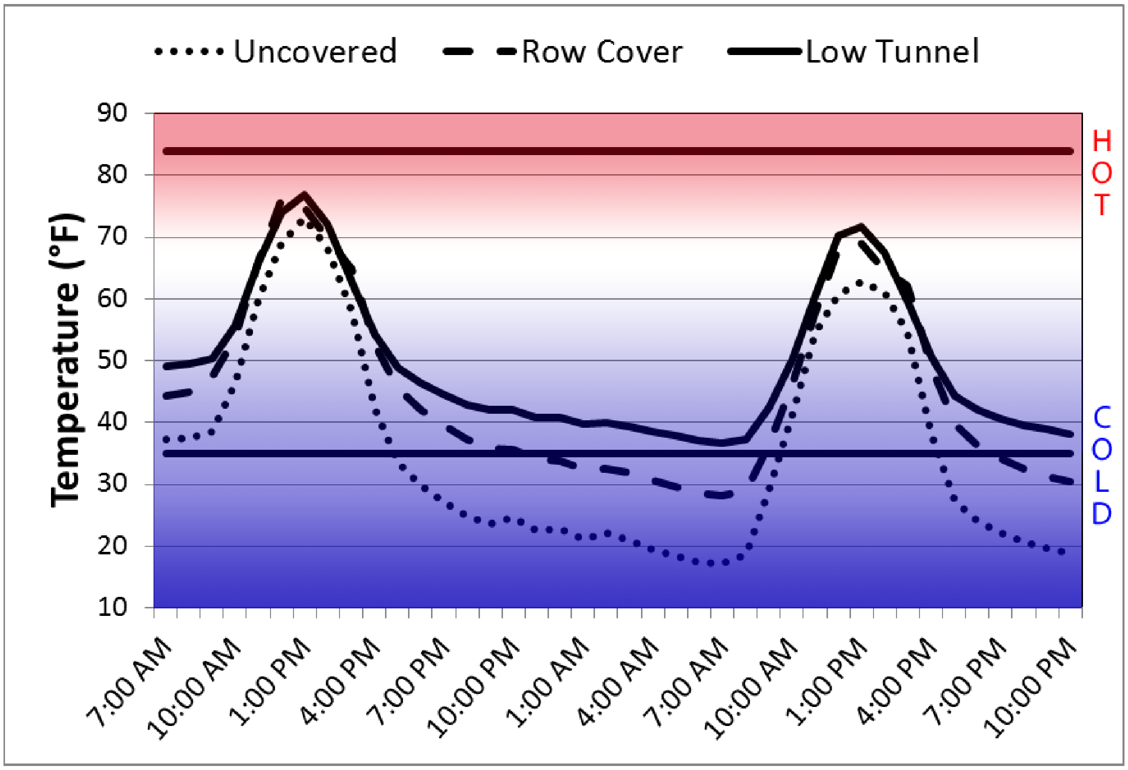


Figure 2. Diurnal air temperatures in three cover treatments over 2 days in winter. The temperature range for spinach growth is 36 to 84°F (2 to 29°C) with optimum growth occurring at 67°F (21°C).

Table 1. Effect of secondary covers and soil heat on final harvest weight (grams/plant) of spinach grown in unheated high tunnels.

Final Plant Weight (g/plant)				
	Fall 2010		**Spring 2011**	
	Unheated	**Heated**	**Unheated**	**Heated**
Uncovered	3.77	7.31	21.50	26.50
Row Cover	5.71	9.30	31.61	34.62
Low Tunnel	11.84	17.67	39.57	45.49

Soil heating increased plant weight proportionally in all secondary covers in both fall trials, but had no significant effect on spring production (Figure 3). Soil-heated low tunnels resulted in the highest total production for both fall and spring plantings. However, it should be noted that as temperatures increased in the spring, plants grown under low tunnels develop elongated stems and small leaves, reducing leaf quality. Ventilation to cool the low tunnels during warmer days may be needed to maintain leaf quality. While the extra heat added to the soil increased plant weight, this extra cost may not be necessary as the secondary covers alone significantly increased final harvest weight.

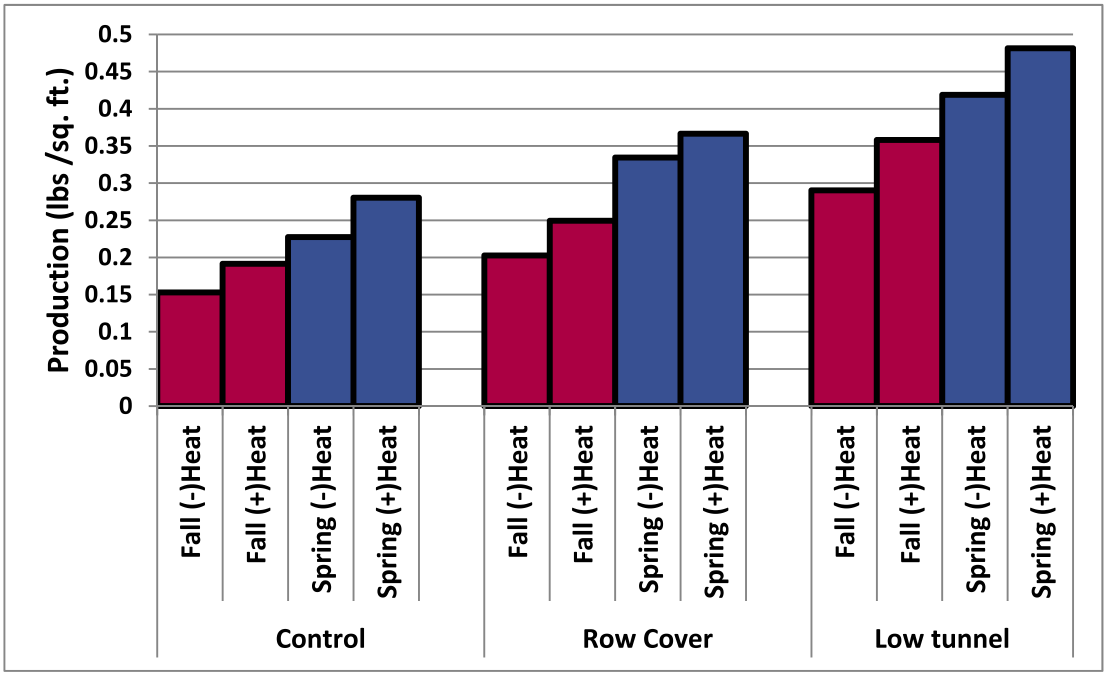


Figure 3. The effect of soil heat (-/+) and secondary covers on fall 2010 and spring 2011 spinach production (lbs/ft^2). Production values were measured 60 days after transplanting.

Spinach Density and Production System Case Study

In a second study, a high tunnel was divided in half and two production systems (directly seeded with leaf clipping or transplanted with selective leaf harvest) and three plant densities (2, 4, or inch row spacing) were evaluated for their effect on spinach productivity. Direct-seeded plots were sown on October 1, 2010, using a handheld four-row pinpoint seeder (Image 1). Transplants were started in the greenhouse on October 1, 2010, and transplanted into the high tunnel on November 2, 2010. Rows were spaced 2, 4, or 6 inches apart. All plots were covered with a double layer of light-weight fabric row cover (Agribon - AG-19) and leaves were harvested every 10 days beginning November 10, 2010, and ending April 1, 2011. At each harvest, leaves were weighed then divided into marketable and damaged produce and re-weighed.

Harvests were divided into three separate growing seasons (fall, winter and spring) of about 50 days. Direct seeded spinach with leaf clipping achieved higher yields compared to selected leaf harvest from the transplanted spinach. During each time period, plants grown at 2 inch row spacing produced the highest leaf yields compared to the 4 or 6 inch spacing (Table 2). While the 2 inch row spacing had the highest yield, spinach plants produced thick, elongated petioles and small leaves, which were deemed of inferior quality and thus had a low percentage of marketable yield (Table 2). For either production system, yields were greatest in the spring period when environmental conditions (temperatures and light levels) were improving. Low yields during the fall were due to late planting dates and deteriorating weather conditions (colder). The 4 inch spaced plants produced significantly higher yields than the 6 inch spacing without a reduction in leaf quality. We estimate a break-even production of 0.25 lb/ft^2 is needed for spinach to be profitable. More work is needed to achieve these levels during both fall and winter production periods.

Summary

Winter spinach production can allow local high tunnel growers to produce additional crops during time periods when weather conditions make outdoor production impossible. High tunnel winter spinach could create new marketing opportunities for growers and may be an excellent way for growers to compliment other products they grow and supply produce to the public year round. An enterprise budget for high tunnel fall and winter spinach is being developed to evaluate the economics of these production systems.

Table 2. Effect of transplanting or direct seeding with different leaf harvest methods and three plant densities on crop productivity (lb/ft^2) and marketable yield (%) for spinach grown during the fall, winter and spring.

Growing Season	Row or Plant Spacing (inches)	Transplants + Leaf Removal		Direct Seeded + Leaf Clipping	
		lbs/ft^2	% Marketable	lbs/ft^2	% Marketable
Fall (Nov. 1 –Dec. 21)	2”	0.03	89.0	0.17	54.7
	4”	0.02	85.3	0.15	60.5
	6”	0.01	81.5	0.09	61.3
Winter (Dec. 22-Feb. 10)	2”	0.06	91.7	0.11	43.2
	4”	0.04	86.1	0.08	59.5
	6”	0.02	77.0	0.05	57.6
Spring (Feb. 11-Apr. 1)	2”	0.30	76.5	0.45	38.1
	4”	0.11	83.4	0.32	45.6
	6”	0.06	80.1	0.24	49.2

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