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Specialty Crop Production Practices for Beginning Farmers in Arizona and the Southwest

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Introduction

Production of specialty crops such as vegetables, herbs, berries, and ornamental crops can be started on a small acreage and over time expand to a commercial farm. Small acreage producers who intend to increase their production will benefit from knowing about production methods, cultural practices, and crop selection. This publication introduces the beginning farmer to a framework of what it takes to expand from small acreage production for home consumption or as a hobby to a small business selling for profit. Other aspects not covered here that are important for producers to know include how to run a small business, including marketing their products, finances, and labor management.

Before ramping up a small acreage operation, a grower should know the market in their area. Before the first crop is ready for sale, marketing channels need to be set up to secure a timely and successful sale. Successful sales at a farmer's market requires knowledge of the markets in the location where a grower plans to sell products. Growers should visit the market or markets to find out what other producers sell, the prices of competing products, the costs to operate a booth, and any other requirements related to selling at the farmer's market. Other venues to sell specialty crops are through community supported agriculture (CSA) programs, and selling to restaurants, schools, hospitals, or other facilities with commercial kitchens. Some smaller farms offer u-pick where customers harvest the produce themselves.

Growing crops for sale requires an investment of money and time. Backyard growers rarely keep track of these components when they have a garden, even a large one. Once growing becomes a business, a producer needs to keep track of the cost of production as well as the time required to run the operation, including production, marketing, and record keeping. Ultimately, a grower should know which products result in a net profit and which ones do not contribute to profit.

Plants can be grown in the open field or in covered structures for protection from harsh weather conditions. The most basic structure, a hoop house or high tunnel, requires minimal financial investment for crop protection. The information on crop selection, scheduling, cultivation practices and basics of soil and irrigation apply to both open field production and hoop houses.

Box 1. Small Farms in Arizona

The number of farmers and farms in Arizona has grown by 28% between 2007 and 2012 to a total of 20,005 (USDA NASS, 2012). Small farms between one to nine acres in size accounted for 11,911 farms in 2012 in Arizona. About half of these small farms are located in Apache, Navajo, and Coconino counties, while almost 1,500 are located in Maricopa County. The majority of Arizona farms between one to nine acres produced livestock in 2012. Vegetable and melons were produced by about 1,000 small farms, and fruit and nuts were produced by 370 operations. Nursery, greenhouse, and floriculture production was reported by 214 farms. Other plant products from small farms included oilseed and grains, hay, and crops such as citrus.

On average, small farms sold products with a market value of about $7,168 and reported farm production expenses of $13,632 in 2012. The number of these farms with net cash farm income was 1,411 while the number of small operations with a net loss was 10,092.

I. THE BASICS OF CROP PRODUCTION IN HOOP HOUSES OR HIGH TUNNELS

What is a hoop house or high tunnel?

A hoop house or high tunnel is a structure covered with either polyethylene glazing or shade cloth to protect the plants from inclement weather, intense sunlight, and some insects and diseases. Hoop houses allow intensive plant cultivation in a small area. They also enable farmers to start plants earlier in the spring and grow them later in fall, providing a longer growing season than under open field conditions. Depending on the climate, plants may be cultivated throughout the winter as well. In warmer climates, hoop houses are covered with shade cloth in summer to protect crops from intense sunlight and heat. Structures are usually built with minimal construction using metal or PVC irrigation pipe to construct ribs, which are connected at the ridge pole and sometimes the sides to build a frame for the glazing. Their low construction costs compared to fully automated greenhouses are attractive for farmers interested in exploring how to grow crops in protected cultivation with a minimal investment.

Hoop houses are generally passively heated by the sun and are vented by opening the structure. Opening doors, end walls, or lifting the sidewalls to various heights allows ventilation of the structure and reduces the passive heating during the day. Hoop houses come in many different sizes from 12 to 40 feet wide and 30 to 140 feet long. Height can vary from 7 to 15 feet, but should at minimum allow an adult to walk comfortably upright within the structure.

Cost for the construction of a hoop house depends on the size, special features such as the type of ventilation, and the materials used. Costs can range from about $0.90 per square foot to $2.00 per square foot. A hoop house that is 14 feet wide and 42 feet long will have an area of 546 square feet and will cost about $720 to build the structure ($1.32/square foot). A hoop house with dimensions of 14 feet wide and 140 feet long will provide 1960 square feet and will cost approximately $1700 to construct ($0.86/square foot). Land preparation, potential footings for a foundation, and double-glazing in cold climates will add to the construction costs..

Hoop house structures

Hoop houses are constructed with various materials (Fig. 1 and 2). The frames can be built from PVC pipes of 1 inch or 2 inches in diameter, or metal pipes, which make the structure sturdier, especially useful in areas with high winds or snow. Stability of the hoop house can be increased by using more than one purlin, the pipe that connects the hoops the entire length of the structure on top, and connecting hoops along the sides with pipe or a wooden board installed halfway between

Fig. 1. This end wall for a hoop house is anchored with four steel T-posts and is sufficient to withstand occasional strong winds (top). The least expensive option to build a hoop house frame is using 1 inch PVC pipe for the hoops and a single purlin connecting the hoops on top along the ridge (bottom).

Fig. 2. Hoop house with end walls, covered with polyethylene glazing (top) and caterpillar style structure built with metal hoops using fence top rail.

the ground and the ridge purlin. Anchoring the end wall posts in concrete footing and bolting them together above ground serves to strengthen that part of the structure and to prevent collapse from wind or snow.

Site selection and orientation

A hoop house should be located in full sunlight without shade from nearby structures or vegetation. Good quality water and well-drained, agricultural soil are necessary. Access to electricity is useful, but the house can function without it. The hoop house location should be outside of any area that can become flooded. In Arizona, hoop houses should be oriented with the ends facing north and south to take advantage of sunlight in winter. However, wind patterns may influence the orientation.

Considerations before building a hoop house

A hoop house can increase the production of vegetables, herbs, or flowers by extending the season into fall, producing through the winter, or getting an early start in spring compared to crops grown in the open field. Plants grown in the hoop house should have a higher value compared to plants that are cultivated in the open field, otherwise the additional investment of a structure is not advisable. The growing conditions that can be achieved in a hoop house need to match the growing requirements of the crops or else the quality and quantity of produce in the hoop house will not justify the investment.

Before building a hoop house, several questions need to be answered. What is the purpose of the structure? A hoop house can be used for seedling propagation, growing plants, or storing plants during the winter. The types of crops that will be produced depend on the climate where the structure will be built. Market demand and current supply will also affect the types of crops that will be cultivated. The hoop house design must match the production area needed, possible height requirements, and other infrastructure necessary to achieve the goals of the operation.

What will be produced?

Production in hoop houses can include vegetables, herbs, flowers, small fruits, tree or shrub seedlings, or transplants. Crop selection, whether lettuce, tomatoes, cucumbers, basil, mint, or flowers will be grown, is the first step. Subsequent selection of cultivars is equally important. Cultivars should be chosen on how well they perform in the hoop house under the local temperature conditions, or whether they represent a niche or specialty product that is not widely supplied by other producers. In a warm winter at low to mid elevation, cultivars that are not heat resistant may start to flower very early and become unsalable and unpalatable once they start bolting (premature flowering). In locations where winter temperatures consistently drop below freezing, low temperature tolerance may be an important trait for a cultivar. Having a number of different cultivars of the same crop also may increase consumer interest and spread a grower's risk of crop or cultivar failure.

What is the climate where the hoop house is located?

Knowing the climate where a hoop house is located is important because it will affect the types of crops that can be successfully cultivated during different seasons in the structure. In the low desert of Arizona below 1,000 feet, temperatures are generally very hot in the summer and mild in winter. Under these conditions, a hoop house should only be covered with shade cloth in summer to mitigate the high temperatures and high radiation, and plastic glazing in winter to protect plants from rain or the occasional cold spell. When desired crops can be grown successfully outdoors, a structure may not be necessary or advantageous to improve on outdoor production. However, starting seedlings in a structure and getting an early start on transplanting crops in the field can be an advantage in marketing the final crop earlier compared to field production. Information about climate zones in Arizona are listed in 'Arizona climate zones and their application to growing plants' (Schuch, 2015).

At higher elevations, climatic conditions may prohibit outdoor cultivation of crops during the winter and the hoop house may be the only production area during that time. Knowing what crops will thrive in a hoop house under the conditions that will be achieved in a colder winter climate is important. During the spring and fall, season extension may be appropriate for some crops and in summer, the structure may serve to shade crops that are sensitive to full sunlight.

Types of production

Crops can be grown in a hoop house in the soil, raised beds, containers, or hydroponic systems. The choice of production system will depend on the final product that is desired and on the level of management and investment. Each production system requires specific infrastructure. Hoop house production always requires a reliable source of water regardless of the type of production. Good quality, well-drained soil is a necessity for growing crops in the native soil or in raised beds. For cultivation in pots, the soil quality is less important, but any water should rapidly drain from the structure.

Hydroponic systems require the highest investment in infrastructure for their sophisticated irrigation system. Depending on the type of system used, injectors, nutrient solution storage, and protection from freezing temperatures can add substantially to the base cost.

Layout of production beds

Production space in a hoop house should be maximized by optimizing the layout of beds. A hoop house 14 feet wide and 40 feet long has a total area of 560 square feet. For hoop houses of that width, a common layout is to have a narrow bed on each side up to the glazing and a wide bed in the middle with two narrow paths, separating and allowing access to the three beds. If the two paths are 1.5 feet wide, then they take up 120 square feet, reducing the total usable growing space to 440 square feet or 78% of the total area.

Alternatives to growing in hoop houses

Growing specialty crops under open field conditions is the most economic option to produce many plant species adapted to their local climate (Fig. 3, Table 1). Start-up costs for field crop production may include leveling the field, tilling the ground, and installation of an irrigation system, especially in the arid Southwest climate. Some tasks in open field production such as sowing seeds are done by machines and only need an equipment operator. However, transplanting seedlings into the field, maintaining perennial plants, or hand harvesting produce can require intensive labor. Crops such as melons, leafy greens, cauliflower, broccoli, and tomatoes have heavy labor demands, especially for harvesting. A producer needs to have sufficient labor at an affordable price available for all labor-intensive tasks associated with production.

Growing crops in a hoop house may limit or restrict access of machinery and therefore increase labor demand throughout crop production. The structure requires daily attention at certain times of the year to ensure proper ventilation by opening and closing the glazing in the morning and to maintain a favorable growing environment. Initial investment in building the hoop house is higher and cultivation in a hoop house requires more intensive management than open field production. Comparing estimates of production costs and potential yields for specialty crops in open field production and in hoop houses may be helpful to choose a production system.

Low tunnels are a less expensive alternative to hoop houses to extend the season and protect crops from inclement weather, cold temperatures, insects, and provide pollination control. Low tunnels are often temporarily placed over crops for seed germination and transplant establishment. In cold climates, low tunnels are sometimes used in a high tunnel structure to protect crops during a cold spell. Hoops are generally 1-1.5 feet tall to accommodate the height of the crop, and spanning one or two rows of plants. Hoops are covered with polyethylene film or spun bound fabric of different weight.

Table 1. Comparing production in hoop houses to open field or low tunnels

Production criteria	Hoop house	Open field	Low tunnel
Length of growing season	Extended versus open field and low tunnels	Weather dependent	Extended versus open field
Crop yield potential and product quality	Higher than field depending on crop and weather	Crop and weather dependent	Higher than field depending on crop and weather
Cost of production	Higher compared to open field and low tunnels	Crop dependent	Higher compared to open field
Initial investment	Higher than low tunnels and field	Crop dependent	Higher than field, lower than hoop house
Labor	Higher input than open field	Crop dependent	Higher input than open field
Pest management	Can be higher or lower than field	Crop and weather dependent	Can be higher or lower than field
Pollination control	No	No	Yes

Fig. 3. Production of summer crops in a hoop house covered with shade cloth next to open field production (left) and low tunnels covered with fabric row cover next to open field production (right).

II. CROP SELECTION AND SCHEDULING

Species selection

Criteria for crop selection in the open field and in hoop houses include that the plants are adapted to the climate, the soil conditions, and the season when they will be grown. Plants need to be able to withstand the lowest and highest temperatures that can be expected during the growing season. The USDA hardiness zones indicate the average annual minimum temperatures, and the Sunset climate zones include a number of climate factors in addition to temperature such as latitude, elevation, rainfall pattern, and length of growing season. Climate zones in Arizona span a wide range (Schuch, 2015) and knowledge of the local climate is essential before deciding which crops to cultivate. Growing vegetables into the winter at higher elevations will yield more produce and better quality in a hoop house because plants are protected from cold temperatures. Plants that are more cold hardy may perform better in this climate. At low elevations, even in winter, heat tolerance may be more important as temperatures can warm up as early as February and may cause species or cultivars sensitive to heat (e.g. broccoli, cauliflower, lettuce) to flower or bolt, and become unmarketable.

Adaptation to the soil conditions, specifically pH and salinity, should be considered when selecting crops. Although planting beds for vegetables are usually amended with organic matter which helps to buffer the pH, many soils and water sources in Arizona have a high or alkaline pH which can interfere with uptake of mineral nutrients and cause nutrient deficiencies. High salinity of soil or water can make some areas unsuitable for production of sensitive crops (Maynard and Hochmuth, 2007). Further details on soils are found in the next section.

Each plant has a base or minimum temperature below which it will not grow and temperatures below this threshold will damage the plant. As the temperature increases above the base, growth will increase up to the optimum temperature range where plants thrive. When this temperature is exceeded, plants will quickly decline and heat damage may appear. Vegetable crops are classified based on their optimum growing temperatures. Cool season vegetables grow well in cooler temperatures but do no thrive in hot weather. In mild climates, they are planted in fall and are harvested through the winter into early spring. They include crops such as carrot, cabbage, cauliflower, broccoli, garlic, kale, leeks, lettuce, onion, parsley, pea, radish, and spinach. Warm season vegetables are planted in spring and are harvested in summer or early fall. Beans, cantaloupe, corn, cucumber, eggplant, okra, peppers, pumpkin, squash, tomato, and watermelon fall in this category.

Optimum temperatures for germination of seeds and for plant growth are not always the same. Lettuce has an optimal germination temperature of 75°F and an ideal range of 40-80°F (Maynard and Hochmuth, 2007). Growing temperatures for cool season crops such as cauliflower, lettuce broccoli, and chard are in the range of 40-75°F and 60-65°F optimum. The ideal germination range for tomato seeds is between 60-85 °F, and for peppers between 65-95°F. Warm season crops such as sweet pepper and tomato thrive between 65-80°F. Different cultivars may be better adapted to the lower or higher temperature range of a crop. Keeping records of temperatures in a growing location outdoors, in a hoop house, or under a low tunnel will help optimize crop and cultivar performance.

Planting dates for vegetables at varying elevations in Arizona are listed in the publication 'Ten steps to a successful vegetable garden' (deGomez et al., 2015). The cool season crop kale can be planted outdoors from seed between September 1 and December 1 at elevations from sea level to 2,000 feet. At 2,000 to 3,000 feet elevation, planting dates are August 15 until February 15. At 3,000 to 4,000 feet elevation planting dates for outdoor production areas are February 1 to March 20, essentially early spring. However, if kale is grown in a hoop house at this elevation, seeds could be sown in early fall and harvest could continue throughout the winter until temperatures become too warm. Tomato, a summer crop requiring warm temperatures, can be grown outdoors using transplants from January to mid-March at elevations up to 1,000 feet, from mid-February until mid-March at 1,000 to 2,000 feet, and from mid-March until mid-April at elevations of 2,000 to 3,000 feet. At these elevations, the goal is to start the plant as early as possible after danger of freezing and to grow as many fruit as possible before temperatures turn too hot and prevent pollination and fruit set. At elevations of 3,000 to 4,000 feet, transplants are moved outdoors into the ground between May 1 until mid-June to protect them from late freezes. Plants in a hoop house at this elevation would be transplanted earlier and produce tomatoes much sooner than plants growing outdoors.

Cultivar selection

The second step in crop selection after identifying a crop species is the selection of the cultivar that will be grown. A cultivar is a distinct type of plant variety selected for their desirable characteristics that are maintained in each generation. Examples of broccoli cultivars are 'Imperial', 'Emerald Jewel', 'Green Gold' and 'Amadeus'.

Criteria to select a cultivar include heat and cold adaptation, production time from planting to harvest, resistance or tolerance to insects and diseases, and popularity of cultivars with customers. Heat or cold tolerance of a cultivar is important in locations where minimum or maximum temperatures can interfere with optimum growing. At lower elevations in Arizona, heat tolerance of leafy green cool season crops is usually more important than cold tolerance. In the case of broccoli, the time from transplanting to harvest can vary from 45 days to 85 days. Growing a faster maturing cultivar can increase income if the yield from the slower and faster growing cultivars are the same. However, the faster growing cultivar may produce smaller heads and although two crops can be grown compared to a slow growing cultivar, yields need to be compared on a pounds per square foot or pounds per acre unit. Seed catalogs often list the disease tolerance or resistance of different cultivars of vegetables. Selecting a tolerant or resistant cultivar can improve yield over the season if a particular disease is present in a growing location. Some cultivars may have a very different appearance compared to the standard cultivar in shape, color, or taste. Customers may not be interested in purchasing something unfamiliar to them and marketing efforts may be required for successful sales.

Crop scheduling

Crop scheduling starts with identifying the desired first harvest date and calculating backwards when seeding or transplanting has to start. The specific dates depend on the plant species, cultivar, the time of year, the location or elevation, whether plants are grown from seed or transplants, and whether they grow outdoors or in a hoop house. Some plants like leaf lettuce, kale, cilantro, basil, and broccoli will be harvested several times by removing larger leaves or flower heads and have a longer period of harvesting, while other plants like carrots, beets, cabbage, and cauliflower are harvested only once and the area can be prepared for the next crop. Starting with seeds will increase the time to harvest while using transplants results in an earlier harvest.

The harvesting potential of different crops will determine how much space is allocated for a species. Average yields per 100-foot row are 40 pounds for spinach, 75 pounds for broccoli and kale, 100 pounds for mustard greens, and 200 pounds for zucchini (Maynard and Hochmuth, 2007). In trials conducted in hoop houses in Tucson, Arizona, different kale cultivars were grown during four winter seasons. Marketable yields ranged from 1.0 to 2.7 pounds per square foot over a harvesting period of eight weeks with up to five harvests. Marketable yield was more than 90% except one year when a very warm winter resulted in considerable damage from insects and vertebrate animals, lowering marketable yield to about 60%. These results demonstrate the importance of keeping records on cultivars grown, sowing date, harvest dates, yield at each harvest and overall yield per unit growing area, marketable and nonmarketable yield, and temperatures in the growing area. Records of mineral analysis of soil and water can further help in understanding yield results and planning for future years.

III. CULTURAL MANAGEMENT

Soil characteristics and water quality

Soil and water are the most important resources for growing crops outdoors or in a structure. Improving the soil quality for long-term sustainable production is an ongoing process. The physical, chemical, and biological soil characteristics determine the fertility, production potential, and possible limitations of a soil. A soil sample analysis from a commercial laboratory will assist in predicting the production potential or limitations of soil that will be used for specialty crop production (Walworth, 2011; Schalau, 2016).

Soil physical characteristics include structure and texture. Structure refers to how soil particles are arranged into larger units called aggregates, which consist of soil particles and the spaces between particles. Soil texture is based on the percentage of sand, silt, and clay, which are soil particles of decreasing size. Soil texture affects water movement and availability, soil structure, and nutrient holding capacity, which influence irrigation and fertilization management. Sandy soils that have a higher amount of sand generally have a lower nutrient holding capacity and a lower water holding capacity than soils with a greater amount of silt or clay.

Soil chemical attributes include pH, salinity, and nutrient holding capacity and availability. The pH is a measure of the acidity or alkalinity of soil or water and ranges from acidic 1-7, neutral at 7, and alkaline from 7-14. In the pH range of 6-7 nutrients are most available for plants. However most desert soils have a pH of 7-8 where some micronutrients are less available and plants may experience nutrient deficiencies under these conditions. Salinity refers to the total amount of dissolved salts in the soil solution and is measured either as total dissolved solids (TDS) or as electric conductivity (EC). Chloride and sodium in higher concentrations can damage or kill plants. The range of soil and water quality based on salinity is shown in Table 2 and Table 3 shows the salinity range of various water sources. Analysis of soil and water salinity and of mineral content can be obtained from commercial laboratories (Schalau, 2016).

Soil also contains small amounts of organic matter, which is the residue from plant and animal tissue, in addition to the

Table 2. Salinity ranges for soil and water quality.

		Salinity	
Soil analysis	**Low**	**Moderate**	**High**
Salinity (dS/m)	0.5 - 2.0	2.0 - 4.0	>4.0
Water analysis			
Electric conductivity, EC (dS/m)	<0.7	0.7 - 3.0	>3.0
Total dissolved solids, TDS (mg/L)	<450	450 - 2,000	>2,000
Chloride (mg/L)	<100	>100	
Sodium (mg/L)	<70	>70	

Table 3. Salinity of different water sources.

Source of water	Total dissolved solids (mg/L)
Rain and snowfall	5 - 10
Snowmelt and rainfall runoff	50-100
Phoenix potable water	350-870
Groundwater	200-10,000
Colorado River at Imperial Dam	750
Tucson potable water	184-500
Tucson reclaimed water	720
Ocean water	35,000

mineral soil. All soils used for growing vegetables benefit from the addition of organic matter such as compost, manure or cover crops to improve the physical and chemical condition, specifically moisture holding capacity, air space and drainage, nutrient holding capacity, and temporary lowering of the pH. Organic matter in the soil decomposes when soil temperatures are warm and the soil is wet. Therefore, organic amendments are added to the soil before planting a new crop.

Arizona soils are characterized by high pH in the alkaline range and some areas have high salinity in soil or irrigation water. Nitrogen content of Arizona soils is generally low, and the amount of soil organic matter is low, often less than 1%. Some areas have caliche at varying soil depths. Caliche is a naturally formed layer of calcium carbonate and soil particles that is impenetrable for roots and water. It prevents water movement and, if it is close to the soil surface, can cause serious drainage issues and restrict plant growth because of the small root zone and limited nutrient availability. The pH is often high in soil with caliche and adding sulfur may help to improve nutrient availability for plants.

Planting bed preparationy

Planting beds need to be cleared of vegetation, unless it is a cover crop that will be tilled into the soil. The soil should be moist, not too dry or too wet when incorporating amendments. Irrigate the area a day or two in advance to a depth of at least one foot or more. Organic amendments, soil sulfur, and fertilizer are spread on top of the bed and incorporated into the soil with a rototiller, fork, or shovel. Larger fields are tilled with appropriate tractor attachments. Organic amendments such as composted plant material or composted manure should be free of weed seeds and low in salinity. Fresh manure can be high in salinity; it is best incorporated well before planting seeds or transplants. Several irrigations of the planting bed will leach salts from the root zone and prevent damage to emerging seedlings or small transplants. Fresh manure may contain pathogens and should not be in contact with fruit or vegetables that will be consumed. Organic amendments are spread approximately 2-4 inches thick on the soil surface, depending on the soil condition. Soil sulfur is added at a rate of 3-5 pounds per 100 square feet or according to recommendations based on results from a soil test by a commercial laboratory. Fertilizer is added according to results from a soil test as well (Doerge et al., 1991). After amendments are incorporated, the soil surface should be raked and leveled in preparation for seeding or transplanting.

Box 2. Measuring Salinity

Salinity in water, soil or compost extracts is measured either as electric conductivity (EC) or as total dissolved salts (TDS). EC measures the specific conductance of salts in the solution and is expressed as millimhos per centimeter (mmhos/cm) or decisiemens per meter (dS/m) or milliSiemens per centimeter (mS/cm). TDS measures the total amount of salt that is left after one liter of water is completely evaporated and is expressed in milligram per liter (mg/L) or parts per million (ppm). The units ppm equal mg/L. EC can be converted to TDS: 1 dS/m EC = 640 ppm or mg/l TDS.

Salinity of soil and irrigation water should be measured before a property is used for crop production to make sure there are no problems. Salinity of compost should be measured whenever a new source is used as it can be high in salts, especially if it contains fresh manure. An alternative to commercial salinity analysis is buying an EC meter to repeat measurements of soil, water and compost on a regular basis. When purchasing a meter it is important to know the range of the instrument. An EC meter should have a range of 0-19.0 mS/ cm or dS/m. That will cover the range you need. Some of them have only a small range of 0-3,999 microSiemens/cm or 3.9dS/m. The maximum values this instrument can measure is too low to accurately measure soils or compost with high salinity. Make sure you purchase the appropriate calibration solutions with the instrument.

Measuring salinity of soil or other solids requires sample preparation unlike irrigation water which is measured directly with an EC meter. Salinity of soil is measured with either the saturated paste extraction method or the 1:1 soil to water method (Matthees et al., 2017). The saturation paste extraction is the most accurate method and is typically used by analytical laboratories; it requires adding the exact amount of water until the sample is saturated. After 24 hours, the water is extracted and the solution measured. Another approach is adding a standard volume of water to a standard weight of soil (e.g. adding 100 ml of water to 100 g of soil) and measuring EC of the solution after a few hours. Results from this method will have lower EC values compared to the saturated paste method. However, as long as the procedures for the 1:1 soil to water extraction method are followed consistently, results may be compared over time.

Seed or transplants

A new crop can be established by seeds or transplants (Fig. 4). Seeds are sown directly into the soil and are commonly used to start plants such as lettuce, corn, kale, beans, carrots, cucumber, spinach, and radish. Seeds are less expensive than transplants, but take slightly longer until ready for harvest. Transplants are young plants with an intact root system that are grown from seeds in a greenhouse and ready to be planted into the prepared soil. Tomato, broccoli, cabbage, peppers, eggplant, and cauliflower are examples of crops commonly established as transplants. The advantage of transplants is starting with uniform plants spaced at the desired distance without the need for thinning and earlier harvest, however, transplants are more expensive than seeds.

The production of transplants for sale is an opportunity for income. Commercial growers specializing in this type of production have equipment for seeding, growth chambers optimized for seed germination requirements of different crops, and greenhouses or shade houses optimized for growing the small transplants or plugs until they are ready for sale. Plug flats need to contain consistent, healthy, uniform plants in each individual cell. Knowledge of the temperature and light requirements for germination and early growth, and appropriate growing facilities are essential to produce high quality transplants.

In recent years, grafted vegetable seedlings have become widely available to commercial growers and consumers. Grafted vegetable seedlings use the same principles that have been used for grafted fruit trees for hundreds of years; a scion of the desired crop cultivar with high fruit quality and taste is grafted onto a vigorous and often disease resistant rootstock. The most common grafted vegetable seedlings are tomato, pepper, eggplants, and melons. Grafted vegetables have greater disease resistance against soil-borne diseases, higher yields, and in some cases bear longer than non-grafted plants. Results of research trials and new cultivars of grafted vegetables are released frequently and it is advisable to explore appropriate species and cultivars based on the growing location. Costs for grafted vegetable transplants is higher than non-grafted transplants.

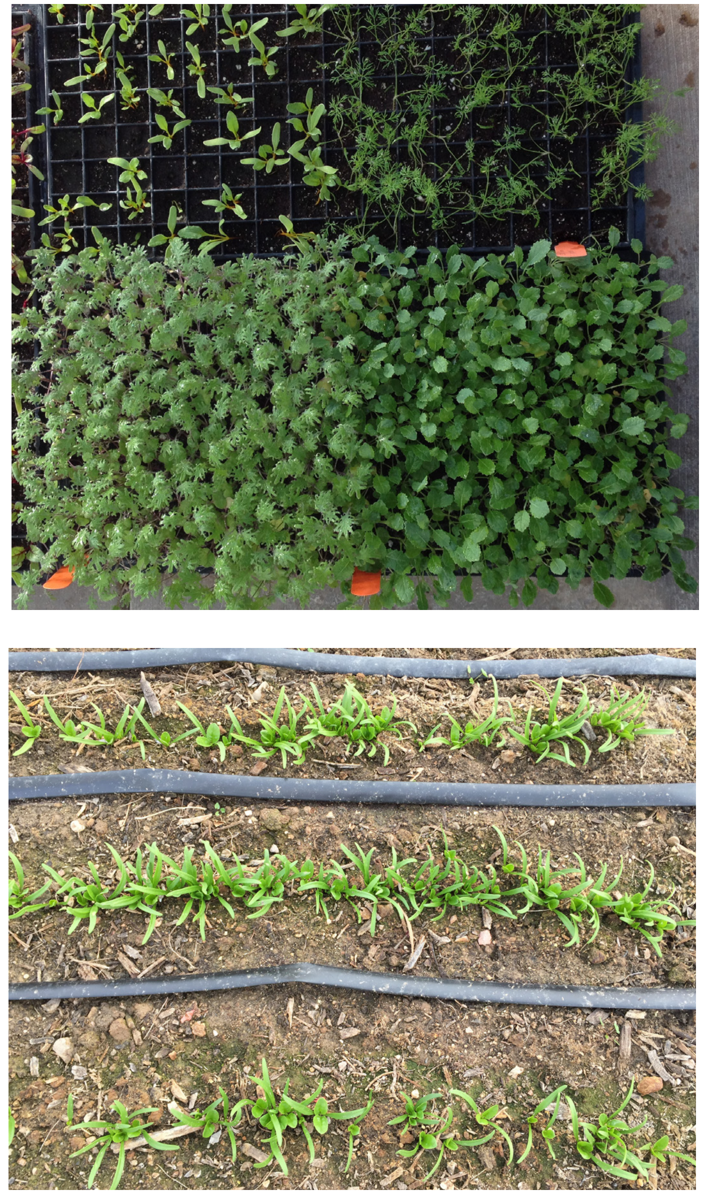

Fig. 4. Plug flats with transplants showing a range of germination (top). Seeds germinated in the planting bed need to be thinned to species appropriate plant spacing.

Plant nutrient management

Plants need essential elements to complete their life cycle. When one or more elements are deficient, plants will not thrive and deficiency symptoms may appear on the foliage or show in poor plant growth. Nutrients are either present already in the soil or added through organic amendments such as compost or fertilizer, or synthetic fertilizer. Specialty crop producers add organic matter to the soil to improve physical and chemical characteristics, and to add nutrients that will be released slowly during decomposition. When using only organic amendments, mineralization or the release of nutrients, is not always sufficient to fulfill the nutrient requirements of a crop, requiring additional sources of fertilizer to be added during the growing season.

Nutrient requirements vary by crop and the soil nutrient content (Doerge et al., 1991). Fertilizer should only be added if it is needed and at the right time when the plant can take up the elements. For example, cucumbers, spinach, and squash need less than 120 pounds of nitrogen per acre, while broccoli, cauliflower, and cabbage need more than 200 pounds of nitrogen per acre. A soil test from a commercial laboratory determines the nutrient levels and assists with recommendations of how much fertilizer is needed for specific crops.

When organic matter or organic fertilizers are used, the rate of mineralization increases with warmer temperature and the duration the materials are in the soil. Common organic nutrient sources are compost, cover crops, manure, and commercial organic fertilizers such as pelleted chicken manure, bone meal, bat guano, fish meal, and potassium or magnesium sulfate. The mineral content of organic materials can vary widely and can change from one batch to the next. For example composted manure may contain little straw in one batch and a larger amount in the next, resulting in higher nutrient content in the first batch. Organic fertilizers are generally low in nutrients (horse manure 0.9% N, 0.1 % P, and 0.5% K, bone meal 1% N, 15% P, and 0% K) and require the application of large amounts of material, often up to 10 tons per acre. Sometimes special equipment may be necessary for transport and spreading of the material.

Synthetic fertilizers are formulated to be either immediately available for plant uptake or to be released over a period of time. Synthetic fertilizers usually contain higher amounts of nutrients and are applied in smaller quantities than organic fertilizers. While the majority of nutrients are added directly to the soil, some micronutrients are applied as foliar sprays. For example, chelated iron can be used as a temporary solution to iron chlorosis.

Ideally, the amount of nutrients present in the soil and through the addition of minerals during the growing season should provide sufficient amounts to produce healthy crops. Adding excessive amounts of organic matter or fertilizer is detrimental to plant growth, can result in runoff with high nutrient concentrations, and can contaminate water sources.

Irrigation

Vegetables require regular irrigation and are not tolerant of very dry or very wet soil. Their growth and quality will deteriorate quickly if exposed to repeated drought cycles. Some vegetables will develop a strong unpleasant flavor and undesirable texture when drought stressed. The soil should dry slightly between irrigations until the top feels dry, but further down there is still moisture for the roots. The soil should be wet to a depth of 6-10 inches, which is where most roots grow. Soil moisture can be checked with a metal rod or stick to determine to what depth the soil is wet after an irrigation and before the next irrigation should be applied.

Water requirements of vegetables differ between species and the stage of plant growth, typically less water is necessary when plants are small and have fewer, smaller leaves, but will increase as the leaf area of plants grows. Some vegetables and herbs are very sensitive and require ample irrigation during certain developmental stages. For lettuce this stage is during establishment, for corn during tassel formation and ear development, and for tomato from bloom to harvest. Water needs will change by season and will be greater during periods of high temperature, low humidity, and windy conditions. Microclimate also affects water use and depends on whether the location is exposed or protected.

Irrigation can be applied with furrow, drip, and sprinkler systems. Furrow irrigation is usually turned on manually while drip and sprinkler systems are generally automated. A number of controllers are available to serve plants with different irrigation needs through various zones and irrigation intervals.

Furrow irrigation requires the preparation of tall, shaped beds with plants growing on top of the furrow and the availability of water from an irrigation ditch. The water should flow slow enough to avoid soil erosion and should not flood the top of the bed. The area is not accessible to work in until the furrows have dried.

Sprinkler irrigation sprays water over an area through overhead sprinkler heads. Some water is lost to evaporation and on areas not used to grow crops. If crops are taller that the height of sprinkler heads, plants may interfere with even distribution of water. Depending on the quality of the irrigation water, mineral deposits may form spots on the leaves. Overhead irrigation can spread foliar diseases. Sprinkler irrigation is less uniform than drip irrigation.

Drip irrigation applies water through tubes containing emitters directly to the soil. The flexible irrigation tubes are placed either on the soil surface or are buried a few inches in the soil. Drip irrigation is the most efficient way to apply water with regard to water conservation. Pressure regulators installed in the irrigation line ensure that water is applied at low pressure and low flow rates, preventing runoff and erosion. Only the area where crops are growing is irrigated, reducing weed emergence in non-irrigated soil. Drip irrigation requires clean water. If well water or other sources are used, a filter may be necessary to prevent clogging of the lines and emitters.

Temperature management in the hoop house

Temperatures in a plastic covered hoop house increase during the day because the radiation from the sun heats the inside (Fig. 5 and 6). As soon as the sun sets, temperatures in the hoop house drop to the outside air temperatures. During the day, it can get too hot for the crops and ventilation is required to maintain optimum growing temperatures. Opening and closing the hoop house sides and doors ventilates the structure, but requires daily attention, often twice a day for effective ventilation. Soil temperatures fluctuate less than air temperatures and provide a buffer during cold nights, especially when crops are small. Measuring soil and air temperature in a hoop house and keeping good records will assist in optimizing plant growth.

In a hoop houses in Tucson, outside air temperature was 46°F during the day and minimum night temperature reached 19°F during a cold spell in January. Air temperatures just above the soil where winter leafy greens and herbs were about one inch tall briefly reached 100°F at noon and a minimum night temperature of 20°F. Soil temperatures just below the surface at 1” depth fluctuated between a daytime high of 70°F and a low of 40°F. The hoop house was not ventilated during these cold temperatures but should have been opened briefly for a few hours to prevent the excessive high temperatures

Fig. 5. Hoop house sides are raised in the morning for ventilation and closed at the end of the day.

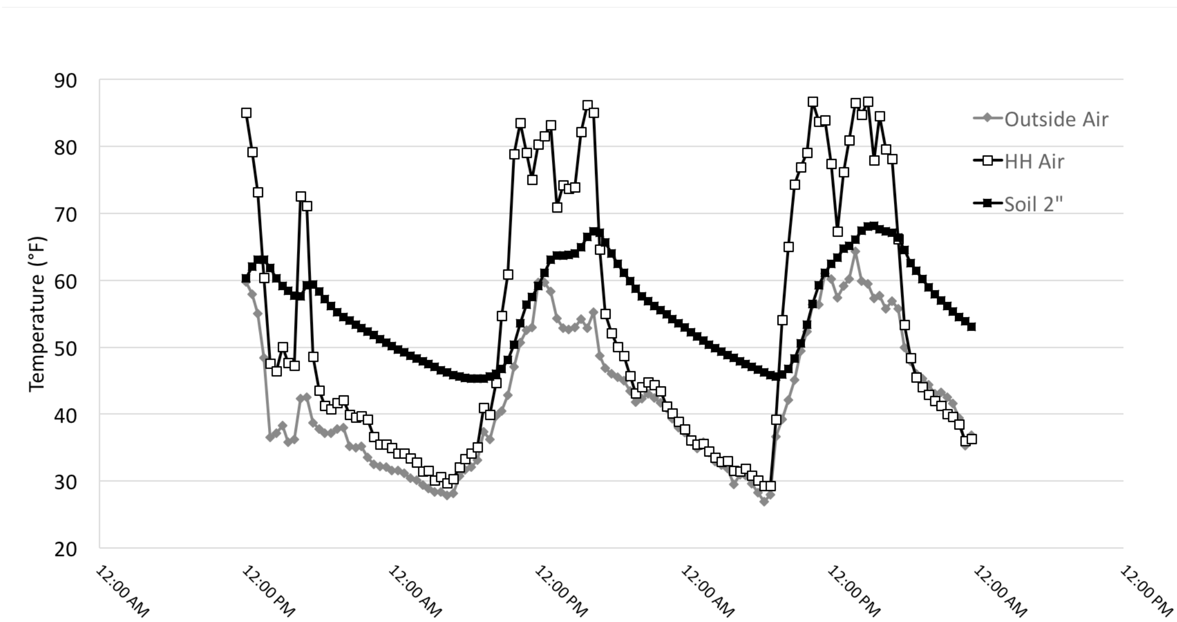

Fig. 6. Outside air temperature and soil and air temperature in a hoop house (HH) during a freezing event in Tucson, Arizona.

in the middle of the day. Spinach, kale, arugula, and cilantro plants were about 1 inch tall at this time and none were injured over the three days of these unseasonably cold temperatures for this area. Fig. 6 shows a less severe freezing event in February, with high temperatures in the hoop house during the day and just below freezing at night.

Daily attention is required, primarily to open the side walls in order to ventilate the structure. When closed during the day, even outside temperatures of 50°F will result in heat buildup up to 100°F unless the sides are rolled up and the doors are opened. Once night temperatures remain above 50°F the sides can be left open permanently when cool season crops are grown. In summer, removal of the plastic glazing and replacement with shade cloth may be required to successfully grow crops at lower elevations.

A thermometer that records daily minimum and maximum temperatures should be installed in the hoop house at the height of the crop, about 5-10 inches above the soil. Knowledge of temperatures around the plant canopy will influence management decisions for how to maintain optimal temperatures for the crops grown.

Pest management

Pests encountered in open field or hoop house production include insects, diseases, and vertebrate animals (Fig. 7). These organisms affect plant growth and can reduce yields or potentially destroy entire crops. Hoop houses have a modified microclimate compared to open fields. This can reduce pest pressures or make pest management more difficult, depending on the crop and time of year. When the hoop house is open for ventilation, natural predators of insect pests have access to the plants. Crops in a hoop house may grow early enough when pest populations are still low and cause minimal damage. Once temperatures rise, conditions in the hoop house may become very favorable for pests that have easy access to many different crops that may be densely planted.

Identification of the problem is the first step in managing pests, however, diagnosis can be challenging because symptoms may be the result of abiotic causes such as drought or heat stress, cold temperatures or wind damage. Disease diagnosis is difficult and often requires that samples of affected tissue are sent to a pathology lab for correct identification. Insects have many different stages and may also require identification by an entomologist. Insects can be monitored by using yellow sticky cards in a hoop house, putting plastic bags over leaves and shaking them, tapping leaves and holding a sheet of paper under the leaves, and inspecting the underside of leaves, inside flowers, or the interior of plants where leaves are tightly packed.

Integrated pest management (IPM) is a scientifically based approach to manage pests by using multiple strategies for the control of pests while reducing risks to environmental and human health. IPM starts with pest identification and assessment of how much damage is tolerable before pests need to be controlled. Monitoring pests will determine what type of management tactics may be appropriate. These include suppressing pests with cultural methods, growing tolerant or resistant plants, rotating crops to prevent buildup of diseases in the soil, use of predators and parasites, or chemical applications. Evaluation of the results through monitoring will assist in selecting the most appropriate methods and likely will require continuous adaptation to changing pest pressures, crops, and weather conditions.

Soil solarization is an effective method of controlling disease, insect, and weed populations in hoop houses. Solarization utilizes solar radiation to raise the temperature of soil by covering it with clear plastic to a level that is lethal to many organisms (Fig. 8). Special films are available for optimal solarization; regular clear plastic may break down and disintegrate quickly in the sun. Elevated temperatures in the soil have be maintained at or above a threshold temperature for a certain amount of time to effectively control soil based pests. For example, root knot nematodes (*Meloidogyne incognita*) can be inactivated at a temperature of 113°F for one hour, while it takes two hours at that temperature to inactivate damping off organisms (*Phytophthora* sp.). Weeds often require higher temperatures and a longer time for control. Common purslane (*Portulaca oleracea*) requires 3 hours at 140°F C or 20 minutes at 158°F soil temperature.

The climate in Southern Arizona is ideal for soil solarization because of the high solar radiation and clear days, especially during the month of June when a hoop house might not be in use. A study in Tucson evaluated how a low density polyethylene film firmly

Fig. 7. Aphids on kale (top), and rodent damage on beets.

Fig. 8. Soil solarization in a hoop house. Highest soil temperatures were reached in soil covered with low density polyethylene and in June can control many soilborne pest organisms within one week. Uncovered soil in the hoop house is not effectively heated to temperatures that control pests.

placed on moist soil and sealed at the edges raised soil temperatures in June, the hottest month of the year, in a polyethylene covered hoop house (Hanson et al., 2014). Soil temperature to a depth of 6 inches was adequate to control many soilborne pest organisms within one week. When the soil was covered but the hoop house glazing was removed similar to an open field condition, it took longer to accumulate enough hours at the threshold temperatures and the soil did not heat up as much at a depth of 6 inches. Hoop house glazing alone is less effective than only covering the soil and may not reach temperatures high enough to control organisms that require high threshold temperatures.

Tools for the grower

Decisions about cultural needs can often be made easier when the correct information is available.

For example, the question when to irrigate can be made by looking at the plants and turning on the water before they are starting to wilt. Feeling the moisture of the soil in the plant root zone can also determine when it is time to water. A soil moisture meter can give information about the soil water status, but the operator still needs to know the threshold when it is time to turn on the water. Automating irrigation delivery is a good insurance against missing a watering, potentially damaging the plants or reducing crop yield.

Temperature information is critical for producing specialty crops in a hoop house to understand how to ventilate the structure or whether to add additional crop protection during a cold spell. Temperature records are also valuable to assess which species and cultivars do well in a hoop house or under field conditions. The daily minimum and maximum air temperatures in the crop canopy is the most basic information that should be recorded and saved. Many temperature data loggers collect data throughout the day at preset intervals. Recorded soil temperatures can be used to understand the effects of hoop house temperatures or outdoor temperatures and how they influence crop growth.

A scale to weigh and record the yield of marketable produce along with the date is indispensable. Weighing unmarketable produce that has to be removed is also of interest to quantify the success of different species and cultivars.

Yellow sticky cards are used to monitor the presence of insects in hoop houses. Insects caught on the traps need to be identified and classified as pests, benign, or beneficials.

An EC and pH meter can monitor the chemical characteristics of soil, water, and organic amendments. See box 2 for tips to buy an EC meter.

A record keeping system either on paper or as a spreadsheet assists producers in keeping information about planting dates, area planted, species, cultivars, yield, labor input, input of fertilizer, water, pest control and other costs. Observations about certain crops, the weather or other noteworthy events should be recorded. When crops are sold, income can be documented. These records are useful to analyze past performance of different crops and to plan for future production.

Economics of a hoop house

Records of all production costs, amount of yield, and income are necessary to calculate whether operating the hoop house results in a profit or loss. Several examples are available from other states that list the items a grower needs to keep track of in order to determine which crops at a certain time of year produce more inside a hoop house or outside (Gatzke, 2012) and which ones are profitable (Bishop et al., 2010; Ernst et al., 2012). Our studies during two winter seasons in hoop houses in Tucson found a great variability in yield, marketable yield, and potential return from leafy greens and herbs. High value crops and cultivars that perform well in the growing location are more likely to result in a positive return.

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