U.S. Greenhouse/Hothouse Hydroponic Tomato Timeline

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Introduction

This timeline has been created to give a general overview of crop production, worker activities, and key pests in greenhouse/hothouse hydroponic tomatoes (GH) in the U.S. This document is intended to describe the activities and their relationship to pesticide applications that take place in the greenhouses throughout the year. This information will be used in worker risk assessments, where risks of concern are identified, and in the assessment of pesticide benefits. The timing of events described may vary due to such factors as the location and target market periods. Pesticide use recommendations are current as of the last update.

Crop timelines were developed to demonstrate the relationship between the greenhouse crop events (preparation through cleanout). These crop events directly relate to worker activity in the greenhouses. The timelines are reflective of the 52 calendar weeks and months for convenience. Crop Timeline 1.0, is broken into three sections indicative of the large grower; winter, summer, and year round growing cycles. Crop Timeline 2.0 is broken into the two cycles used by small growers, i.e., winter cycle growers and summer cycle growers. Most small GH growers are summer cycle growers [21/]. Crop Timeline 3.0 was developed to indicate a typical summer cycle GH and the relationship of pests and pesticide pre-harvest intervals (PHI) acceptable to the greenhouses.

Greenhouse/hothouse hydroponic tomatoes are used for the fresh tomato market only. While these tomatoes command a premium price in the market place, they are never used in processing. GH tomatoes would be considered trash in processed markets due to water content. Additionally, no bioengineered varieties are grown; most greenhouse varieties are produced by Dutch or Israeli seed companies.

General

Tomatoes are the major vegetable crop grown in greenhouses. The large scale U.S. commercial growers, (greenhouses/hothouses greater than 1 acre), all have automatic climate control and all use hydroponic growing systems. The sophisticated growing systems, coupled with indeterminate varieties, and a controlled environment, enable a longer production season than would be possible in field agriculture. This results in the greenhouse growers being able to produce an average of ~15 times more per acre that the field growers. Greenhouse growers also have a much greater percent of marketable fruit, greater that 90% in GH production than does field production ~ 40-60% (Refer to TABLE 4.0). Production cycles vary according to the level of technology employed, and the location of the greenhouse. Growers in northern states typically follow the traditional cycle, planting in the winter and harvesting spring through fall. In southern states, growers have better sunshine in the winter so they typically plant in the summer and harvest from the fall through to the beginning of next summer. Some growers are able to harvest tomatoes through the whole year, where the local climate is suitable, or the greenhouse has supplementary lighting for winter and/or cooling systems for the summer.

Large Scale Commercial Growers (Greenhouses/Hothouses greater than 1 acre)
Most greenhouses are built to one of two basic designs, either with a glass roof (most of the largest growers), or with a plastic roof (older greenhouses and smaller growers). Glass greenhouses have opening windows over the whole roof of the greenhouse, whereas plastic greenhouses utilize fan ventilation. A single greenhouse can be as large as 20 acres (Table 3.0). Heating is achieved using hot water in a pipe system, or hot air heating and circulation fans. Most greenhouses enrich the CO_2 levels using either liquid CO_2 or CO_2 recovered from the natural gas fired boilers. No U.S. large growers are planting in the soil, tomato plants are grown in hydroponic systems with individual drip-feeding. Computers control all irrigation, fertilization, and climate functions. The grower can determine the desired conditions and the computer constantly monitors and adjusts to achieve them.

The dimensions of a typical 20 acre greenhouse will be ~600 feet by ~1400 feet and contains greater than 200,000 plants. The tomato crop is laid out with two lines of plants and a pathway between them. A 10-foot concrete roadway divides the center of the greenhouse into 270 pathways that are 300 foot long on both sides.

Crop growing
Tomato plants are normally produced by specialist propagators and delivered to the grower at 3-6 weeks old. At this stage they will be planted out in the greenhouse at 8,000-11,000 plants per acre. Indeterminate varieties of tomatoes are used exclusively, and they are trained on a single stem. Tomato plants will grow 8-12" per week; they are clipped to, or wrapped around, the support string. The support string is held on a bobbin or hook, and as the plant gets too tall it can be lowered and laid to one side (Refer to Table 1.0). The plant stem may be 35 feet long at the end of the crop.

The speed of development of a tomato plant is related to temperature and age of plant, (a young plant in the summer will grow quicker than an old plant during the winter). Tomato plants flower and set the first cluster at 6-8 weeks old and continue to flower and set additional clusters every 7-10 days. The plant grows 3 leaves between clusters. The clusters of tomatoes continue to grow sequentially and the first cluster of tomatoes will be ready for harvest 6-9 weeks after flowering. Additional clusters will ripen every 6-12 days. A producing tomato plant will have 6-8 clusters of tomatoes at different stages of development. Leaves are removed from the tomato plant to expose the lowest ripening cluster.

Tomatoes are harvested 2-4 times weekly, as they start to ripen. Most large greenhouses have a packinghouse attached where fruit is graded, packed, and held in cool storage before shipping. Growers with a single planting will harvest 20-35 weeks from one plant. Year round GH tomato growers and most large winter cycle growers, use 2 plantings yearly and harvest 13-30 weeks from each plant. Crop changes can be accomplished with continuity of production by 'interplanting', where the new plant is planted between the rows of the producing crop. The head is removed from the producing crop as the first fruit sets on the new plant. Harvesting continues from the old plant as the new plant continues to develop more clusters. The first tomatoes will be ready to harvest from the new plant as the last tomatoes are harvested from the old plant.

Such long harvest periods are rare in agriculture. Most crops have separation between the vegetative growing phase and the harvest phase. Greenhouse tomato crops have concurrent growing and harvest phases through most of the year (the growing phase corresponds with the crop-training period on Crop Timeline 1.0 and 2.0).

Year round, tomato growers may continue for 2-3 years between clean-up cycles, but most growers clean up and replant each year. The clean up is necessary to create a break in disease cycles. After the last harvest, the tomato vines and growing medium are removed from the greenhouse. All debris is carefully cleaned out, and the greenhouse is washed down and disinfected. The irrigation systems and all equipment are also cleaned before new floor covering and growing media are laid out. The greenhouse is now ready for planting.

Hydroponic system

Hydroponic systems are favored for their uniformity and because they allow the grower more control. Being isolated from the soil, hydroponic systems start out disease free. The commonly used substrates are, rockwool (an extruded rock fiber mat - 75% of acreage), coco fiber (coir) (13%), perlite, or peat (10%), and others such as sawdust and pine bark (~2%). Pumps, fertilizer mixing, and pH control are usually centralized and computer controlled. All plant nutrients are supplied constantly in the irrigation water. The concentration of nutrients varies with the season and growth stage of the plant. A network of piping with individual drippers delivers the irrigation to each plant.

Watering cycles give approximately 4-fl. oz. of aqueous feed solution to each plant up to 7 times per hour, depending on solar radiation. The extra irrigation ensures that no plants are short of water, and flushes excess salts from the growing medium. Many growers collect the drain water in a gutter, and pipe it back to the fertilizer area. The drain water is mixed with more fresh water and fertilizers and re-circulated to the plants. Most growers treat the drain water to reduce the risk of spreading root diseases. Pasteurization, Ultra Violet treatment, or chlorine dosing are the most common treatments

Working conditions

The large growers employ 2-3 people per acre in the greenhouse and 1 person per greenhouse acre for the packing area. Packing operations are highly mechanized, but most of the greenhouse tasks are still done manually, though mechanical aids are widely employed. Most greenhouses have a center roadway, with the plant rows perpendicular to the center roadway. The tomato crop is laid out with two rows of plants and a pathway between them, spacing is ~ 64" between pathways. Plant rows can be 120-300 ft long depending on greenhouse dimensions. In all the large greenhouses, the heating pipes form a loop in each crop pathway. The heating pipes also serve as a rail system that supports different carts to facilitate the different worker operations. The weekly crop training operations (clipping and shoot removal, truss prune and support, lowering) are performed on motorized cart with a 2-5 foot elevated platform. For leaf removal, a simple cart is used with large containers to dispose of the leaves. The same type of cart is used to carry the harvest crates. Workers are moving through the crop and handling the plants to perform all these operations. Most greenhouse dress codes require long-sleeve shirts, hat, gloves, and shoes.

Small growers (Greenhouses less than 1 acre)

These are typically 'mom and pop' or hobby operations with less sophisticated greenhouses. Almost all are plastic greenhouses with fan ventilation, most have some heating, and hydroponic systems are common, but many growers still plant in the soil. Growing media for the small GH grower include, planting into the rockwool, soil, pine bark, saw dust, peat, and perlite. The U.S. small GH grower generally follows the summer cycle for growing (refer to Crop Timeline 2.0). They market locally. There is currently approximately 160 acres [4/] of U.S. small GH tomato growers. Refer to Table 2.0. The range of management skills that are available in the large GH can not be replicated in the small environment. Growing techniques, climate control and pest management are only available to the small growers by way of extension and co-op efforts. Large GH have their own team of highly skilled specialists on staff. The average small GH production is less than 60% of that of the large commercial operation.

TABLE 1.0. This table lists the main labor operations and how frequently they are performed. Please refer to the crop timelines for the duration of each operation, and the time of year, since these vary depending upon the production cycle

Operation	Frequency	Description
Crop training **		
Clipping and shoot removal	Weekly	Train plant to the support string, either with plastic clip or winding the head of the plant around the string. Remove small side-shoots when they are 2-4" long, to maintain single stem. Workers are handling the new growth (<10days old) in the top of the plant, no tools are used.
Truss prune and support	Weekly or bi-weekly	Excess flowers are removed from the cluster after the desired numbers of tomatoes have set. Deformed fruit are removed at an early stage. Beefsteak tomatoes have heavy fruit, to prevent the cluster stem from kinking, an arched plastic support is placed over the cluster stem. Workers are handling the newly formed clusters in the top of the plant (<17 days old). No tools are used.
Lower plant	Bi-weekly	Release string from bobbin and re-hang plant. No plant contact
Leaf Removal**	Weekly	Trim 2-3 leaves from the bottom of the vine to expose ripening cluster, some growers remove leaves in tubs, and others will leave them to dry in the pathway. Workers are handling the stem and leaves of the plant that is 6–8 weeks old, knives or clippers are often used to achieve a clean cut. Some growers remove the leaves by simply breaking them from the stem.
Harvest**	2-4 times weekly	Pick ripening fruit with calyx and place in crates – take to center roadway for delivery to pack-house. Workers are only handling the fruit that is ready to pick. The leaves have already been removed to expose the cluster.
Clean out	Yearly	
Remove plants		Plant support strings are cut, the vines are laid in the pathway, and the base of the vine is cut away from the growing media. Machinery is used 'bale up' the bundle of vines. Smaller growers will remove the bundle of vines manually.
Remove media		The growing media, and remaining plant debris are collected on carts and brought to the center roadway, palletized, and removed from the greenhouse. The plastic floor covering is rolled up and removed.

Disinfection		After all the old materials are removed, the irrigation system, heating pipes, and greenhouse structure are hosed down to remove any plant debris. The whole greenhouse is disinfected using bleach solution or a quaternary ammonium compound.
Preparation	Yearly	New plastic floor covering is re-laid and the heating pipes, irrigation, and drain gutter are relocated. The bags of growing media are spaced in the rows and planting holes are cut in the top of the plastic media wrapper. The irrigation drippers are placed at each planting hole and the growing medium is wetted.
Planting	Yearly	8"-16" plants in rockwool cubes are delivered to the production greenhouse, on trays. They are placed on the growing medium and the irrigation dripper is attached. Subsequently they are tied to the support string and the weekly cycle of crop training starts.
Interplanting		Same process as planting except that the young plant is planted underneath a mature producing plant. Interplanting is only used in 2 plant crop cycles and year round production.
Propagation		Most growers buy plants from specialist propagators. If plants are grown 'on site' the process is the same as any other plant raising operation, except that the seed is sown in a small ½ inch plug of rockwool and transplanted to a 4" cube of rockwool at 12-14 days. If a large plant is desired the cubes are separated at 21 days at 12" apart.
The weekly work cycle ** consumes 73% of annual labor inputs in a tomato greenhouse. An additional 20% of labor is for supervision, scouting & recording, cleaning, maintenance, and material handling (mainly delivering tomatoes to the packhouse). The annual clean out, preparation, and planting account for 7% of labor inputs.		

Packing house

At the majority of greenhouses, the tomatoes are delivered to the packhouse in crates on pallets, though some greenhouses have a water flume to transport tomatoes from the greenhouse to the packhouse. The water in flume is dosed with chlorine to maintain 10-50 ppm. Beefsteak tomato (61% of 2001 U.S. production) in U.S. large greenhouses, uses machinery to sort the tomatoes for size and color, they are packed in single layer 15 lb. boxes. Cluster tomatoes or Tomatoes-On-Vine (39% of 2001 production in large U.S. greenhouses), are trimmed and packed in single layer 11 lb. Boxes. UPC labels are applied to all fruit before the boxes are palletized. Completed pallets are stored in the cooler at 55-60^{o}F until shipped. All greenhouse tomatoes are packed with a calyx, or the whole cluster stem.

Packhouse workers responsible for quality selection, or packing into the final container, are handling the fruit. Other workers are handling the harvest crates or the packed boxes. Good Agricultural Practices (GAP) require packhouse workers to wear gloves, aprons and hairnets.

US Acreage for 2001					Annual Production	Calculated Average Yield		
STATE	**ACREAGE**	**BEEF**	**CLUSTER**	**CHERRY**	**Estimates based on average yield (lbs)**	**Ave.Kg/m2**	**Range Kg/m2**	**Ave lbs./ft2**
CO	92	72	20	-	46,700,000	57	50-65	12
AZ	148	48	100	-	75,200,000	57	50-65	12
NY	28	18	10	-	12,500,000	50	45-55	10
PA	30	30	-	-	13,400,000	50	45-55	10
NV	10	10	-	-	4,000,000	45	40-50	9
TX	106	53	53	0.25	51,100,000	54	50-65	11
CA	93	48	45	-	44,500,000	54	50-65	11
DE	5	5			1,600,000	36	35-45	7
VA	36	24	12	-	12,500,000	39	35-45	8
NM	40 (out of production)					57	50-65	12
MN	10	10	-	-	4,800,000	54	45-62	11
SMALL	160	120	40	-	42,800,000	30	25-45	6
TOTAL	**718**	**438**	**280**	**0.25**	**309,100,000**			
PERCENT	**100%**	**61%**	**39%**	**0%**				
Small Grower Source: 5/ 6/ 21/ Large GH Source: 5/ 6/ 15/								

MEXICO 2001								
TOTAL	**1561**	**1108**	**187**	**266**	**278,300,000**	20	15-60	4
PERCENT	**100%**	**71%**	**12%**	**17%**				
80% Soil grown. 23/ Growth in Mexico expected to exceed 1800 acre in 2002: 23/								

CANADA 2001								
TOTAL	**900**	**450**	**450**		**433,200,000**	54	45-62	11
	100%	**50%**	**50%**					
SOURCE: 15/								

Dutch 2000								
		BEEF	**CLUSTER**	**ROUNDS**				
TOTAL	**2852**	**50**	**1402**	**1400**	**1,372,900,000**	54	45-62	11
PERCENT	**100%**	**2%**	**49%**	**49%**				
SOURCE: 20/								

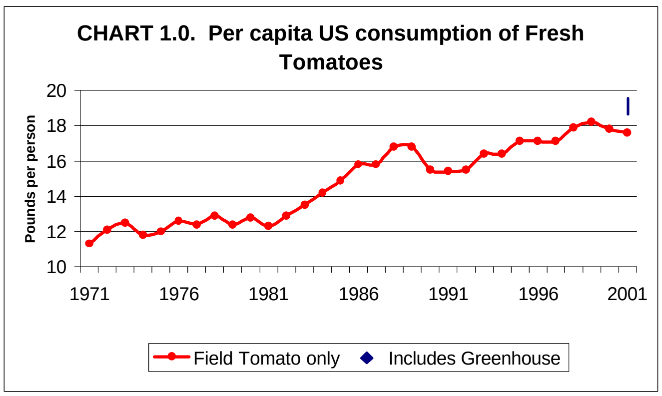
TABLE 3.0 MAJOR LARGE U.S. GH TOMATO PRODUCERS 2002 There are four major growers (greater that 20 acres each) in the U.S.. They represent approximately 65% of the U.S. acres.	
Company	**Acres**
Village Farms (VA, TX, PA, TX)	152
Eurofresh (AZ)	140 [10/]
Sunblest Farms (CO)	92 [25/]
Houweling (CA)	85 [16/]
TOTAL	469

Market Growth

In 2001, there were 128,000 harvested acres of U.S. field fresh tomato (FF) acres [16/]. Compare this to the 718 acres of U.S. greenhouse/hothouse tomato (GH) production. The United States GH market is a young industry that is less that 12 years old. In the last decade, this industry has grown from infancy to an estimated production of 309,100,000 pounds of fruit in 2001 (Tables 2 & 4).

Table 4.0. **U.S. Fresh Field (FF) and U.S. Greenhouse/ Hothouse Hydroponic (GH) Production**			
Category	**2001 Acres Harvested**	**2001 Harvest Pounds 1000 cwt.**	**2001 Average Pounds/Acre**
Field (FF)	128,000 [18/]	37000 [28/]	28,906
Greenhouse (GH)	718 [4/]	309.1	430,501

U.S. GH production has increased over the last ten years due to improved production at each site and a steady increase in acreage, especially in the large (>10 acre) sites. Average yields in the larger greenhouses can approach 12.3 lbs/ft^2, while the smaller GH growers are producing around 7.17 lbs/ft^2.



The per capita consumption of vegetables grew 47% between 1970 and 2000. The fresh tomato per capita has climbed from 11.3 lbs. in 1971 to as high as 18.2 lbs. in 1998. The European per capita for fresh tomatoes ranges between 15 lbs. in Holland and approximately 74 lbs. in Spain. The European average per capita varies but it likely exceeds 30 lbs.[6/]. Based on the continued growth over the last two decades, the U.S. per capita consumption is expected to continue to slowly grow. The 17.8 lbs. reported in 2001 does not reflect the production numbers from unreported Mexican GH imports and domestically grown GH tomatoes. The actual number may actually be as high as 19.1 lbs.(not captured in U.S. Statistics) [7/]. Refer to Chart 1.0.

Industry Trends

Good Agricultural Practices (GAP)

Good agricultural practices (GAP) are voluntary guidelines established to ensure a clean and safe working environment for all employees while eliminating the potential for contamination of food products. The U.S. greenhouse hydroponic tomato industry is adopting the Food Safety Good Agriculture Program which addresses the issues of site selection, adjacent land use, fertilizer usage, water sourcing and usage, pest control and pesticide monitoring, harvesting practices (including worker hygiene, packaging storage, field sanitation and product transportation) and cooler operations. Standard operating procedures (SOP) are developed and incorporated into the GAP program providing guidance with respect to potential points for contamination and preventative or corrective measures to mitigate their effects. Third party independent audits are routinely scheduled to assure compliance.

Good agricultural practices sanitation includes, mandatory use of extensive sanitation equipment including gloves, aprons and hairnets, cleaning schedule and minimization of human contact with fruit. While not all greenhouses in the U.S. are currently under this voluntary program, the larger greenhouses are recognizing the need and implementing procedures. The grocery chains, such as Albertson's, Safeway, Costco, Subway's, etc., are requiring GAP compliance and independent third party validation from its produce suppliers.

Worker Protection Standards (WPS)

The WPS contains requirements for pesticide safety training, notification of pesticide applications, use of personal protective equipment, restricted entry intervals following pesticide application, decontamination supplies, and emergency medical assistance. All U.S. GH hydroponic tomatoes fall under these regulations when using pesticides. Personal protective equipment (PPE) is dictated by the specific pesticide, as are the worker re-entry intervals (REI).

Pesticides

Greenhouse production is a year round process. Pesticides are not the favored means of pest control. Screens, location, and the use of beneficials are preferred for controlling insect pests. Selection of location by climate, phytosanitation, and greenhouse microclimate management, are the best tools for disease control. Growers minimize pesticide applications due to the negative effect on the growth of the crop.

The greenhouse/hothouse hydroponic tomato industry is a relatively new agricultural industry for the U.S. It has grown over the last decade to become a significant player in the fresh tomato market. The GH industry needs for pest control are significantly different from the fresh field tomato (FF) market.

PHI: Once into the harvest cycle (Refer to Crop Timelines 1-3), tomatoes are harvested up to 4 times a week. This makes having a short pre-harvest interval (PHI) critical. A PHI longer than 3 days forces the grower to pick greener fruit prior to application, and if the PHI is as long as 7 days, some of the fruit will be too mature for market once the pickers can reenter the greenhouse. The GH industry needs products with PHI of 3 days or less during the harvest period. The shorter the PHI the better.

REI: Worker Protection Standards (WPS) establish the re-entry interval for each pesticide product. Due to the same factor affecting the PHI, short REI products are required for this industry. While the most the commonly used products in the GH have a 12-hour or less REI, a few have longer REI than PHI on the label. In this case, harvest is dictated by the REI.

Application Method: Most spray applications are made late afternoon and into the night, when other workers are not present in the greenhouses. The large scale GH grower set up is often two-20 acre greenhouses. There are greater than 1000 pathways in a typical 40-acre greenhouse. For large GH to make a foliar application to an entire 40-acres, they will have to travel a total of 121 miles up and down all of the pathways. This requires 40 hours to apply, that is 5 nights at 8 hours each. Compare this to a field air application of about 20 minutes. So, in large GH, foliar applications are often the least desirable application technique.

Large growers all use motorized carts fitted with spray booms, these carts travel on the double railed heat pipes between each row of plants. Fully automatic carts are common, the operator only has to monitor these carts from the center roadway and move them from row to row. Nozzles can be opened or closed to direct the spray at the target plant area. Electrostatic sprayers are used in some locations. Volumes of spray applied depend upon the target disease and leaf area, but are typically between 100 - 200 gallons per acre. Most applications require accessing every pathway to get adequate coverage.

Drip Chemigation
Where the pesticide label supports chemigation, it is often the favored application method. The fertigation equipment is independent of the water source, and easily adapted to dilute the material and apply it to the crop in 1 or 2 irrigation cycles under computer control. This is the most efficient application technique, assuring an accurate dosage to each plant.

Dusting Equipment
Growers apply some materials as a dust formulation, blowing the dust either above or below the crop canopy, depending upon the target problem. The advantage to dusting is that it only requires dusting every fifth row.

Ultra Low Volume (ULV) Equipment
Low volume sprayers can be used for some materials ULV sprayers atomize the spray mixture, which is distributed through the greenhouse using air circulation fans. Remote operation is possible if the greenhouse configuration permits. Air circulation is required to use this effectively in greenhouses.

Thermal (Hot) Fog Equipment
Thermal foggers use heat to vaporize the spray mixture, creating a fog that remains suspended for a longer time than ULV applications. By moving the fogger along the center roadway, in most greenhouses the fog can penetrate throughout the greenhouse without the need for additional fans

BENEFICIALS AND IPM:
IPM pest management, especially as it relates to use of beneficials, is not an option with large greenhouse growers, it is a way of life. It is the preferred method and all chemicals must be integrated into the IPM to succeed. Large greenhouse hydroponic tomatoes growers are

dedicated to the integrated pest management (IPM) process, that includes being one of the largest consumer of beneficials per acre in the U.S. It is not unlikely for a GH grower to spend up to $4,000 per acre for beneficial insects and mites, and an additional $2,000 per acre for bombids (bumble bees). Bumblebees are the most effective pollinators and are used in all large greenhouses. Good pollination is essential for fruit size and quality.

A combination of sanitation, introduction of beneficials, and scouting, reduce the industry dependence on pesticides. This intensive IPM program adds to the challenge of pesticides. Pesticides used until the end of the crop cycle must be safe to the beneficials and bombids. Only pesticides with a proven track record with beneficial are generally employed in the GH.

TABLE 5.0. Importance of PHI and compatibility with IPM at various crop stages. For additional information, refer to Crop Timelines 1.0-3.0.

Stage	Duration	Acceptable PHI	Effect on bees and Beneficials
Planting – first harvest	8-10 weeks	Not critical	Important
First harvest - last crop training	20–34 weeks	3 day	Important
Last crop training – last harvest	6-8 weeks	3 day	Not important
Clean out		N/A	Not important
Note that for year-round growers, a 3-day or less PHI and IPM compatibility is critical all year.			

Table 6.0. Primary Arthropod Pests of GH tomatoes

Common Name		Pesticides meeting 3 day or less PHI and Integrated Pest Management (IPM) procedures sensitive to beneficials.
1	Whitefly	Azadirachtin, *Beauveria bassiana* (in high humidity conditions), Capsaicin (not effective), pyrethrin + pbo
2	Spider Mites	Azadirachtin, bifenazate (TX, CO, VA), cinnaldehyde (phytotoxic to tomatoes), sulfur,
3	Psyllids	Azadirachtin, *Beauveria bassiana* (in high humidity conditions), , paraffanic-oil, pyrethrin + pbo
4	Lepidoptera (Moths and Butterfly)	*Bacillus thuringensis* (B.t.)
5	Leaf Miners	Azadirachtin, *Beauveria bassiana* (in high humidity conditions), paraffinic-oil
6	Russet Mites	Bifenazate (TX, CO, VA), cinnaldehyde (phytotoxic to tomatoes), , sulfur
7	Thrips	Azadirachtin, *Beauveria bassiana* (in high humidity conditions), fatty acids

Insect proof screens are installed over the ventilators on some greenhouses in regions with extensive outdoor vegetable crops [16/]. In areas of intense adjacent agriculture, resulting in high insect pressures from outside, screens greatly reduce incoming pest populations and permit the use of biological control. Without screens, these greenhouses would be forced to rely only insecticides to manage the incoming populations. One of the primary reasons for the selection of the Village Farms Texas greenhouses was its remoteness from other agriculture, to reduce the risk from adjacent pest populations.

Careful climate management is the primary control strategy for foliar fungal diseases. Growers try to prevent conditions that enable the transmission of fungal spores. However, if a disease becomes established the spores can become highly concentrated within the greenhouses causing increased new infections despite the management of microclimate.

Table 7.0. Plant Pathogens of GH tomatoes		
	Disease	**Pesticides meeting 3 day or less PHI and Integrated Pest Management (IPM) procedures sensitive to beneficials.**
1	Botrytis	*Bacillus subtilis*, potassium bicarbonate,
2	Pythium	*Bacillus subtilis, pseudomonas cepacia*, Gliocladium virens, *Trichoderma harzianum*
3	Fusarium	*Bacillus subtilis, pseudomonas cepacia, Gliocladium virens*
4	Rhizoctonia	*Bacillus subtilis*
5	Mildews	*Ampelomyces quisqualis*, cinnaldehyde, Hydrogen dioxide, potassium bicarbonate
6	Verticillium	None
Beneficial fungi and bacteria are labeled for disease control in GH tomatoes, but in practice, the efficacy has been variable and unreliable. [25/]		

TABLE 8.0. Other labeled tomato pesticides that do not meet the 3 day PHI and/or incompatible to beneficials	
Insecticides	**Fungicides**
Abamectin	Azoxystrobin methyl
Azinphos methyl	**Copper**
Buprofezin (IGR)	Dicloran
Cyfluthrin	Hydrogen dioxide
Dicofol	Mancozeb
Dimethoate	Trifloxystrobin
Endosulfan	Fosetyl aluminum
Esfenvalerate	
Fenpropathrin	
Imidacloprid	
Methomyl	
Malathion	
Methamidophos	
Oxamyl	
Permethrin	
Pymetrozine	
Pyriproxifin (IGR)	
Sodium fluoaluminate	
Spinosad	
Bold: Indicates that these are preferred by the large GH growers.	

A clean start to the crop is critical to good pest management. In the last 3 weeks of the old crop, 2 applications of chemical controls (provado or vydate or azadirachtin or bifenzate) are used to reduce pest populations. After the last harvest a single application of naled is very effective in eliminating the remaining pests. When the new crop is planted 1 application of pyriproxifin or imidacloprid may be applied. With good IPM practices (best case scenario), 4 additional programmed insecticide applications and 2 or 3 fungicide applications are all that is necessary for the year.

Whitefly: greenhouse whitefly (*Trialeurodes vaporariorum*), sweet potato whitefly *(Bemisia tabaci*) and the silverleaf whitefly (*Bemisia argentifolii*). Whitefly is the primary insect pest in greenhouses. The greenhouse whitefly sucks sap from the plant, primarily from the phloem. Heavy infestations cause decline of plant vigor. Stunting, yellowing of foliage and premature leaf drop are among the symptoms of injury. Whiteflies excrete sticky honeydew during feeding. This detracts from plant appearance and allows gray sooty mold fungi to grow on the foliage. The whitefly is also suspected to be host to arboviruses and phytoplasmas. Whitefly is a vector of TIC, TOC, and Gemini viruses, all of which have been recent problems. Whitefly can reproduce year-round in greenhouse tomatoes, migrating populations can occur spring through fall. For all the large greenhouse growers biological control using *Encarsia formosa* and *Eretmocerus californicus* is the primary method. Scouting is essential to monitor populations, requiring a labor input of 6 hours/acre/week. When everything works only 3 or 4 pesticide applications (pyrenone) are required in the whole year. Some 'hot spots' may require additional spot sprays. If populations get out of balance, additional monthly IGR applications may be necessary [25/] [9/]. Growers not using biological control may require weekly sprays when whitefly pressure is high. (Refer to TABLE 8.0).

Tomato (potato) Psyllid: *Paratrioza cockerelli*
Is a significant arthropod pest in southern U.S. GH tomatoes in spring and summer. Adult tomato psyllids do not cause damage [27/]. Damage is caused by the developing nymphs, which injects a toxic saliva into the plant during feeding. They are also believed to be capable of transmissions of plant viruses and phytoplasmas. The plant damage includes symptoms called “psyllid yellows”. Other symptoms include upward leaf curling. Greenhouses are establishing zero tolerance for psyllids when virus or phytoplasma symptoms are present. Scouting and mechanical controls, (removing infested leaves and symptomatic plants) and sprays in 'hot spots', are the primary control methods. When present, 1 or 2 well timed (pyrenone) applications in the fall and 1 in the spring are all that is necessary.

Twospotted Spider Mites: *Tetranychus urticae* Koch, Tetranychidae, Prostigmata. Mites pierce the epidermis and extract sap from the undersides of leaves. Infested foliage soon assumes a whitish or bronze appearance. Lightly infested leaves have pale blotches or spots showing through the leaf; heavily infested leaves turn completely pale and dry up. Biological control includes *Phytoseiulus persimilis*, and *Feltiella acarisugaper*. The biologicals are the primary control followed by mechanical leaf removal and spraying hot spots as needed. Applications of sulfur, bifenazate (state section 18 for TX, CO, and VA) and dicofol are effective.

Lepidoperious Pests: Various. The larval stages of the tomato worms, beet armyworms, and tomato fruitworms all damage the tomato and its plant. These pests are all successfully controlled by *Bacillus thuringensis* (B.t.) materials, and therefore are not a serious problem. Tomato pinworm is controlled using pheromone hormone disruption.

Phytoplasmas: (previously known as mycoplasmas): These are cell wall-less prokaryotes in the class mollicutes which infest plants. They exist in plant phloem and cause yellowing, stunting, phyllody, and witches’ brooms [19/]. Originally known as Microplasma-Like Organisms

(MPLO) these organisms are becoming very important in commercial greenhouses around the world. Leafhoppers, planthoppers, psyllids, and possibly whitefly are vectors of this organism. For this reason alone, psyllids currently have a zero tolerance in GH tomato production, when symptomatic plants are present.

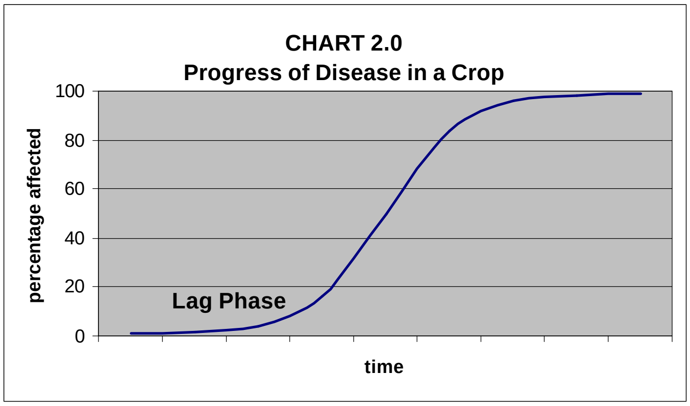
Serpentine and Vegetable Leaf Miner: Family Muscidae. Leaf minors are the larvae of a dipterous gnat. Like the adult, which lay their eggs between the leaf membranes, the larvae feed in the middle of the leaf. This leaves an empty tunnel or trail beneath the skin of the leaf. The larvae will grow inside the leaf. When it has gotten big enough it will leave the leaf and turn into a pupae. From the pupae stage the leaf minor transforms to the adult to start the process all over again. Non-systemic or contact pesticides have no effect on the larval stage of this pest, because the larvae are protected from the pesticides by the leaf. Therefore, a systemic or translocated pesticide must be used. Most greenhouses currently do not have significant leaf minor problems. Biological control includes *Diglyphus isaea* as effective predators.

Tomato Russet Mite. : *Aculops lycopersici*. Russet mites can defoliate plants in the warm season. The mite populations explode and damaged foliage dries out quickly. Damage can be prevented with sulfur. One to 2 sprays of sulfur or dicofol are used for control.

Thrips: Order Thysanoptera. These can be found in large numbers and they destroy plant cells by their feeding. Thrip populations will not preferentially colonize tomato crops however they are vectors for Tomato Spotted Wilt Virus (TSWV). Historically, TSWV has caused >50% crop loss in some locations [25/]. These are spring / summer pests. Of the many insecticides used to control thrips, spintor is the most effective.

Tomato Crop Diseases including virus, bacteria, fungal and phytoplasmas:

Diseases that cause plant loss are especially damaging in a greenhouse crop because of the long harvest season. Occasional plant losses can be replaced by creating an extra shoot from neighboring plants. Loss of individual plants results in crop losses of approximately 8 weeks. In cases where plant losses are large scale, from diseases such as botrytis, repopulating requires replanting an area, that will be out of production for 12-15 weeks. Control techniques include crop sanitation procedures and techniques that extend the lag phase as long as possible. When controls fail, diseases follow the standard curve. However, with a long production season there is an increased opportunity to reach a higher percentage plant loss than with shorter field crops. GH tomato production is devastated annually by diseases resulting in losses as high as $1,000,000 in loss in a single 40-acre site.



Bacteria: Including *Ralstonia (Pseudomonas) solanacearum* (Pseudomonas), *Clavibacter michiganense* (Bacterial Canker). There are no effective chemical controls. Sanitation, quarantine, and removal of affected plants are used to control the spread of the disease.

Botrytis: *Botrytis cinerea*. Gray Mold: Botrytis is the single largest cause of crop loss in GH tomatoes in the U.S., because of a lack of labeled effective chemicals. On the stem, gray mold appears first as elliptical, water soaked lesions. Under high humidity these lesions develop into a heavy, gray, moldy growth, which can girdle and kill the plant. Pruning wounds on the stem, are a common point of entry of the disease. Botrytis is associated with cool, humid periods. December through February are the most severe periods in year round greenhouses. (Refer to Crop Timeline 3.0) Gray mold commonly infects the stem-end of the tomato forming a gray-green to gray-brown lesion. Prevention includes foliar applications of magnesium sulfate (fertilizer), and hydrogen dioxide. Chemical control is limited to dicloran but it has a 10-day PHI. That limits use to early pre-harvest stage of the crop. Mechanical controls include careful leaf removal, and excising affected tissue.

Powdery Mildew. *Leveillula taurica.* Disease symptoms begin with yellowing of the older leaves and blotchy areas. Later the tissue turns brown and the leaf dies. These dead leaves do not abscise and the powdery growth may develop. Affected plants are weakened by the disease resulting in reduced yields, smaller and sunburned fruit. Climate controls combined with sulfur sprays have demonstrated efficacy on this disease.

Pythium. *Pythium sp*. Damping Off: Pythium fruit rots are rare, biggest problem is with root rots especially soon after planting and during hot weather on mature crops. Chemical control pre-harvest is limited to Fosetyl aluminum, but it causes phytotoxicity to the plant in hydroponic systems. Biological fungicides have shown limited success. Cultural controls include restricting irrigation to create a dryer root environment and heavy shade on the greenhouse roof to reduce GH temperatures and stress on the plants.

Fusarium. *Fusarium oxysporum.* Crown rot and wilt: Almost all greenhouse varieties are resistant to Fusarium races 1& 2 though the disease can establish if the crop is weakened through other causes. New races of *Fusarium* are suspected in some greenhouses. Infected plants are stunted and chlorotic. The yellowing begins with the oldest leaves and progresses to the younger leaves resulting in wilting and death. The root system is brown with taproots rotted. *Fusarium* favors cool temperatures. There are no labeled chemical controls. Sanitation at cleanout and preparation periods and removal of affected plants during the crop cycles, are the primary means of control.

Verticillium. *Verticillium dahliae.* Verticillium Wilt: Wilting of the older leaves begins at the leaflet margin developing later into a yellow to brown "V" shaped pattern. Diseased plants are stunted and respond poorly to fertilizer and water. This cool season disease is wide spread. Resistant varieties are available but in recent years many are believe to be susceptible to some strains of verticilium. No control measures available. Sanitation at cleanout and preparation periods, and removal of affected plants during the crop cycles, are the primary means of control.

Weeds
Herbicide control at or around greenhouses is to control weeds adjacent to the structures. Mechanical control is often the control of choice. Glyphosate or diquat, paraquat are the chemical options most often used. Herbicides are not used in the greenhouses for production, only around the perimeter for keeping a clean zone.

Vertebrate Pests
Rodent control is a critical portion of a greenhouse and packhouse sanitation program. Baiting stations are the preferred method of control. Prevention in the packhouse consists of storing pallets with 18" wall clearance and rows between pallets.

Post Harvest Diseases
Greenhouse tomatoes are subject to the same post-harvest disease, as are field tomatoes. GH tomatoes are not waxed or sprayed with post harvest fungicides for disease control. Chlorine washes are used by many GH to remove surface dust and to help prevent post harvest botrytis on the stem.

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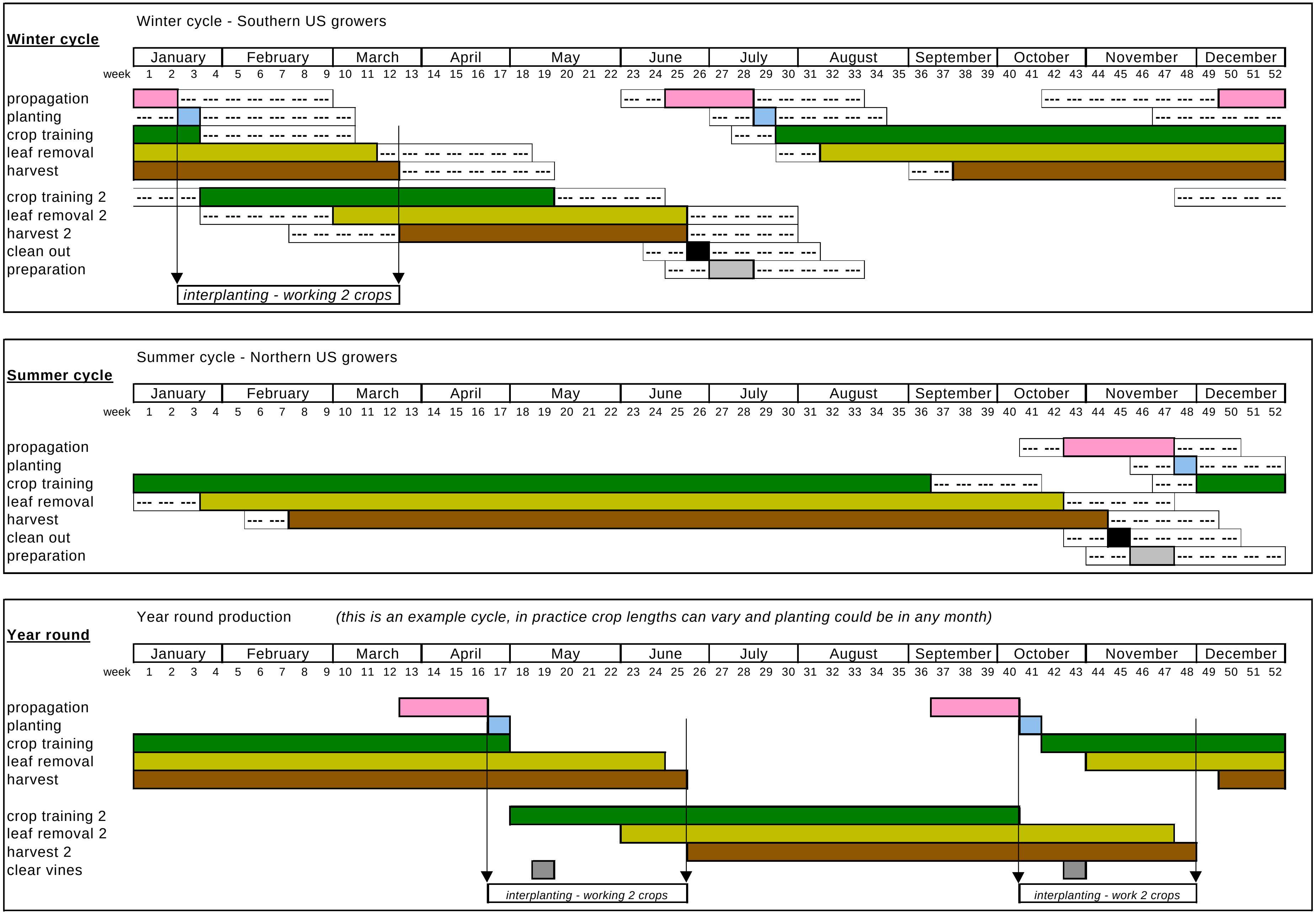
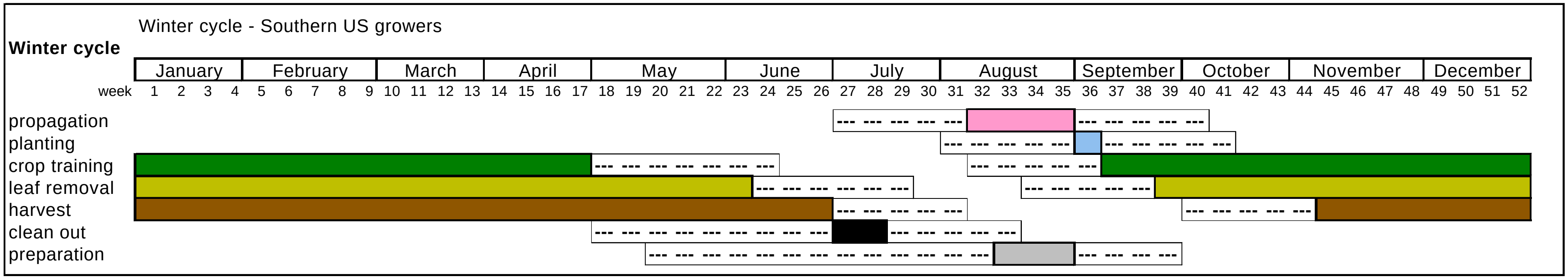
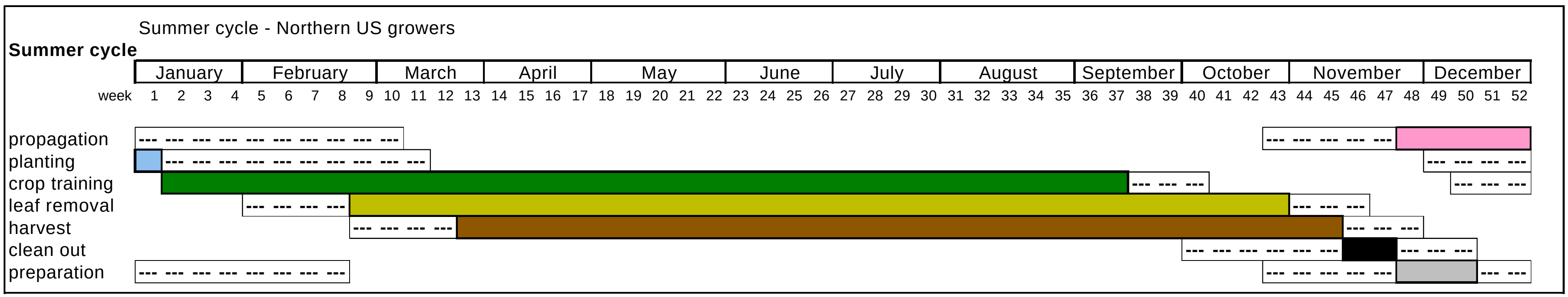
Crop Timeline 1.0. Large grower growing cycles



Crop Timeline 2.0.   Small growers(less then 1 acre) cropping cycles





Crop Timeline 3.0. Major pest pressure and pesticide selection criteria related to cropping phase