New York State

Cannabis sativa L. Production Manual 2023

maximize yield, quality, profitability, and product integrity

Cornell Cooperative Extension

Integrated Pest Management

Cornell Cooperative Extension
Harvest New York

Cornell CALS
College of Agriculture and Life Sciences

Preface

Dedicated to the growers who work tirelessly to produce crops that sustain our world.

The *Cannabis sativa* L. Production Manual is a living document: a work in progress intended to provide current data and findings about sustainable hemp cultivation to growers and members of the Cannabis industry to achieve a high-quality, profitable, and compliant yield. *Cannabis sativa* yields are used for the development of hemp-based cannabinoid products, fiber, grain, and medicine. As research and knowledge about hemp and, in general, the *C. sativa* plant increases, this manual will be updated to include new information. The perspectives of the manual authors are largely, but not exclusively, directed to the industry in New York State.

The manual also includes information about the regulatory environment around hemp in New York and the United States, a description of *C. sativa* cultivation, information about testing and grading, as well as tips on how to produce a crop that meets international environmental and labor standards. Our objective is to help growers maximize yield, quality, profitability, and product integrity while maintaining compliance.

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Hemp Definition

This manual will adhere to the legal definition of hemp which is *C. sativa* containing less than 0.3% THC by dry weight. Hemp yields are used for the development of hemp-based cannabinoid products, fiber, grain, and medicine.

CANNABINOIDS
including CBD or CBG products

The flowers of female *C. sativa* plants are harvested for cannabinoids—including CBD or CBG among multiple others—used in products such as tinctures, capsules, and creams.

SEED/GRAIN
Flour, biofuel, animal feed, oil extracts, paint

Seed is used for multiple purposes, such as animal feed (eg. bird seed), granola and cereals, and for oil extraction. The oil extracted from the seeds can be used for food products or can also be employed in personal care products, such as shampoo and cosmetics, and biofuel.

FIBER/HURD
Textiles, insulation, paper, rope

Hemp that is cultivated for fiber or hurd—extracted from the stalk—is used worldwide. The fiber can be used for cordage, textile materials, and paper among multiple other uses. The hurd from these fiber varieties is used for insulation materials, concrete (hempcrete), and landscaping. Fiber can also be used to produce an ethanol-based biofuel.

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Introduction to *Cannabis sativa* Cultivation

general information about *C. sativa* and growing methods

The *Cannabis sativa* L. Plant

Cannabis sativa L. is a flowering plant from the family Cannabaceae with multiple uses. Two of the main colloquial distinctions, marijuana and hemp, are based on the content of one of the compounds produced by the plant (THC - Δ9-Tetrahydrocannabinol; and its acidic form THCA -Δ9-Tetrahydrocannabinolic Acid). 'Hemp' commonly refers to plants that produce less than total 0.3% (<0.3%) THC by dry weight, while those that produce more than 0.3% total THC are considered marijuana. Regulatory authorities have adopted this purported distinction to regulate hemp and marijuana plants, their uses, consumption, growing and processing.

Throughout this manual, we will refer to high-THC C. *sativa*, also known as marijuana or marihuana, as "high-THC Cannabis", and to "high-cannabinoid Cannabis" when referring to C. *sativa* bred for other cannabinoids such as CBD or CBG.

Marijuana vs. Hemp: The Differences

Cannabis sativa L. is considered one species and was originally described by Carolus Linnaeus in 1753. In 1785, Jean Baptiste Lamarck described a second species (*Cannabis indica*). The cannabis industry often recognizes the terms "indica" and "sativa", however C. *sativa* is considered one species. Recent scientific research has found that there are indeed genetic clusters within the species and one of these clusters is bred for fiber or grain. Therefore, hemp varieties that have been cultivated for fiber (e.g. rope, paper, textiles) or for grain (e.g. animal feed, or oil extraction), are more related to each other than to high-THC or high-cannabinoid Cannabis used for medical purposes or adult-use.

The legal definition of hemp varies between jurisdictions across the world. United States federal law defines hemp as containing 0.3% or less THC. Marijuana, according to U.S. federal law, contains levels of THC higher than 0.3% and typically between 15% to 20% THC, but can be as high as 33-35%. Low THC plants grown legally as hemp may be grown to produce other cannabinoids, mainly CBD (Cannabidiol) and its acidic form CBDA (Cannabidiolic Acid), even though some may be genetically closer to high-THC Cannabis types than fiber or grain hemp.

This manual adheres to the legal definition of hemp which includes high-cannabinoid Cannabis, and grain and fiber hemp.

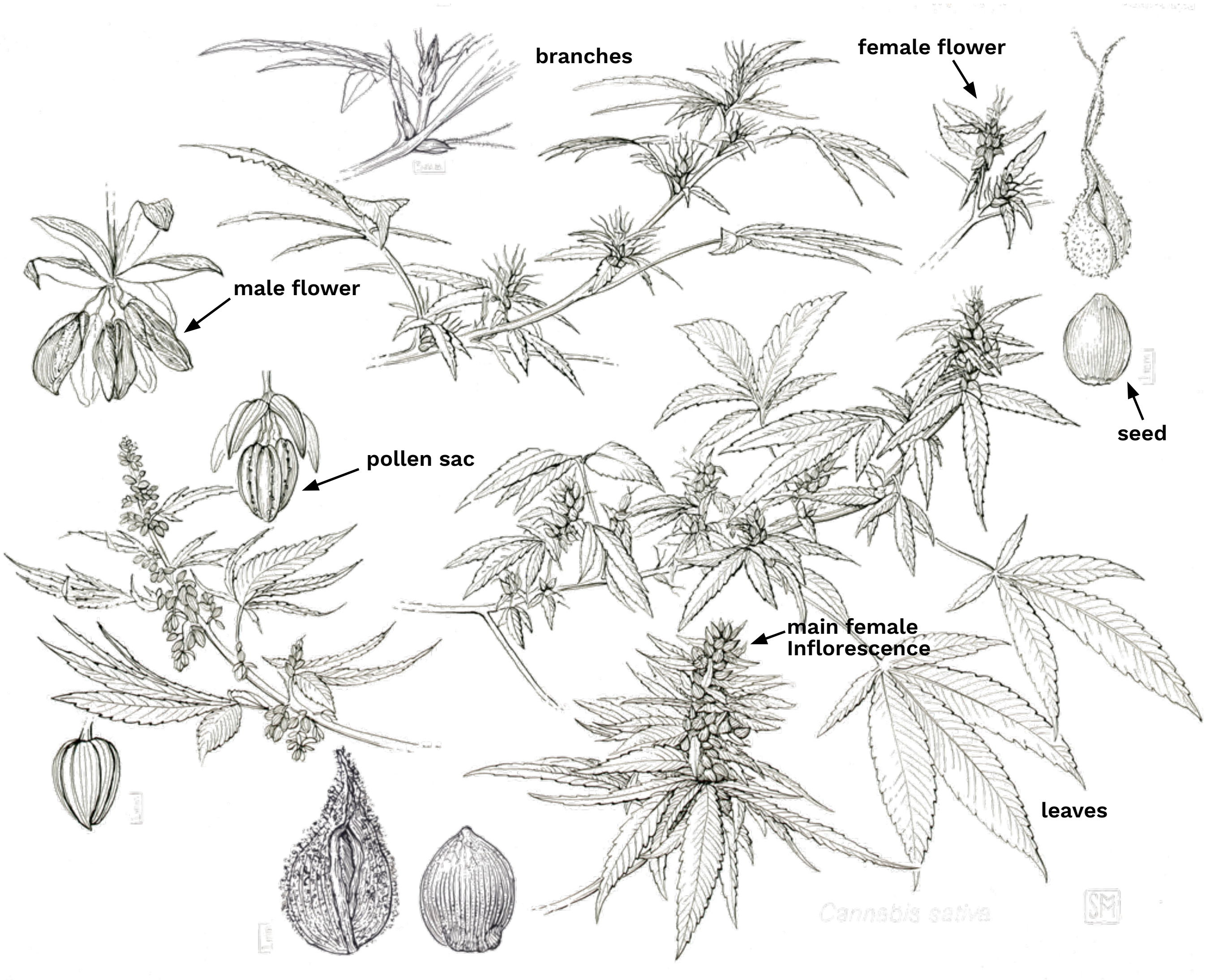
Although high-cannabinoid Cannabis and hemp share growth habit similarities, the plant's morphological characteristics are variety dependent and also determined by intended use and production practices.

THC is a psychoactive component within C. *sativa*, implicated in intoxicating experiences when consumed (e.g., the "high").

CBD, in contrast, is is psychotropic but not psychoactive, and some research indicates a therapeutic benefit.

Although C. *sativa* **produces hundreds of biochemical compounds, the most prominent cannabinoids are THC and CBD.**

Plant Anatomy

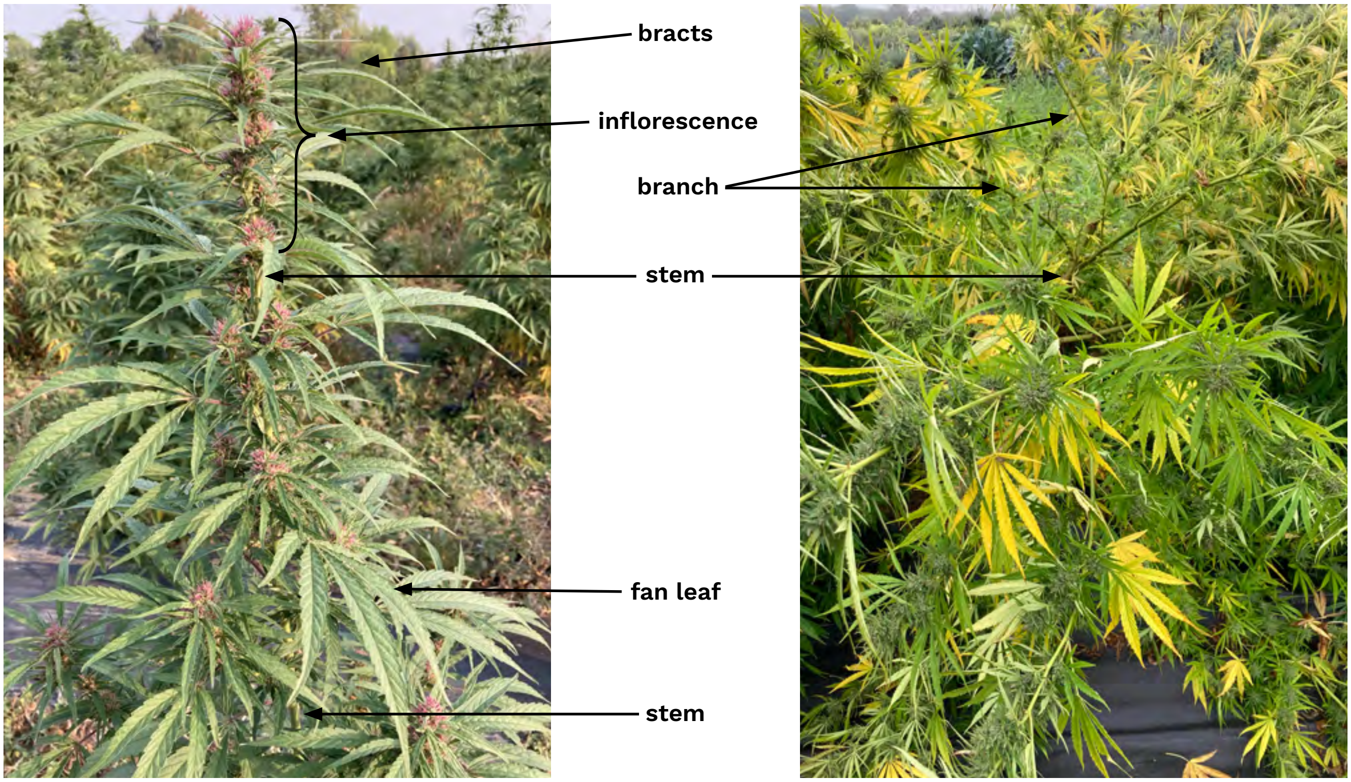


Anatomical parts of *Cannabis sativa. Illustration by Shiere Melin from the Rocky Mountain Society of Botanical Artists*

Cannabis sativa is a dioecious species, producing male and female parts on separate plants, although monoecious populations also exist. The *C. sativa* plant's physical characteristics vary depending on its use. Plants grown for fiber have been bred for height, and tend to have reduced branching and thinner stem diameter.

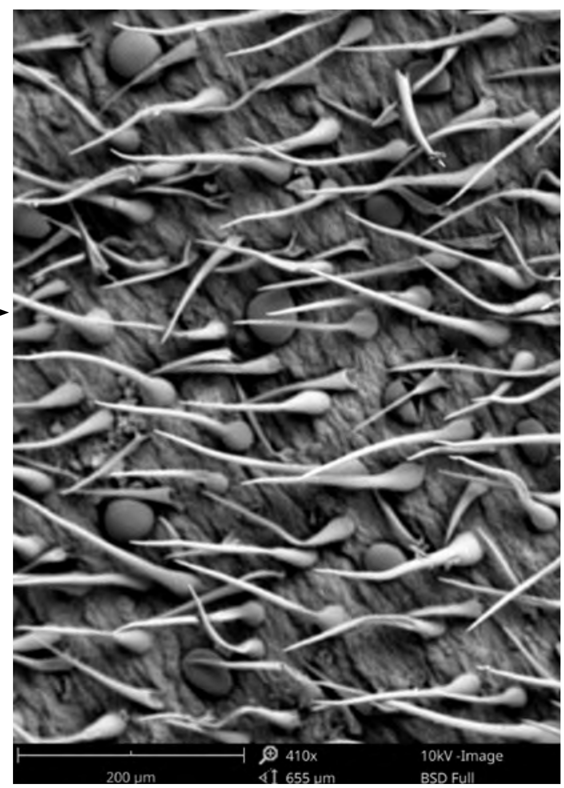
Female, Male, and Monoecious Plants

Female plants produce a harvestable inflorescence and seeds. The inflorescences have abundant trichomes, which are the plant organs where cannabinoids and other compounds are more abundant. Female plants grown for their flowers tend to have multiple branches with many inflorescences. The leaves found in between the inflorescence are called bracts–or "sugar leaves" in the cannabis industry–and usually have many trichomes. The apical meristem found within the tips of the new shoots is where the main inflorescence–referred to as "cola" in the cannabis industry–will develop. Once the female flower is pollinated, seeds are produced.



Female *C. sativa* plants grown for cannabinoid production. *Photos: Daniela Vergara, CCE*

Female inflorescence with bracts and multiple trichomes in the leaves and the inflorescence. *Photo: Daniela Vergara, CCE*

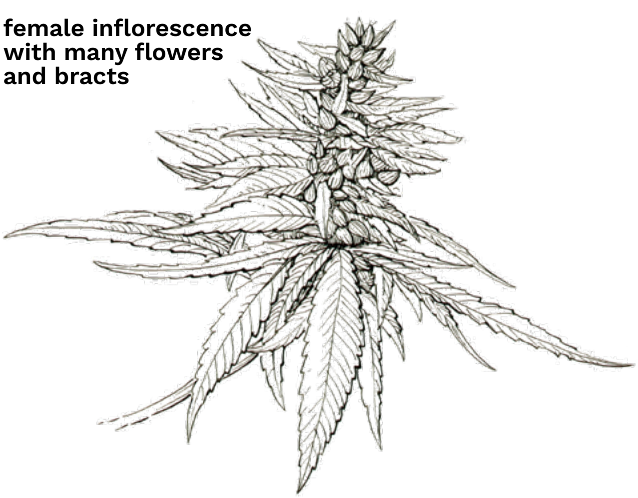


Microscopic closeup of trichomes in female inflorescences. *Photo: Jacob Toth*

Male plants produce male flowers which generate abundant pollen. Male plants present in cannabinoid production settings can jeopardize the crop through development of seed production in female plants, thus reducing the cannabinoid content of the overall biomass and seed can interfere with extraction or smokable quality. Male plants should be removed from cannabinoid production as pollen spreads easily in the field or greenhouse.

Female plants have two X chromosomes (XX), while male plants have an X and a Y chromosome (XY). Monoecious individuals produce male and female flowers on the same plant–either on the same inflorescence or on different parts of the plant–and also appear to have two X chromosomes (XX). The term "hermaphrodite" is commonly used, but hermaphrodites have male and female parts on the same individual flower, which is rare in C. *sativa*.

Female (left), male (center), and monoecious (right) individual plants. *Photos: Daniela Vergara, CCE, and Christine Smart, Cornell*



Female inflorescence with leaves and multiple pistils. *Illustration by Shiere Melin from the Rocky Mountain Society of Botanical Artists (RMSBA)*

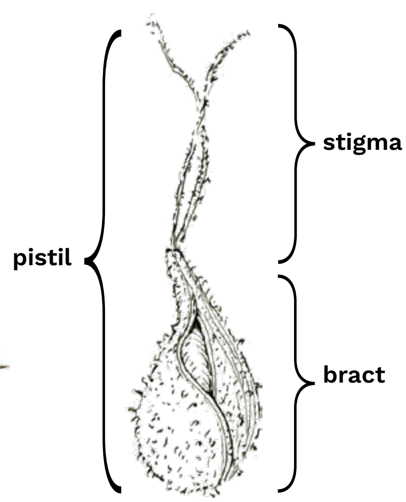
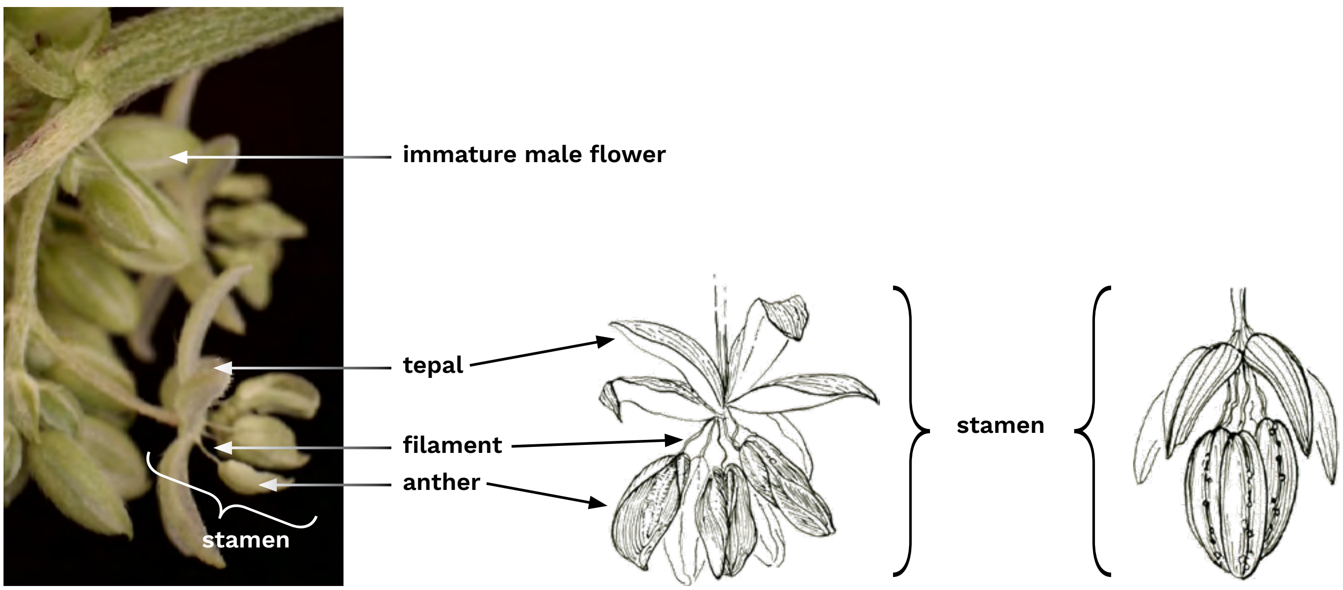


Diagram of the female reproductive organs. *Illustration by Shiere Melin, RMSBA*

Female inflorescence with white stigmas. *Photo: Cornell Hemp team*

Female plants produce a harvestable flower. The trichomes, which are abundant in the female inflorescences, are the plant organs where cannabinoids and other compounds are most abundant. Female plants also produce grain when the flowers are pollinated.

Males and/or monoecious individuals may be included when pollination is desired to produce seed for planting or for food/feed. Once pollinated, each flower produces a single-seeded fruit called an achene.



A male inflorescence with the male flower organs.
Photo: Cornell Hemp team

Diagram of a male stamen with its multiple parts.
Illustrations by Shiere Melin from the Rocky Mountain Society of Botanical Artists

Stages of Growth

Cannabis sativa is a photoperiod sensitive crop, meaning that its transition from vegetative growth to flowering is regulated by the duration of light received. Like all crops, C. *sativa* has a vegetative and reproductive growth stage. *Cannabis sativa* can be kept in a vegetative state indefinitely under approximately 18-plus hours of light per day; however, this practice is not recommended due to the accumulation of somatic mutations that can lead to less vigorous plants over time. As light duration decreases, the reproductive growth stage begins initiating the flowering period.

In outdoor production systems, the vegetative stage typically lasts from mid-late May through mid-to-late August or when the day-length is greater than 14.5 hours in New York State. Photoperiod varies with latitude and date. Some varieties are known to flower early and “autoflower” varieties do not require light cues to flower. During the vegetative stage, the C. *sativa* plant quickly increases foliar biomass. High-cannabinoid Cannabis continues to accumulate floral biomass during the flowering stage.

“Autoflower” Varieties

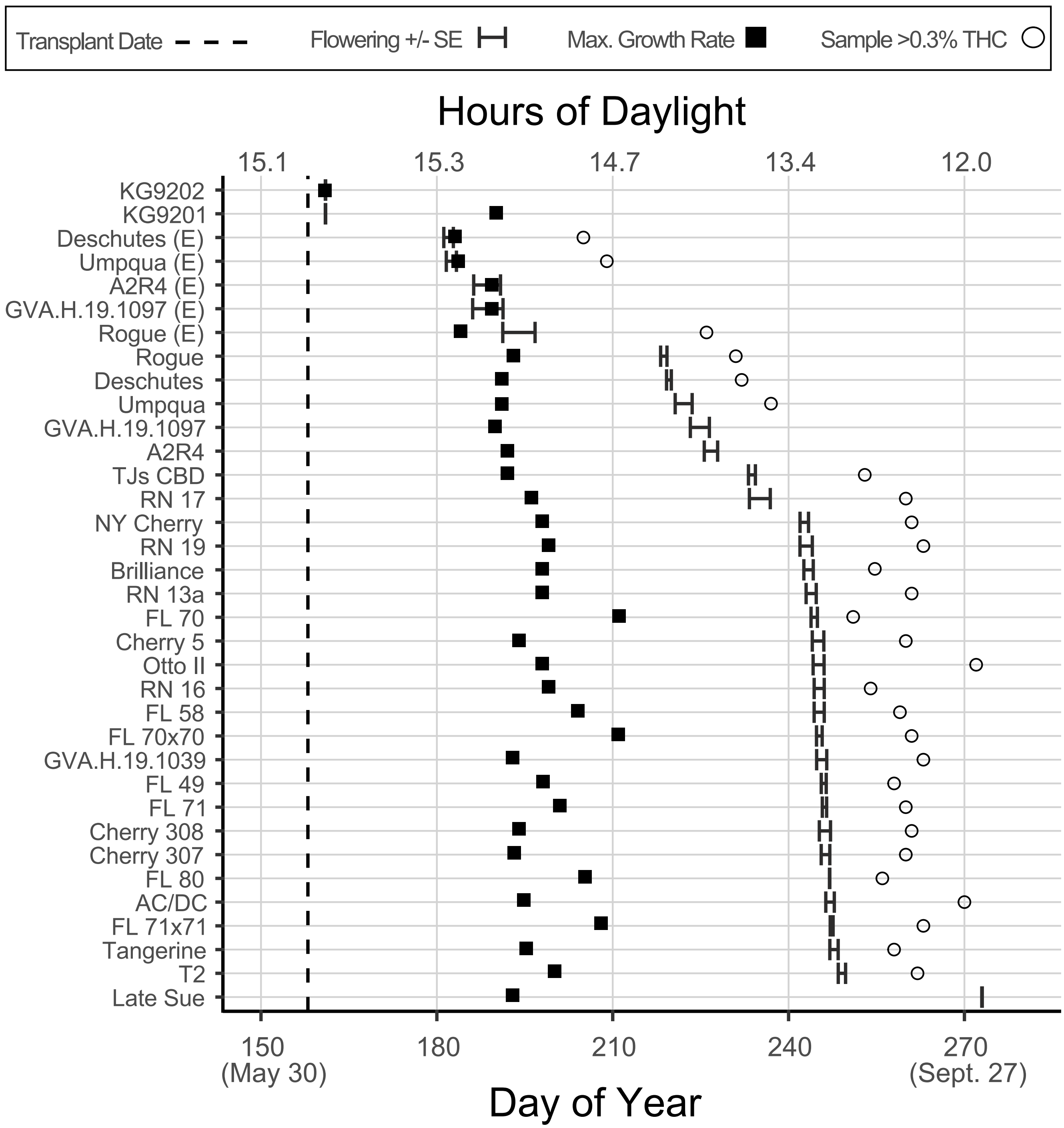
Photoperiod insensitive varieties are commonly referred to as “autoflower”, meaning that the plant flowers independently of daylength. These individuals usually begin flowering four to five weeks after seeding and are generally fully mature eight to ten weeks after emergence. Daylength insensitive varieties are useful when growers do not have control over photoperiod, such as in un-lit greenhouses in mid-winter and in early spring as day length increases. Since the nature of daylength insensitivity means that “autoflowers” cannot be maintained in vegetative mode, all plants must be started from seed. Producers should avoid transplanting these varieties whenever possible as they are extremely sensitive to any disturbance of their root system, which may induce premature flowering.

Full Season (Daylength Sensitive)
‘Rogue’

“Autoflower” (Daylength Insensitive)
‘Auto CBD’

Full season (daylength sensitive) plants from the variety ‘Rogue’ (left) and “autoflower” (daylength insensitive) variety ‘Auto CBD’ (right). “Autoflower” varieties are useful in situations where growers may not have control over the photoperiod, such as in un-lit greenhouses in mid-winter and in early spring as daylength increases. *Photos: Savanna Shelnutt, Cornell*

Most *C. sativa* is photoperiod sensitive and the flowering stage will begin once the days get shorter, typically in fall. Once exposure to light decreases–on average less than 14 hours per day–vegetative growth will slow significantly and reproductive growth begins. Most varieties will flower for between 7 and 8 weeks, as seen in the diagram on the next page.



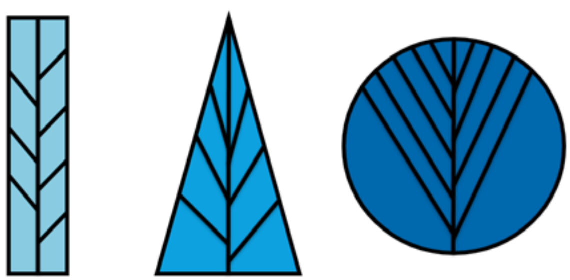
Timeline of growing season milestones for 30 high-cannabinoid Cannabis varieties. Varieties were ordered from earliest flowering (top) to latest flowering (bottom). The vertical dashed line indicates transplant date (June 5). Squares indicate the estimated day of maximum growth rate. Error bars indicate terminal flowering date ±SE (plus or minus standard error) of the mean. Crossed out circles indicate the estimated date when shoot-tip sampled chemotype III individuals will exceed 0.3% total THC. Day lengths are listed along the top of the plot at 30-day intervals. The day length on the summer solstice (Day 173) was 15.35 hours. *Figure modified from Stack et al. 2021.*

Plant Form

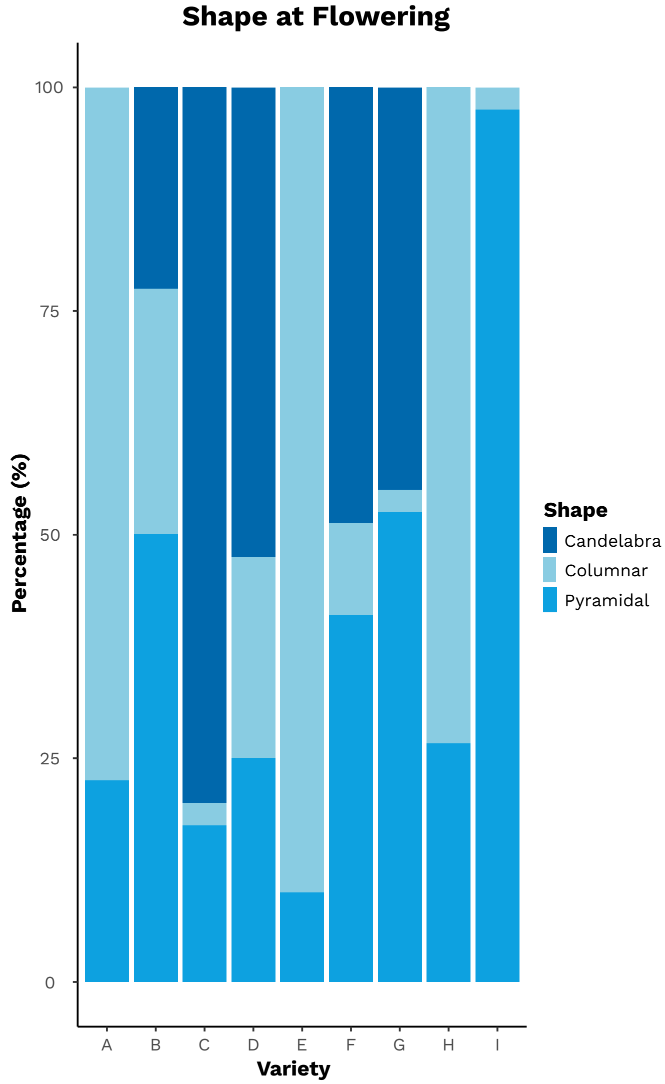
Architecture of plant branches influences the overall distribution of biomass.

- Columnar or pyramidal forms may be better suited for mechanical harvest of direct seeded hemp as the plants may feed onto the stripper-header more easily.
- Candelabra forms may be more desirable for producers focusing on hand harvest of high cannabinoid flowers as the plant produces more branches with dense inflorescences.

Plant architecture may provide some insight into the overall genetic stability of a variety as varieties heavily segregating for growth habit also tend to be segregating for other traits like chemotype or flowering time (see diagram).



Different plant architecture may affect overall biomass distribution. *Illustration: Savanna Shelnutt, Cornell*



Distribution of plant architecture by variety. Some varieties, like F, are heavily segregating for plant form, while variety I is highly uniform and stable.

All Pyramidal

Mix of Pyramidal and Columnar

Different plant architecture in Cornell's high-cannabinoid Cannabis fields with a mix of pyramidal and columnar forms (right) and all pyramidal forms (left). *Photos: Savanna Shelnutt, Cornell*

Types of Plants

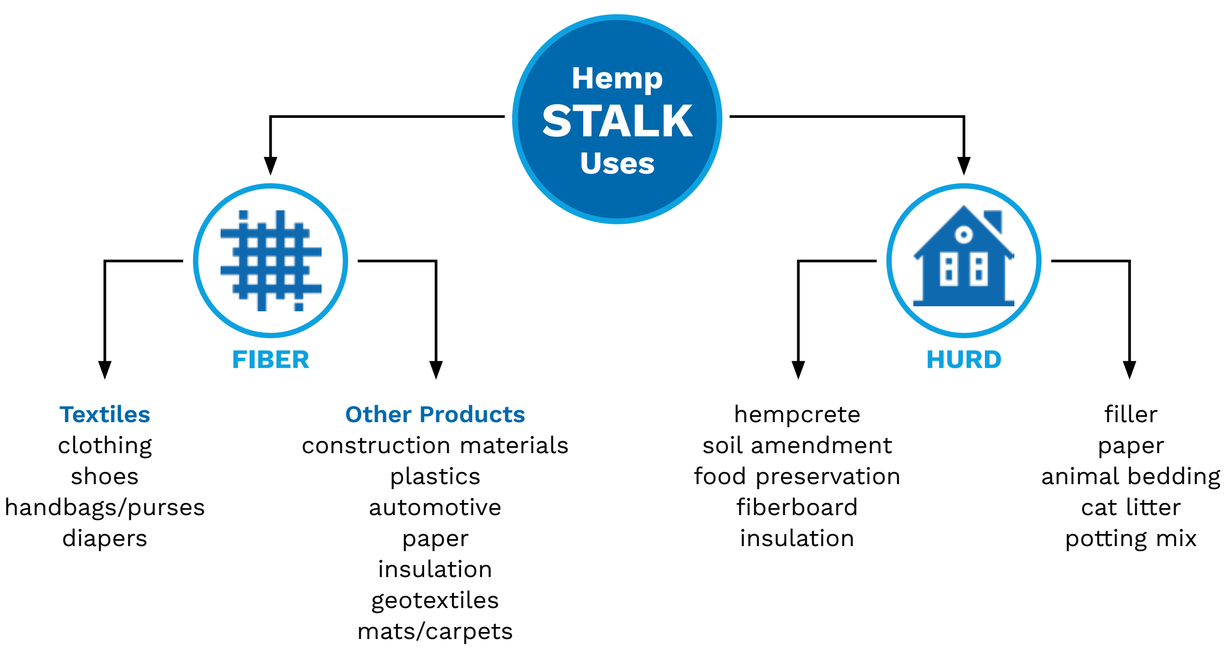
Fiber

Hemp is internationally cultivated for fiber. Fiber is processed from the stalk. There are multiple fiber varieties, currently originating mostly from Europe or China. These fiber varieties tend to be dioecious, have few branches, and a long stalk. Plants can measure up to 16 ft (~5 m) tall. The fiber can be used for cordage, textile materials, and paper among multiple other uses. Hurd from these fiber varieties is used for insulation materials, concrete (hempcrete), and for animal bedding and other absorbent products. Fiber can also be used to produce an ethanol-based biofuel.

Planting density varies depending on variety type. Plants grown for fiber production are commonly sown at a high density of 60-100 lb/ac (40-70 kg/ha) and at a depth of no more than 1.2 in (3 cm). High density plantings of fiber hemp encourage competition between plants, which creates tall, thin stems ideal for decortication. When fiber hemp is sown at a lower density, stems can become too thick and more difficult to harvest and process.

Fiber bundles left for field retting at Cornell's hemp fields. *Photo: Daniela Vergara, CCE*

Cuttings from various plant stalks differing in the amount of hurd and the size of the inner core. *Photo: Daniela Vergara, CCE*

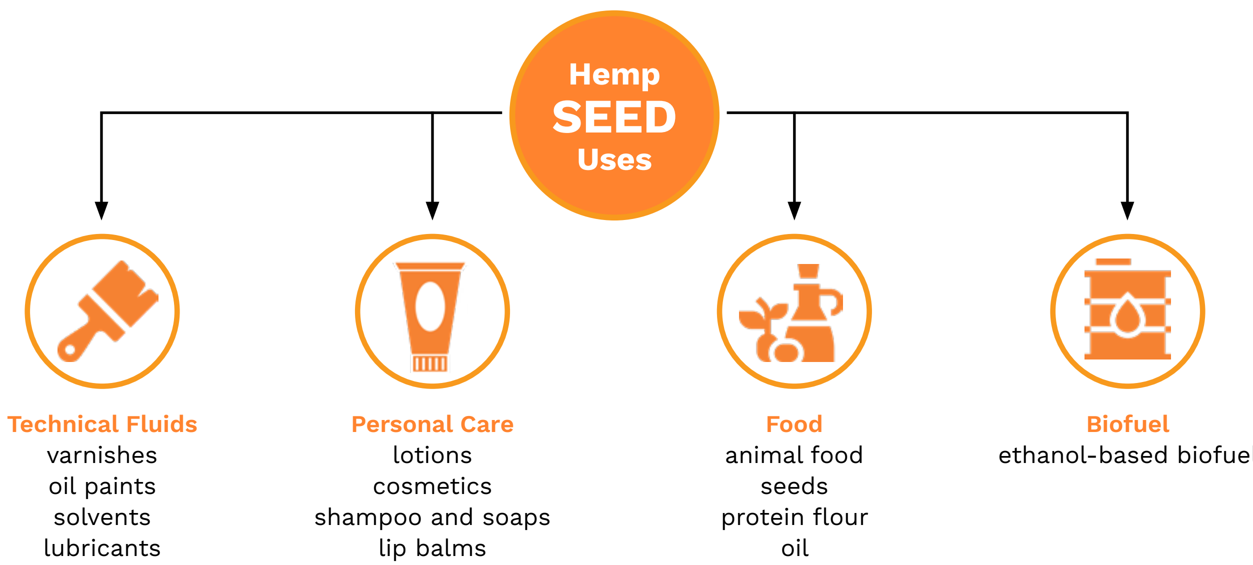


Information from Ahmed et al. 2022

Seed/Grain

Hemp varieties grown for seed or grain are either dioecious or monoecious. The seed is used for multiple purposes, such as biofuel, animal feed (e.g., bird seed), granola and cereals, and personal care products such as shampoo and cosmetics.

Seeds from different hemp varieties (left and right). *Photos: Daniela Vergara, CCE*



Information from Ahmed et al. 2022

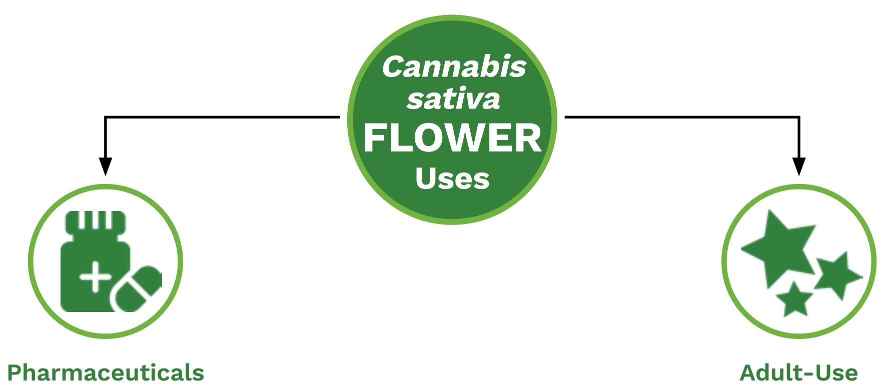
Current research seeks to understand whether varieties for dual purpose hemp—for both fiber and grain production—are viable and the yields for these varieties.

Cannabinoids

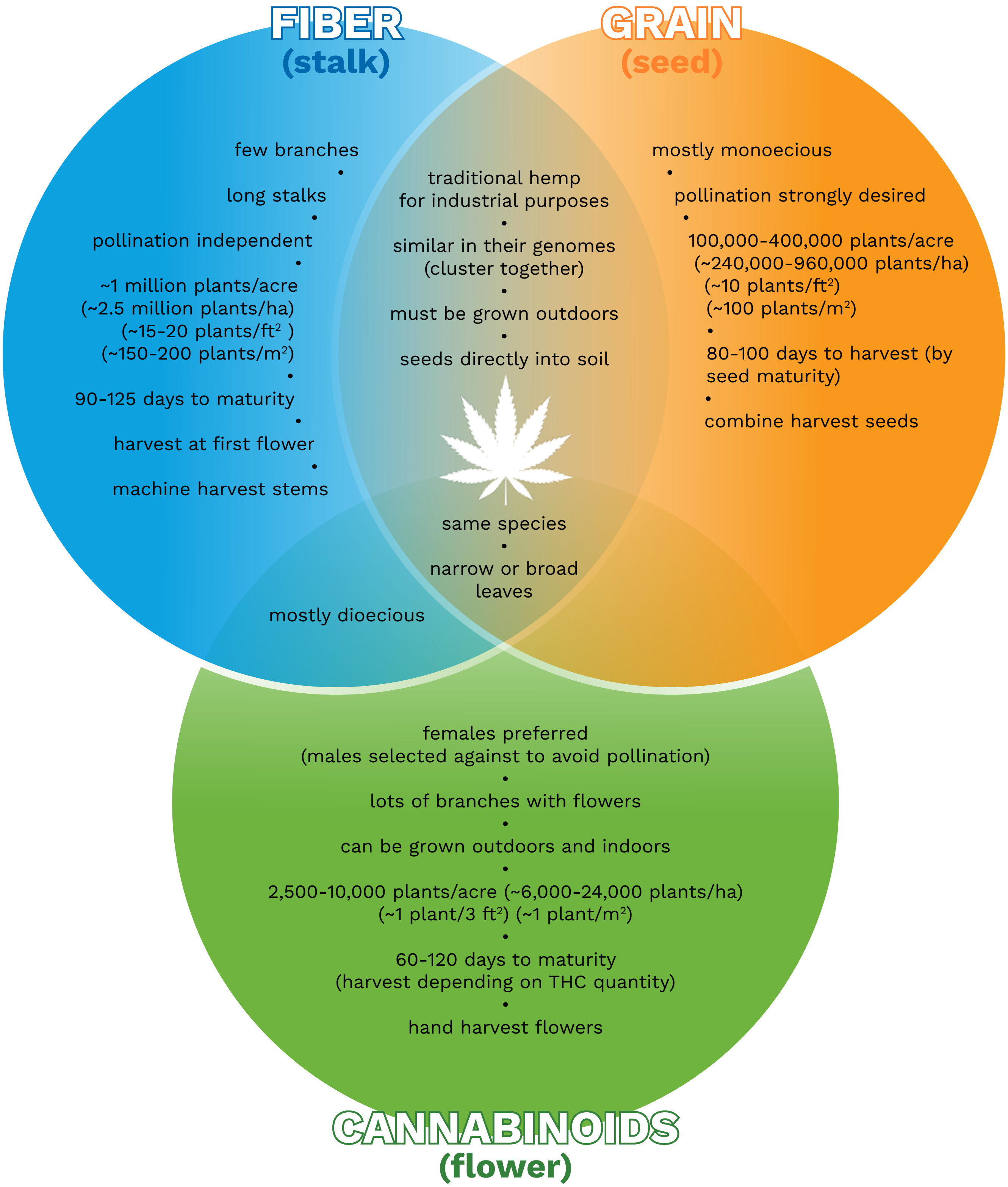
Female inflorescences with abundant trichomes and white stigmas (left) and with pink stigmas (right). *Photos: Daniela Vergara, CCE*

At the time of regulatory compliance testing high-cannabinoid Cannabis must produce less than 0.3% THC. Currently the most sought cannabinoid is CBD, but interest in other cannabinoids such as CBG, CBC, and THCV continues to grow. In most cultivars grown for cannabinoids, the amount of other cannabinoids remains low. The highest amount of CBD obtained has been around 20% in a few varieties.

Because cannabinoids are mostly found in female inflorescences, plants with multiple branches that hold several flowers are preferred.



Similarities and Differences Between *C. sativa* Types



Cannabis sativa in the United States

Milestones Influencing *Cannabis sativa* Production in America

1500s

Introduced into North and South America by the Spanish

1600s

Widely grown in English settlements for production of rope, sails, paper, canvas, and clothing

1700s

Hemp is used for both nutritional and industrial value; rope factories are established

American colonies heavily produced hemp—in many cases it was required by law

George Washington, Thomas Jefferson, James Madison, and Benjamin Franklin all farmed hemp

Benjamin Franklin began one of America's first paper mills using hemp

1800s

1850 – The United States Census counted 8,327 hemp plantations (minimum 2,000-acre farms) growing hemp

1900s

1906 –The Pure Food and Drug Act—a law protecting consumers against harmful and addictive additives to food and medicine—was enacted; *C. sativa* was added to the list of dangerous drugs along with alcohol, morphine, and opium

1917 – At its peak, Kentucky led the nation in hemp production with approximately 18,000 acres

1937 – The Marijuana Tax Act was enacted, placing a tax on all *C. sativa* products including hemp, which discouraged production

1942 – USDA initiates Hemp for Victory, lifting the tax act of 1937 and subsidizing production and processing to boost fiber production for war efforts, resulting in 150,000 acres of production

1950s – After the war effort and the introduction of nylon and synthetic fibers, hemp production ceased in the United States

1970s – The Controlled Substances Act of 1970 places *C. sativa* under federal control, leading to the creation of the Drug Enforcement Agency (DEA) in the Department of Justice in 1973

1990s – Cannabinoid oil found to be a powerful cellular antioxidant by the National Institute of Mental Health

1996 - California becomes the first state to legalize high-THC Cannabis for medical use

1998 – British government licenses GW Pharmaceuticals to grow CBD-rich *C. sativa* plants for medicinal extract clinical trials with the pharmaceutical drug Epidiolex

2000s

Evidence grows that CBD could be used to treat diseases like epilepsy, anxiety, cardiovascular diseases, schizophrenia, and cancer

2003 – CBD is patented as a neuroprotectant by the United States government

2004 – Hemp Industries vs. DEA protects sales of hemp food and body care products in the U.S.

2012 - Colorado and Washington become the first states to legalize high-THC Cannabis for recreational use

2013 – CBD grabs the media spotlight through a media special ran by CNN on the medicinal impacts of CBD and the story of 6-year-old epilepsy patient Charlotte Figi

2014 – President Obama signs the 2014 Farm Bill, allowing research institutions and departments of agriculture the ability to create pilot programs studying hemp production

2018 – President Trump signs the 2018 Farm Bill, removing hemp from the Controlled Substances Act and officially designating the difference between hemp and marijuana. Hemp production becomes legal throughout the United States upon state approval.

2019 – Forty-six (46) states had legal hemp farming with approximately 500,000 acres licensed across the U.S.

2020 – Licensed acres decreased from 2019 to approximately 330,000 resulting in unsold biomass due to regulatory uncertainty, COVID-19, flooded market, and slow sales

2021 – Multiple states legalized recreational and medical *C. sativa*, including New York State

Legal and Regulatory Environment

Global Overview

As of 2019, approximately 30 countries in Europe, Asia, and North and South America permit farmers to legally grow hemp. Based on aggregated production data from the United Nations, the global acreage in hemp cultivation in 2016—both hemp seed and hemp tow waste (raw or unprocessed residue)—is reported at approximately 192,000 acres* (~77,700 ha), with a reported total production of 355 million pounds (~161 million kg) and a revenue of approximately 5B USD with projections to increase to 36B by 2026. Due to a wide range in market classes and production systems, C. *sativa* cultivation data for specific uses is currently unavailable.

Data from the United Nations does not include all countries—most notably Canada, a major hemp producer and exporter—and may differ from other sources. Including 2016 data for Canada, aggregate acreage totaled at about 225,000 acres (~91,000 ha).

Canada is a major supplier of U.S. hemp imports, not including cannabinoids. Canada's current focus, largely due to its inability to export cannabinoids, is hemp-based foods and food ingredients and other related imported products. Preliminary information for 2017 indicates that acreage in Canada and the European Union (EU) countries alone reached record levels, which would put global acreage at more than 330,000 acres (~134,000 ha). Still, hemp production accounts for a negligible share, less than 0.5% of total crop production in these countries.

U.S. Legal and Regulatory Environment

Under the 2018 Farm Bill, individual states and tribes are permitted to submit research and management hemp plans to the USDA for approval. States and tribes are not prohibited from adopting more stringent requirements for hemp production than specified by USDA/AMS "baseline regulations," nor are they restricted from prohibiting hemp production altogether. The baseline regulations provide requirements for licensing, sampling, testing, disposal, and information collection. To date, at least 47 states have enacted hemp production programs or allow hemp cultivation research in their state.

The New York State plan was approved under the USDA Final Rule, which took effect on March 22, 2021.

As of November 2022, 37 states, Guam, Puerto Rico, The US Virgin Islands, the Northern Mariana Islands, and the District of Columbia have voted to allow medical use of high-THC Cannabis and products. These 37 states include: Alaska, Alabama, Arizona, Arkansas, California, Colorado, Connecticut, Delaware, Florida, Hawaii, Illinois, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Dakota, Utah, Vermont, Virginia, Washington, and West Virginia.

Additionally, 18 states, Guam, the Northern Mariana Islands, and the District of Columbia have voted to legalize and regulate adult consumption of C. *sativa* flower and products. These 18 states include: Alaska, Arizona, California, Colorado, Connecticut, Illinois, Maine, Massachusetts, Michigan, Montana, New Jersey, New Mexico, New York, Nevada, Oregon, Vermont, Virginia, and Washington.

Despite changes at the state level, high-THC Cannabis remains a Schedule I drug according to federal law under the Controlled Substances Act of 1970. The DEA holds the position that high-THC Cannabis has "no currently accepted medical use and a high potential for abuse."

2014 Farm Bill

The 2014 Farm Bill defined the term "hemp" and provided states with the ability to establish industrial hemp pilot programs, which govern(ed) the growing, cultivation, processing, and the distribution or sale of industrial hemp for lawful purposes. Numerous states enacted their own programs. These states' programs generally define(ed) hemp as all parts of the C. *sativa* plant with a 0.3% THC concentration or less and have established license, permit, or registration procedures, and manage everything from the possession of hemp seeds for planting and the cultivation and harvest of hemp to the distribution, storage, and transportation of the plant to market for sale. The 2014 Farm Bill also permitted State Departments of Agriculture and higher education institutions to produce hemp as part of pilot programs for research purposes.

2018 Farm Bill

The 2018 Farm Bill superseded the 2014 Farm Bill and other elements that were retained in the 2014 Farm Bill from the Agricultural Markets Act of 1946. The 2018 Farm Bill permanently removed hemp from scheduled control under the federal Controlled Substances Act (21 U.S.C. 801) ("CSA"), deeming it an agricultural commodity.

Hemp was federally redefined as "*the plant Cannabis sativa L. and any part of that plant, including the seeds thereof and all derivatives, extracts, cannabinoids, isomers, acids, salts and salts of isomers, whether growing or not, with a delta-9 tetrahydrocannabinol concentration of not more than 0.3 percent on a dry weight basis.*"

The 2018 Farm Bill explicitly protects interstate commerce involving hemp and hemp-derived products. However, states, including the District of Columbia and any territory or possession of the United States, as well as Native American tribes, may assume primary regulatory authority over the production of hemp in their jurisdictions through a regulatory or tribal plan approved by the U.S. Department of Agriculture (USDA). These state- or tribal-specific regulatory plans will be guided by regulations promulgated by the USDA.

The 2018 Farm Bill does not preempt state or local law. As such, through their regulatory plans, states or tribes may impose separate (and greater) restrictions or requirements on hemp production in their jurisdiction. Until states enact their own regulatory guidelines, however, those that previously instituted hemp pilot programs may continue to govern through them.

The 2018 Farm Bill allowed upon approval from the USDA that states and tribes have full jurisdiction over their respective program but are required to report necessary data to the Agricultural Marketing Service (AMS) and the United States Department of Agriculture (USDA).

Interim Final Rule (IFR)

The Interim Final Rule established a national program for production of industrial hemp on October 3, 2019. While many states initially switched to the Interim Final Rule, some states chose to remain operating under the 2014 Farm Bill.

USDA Final Rule

Effective March 22, 2021, the USDA Final Rule supersedes the Interim Final Rule (IFR) and establishes a Domestic Hemp Production Program as previously mandated in the Agriculture Improvement Act of 2018.

- New York State extended the 2014 Farm Bill until January 1, 2022. Since that date has passed, all hemp programs are operating under the USDA Final Rule.

Key Definitions

Hemp: The plant species *Cannabis sativa* L. and any part of that plant, including the seeds thereof and all derivatives, extracts, cannabinoids, isomers, acids, salts, and salts of isomers, whether growing or not, with a delta-9 tetrahydrocannabinol (THC) concentration of not more than 0.3 percent (0.3%) on a dry weight basis.

- Hemp that tests above 0.3% THC on a dry weight basis is considered a Schedule 1 substance under the Controlled Substances Act (CSA) as enforced by the Drug Enforcement Agency (DEA).

Cannabinoid Hemp: Any hemp and any product processed or derived from hemp, that is used for human consumption provided that when such product is packaged or offered for retail sale to a consumer, it shall not have a concentration of more than three tenths of one percent delta-9 tetrahydrocannabinol.

Marijuana: All parts of the plant *Cannabis sativa* L., whether growing or not; the seeds thereof; the resin extracted from any part of such plant; and every compound, manufacture, salt, derivative, mixture, or preparation of such plant, its seeds, or resin. The term marijuana does not include hemp, as defined in this plan, and does not include the mature stalks of *Cannabis sativa* L., fiber produced from its stalks, oil, or cake made from its seeds and any other compound, manufacture, salt, derivative, mixture, or preparation of such mature stalks (except the resin extracted therefrom), its fiber, oil, cake, or sterilized seed incapable of germination. Except as otherwise provided by this plan, marijuana means all *C. sativa* that tests as having a total THC concentration level of higher than 0.3 percent (0.3%) on a dry weight basis.

Indian Tribes: Any Indian or Alaska Native tribe, band, nation, pueblo, village, or community that the Secretary of the Interior acknowledges to exist as an Indian tribe. Indian tribes are considered independent entities.

Territory of the Indian Tribe:

a) All land within the limits of any Indian reservation under the jurisdiction of the United States Government, notwithstanding the issuance of any patent, including rights-of-way running through the reservation;

b) All dependent Indian communities within the borders of the United States whether within the original or subsequently acquired territory thereof, and whether within the limits of a state;

c) All Indian allotments, the Indian titles to which have not been extinguished, including rights-of-way running through the same; and

d) Any lands title to which is either held in trust by the United States for the benefit of any Indian Tribe or individual or held by any Indian Tribe or individual subject to restriction by the United States against alienation and over which an Indian Tribe exercises a jurisdiction.

Key Participants: Key participants are a person or persons who have a direct or indirect financial interest in the entity producing hemp, such as an owner or partner in a partnership. A key participant also includes a person in a corporate entity at executive levels including the chief executive officer, chief operating officer, and chief financial officer.

- The AMS defines "key participants" as those that "exercise managerial control over hemp production." States/Tribes are free to incorporate the AMS definition of key participants into their plan but are not required to do so.

- They must, however, define who participates in their plan and for each license or authorization they issue, must identify at least one individual who will be subject to a criminal history check.

Hemp Processor: Cannabinoid hemp processor means a person licensed by the department to extract hemp extract and/or manufacture cannabinoid hemp products, whether in intermediate or final form, to be used for human consumption. Must be licensed in compliance with Article 5 of Cannabis Law

Hemp Manufacturer: Cannabinoid hemp manufacturer means a person licensed by the department to prepare, treat, modify, compound, process, package or otherwise manipulate hemp or hemp extract into a cannabinoid hemp product. Does not include growing, cultivating, cloning, harvesting, drying, curing, grinding, or trimming, or extraction.

Marijuana Regulation and Taxation Act (MRTA)

Effective March 31, 2021, the MRTA legalized adult-use high-THC Cannabis and established the Cannabis Control Board (CCB) that oversees the Office of Cannabis Management (OCM). The CCB regulates high-cannabinoid and high-THC Cannabis and is an independent entity within the division Alcoholic Beverage Control. The board retains the right to make regulations pursuant to: processing, distribution, marketing, transportation, and sale of cannabinoid hemp and hemp extracts used for human consumption. The CCB consists of a chairperson nominated by the governor and with the advice and consent of the senate. The governor will have two direct appointments to the board, and the president of the senate and the speaker of the assembly will each have one direct appointment to the board—each of which will have term limits of 3 years.

Licensing Agencies

Since New York State has an approved USDA plan, producers growing grain, fiber, or cannabinoid hemp will report to the New York State Department of Agriculture and Markets. Individual high-cannabinoid Cannabis, Adult-Use, and Medical Producers will be regulated by the New York State Office of Cannabis Management.

License Type by Responsible Granting and Administrative Agency

USDA	New York State Department of Agriculture and Markets	New York State Office of Cannabis Management
• Tribal Hemp Production Plans • State Hemp Production Plans	• Grain Hemp Production • Fiber Hemp Production • Cannabinoid Hemp Production • Sampling Agents	• Cannabinoid Hemp Products • Adult-Use high-THC Cannabis • Medical high-THC Cannabis

New York State Hemp Licensing Program

New York State Department of Agriculture and Markets regulates the growth, cultivation, and production of hemp. No person shall grow, cultivate, or handle hemp in New York State without a valid commercial or research license issued by the Department. A non-refundable application fee is required for each type of license sought.

The New York State Hemp Licensing Program pertains to the following license types:

Hemp Grower License

Authorizes the growth, cultivation, and handling of hemp plant material for market.

- License cost: $500
- License term: 3 years
- More information and the New York State Hemp Grower Application can be found at https://agriculture.ny.gov/plant-industry/hemp-grower-licensing

Nursery Grower License

Authorizes the sale of rooted hemp plants or seedlings.

- License cost: $100
- License term: 2 years
- More information and the New York State Hemp Nursery License can be found at https://agriculture.ny.gov/plant-industry/licensing-and-plant-inspections

Hemp Seed Retail License

Authorizes the sale of hemp seeds.

- License cost: $100
- License term: 3 years
- See the New York State Hemp Seed Retail Application.

Hemp Research License

Authorizes the growth or cultivation of hemp for scientific, academic, or commercial research purposes but does not authorize hemp to move into commerce.

- License cost: $500
- License term: 3 years
- The New York State Hemp Research License Application is the same document as the New York State Hemp Grower Application.

Individuals and businesses that would like to participate in this program must submit for consideration a completed application form with all required maps, fees, and an FBI Identity History Summary for all key participants dated within 60 days of the date of application. Incomplete applications will be denied.

The New York State Hemp Licensing Program Guidance Document provides more information on applications and requirements, testing facilities, seed and plants, testing, reporting requirements, and much more.

Sampling Agent Certification License

For those seeking to become a private hemp sampler.

- Application fee: None
- License term: 3 years
- The NYS Hemp Licensing Program Sampling Agent Application requires the applicants contact information, a list of the NYS counties to cover as a private hemp sampler, and an FBI Identify History Summary Check dated no more than 60 days prior to the date of application. Disqualifying factors may include but are not limited to:
    - Having an active hemp license in any state
    - Being a current employee of a hemp growing facility in any state
    - Having a financial stake in a hemp growing operation in any state
    - Being a nuclear or extended family member of a hemp licensee
    - Being a hemp broker, distributor, or processor
    - Soliciting hemp for sale, processing, or distribution or being an employee of an entity that is soliciting, producing, processing, or distributing hemp, and/or having a drug-related felony conviction within the past 10 years in any state.
- Once the department has completed its review, applicants must complete the required Hemp Sampling Agent Training and pass the Sampling Agent exam.
- Applicants are not authorized to sample hemp for Department compliance until they have received a New York State Sampling Agent Certification from the Department.

High-Cannabinoid Cannabis Product Licenses from the OCM

The Office of Cannabis Management (OCM) is an independent state office established by the Marijuana Regulation and Taxation Act (MRTA) and housed within the Division of Alcoholic Beverage Control. The OCM provides a unified regulatory structure to comprehensively regulate and control the cultivation, processing, manufacture, distribution, transportation, and sale of high-THC Cannabis in New York State.

Regulations do not apply to:

- High-cannabinoid Cannabis, extracts, or other products that are not used for human consumption
- Products deemed GRAS (Generally Recognized As Safe) pursuant to federal law (ex. Hemp seed oil, proteins derived from hemp grain, etc.)

Applications are available on the New York State Office of Cannabis Management website, https://cannabis.ny.gov/cannabinoid-hemp

High-cannabinoid Cannabis Processor Extraction and Manufacting License

- Application fee: $1,000, non-refundable
- License fee: $3,500 per location (refundable if denied)
- License term: 2 years

High-cannabinoid Cannabis Manufacturing Only License

- Application fee: $500, non-refundable
- License fee: $1,000 per location (refundable if denied)
- License term: 2 years

High-cannabinoid Cannabis Retail License

- License fee: $300 refundable fee per retail location
- License term: 1 year

State of New York Legislation 8084A: Conditional Cultivation Licenses

Legislation 8084A provides a conditional adult-use cultivator license to process and distribute high-THC Cannabis flower products without holding an adult-use processor or distributor license, and provides a conditional adult-use processor license to process and distribute high-THC Cannabis products.

Conditional licenses are valid for two years. Conditional license holders will have the option to apply for full adult-use licenses before the conditional period expires on June 1, 2023.

No later than 90 days before the expiration of a conditional adult-use cultivator license, the office shall, pursuant to a request by the licensee, review the conditional adult-use cultivator licensee to determine whether they remain in good standing

Any licensee found to be in good standing shall be eligible to apply for and receive an adult-use cultivation license—provided the licensee can meet all the requirements of the new license.

Note: Application windows, fees, restrictions, and requirements change frequently. For the most up-to-date information, visit the New York State Office of Cannabis Management website: https://cannabis.ny.gov/licensing.

Full Adult-Use License Types

Full adult-use applications are not yet available, but can be found at a later date on the New York State Office of Cannabis Management website: https://cannabis.ny.gov/licensing.

Number and Combination of Adult-Use Licenses Permitted Under the Marijuana Regulation and Taxation Act (MRTA)

Allowable License Combinations	Adult-Use Cultivator	Adult-Use Conditional	Adult-Use Nursery	Adult-Use Processor	Adult-Use Distributor	Adult-Use Cooperative	Adult-Use Microbusiness	Adult-Use Retail Dispensary	Adult-Use On-Site Consumption	Adult-Use Delivery	Registered Organization Processor, Distributor, Retail	Registered Organization Cultivator, Processor, Distributor
Adult-Use Cultivator	Yes, one	No	No	Yes, one	Yes, one	No	No	No	No	No	No	No
Adult-Use Conditional	-	Yes	No	No	No	No	No	No	No	No	No	No
Adult-Use Nursery	-	-	Yes, one	No	No	No	No	No	No	No	No	No
Adult-Use Processor	-	-	-	Yes, one	Yes, one	No	No	No	No	No	No	No
Adult-Use Distributor	-	-	-	-	Yes, one	No	No	No	No	No	No	No
Adult-Use Cooperative	-	-	-	-	-	Yes, one	No	No	No	No	No	No
Adult-Use Microbusiness	-	-	-	-	-	-	Yes, one	No	No	No	No	No
Adult-Use Retail Dispensary	-	-	-	-	-	-	-	Yes, up to three	No	No	No	No
Adult-Use On-Site Consumption	-	-	-	-	-	-	-	-	Yes, up to three	No	No	No
Adult-Use Delivery	-	-	-	-	-	-	-	-	-	Yes, one	No	No
Registered Organization Processor, Distributor, Retail	-	-	-	-	-	-	-	-	-	-	Yes, one; 3 locations	No
Registered Organization Cultivator, Processor, Distributor	-	-	-	-	-	-	-	-	-	-	-	Yes

Allowable Activities Associated with Each License Type

Allowable License and Activity Combinations	Cultivation	Acquisition	Possession	Distribution	Sale	Processing	Manufacturing	Extraction	Delivery	On-Site Consumption
Adult-Use Cultivator	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-	-
Adult-Use Conditional	Yes	Yes	Yes	Yes	-	Yes	Yes	-	-	-
Adult-Use Nursery	Yes	Yes	Yes	Yes	Yes	-	-	-	-	-
Adult-Use Processor	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-
Adult-Use Distributor	-	Yes	Yes	Yes	Yes	-	-	-	-	-
Adult-Use Cooperative	Yes	Yes	Yes	-	Yes	Yes	-	-	-	-
Adult-Use Microbusiness	Yes	Yes	Yes	Yes	Yes	Yes	-	-	Yes	-
Adult-Use Retail Dispensary	-	Yes	Yes	-	Yes	-	-	-	Yes	-
Adult-Use On-Site Consumption	-	Yes	Yes	-	Yes	-	-	-	-	Yes
Adult-Use Delivery	-	Yes	Yes	-	-	-	-	-	Yes	-
Registered Organization Processor, Distributor, Retail	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-
Registered Organization Cultivator, Processor, Distributor	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-

Descriptions of activities that are permitted under each license:
Restrictions pertaining to holding multiple license ***types*** does not necessarily prohibit ***activities*** of other license types within a particular license.

- **Adult-Use Cultivator** – Authorizes a licensee to engage in activities related to the acquisition, possession, distribution, cultivation, and sale of high-THC Cannabis from the licensed property of the adult-use cultivator to a licensed processor. The MRTA defines high-THC Cannabis cultivation activities as related to: growing, cloning, harvesting, drying, curing, grading, and trimming.
    - Licensees may not own more than one cultivator license. A cultivator is allowed to obtain one processor license and one distributor license, but only for the distribution of their own high-THC Cannabis products. Cultivator licensees are not allowed to own or have any ownership interest in a licensee in the high-THC Cannabis retail tier.

- **Adult-Use Conditional Cultivator** – Authorizes a licensee to cultivate high-THC Cannabis outdoors or in a greenhouse for (up to) two years from the date of license issuance. Under this license type, licensees are allowed to minimally process, manufacture, and distribute high-THC Cannabis flower products without needing an adult-use processor or distributor license. This provision expires on June 1, 2023 when conditional cultivators are then eligible to apply for full adult-use licenses.
    - No licensee is allowed to own more than one Adult-Use Conditional Cultivator license. Adult-Use Conditional Cultivator licensees that remain compliant during the conditional period will be eligible to apply for and receive a full adult-use cultivation license. Conditional cultivator licensees are not allowed to own or have any ownership interest in a licensee in the high-THC Cannabis retail tier.

- **Adult-Use Nursery** – Authorizes a licensee to produce clones, immature plants, seeds, and other agricultural products that are specifically used for planting, propagation, and cultivation of high-THC Cannabis by other licensed adult-use high-THC Cannabis cultivators, microbusinesses, cooperatives and registered organizations. A nursery license does not allow licensees to sell directly to consumers.
    - An adult-use cultivator licensee may only hold one nursery license.
- **Adult-Use Processor** – Authorizes a licensee to extract high-THC Cannabis compounds and produce blends, extracts, infusions, or concentrates. A processor's license allows the licensee to engage in activities related to acquisition, possession, processing, and sale of high-THC Cannabis between the licensed premises of adult-use cultivators to the licensed premises of adult-use distributors.
    - No licensee is allowed to own more than one processor license. A processor licensee is allowed to obtain a distributor license, but only for the distribution of their own products. Processor licensees are not allowed to own or have any ownership interest in a licensee in the high-THC Cannabis retail tier.
- **Adult-Use Distributor** – Authorizes a licensee to sell any high-THC Cannabis flower or products at wholesale. The licensee is allowed to engage in activities related to the acquisition, possession, distribution, and sale of high-THC Cannabis flower or products from the licensed premises of licensed adult-use processors, adult-use cooperatives, microbusinesses, or registered organizations that are allowed to sell high-THC Cannabis flower or products to licensed retail dispensaries, on-site consumption sites, and adult-use delivery licensees.
    - No licensee is allowed to own more than one distributor license. Distributor licensees are not allowed to own or have any ownership interest in a licensee in the high-THC Cannabis flower or products retail tier.
- **Adult-Use Cooperative** – Authorizes a licensee to engage in activities related to acquisition, possession, cultivation, processing, and sale from the property of the adult-use cooperative to licensed distributors, on-site consumption sites, registered organization and/or retail dispensaries. The cooperative license does ***not*** allow the licensee to sell directly to consumers.
    - No licensee is allowed to own more than one cooperative license, and cooperative licensees are not allowed to own or have any ownership interest in a licensee in the high-THC Cannabis retail tier
- **Adult-Use Microbusiness** – Authorizes a licensee to act as a high-THC Cannabis producer for the cultivation of high-THC Cannabis, a high-THC Cannabis processor, a high-THC Cannabis distributor, and a high-THC Cannabis retailer. The licensee is allowed to engage in activities related to limited cultivation, processing, distribution, delivery, and sale of their own adult-use high-THC Cannabis flower and products.
    - No licensee is allowed to own more than one microbusiness license. Microbusiness licensees are not allowed to own or have any ownership interest in any other adult-use license type.

- **Adult-Use Retail Dispensary** – Authorizes a licensee to sell any high-THC Cannabis product to consumers at retail. The licensee is allowed to engage in activities related to the acquisition, possession, sale, and delivery of high-THC Cannabis from the licensed property of the retail dispensary directly to consumers.
  - No licensee is allowed to own more than three retail dispensary licenses. Retail licensees are not allowed to own or have any ownership interest in a licensee in the cultivation, processing, or distribution tier.

- **Adult-Use On-Site Consumption** – Authorizes the licensee to acquire, possess, and sell high-THC Cannabis from the licensed premises of the on-site consumption licensee to consumers for use at the on-site consumption location. The consumption area must be specified and approved by the Cannabis Control Board.
  - No licensee is allowed to own more than three on-site consumption licenses. On-site consumption licensees are not allowed to own or have any ownership interest in a licensee in the cultivation, processing, or distribution tier.

- **Adult-Use Delivery** – Authorizes the delivery of high-THC Cannabis flower and products by licensees, independent of another adult-use high-THC Cannabis license, to consumers. Delivery licensees are not allowed to have more than twenty-five individuals, or the equivalent thereof, engaged in full-time paid delivery services to consumers on a weekly basis under one license.
  - No licensee may own more than one delivery license. Delivery licensees are not allowed to own or have any ownership interest in another adult-use license type.

- **Registered Organization Adult-Use Cultivator Processor Distributor Retail Dispensary** Authorizes a licensee to have the same privileges and conditions as adult-use cultivator, processor, distributor, and retail dispensary licensee. The licensee's adult-use retail dispensaries will be limited to three of the organization's medical dispensaries' and only authorizes the distribution of the licensee's own products. The CCB will, at a later date, further specify the extent of a registered organization's participation in the adult-use market.
  - Licensees are not allowed to have an interest in or own any other adult-use license type.

- **Registered Organization Adult-Use Cultivator Processor Distributor** – Authorizes a licensee to have the same privileges of adult-use cultivator, processor, and distributor licensee. The CCB will, at a later date, further specify the extent of a registered organization's participation in the adult-use market.
  - Licensees are not allowed to have an interest in or own any other adult-use license type.

Taxes on Adult-Use High-THC Cannabis

The Marijuana Regulation and Taxation Act (MRTA) establishes three taxes on adult-use high-THC Cannabis. The taxes listed do not apply to medical Cannabis.

1. There is a tax imposed at the distributor tier based on the milligrams (mg) of total THC in the product.
2. There are different rates of tax depending on the high-THC Cannabis product form:
   - Edibles, such as food and beverages, are taxed at $0.03 per mg of THC.
   - Concentrates, such as vape oil, waxes, shatter, and resin, are taxed at $0.008 per mg of THC.
   - High-THC Cannabis flower and flower products, such as pre-rolls, are taxed at $0.005 per mg THC.
3. For sale to the retail consumer, two taxes are imposed:
   - 9% state excise tax
   - 4% local excise tax

All high-THC Cannabis taxes are deposited in the New York State cannabis revenue fund. The revenue is used to cover costs to administer the state program and implement state law.

The remaining funding are split in three ways:

- 40% toward education
- 40% toward Community Grants Reinvestment Fund (CGRF)
- 20% to Drug Treatment and Public Education Fund (DTPEF)

Federal and Individual Growth, Cultivation, and Production of Hemp

The USDA, provides leadership on food, agriculture, natural resources, rural development, nutrition, and related issues based on public policy, the best available science, and effective management.

To obtain a license, a producer must create an account using the Hemp eManagement Platform (HeMP) to submit a USDA Hemp Application. Applications are accepted year-round on a rolling basis. For more information, visit https://hemp.ams.usda.gov/s/

For producers operating directly under the USDA, the following instructions apply:

- Individual producers from States/Tribes that do not have USDA-approved plans may file separate applications for hemp production licensees under the general USDA Hemp Production Plan.
  - The USDA will not approve applications sent to them from producers in States/Tribes that already have their own plans.
- Complete the USDA Hemp Plan Producer Licensing Application
- Submit an FBI Identity Summary (https://www.fbi.gov/services/cjis/identity-history-summary-checks)
- USDA producers must submit the USDA Producer Annual Report (https://omb.report/icr/202004-0581-003/doc/100202700)
- Disposal documentation must be created and submitted to USDA through the USDA Hemp Plan Disposal Form (https://omb.report/icr/202108-0581-002/doc/113907900.pdf)

Individual Producers:

- Individual producers from States/Tribes that do not have USDA-approved plans may file separate applications for hemp production licensees under the general USDA hemp production plan

Fees and Administrative Costs:

- The estimated average cost of program administration fees is $800 annually, which includes:
  - Application fees
  - Site registration fees
  - Licensing fees
  - "Other fees"
- The estimated administrative fees ***exclude*** sampling and testing costs.
- Criminal background checks cost $18 for each key participant.

Production

Breeding

There is tremendous potential to breed new C. *sativa* varieties, because of the breeding activity in the last 50 years. During this time, genetic and genomic tools have advanced tremendously.

The term "cultivar", meaning "cultivated variety" was coined by Liberty Hyde Bailey in 1923 to describe "*a botanical variety, or for a race subordinate to species, that has* ***originated under cultivation****; it is not necessarily, however, referable to a recognized botanical species. It is essentially the equivalent of the botanical variety except in respect to its origin.*"

Often "variety" is used interchangeably with cultivar, although a botanical variety is subordinate to species and arose through natural selection, not breeding.

The term "strain" is mostly used in biology for a genetic variant of a microbe, such as a bacterial strain derived from a single colony, and some consider the term "strain" used in the cannabis industry not appropriate. However, some C. *sativa* scientists do consider the use of the word "strain" appropriate to describe C. *sativa* plants with undocumented backgrounds, and international horticulturist have also used this "*confused term having several meanings*". The term remains controversial among the Cannabis and academic communities.

For more information, please refer to:

- https://www.actahort.org/chronica/pdf/sh_10.pdf
- McPartland JM, Small E. 2020. A classification of endangered high-THC cannabis (*Cannabis sativa* subsp. indica) domesticates and their wild relatives. PhytoKeys.
- Pollio A. 2016. The Name of Cannabis: A Short Guide for Nonbotanists. Cannabis Cannabinoid Research.

Cultivar is a legal term to describe plants that were selected in cultivation – most often through breeding – that are distinct, uniform, and stable. To meet this definition, these plants must be different from any other cultivar that has been described (distinct); each plant must be phenotypically identical when grown in commercial cultivation (uniform); and they must display those same phenotypic characteristics across different sites and when planted in different years (stable).

Cultivar descriptions may be published in the *Journal of Plant Registrations*, they may be submitted for intellectual property protection to the US Patent and Trademark Office or Plant Variety Protection Office, or they may be submitted to the Association of Official Seed Certifying Agencies (AOSCA) which is responsible for certifying that seed is true to a cultivar type description when it is produced.

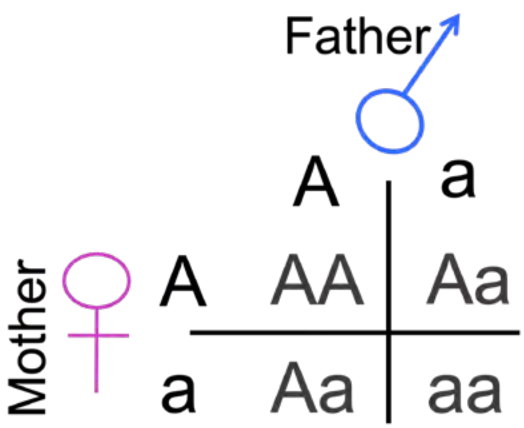
There are four types of plant cultivars: inbred pure lines, open-pollinated populations, hybrids, and clones.

Inbred Pure Lines

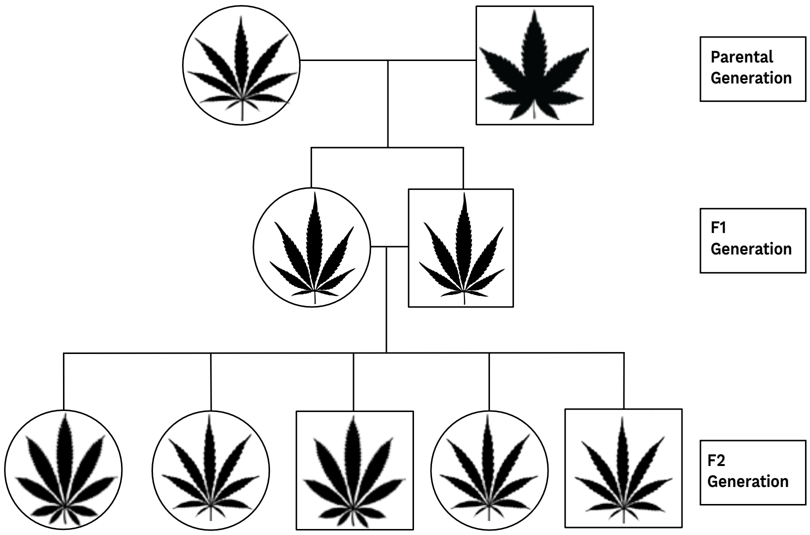
Inbred pure lines are developed through several generations of inbreeding, which results in genetic homozygosity, and thus uniformity. Inbreeding can be accomplished through self-pollination, the repeated intercrossing of very closely related individuals, or the repeated backcrossing of progeny to a recurrent parent.

Self-pollination occurs when a female flower is fertilized by pollen from the same plant and is the fastest way to increase homozygosity over generations. Selfing is possible for plants that are either monoecious (some C. *sativa* lines produce both female and male flowers on the same plant). Plants that are strictly dioecious cannot be selfed, although female C. *sativa* can be induced to produce pollen using plant growth regulators, such as silver thiosulfate. The pollen produced by genetically female plants is XX, and the seeds produced form that self-pollination will be entirely female or monoecious.

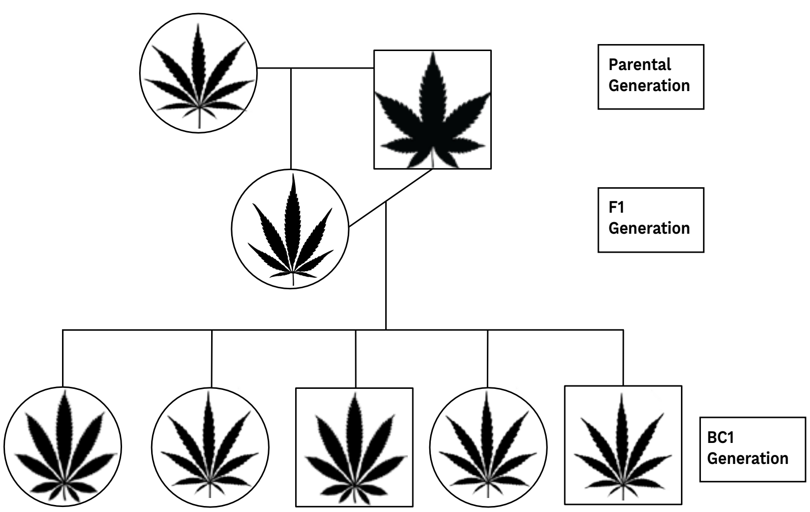
A high overall level of homozygosity will increase the likelihood that phenotypic characteristics become uniform across a seed lot and that those characteristics are maintained. This homozygosity is achieved when progeny seedlings inherit identical alleles (versions of a gene) from both parents. In contrast, a heterozygous individual has received different alleles for that particular gene and across a population of seedlings, we will often see variation in phenotypic traits. When all individuals carry a particular allele, it is considered 'fixed' in the population.



A Punnett square that represents a cross between a heterozygous mother that contains different alleles for a particular gene, in this case Aa, and a heterozygous father that also holds A and a alleles. When crossed, the heterozygous parents will produce, on average, ½ offspring holding both alleles (heterozygous), ¼ offspring homozygous who will bear only the A allele, and ¼ offspring homozygous for the a allele.

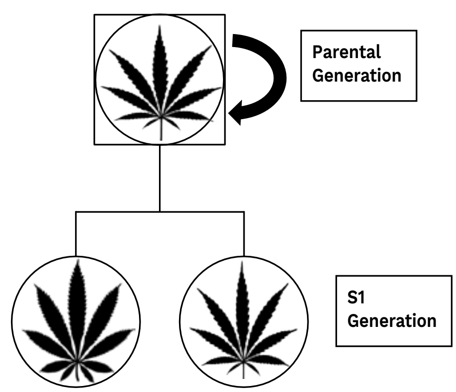


Depiction of a cross between two parents (parental generation) whose progeny is the Filial 1 (F1) generation. When two siblings from the F1 generation are crossed, these produce the Filial 2 (F2) generation. This process can be repeated for multiple generations and the degree of inbreeding and of homozygosity increases with further crosses (ie. F3, F4, etc). Males are depicted in squares and females in circles.



Depiction of a cross between two parents (parental generation) whose progeny is the Filial 1 (F1) generation. When one of the F1 individuals is crossed back to one of the parents, the resulting progeny is called the Backcross 1 generation (BC1). In the figure a daughter is crossed back to her father, given that pollen is usually easier to store for subsequent generations. However, if ovules from the parental mother are kept, these can be used to cross with one of her sons. If one of the BC1 offspring are crossed back to one of the parents, the resulting progeny is the BC2 generation, and so on. Males are depicted in squares and females in circles.

Due to the possibility of inducing the appearance of flowers from the opposite sex in multiple C. *sativa* varieties, selfing can be done with a genetically XY or XX plant. In C. *sativa*, the females are the homogametic individuals with two X chromosomes (XX) while males are heterogametic with an X and a Y chromosomes. When a XX C. *sativa* plant is crossed to another XX plant after sex reversal, the resulting progeny are called feminized seeds due to the lack of the Y chromosome. In C. *sativa*, initial evidence indicates that only XY males are viable and YY males are inviable, which is why (in the figure below) only females are depicted in circles. The parent individual could be a monoecious or a reversed individual. More research is needed in C. *sativa* to understand whether selfed males could produce viable YY males.



Depiction of a self-cross, or selfing. In *C. sativa*, selfing can be done with monoecious or with individuals who are induced to produce flowers of the opposite sex.

Although inbreeding ensures that specific characteristics will be inherited by all progeny, it does come with consequences. Some of these consequences include inbreeding depression, which is the reduced fitness (survival, fertility, yield) of individuals due to the increased prevalence of deleterious alleles. Deleterious alleles are those that decrease fitness (survival or reproductive abilities). Initial results suggest that within a few generations, even three or four generations of self-pollination, C. *sativa* starts to display signs of inbreeding depression: variegated individuals, stunted plants, and—most importantly for grain production—a loss of fertility, including reduced production of pollen.

Open-Pollinated Populations

Most grain and fiber varieties are open-pollinated populations (OPP). These cultivars have been selected for uniformity and stability in the population but are maintained through seed production under controlled conditions where no pollen from other populations is allowed to cross pollinate those plants. Through repeated planting of isolated seed production fields and culling or roguing of off-type individuals, a uniform, but still somewhat genetically heterogeneous population is maintained.

Hybrids

Hybrid cultivars are produced by the crossing of two inbred parent lines to generate a uniformly heterozygous seed lot of F_1 progeny. Often hybrids display hybrid vigor for yield (heterosis) as well as beneficial traits inherited from both parents, but if the F_1 is used to produce seed, the F_2 progeny will not display the characteristics of the F_1 hybrid cultivar. That gives hybrid cultivars inherent intellectual property protection and forces growers to purchase new seed every year.

Hybrid seed production tends to be more expensive because a method must be devised to assure that the female parent does not produce any pollen and that harvest of seed is only from that female parent. This can be accomplished for C. *sativa* by using female clones or a feminized population as the female parent. There are new hybrid grain cultivars being developed by using dioecious lines that are heavily biased to female in their sex ratio, so they can more efficiently be used for hybrid seed production.

In registering a hybrid for Plant Variety Protection (PVP) or certified seed production, the inbred parental lines must also be described and a plan for maintaining those must be presented.

Clones

Clonal varieties of C. *sativa* are easy to maintain and propagate, because stem cuttings are easy to root from clonally propagated mother plants. The selection of clonal cultivars is a straightforward process of generating segregating progeny through crossing, screening the progeny for traits of interest (high yield, high cannabinoid content, terpene profile, disease resistance, etc.), then propagating those selected individuals to confirm that the traits are stable across time and environment. Clonal varieties are used mostly for high-cannabinoid Cannabis and are not feasible for grain or fiber production, because the cost of vegetative propagation and field transplant is much too high compared with seed propagation.

Once a cultivar has been bred, selected, and verified to be distinct, uniform, and stable through repeated trialing, it can be described and protected through either a Plant Variety Protection (PVP), plant patent, or utility patent. It may also be kept proprietary and only propagated in-house, or may be distributed with contractual protection from material transfer agreements.

Plant Variety Protection Act

The Plant Variety Protection Act (PVPA) certifies varieties during 20 years through a certificate that are recognized worldwide. People who have a certificate have lawful security, may protect their varieties by prohibiting other entities or people market or sell their varieties, and may control the use, propagation, and sale of their variety by others. For more information, visit: https://www.ams.usda.gov/rules-regulations/pvpa

Agricultural Marketing Service

The Agricultural Marketing Service (AMS) is an agency part of the United States Department of Agriculture (USDA). The AMS programs are aimed to generate opportunities for U.S. producers nationally and internationally, including ensuring the quality of seed stocks. For more information, visit: https://www.ams.usda.gov/

Plant Variety Protection Office

The Plant Variety Protection Office (PVPO), part of the AMS, protects new varieties developed by breeders through the implementation of the Plant Variety Protection Act (PVPA). The PVPO encourages the advancement of new and better varieties that are appropriate for specific environments and diseases, and that stimulate production and food worldwide.

These new developed varieties are considered intellectual property, and in the U.S., breeders can protect their intellectual property through three different means supplied by two different entities:

- Plant Variety Protection – protects seeds, tubers, and asexually reproduced plants and is supplied by the PVPO
- Plant Patents – protects asexually reproduced plants and is supplied by the Patent and Trademark Office (PTO)
- Utility Patents - protects genes, traits, methods, plant parts, or varieties and is supplied by the PTO

For more information, visit: https://www.ams.usda.gov/services/plant-variety-protection

International Protection of Plant Breeders Rights: OECD

The Organization for Economic Cooperation and Development (OECD) is an international organization with 38 countries to promote worldwide trade and economic advancement. The OECD has seed rules to certify variety purity. In the U.S., the OECD certification is fulfilled by State agencies who assist the AMS. Currently, many of the hemp varieties developed in Europe are being certified by the OECD, however, their seed regulations do not include C. *sativa*.

OECD seed regulations: https://www.oecd.org/agriculture/seeds/documents/oecd-seed-schemes-rules-and-regulations-2022.pdf

For more information about OECD, visit: https://www.oecd.org/

Seed Certification

Seed certification is the process in which seeds from crops are approved for specific characteristics ensuring that standards for trueness to type, germination rate, lack of weed seeds, and lack of inert debris. Seed certification confirms purity and distinction between varieties. These standards are particularly important for hemp farmers as many hemp seed companies selling uncertified seed have struggled to meet acceptable germination and uniformity levels in the past and have not conformed to standards regarding variety naming, description, and registration.

To certify seeds, the crop must have standard characteristics which include, germination rate, days to maturity, height, and flower color among other phenotypic traits defined in the variety description filed with AOSCA or PVPO. Additionally, the fields used for certified seed production must meet standards for no C. *sativa* cultivation in the previous three years, and isolation from any other C. *sativa*, including feral hemp or ditch weed, of at least 3 miles (5 km). Many hemp varieties are monoecious and standards for certified seed production require that the proportion of true males (XY) is less than 1% during Foundation seed production as verified through field inspections when the plants are growing. This requires extensive manual culling of true male plants in registered fields.

There are different classes of certified seeds:

1. **Breeder seed** is the original source of seed produced by a plant breeder or a breeding company that developed the cultivar. It is held, maintained, and controlled by the originating plant breeder, sponsoring plant breeder or institution, in such a way to maintain its genetic purity and identity. Breeder seed provides the direct source of Foundation seed.

2. **Foundation seed** is the progeny of Breeder or Foundation seed but is no longer controlled by the breeder, but rather by the licensee who has the rights of production. As applied to certified seed, Foundation seed is a class of certified seed that is produced according to policies and procedures established by AOSCA for the purpose of maintaining genetic purity and identity of a variety.

3. **Registered seed** is produced from Breeder or Foundation seed according to policies and procedures established by AOSCA for the purpose of maintaining genetic purity and identity of a variety.

4. **Certified seed** is produced from Breeder, Foundation, or Registered seed. Certified seed is produced according to policies and procedures established by the California Crop Insurance Association (CCIA) for the purpose of maintaining genetic purity and identity of a variety. It is typically labeled with a blue AOSCA approved tag issued by the state certifying agency with the cultivar name, germination rate, and test results and is intended for commercial sale.

Due to the legality of high-THC Cannabis, there is currently no certification available but multiple renowned companies exist with high reputation among the industry.

Important Entities and Rules for Seed Certification

Federal Seed Act

The Federal Seed Act (FSA) is an act that regulates commerce between states of seeds, requiring that these include labeled information to grant consumers the possibility of making educated and informed choices. The FSA allows for consistency throughout States and provides a reasonable trade. The FSA is enforced by the AMS. For more information, visit: https://www.ams.usda.gov/rules-regulations/fsa

Association of Official Seed Certifying Agencies

In the U.S., the Association of Official Seed Certifying Agencies (AOSCA), a trade organization founded in 1919, develops and promotes certified varieties of seed. AOSCA's mission includes the production, identification, distribution, and promotion of certified seed. Production of certified seed of hemp varieties in the United States is approved by AOSCA member agencies, which are typically the seed improvement programs in each state, often associated with the land-grant university of that state. AOSCA maintains a list of hemp varieties that are eligible for certified seed production, which includes those that have been approved by the AOSCA Hemp Variety Review Board, those that have been issued PVP, and those that have been approved by other OECD agencies. See: https://www.aosca.org/hemp/

A variety description may be submitted for approval by the AOSCA Hemp Variety Review Board. The current cost of an application for review is $850 (https://www.aosca.org/hemp/) and consists of two files:

- Part A (https://www.aosca.org/wp-content/uploads/2022/08/2023-Hemp-App.-Part-A-1.pdf) and
- Part B (https://www.aosca.org/wp-content/uploads/2022/08/2023-Hemp-App.-Part-B-1.pdf). Part B includes several phenotypic traits that must be uniform in the variety that is being described including proportion of the different sex expressions (female, male, monoecious), flowering time, height, branching, and characteristics for the stem, leaves, inflorescence, and seed.

Fields for production of Foundation, Registered, or Certified seed must be registered with the seed certifying agency in the state of production, which includes a fee, field inspections, and final seed quality tests before conditioned seed can be bagged and tagged with the appropriate class.

Importing Seeds and Plants

Importing hemp seeds and plants into the U.S. is possible with the appropriate paperwork. This is regulated by USDA APHIS (Animal and Plant Health Inspection Service). See current regulations on plant and seed imports and exports on their website: https://www.aphis.usda.gov/aphis/ourfocus/importexport

Hemp Seeds Imported from Canada

Include either a:

- Phytosanitary certification–confirms the seeds' origin and the absence of pest and disease–from the Canadian national plant protection organization; or
- Federal Seed Analysis Certificate–confirms that hemp seeds were harvested from plants grown in Canada. Use PPQ Form 925.

Hemp Seeds Imported from Elsewhere

- Include a phytosanitary certification–confirms that plants are absent of pest and disease–from the exporting country's plant protection organization
- Hemp seed shipment is inspected upon arrival at the U.S. entry port by the U.S. Customs and Border Protection
    - Ensures the shipment meets the Animal and Plant Health Inspection Service (APHIS) regulation. More information is available at: https://www.aphis.usda.gov/aphis/home/
    - Confirms that plants are absent of pest and disease

Hemp Plants Imported from Canada

- Must include a phytosanitary certificate from the Canadian National Plant Protection Organization (NPPO) that certifies:
    - the origin of the plants
    - the absence of pests and diseases

Hemp Plants Imported from Elsewhere

Must have:

- Phytosanitary certificate from the exporting country's national plant protection organization that certifies:
    - the origin of the plant
    - the absence of pests and diseases
- Application for Permit to Import Plants or Plant Products. See PPQ Form 587 for more information at https://www.aphis.usda.gov/library/forms/pdf/PPQ587.pdf)

For more information, please visit:

- https://www.aphis.usda.gov/aphis/ourfocus/planthealth/import-information/hemp
- https://help.cbp.gov/s/article/Article-1751?language=en_US

Due to the current federal legality of high-THC Cannabis, products containing THC are illegal to import into the United States. High-THC Cannabis seeds can be sent to most countries within the European Union but not to the United States. Presently, high-THC Cannabis seeds cannot be transported across state lines due to federal rules. However, because high-THC Cannabis seeds have less than 0.3% THC, there is currently a dispute between the DEA and attorneys regarding the possibility of transporting seeds across state lines.

Site Selection for Ideal Growing Conditions

A common myth is that C. *sativa* can grow anywhere. In reality, the marketable yield is sensitive to many environmental conditions, including soil qualities, light, and water quantity. Soil type, field drainage, and environmental settings largely control the nutrient, water, and light availability, and thus should be carefully considered prior to planting. However, fields can be managed to improve drainage, soil health, and maximize light. This section describes the site characteristics that farmers should consider prior to planting, and steps they can take to ensure ideal conditions continue.

Things to keep in mind when selecting a site for hemp production include:

- The site must have adequate drainage to direct excess water away from the crop.
  - Hemp does not perform well in over-saturated or over-moistened soils which may result in stunted root development, poor nutrient uptake, uneven growth, and subsequent harvest difficulties.
  - Diseases such as root rot can result from poorly drained or wet soils.
- Clay-rich soils hold more moisture, whereas coarser (sandy, gravel-rich) soils will direct excess water away from roots faster.
- Topography also may contribute to drainage.
  - Fields along streams or in topographic lows will retain more moisture than fields higher above the water table.

Site modifications can improve drainage and water conditions:

- Soil management—including cover crops, biochar or compost—may improve soil water retention and drainage by improving soil aggregate structure and humus.
- The addition of 'tile' drainage in the soil is commonly used to increase water flow out of field.
- Reducing compaction of soils will also improve drainage
  - Controlled traffic farming (reducing equipment travel over soil) can reduce compaction over time.
  - Avoid working soils that are wet.
- Methods to reduce soil crusting (where soils preferentially over-dry on the surface, increasing the amount of standing water above the soil) will improve drainage
  - Top-applied amendments like compost and mulch reduce crusting (Jordán et al. 2011). Detailed information on soil drainage can be found at: http://cceoneida.com/agriculture/crop-production/soil-drainage-resources.

Soil should be selected and managed to optimize nutrient availability and chemistry for ideal performance. *Cannabis sativa* absorbs soil nutrients for growth, tissue development, and chemical biosynthesis, and also absorbs potentially unwanted chemicals, including certain heavy metals and some pesticides. As a result, products from fiber to oils are dependent on soil chemistry.

Soil chemistry and physical properties are generated by the slow weathering of underground rock by plants, microbes, and animals, and thus can vary greatly across landscapes depending on the location's geology, past ecology, and past agricultural production. The mineralogy of rock types can determine the soil's pH, its ability to retain nutrients, the availability of its nutrients, its ability to drain or retain water, and its ability to resist erosion.

Previous agricultural practices on the land alter its conditions by the addition of fertilizers, pesticides, and other amendments which changes the soil chemistry. For example:

- Manures, often applied as soil amendments to improve organic carbon content and nutrients may add high levels of heavy metals to soils
- Tillage can reduce soil organic carbon content and result in loss of nutrients, water retention capacity, and can encourage soil erosion.
- The types of crops grown on a soil can impact the physical and chemical conditions
    - Some crops deplete soils of macronutrients like nitrogen and phosphorus
    - Other crops (particularly legumes) restore nitrogen.

Cannabis sativa is a bioaccumulator of some elements and compounds, meaning it absorbs certain pesticides, heavy metals, and other potentially harmful soil compounds from surrounding soil, and accumulates those chemicals in its tissues, mostly in the roots. Many nutrients, from magnesium to zinc, are required in lower concentrations, but can be harmful to C. *sativa* development at elevated concentrations. Market regulations and pressures may also discourage the use of soils with high metal or contaminant levels.

Testing soils for nutrient content and chemistry prior to planting is an important step to properly prepare soils for healthy C. *sativa* growth and ensure that resulting products are marketable.

Additional site characteristics can be important practical aspects of C. *sativa* production and growth. For example:

- Some growers prefer sites with low public visibility to prevent crop theft.
    - Visual barriers from fences and walls to tree rows and distance reduce the potential for passersby to engage in theft or tampering with cultivation.
- Surrounding cropland may impact production.
    - Neighboring land applied with pesticides or herbicides, or growing different varieties, may negatively impact a site's C. *sativa* viability due to wind-transport of chemicals and pollen.

      A single C. *sativa* flower can produce about 350,000 pollen grains, with large plants containing hundreds of flowers. Estimates suggest that pollen can travel hundreds of miles, posing problems for farmers to avoid unwanted pollination from neighboring cultivation.

***Cannabis sativa* requires specific growing conditions to thrive:**

- Warm weather conditions: 60-82°F (15-27°C)
- Well-drained uniform soil, not heavily compacted or saturated
- Soil with pH level ideally between 6.0-6.5
- Shallow planting depth (when planting from seed): 0.5-0.8 in (1.2-2 cm)
- High photointensity, so make sure to plant in a location with little shade and full sun exposure.

Soil Testing

Sampling

It is critical that soil samples be taken properly for reliable analytical results. When, where, and how the sample is taken; what equipment is used; how much contextual information is provided; and how well it is packaged all can affect sample quality and resulting analyses. Most soil analysis locations provide guidelines for ideal soil sampling, and what analysis is performed will determine the specific guidelines. However, some best practices apply to all sampling. For example, many samples should be taken from a field to represent its variability in texture and chemistry–which can change significantly over relatively short distances.

Recommendations:

- Approximately 10 samples per acre (~20 samples per Ha) are required to accurately reflect variability.
- Avoid small areas where soil conditions differ markedly from those in the rest of the field:
    - wet spots
    - severely eroded areas
    - old building sites
    - fence rows
    - spoil banks
    - burn areas
    - old woodpile sites
- If an area is unique and large enough to manage independently, then it should be sampled independently.

Some soil analyses, such as those for physical properties, will require a slice of soil taken with a spade, shovel, or trowel. Other analyses, particularly for soil chemistry, will require a 6-12 inch (~15-31cm) soil core taken with a probe. Using the proper recommended location can determine whether results are reliable, and thus the success of soil management thereafter.

A 12-inch (30 cm) soil probe core taken in the spring before planting (left) and fall after harvest (right). Ten cores were combined in a gallon Ziplock bag (left) or buckets (right) to represent a 1-acre field.
Photos: Garrett Boudinot, Cornell

A 2-inch (5 cm) thick slide of soil taken with a spade for aggregate stability analysis in the spring.
Photo: Garrett Boudinot, Cornell

A 2.75-inch (7 cm) wide auger used for taking samples of the top 3 inches soil for bulk density analyses. *Photo: Garrett Boudinot, Cornell*

Nutrient and Chemistry Testing

Many different analyses are available to determine the nutrient content and chemistry of the soil. Local cooperative extension offices can provide information on what options are available for each location. Some provide simple measurements of important plant nutrients, recommendations on what nutrients are lacking, in excess, and management options to optimize those nutrients. Others provide information on a full suite of metals, elements, and chemicals that may accumulate in C. *sativa* or impact its performance.

Pre-Heavy Metal and Pesticide Residual Testing

Since C. *sativa* is a bioaccumulator, it readily absorbs certain heavy metals, radioactive elements and other soil compounds, pesticide residue and heavy metals testing are important to determining source contamination in any potential plot. Growers should consider conducting soil sampling to determine source contamination. Mercury (Hg), cadmium (cd), lead (Pb) and arsenic (As) are the specific heavy metals of concern.

Recommendations:

- Visit the USDA for some guidelines: https://www.ams.usda.gov/sites/default/files/media/TestingGuidelinesforHemp.pdf

Soil Physical Property Testing

Several tests can be performed to assess soil physical characteristics that control drainage and C. *sativa* health. A penetrometer is a quick and easy way to test soil compaction. Aggregate stability analyses often requires samples to be sent to analytical labs, but can provide more detailed information on a soil's drainage and nutrient availability. The development of streamlined analyses is improving these measurements.

Recommendations:

- Download the app "Slakes" designed to provide quick aggregate stability results on a smartphone.
- Consult your local Cooperative Extension for available physical property analyses such as bulk density.

Soil Carbon Opportunities

In addition to managing soils for nutrient availability and water content, many farmers are increasingly practicing various management strategies to improve soil carbon. Soil organic carbon—the dark, humus-like component of soils—provides several benefits for crop production. Soil organic carbon contains and releases nutrients for plant intake, and absorbs water to reduce soil crusting, flooding, and over-drying. Soil organic carbon has been shown to increase crop productivity, and reduce impacts of extreme weather, including droughts, heat waves, and floods, on crop yield. Soil carbon also has ecological benefits away from the farm—as soil carbon increases, the amount of carbon released to the atmosphere decreases, sequestering carbon and reducing the impacts of climate change.

Because of these climate benefits, increasing soil carbon is gaining attention from farmers as a mechanism for increased value for agricultural production. Some farmers can add value to their commodities when grown with practices that increase soil carbon, often called "climate-smart commodities." Others can receive payments for increasing soil carbon under a "carbon offsets" and "carbon credits" program. In February 2022, the USDA announced a $1 billion program to incentivize farmers to grow crops with practices that increase soil carbon. Those practices include no-till or reduced-tillage, cover-cropping, and agroforestry, as well as the application of soil amendments like compost, biochar, or "rock dust" to increase soil mineral carbon. Often, these practices require "verification" of the carbon benefits –typically including additional soil testing–with some resources available to help farmers test and verify soil carbon. Because of hemp's marketability for "sustainable" products, practices that increase soil carbon may be able to significantly increase hemp market value.

Growing Methods

Two common growing methods for C. *sativa* are open ground and plasticulture. Growers must evaluate and determine the method of production based on their equipment and infrastructure. Open ground production (see Open Ground Production for Grain section or Open Ground Production for Fiber Hemp section) requires tillage implements and tractors capable of efficiently operating those implements to control weed pressure. Plasticulture, usually used for high-cannabinoid or high-THC Cannabis production, employs a layer of plastic mulch over the plant bed to control weed pressure within the row, as well as drip irrigation for efficient and directed water and fertilizer application.

Although some suggest that hemp performs best under conventional-tillage programs that utilize pre- and post-transplanting cultivation practices, use of no-till drills are increasing in popularity as a conventional method. No-till seems to be a sustainable and environmentally friendly practice that farmers are adopting which may also increase yield, soil quality, and allows for carbon sequestration.

Prior to transplanting, usually for high-cannabinoid or high-THC Cannabis, fields selected for production are often tilled with a moldboard plow (bottom plow) or a disc-harrow type device. This practice often tills the top 4-5 inches of the soil profile while breaking up vegetative residue. The process can also help to incorporate fertilizers that have been applied to the top of the soil.

Pest Management

Managing Weeds

Weeds interfere with crops both directly and indirectly. Directly, by competing for water, light, nutrients, therefore affecting growth and yield. Indirectly, by restricting crop production by altering microclimates that can impact disease development, harboring pests and pathogens, physically interfering with crop harvest, and reducing harvest quality if weedy biomass becomes intermixed with crop materials.

Although hemp has been reported as being competitive with weeds, particularly when it is grown for fiber, there is limited scientific data supporting this assertion. Consequently, growers should expect to manage unwanted vegetation in their production systems.

Integrated Weed Management (IWM) is a dynamic control strategy that incorporates multiple and effective tactics into a diversified program that limits one's reliance on a single tool or method of suppression. A dynamic approach to weed control will consider the use of both preventative and reactive practices to limit weed establishment, growth, and seed set.

Weed Identification

To develop a successful weed management program you must accurately identify the weeds. Once you know the species, you can learn more about their biology and ecology, which will assist you with the development of targeted plan of action.

Resources to Assist with Weed ID:

- *Weeds of the Northeast*, an excellent guidebook by Uva, Neal, and DiTomaso, contains a dichotomous key for species listed in the text, line drawings and color photographs, details about closely related species that target specimens could be confused with, a fold-out grass identification table, and shortcut keys for identifying species with distinct, physical characteristics.
- Apps such as Pl@ntNet and iNaturalist are available for download and use on smartphones. They allow you to upload pictures of leaves, flowers, or fruit and compare your photos with a larger database of images using visual recognition software returning a list of species.
    - When choosing to use a phone app, images should be focused on individual plant parts. Care should be taken to minimize the number of background features that could affect the analysis and reduce your chances of attaining a proper identification.
    - Images should be taken at a distance that is close enough to highlight a morphological feature, but not so close to make a structure indistinguishable.
    - Understand that apps are not 100% accurate and users should always double-check results against a trusted source.
- Cornell's Weed ID website (https://blogs.cornell.edu/weedid/)
- Virginia Tech's Weed Identification website (https://weedid.cals.vt.edu/)
- Consult Cooperative Extension specialists to help with weed ID using either live specimens or digital images. Be sure to include your contact information and the location where the plants were found (e.g. GPS coordinates, address, etc.), as well as any other relevant information.
    - If submitting plant samples, include individuals that are representative of the infestation at large. Seal samples in a Ziploc bag with damp, but not wet, paper towels.
    - If emailing digital images, be sure to capture photos of leaves, stems, roots, flowers, etc, and especially unique structures (such as spines) that could be diagnostic tools.

Bindweed rhizome and vine fragments caught on cultivation equipment (above). Cleaning machinery between fields can reduce the spread of weeds. Cultivation is effective against small seedlings; larger plants, like this Powell amaranth (left), may be able to re-root and regrow following soil disturbance. *Photos: Lynn Sosnoskie, Cornell*

Field Selection and Starting Clean

Site selection is important for weed management in C. *sativa* because herbicides are limited or absent from the toolbox.

Recommendations:

- Avoid ground that contains high weed densities, large or fast-growing species, and/or perennials, which will be difficult to manage.
- Assure that your hemp seed is free of weed seed, itself, to avoid recruiting a problem. The same recommendations apply to cover crop seed that may be planted in the preceding year.
- Manage weeds in field margins and any weeds that emerge after the crop is harvested. These plants can be a source of seed that may complicate control efforts in following years.
- Consider using a stale seedbed technique to manage unwanted weedy competitors prior to crop planting.
- Goal: To reduce the number of germinable weed seeds in the topmost profile of the soil (e.g. deplete the weed seedbank) to minimize weed pressure in current and future planting seasons
    - With this practice, the germination of weed seeds is stimulated (e.g. using shallow cultivation, rainfall, or irrigation) and the resulting flushes of seedlings eliminated using physical implements or herbicides.
    - Cultivation can control young weeds at the "white thread" stage, but care must be taken to prevent more deeply buried seeds from being brought up to the soil surface.
    - Multiple stimulation and control events may be needed depending on the size and composition of the seedbank
    - The stale seedbed technique may need to be initiated weeks to months before hemp planting.
    - While many weeds can be managed using a stale seedbed strategy, species with highly dormant seeds (e.g. seeds that do not germinate readily, even when placed in favorable environments) are unlikely to respond.
    - Weather events that prevent the timely removal of seedlings will result in larger or more numerous weeds that could make control operations even more difficult.

Small pigweed seeds (left) may respond better to stale seedbed techniques as compared to velvetleaf (right), which has large and dormant seed that can persist in the soil for decades. *Photo: Lynn Sosnoskie, Cornell*

At the time of planting, ensure that the seedbed is as smooth, firm, and as level as possible to achieve good seed-to-soil contact. This will facilitate uniform crop germination and emergence.

Recommendations:

- Always use high quality seed of adapted varieties to maximize vigor. A strong and even crop stand will be more competitive against weeds.
- The use of appropriate planting densities will reduce the amount of open space that weeds are able to colonize.
- Where applicable, transplants can maximize the height differential between crops and weeds to improve competitiveness.
- In temperate latitudes, summer crops will intercept more light if rows are oriented north-south rather than east-west. This will support crop development while casting shade into row middles, which may suppress weed growth.

Cultural and Physical Control Strategies

Once weed seedlings emerge, they must be controlled using physical methods. The type of implements that will be required can vary depending on the type of C. *sativa* that you are growing. Drilled seed/fiber fields will likely require different tools than more widely spaced floral plantings. To maximize the efficacy of cultivators (and minimize damage to the crop), make sure that:

- Your rows are straight and evenly spaced.
- Always manage weeds when they are small and succulent and easy to destroy, preferentially at the “white thread” stage regardless of the specific implements applied
- Repeat passes may be required as soil disturbance can stimulate new seed germination.
- Always make sure to clean equipment to prevent the movement of weed seeds, root fragments or other propagules between fields.
  - This step is especially crucial if you must move from a very weedy field to a clean one.
  - This advice also holds true for harvest; always try to do the cleanest fields first.

- There is some exploration into the use of flame weeders in hemp systems although there is not enough data available to make recommendations about rates and timing.

When growing C. *sativa* on plastic systems, it is important to keep the middle spacing in mind for weed mitigation purposes; some growers till or mow between rows to manage weeds and grass.

Recommendations:

When mowing or using weed whackers, avoid throwing debris on plants which could facilitate the spread of pathogens.

Certain persistent weeds, such as nutsedge, can grow directly through the plastic barrier. Others, like field bindweed, can grow in the planting holes and around mulch edges. The presence of these persistent weeds should be heavily considered in field selection for hemp production.

Recommendations:

- Hand-weeding in both mulched (e.g. weeds in planting holes) and non-mulched (e.g. around the base of plants) may be required depending on the degree of weed pressure.
- Eventually, mulch must be disposed of. Remember to factor in the time and cost of waste removal.
- Reusable tarps that block light can be applied to fields at a small scale to aid in weed management, particularly when used in conjunction with stale seedbed practices.
    - When using tarps in place of physical disturbance or chemical control strategies, emerging weeds are killed by the absence of light, which is required for photosynthesis, when stored nutrient reserves are exhausted.
    - A minimum of two weeks of soil coverage is required when "tarping" to allow for weed seed germination and seedling death.
    - Tarps can be difficult to maneuver and secure because they are made from heavier materials than traditional plastic mulches and are therefore best used on small areas (less than 500 square feet).
- Additional resource:
    - University of Maine Bulletin #1075, Tarping in the Northeast: General Logistics of Tarp Management. Lounsbury, Birthisel, Lilley and Maher. https://extension.umaine.edu/publications/1075e/

Rotating crops (between seasons) that vary with respect to planting and harvest dates, planting density, row spacing, nutrient requirements, and in crop weed management strategies to vary the selective forces that are exerted on in-field weed communities. This can include the incorporation of cover crops into a multi-year planting program.

Recommendations:

- Have C. *sativa* follow a commodity in which weeds can be managed effectively to try and reduce the pressure.
- If herbicides are a component of a weed control program in preceding crops, review the rotation restrictions on the product labels to ensure that hemp can safely, and legally, be planted.
    - If C. *sativa* is not purposely listed, follow guidelines recommended for "other" or "non-labeled" crops.

Herbicides

Many producers of agricultural and horticultural crops in the United States rely heavily on herbicides for the control of unwanted vegetation. At the time this section was prepared, there were no synthetic herbicides registered for use on C. *sativa* in the United States. Additionally, C. *sativa* is reported as being sensitive to many commonly used herbicide active ingredients according to results in university trials across the U.S.; this includes greenhouse and field trials conducted at Cornell.

Recommendations:

- Care must be taken to ensure that soil residue carryover, spray drift from adjacent crops, or other off-target herbicide movement does not occur to reduce the potential for significant injury to hemp.
- There are several organic herbicides (e.g. capric and caprylic acid, acetic acid) approved for use in C. *sativa*, although their utility may be limited under certain conditions.
    - Because these products are used to control emerged weeds, no residual suppression of emerging seedlings should be expected.
    - Good spray coverage is required for efficacy, so applications should be made at high spray volumes and to weeds that are small and succulent.
    - Perennial weeds and grasses will be less well controlled than annual broadleaves.
    - Because these herbicides are non-selective, injury can occur to any parts of hemp plants that come into contact with these chemicals.

Additional Resources

For more information about ecological or Integrated Weed Management, please see:

- What is Integrated Weed Management? https://growiwm.org
- SARE Handbook Series 16. Manage Weeds on Your Farm: An Ecological Approach. Mohler, Teasdale, DiTommaso. https://www.sare.org/resources/manage-weeds-on-your-farm/

Diseases

Disease resistance in C. *sativa* seems to be strongly related to genetic effects as some varieties may be resistant to disease such as powdery mildew. However, since disease poses a co-evolutionary arms race between the host (in this case C. *sativa*) and the pathogen, it is likely that the varieties that are resistant at a given timepoint will become susceptible in the future, as seen in other plant systems. Therefore, it is recommended to plant diverse varieties to avoid all the individuals getting sick which is more likely when planting one single variety. It is also recommended, if possible, to plant from seed. If cloning from mother plants, it is recommended to keep multiple mothers from the same variety, especially because some pathogens, particularly viruses, are systemic in the plant and will be present in clones taken from an infected mother plant.

As with any crop, there are numerous diseases growers should be aware of when cultivating C. *sativa*. Proper disease management is vital to a successful crop. Starting with a disease-free plant source is the best way to ensure a clean crop. Disease management should begin before plants are propagated, particularly if transplants are being produced. Sanitation is critical to clean transplants, therefore sanitizing a greenhouse prior to use—and any materials that will touch the plants including flats, benches, and propagating tools—will help ensure clean transplants.

Disease Management

The following are descriptive practices for disease management:

- Regularly observe your plants for pests and disease.
- Inspect all growing areas.
    - If growing indoors, make sure vents are properly screened.
    - If growing outdoors, avoid growing in areas that were previously affected by disease.
- Carefully inspect any plant particularly if using transplants that come from off-farm and quarantine them before adding them to your grow.
- Keep planting and growing equipment and media clean and pathogen-free.
    - To limit virus transmission, clean pruners and hands between plants.
- Ensure the correct identification of any disease.
- Reduce humidity and overhead watering where possible to diminish leaf wetness which will lower foliar diseases.
- Reduce water saturation of soil (use raised beds, drain tiles, etc.).
    - Some pathogens, like oomycetes and nematodes, travel in water.
    - Plants are not adapted to wet feet: lack of oxygen kills roots and increases susceptibility to diseases and pests.
- Maintain a healthy soil or provide adequate nutrition and maintain ideal soil pH levels to reduce plant stress. Consider using amendments, fertilizers, or compost.
- Consider crop rotation, however, avoid the following:
    - Soybeans, dry beans, snap beans, sunflower to limit incidence of white mold (caused by *Sclerotinia sclerotiorum*), althought the pathogen has a very broad host range.
    - If growing in locations where southern blight (caused by *Sclerotium rolfsii*) is present, peanuts, peas, beans and tomatoes should be avoided.
- Limit distance between the crop and hop yards to reduce incidence of powdery mildew.
- Cultivate quickly after previous crops.

- Remove diseased plant debris from fields.
    - Cull and remove dead plants during the growing season to reduce inoculum buildup.
    - Deeply bury or promptly burn infected material to avoid propagation.

Fungi and Oomycetes

Pythium Root Rot

Young plants infected with *Pythium* (left and middle). *Pythium* in young plants causing damping off of the two right hand plants compared to healthy plants on the left (right). *Photos: Nicole Gauthier, and Christine Smart, Cornell*

Pythium root rot can be caused by several species of the soilborne pathogen *Pythium*. These pathogens are part of a larger group of water molds known as oomycetes, that look like fungi, but are not related. The disease can occur at any time during the crop cycle and is common in areas that are poorly drained or over irrigated, although the disease can still occur in well-drained areas, typically following extended periods of rain. *Pythium* can also cause early death of seedlings, known as damping off.

Pythium has a wide host range that is shared with field and vegetable crops. The initial infections are usually initiated from movement of propagules (i.e. zoospores) in water following rain or irrigation. Once established, *Pythium* can survive for longer periods of time through survival structures (i.e. oospores), which can overwinter and infect new hosts.

Since *Pythium* attacks a plant's root system first, it is not as easily detected as other diseases. Symptoms include:

- Rotting roots
- Root epidermis easily sliding off from the endodermis
- Wilting
- Damping off (death of seedlings or small plants)
- Chlorosis of the leaves, in larger plants, from the margins inward

The best way to manage *Pythium* root rot is to prevent the initial introduction and infection.

- Avoid excess watering; damaged roots are more susceptible to the disease.
- Use water from a well or city resources–not water from streams, lakes, or ponds.
- Avoid water splash between pots which can transfer inoculum.

Powdery Mildew

Cannabis sativa flower (left) and a leaf (right) affected by powdery mildew. *Photos: Marion Zuefle, NYS IPM Program, Cornell*

Powdery mildew in C. *sativa* is a fungal disease that can be caused by several powdery mildew genera, but primarily caused by *Golovinomyces ambrosiae*. The pathogen develops mycelia (fungal filaments) and chains of conidia (spores) on the leaf surface and will also attack stems and flowers of the C. *sativa* plants, which make up the fluffy, white, powdery growth, the most noticeable symptom of the disease. Infective conidia carry the disease by air to healthy plant material. This fungus can only grow on living plant tissue.

Hop (*Humulus* sp.) is the most closely related plant species to C. *sativa*, and it has been reported that hop powdery mildew caused by *Podosphaera macularis*, is also able to infect C. *sativa*.

The onset of powdery mildew is dependent on environmental conditions, the presence of the pathogen and a plant's susceptibility. Ideal environmental conditions for the disease are moderate temperatures and high humidity. This disease is unlikely to kill the plant but can cause leaf drop or defoliation and impacts the overall health of the plant.

The best way to manage powdery mildew is to manipulate one or more of the contributing disease factors—environment, pathogen, and host.

- Select varieties/cultivars that are more tolerant to infection, if available.
- Less bushy cultivars allow air to flow through, reducing reducing leaf wetness which is necessary for the fungusto infect the plant.

- Manipulate environmental factors (i.e. temperature and humidity to increase airflow).
- Maintain a pathogen-free growing area through proper sanitation tactics (i.e. pruning and quarantining affected plants; properly disposing severely affected plants; etc.).
- Avoid rotating with or growing near plants that are also susceptible to the same species of powdery mildew, including zinnia, sunflowers, some cucurbits, okra, sun hemp, and hops.

Powdery mildew does not seem to affect cannabinoid production according to preliminary findings with field trials at Cornell, which have also tried to understand the effect of different fungicide treatments in several C. *sativa* varieties.

Other field trials established that C. *sativa* varieties are differentially susceptible to powdery mildew. Throughout a growing season, powdery mildew was rated, and the different C. *sativa* varieties varied in disease severity. Cultivating diverse varieties will help with suppressing infections as the fungus will reproduce less rapidly on less susceptible cultivars, reducing overall disease severity.

Downy Mildew

Leaf (right) and closeup of a leaf's underside affected by downy mildew. *Photos: Marion Zuefle, NYS IPM Program, Cornell*

Downy mildew is caused by the oomycete water mold *Pseudoperonospora cannabina* and can only grow on living C. *sativa* tissue. Downy mildew symptoms appear as necrotic lesions on the upper leaf surface with gray spores on the lower leaf surface. The spores are produced under high humidity and are blown from plant to plant in the wind. The pathogen may overwinter in the soil, but more research is needed to better understand the pathogen.

Recommendations to avoid downy mildew:

- Do not plant C. *sativa* in a field that had downy mildew the previous year.
- Removing diseased plant debris from the field.
- Ensuring proper space between plants to assure air circulation allowing leaf surfaces to dry quickly.

Botrytis Blight (Gray Mold)

Inflorescence (left) and plant material (right) with *Botrytis* gray mold. *Photos: Larry Smart and Chris Smart, Cornell*

Botrytis blight, commonly referred to as gray mold, is caused by *Botrytis cinerea*, a necrotrophic fungus. The disease can onset following periods of rain and high humidity and is carried by air and splashing water to healthy plant material.

Plants can contract *Botrytis* blight when there is necrotic plant tissue. The disease is easily recognizable due to the gray, moldy growth (masses of mycelia and clusters of conidia), which commonly infect the plant's flower buds; however, the plant's stems, petioles and growing tips can also be affected. Under high moisture levels, those lesions become gray and fluffy.

The best way to prevent the occurrence of gray mold is to:

- Reduce moisture by increasing airflow.
- Use proper sanitation tactics such as removal of decaying plant debris.

Damping Off and Root Rot

Damping off refers to seedling death right after emergence and is a disease that impacts emerging seedlings and cuttings. Root rot refers to the degradation of the roots by soil pathogens, and along with damping off it can be caused by the same soilborne pathogens including *Rhizoctonia solani*, *Pythium* spp., and *Fusarium* spp. Spores of pathogens in the soil can germinate and penetrate the root epidermis. Once the fungus has entered the plant, it can destroy the roots and girdle the stem.

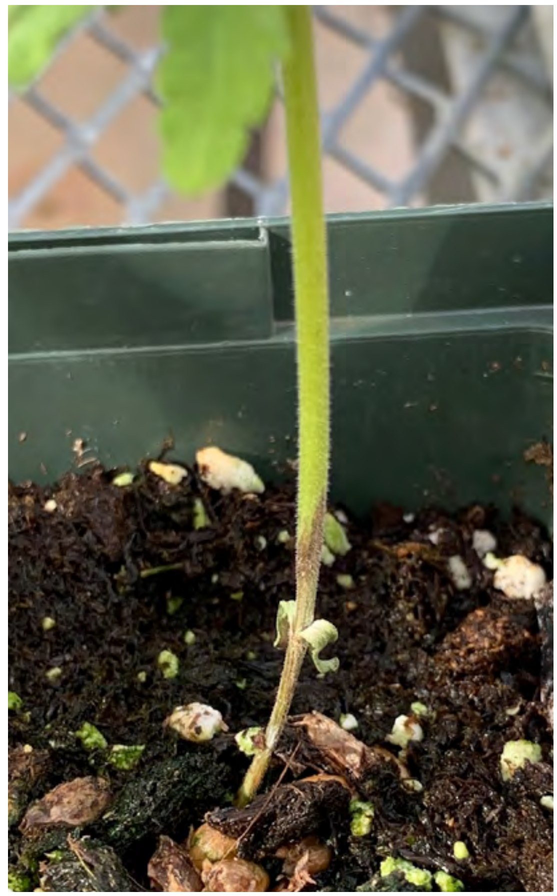
Damping off can result from several conditional factors:

- Presence of the fungus in the growing medium
- Overly moist soil due to overwatering or poor drainage
- Excessive humidity
- Poor air circulation
- Damage to parts of the plants, specifically the roots

Plants that contract the disease experience rotting of the roots and lower stems, eventually becoming girdled causing the plant to lodge and die.

Depending on the fungus, the following signs of the pathogen and symptoms of the disease could be noticed:

- *Pythium* root rot causes a wet rot of roots and root cortex.
- *Rhizoctonia* hyphae may be observed on infected roots, and stem lesions or cankers can occur.
- *Fusarium* hyphae appears on the roots as a fluffy pink or white mass and reddening of the roots may occur.



Close-up of a seedling stem affected by damping off. *Photo: Larry Smart, Cornell*

Due to the early onset of the disease, it is fatal to the plant. To prevent the onset of the disease, it is recommended to:

- Avoid planting into cool, wet soils.
- Encourage rapid emergence to get a good stand.
- Improve drainage in the field where possible.
- Remove diseased plants, including infected roots.

Southern Blight

Stem (left) and close-up of the ground (right) of plants affected by southern blight. *Photos: Nicole Gauthier*

Southern blight is caused by the soilborne pathogen *Sclerotium rolfsii* which has a very wide range of 500 host plant species. It results in wilting and chlorosis of the upper portions of plants. Plants with this disease often have a white hyphal mat surrounding the base of the plant and the roots. In some cases, BB-shaped sclerotia are present which tend to be at the base of the plant. Sclerotia may survive in the soil for 3-4 years. Southern blight has not been observed on *C. sativa* in New York State.

Southern blight may affect multiple plant species including tomatoes, beans, peas, and peanuts.

To control southern blight, it is recommended to:

- Remove dead plant material and leaves as the fungus can grow on them.
- Deeply bury infected material to avoid propagation.
- Do not grow plants in a previously affected area.

C. sativa DISEASES in NEW YORK

Disease*	Scientific Name
Bipolaris leaf spot	*Bipolaris gigantea*
Botrytis gray mold	*Botrytis cinerea*
Downy mildew	*Pseudoperonospora cannabina*
Powdery mildew	*Golovinomyces ambrosiae*
Septoria leaf spot	*Septoria spp.*
Hemp rust	*Uredo kriegeriana*
White mold	*Sclerotinia sclerotiorum*
Fusarium wilt	*Fusarium spp.*

* List of hemp diseases observed at two farms in Ontario and Monroe counties in 2020. Provided by Marion Zuefle, NYS IPM Program, Cornell

White Mold

Hemp canker, also known as white mold, is caused by the fungus *Sclerotinia sclerotiorum*, which overwinters in the soil but produces spores that are wind-borne. Environmental factors such as high humidity and excess moisture favor transmission.

White mold can be distinguished from southern blight (*Sclerotium rolfsii*) or gray mold (*Botrytis cinerea*) by the black pebble-like sclerotia it produces. The fungus produces these irregularly shaped sclerotia but does not produce any spores on the plant. White mats of fungal mycelia can sometimes be seen. The pathogen will infect the main stem or a lateral stem and eventually girdle it causing wilting and chlorosis of portions of the plant above the canker.

Hemp canker is fatal to the plant. To prevent the onset of the disease, it is recommended to:

- Avoid planting in fields with a history of white mold in other crops, however given that the fungus has a very broad host range (over 400 plant species) this can be difficult.
- Increase airflow to reduce leaf wetness.

Stem affected by hemp canker. *Photo: Patrick McMullen*

Stem affected by white mold. *Photo: Marion Zuefle, NYS IPM Program, Cornell*

Stem affected by white mold. Notice the black sclerotia developing. *Photo: Larry Smart, Cornell*

Fusarium Root Rot and Wilt

Plant killed by root rot (left). A close-up of the extreme degregation of the roots (right). *Photos: Patrick McMullen*

Fusarium is a common soil fungus that can result in root rot (*Fusarium solani*) and vascular wilt (*Fusarium oxysporum*). The wilting and ultimately death occurs because the fungus enters through the roots, colonizes the root vascular tissue, and eventually clogs the xylem, preventing water flow. Plants that have contracted Fusarium wilt experience wilting and yellowing and browning of the leaves from the bottom up, as well as reddish-brown discoloration of xylem tissue and roots. The plants can also experience red to brown lesions or cankers at the crown.

Fusarium favors high humidity levels and acidic soils. It can survive in the soil for multiple years. Plants with root damage are more susceptible to the disease (i.e. nematode damage, wounds or excess water to the roots). Fusarium has an extensive host range and can survive in the soil for years, making eradication difficult.

Fusarium can be fatal to the plant, as few management strategies are available to growers. To prevent the onset of the disease, it is recommended to:

- Avoid planting in fields with a history of significant damage from *Fusarium* spp.
- Avoid overwatering of the crop.
- Avoid damaging the roots during cultivation.
- Maintain proper field drainage.
- Avoid planting in wet and poor draining areas.

Bipolaris Leaf Spot

Leaf affected by bipolaris leaf spot (left) and close-up of the spots (right). *Photos: Marion Zuefle, NYS IPM Program, Cornell*

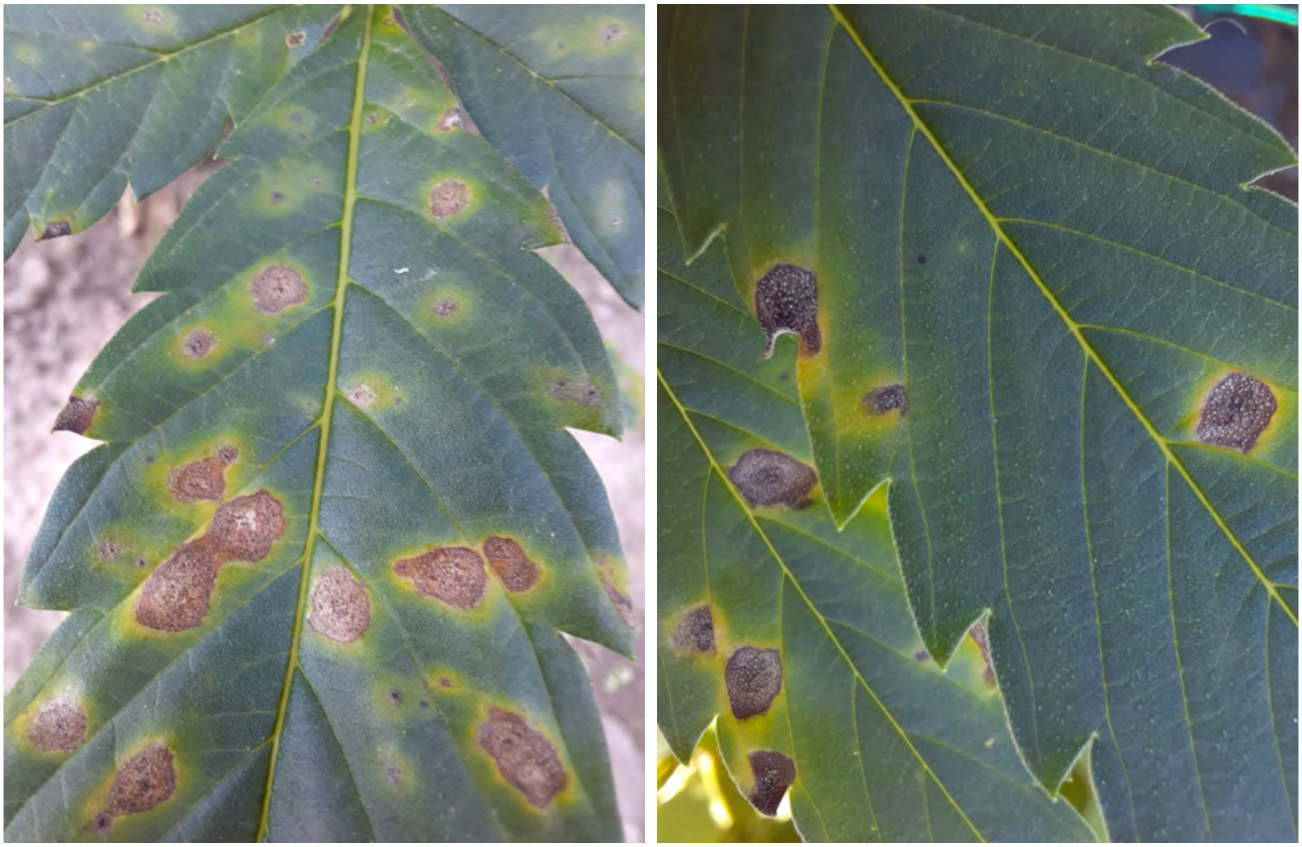
Bipolaris leaf spot (*Bipolaris gigantea*) is a disease caused by the fungus *Drechslera gigantea* that also affects other plants such as grasses. This disease has been reported in hemp fields in states such as Texas, Kentucky, and New York. In New York, bipolaris leaf spot was first detected on July 15, 2020 and the percent of infected plants continues to increase in the state.

In Kentucky, it has been reported that the disease can cause up to 100% yield loss.

Control strategies include:

- Increase airflow to reduce leaf wetness.
- Remove infected debris from field.
- Three year crop rotation out of C. *sativa*

Septoria Leaf Spot



Leaf close-ups (left and right) affected by *Septoria* leaf spot. *Photos: Marion Zuefle, NYS IPM Program, Cornell*

Septoria leaf spot is a disease caused by the fungus *Septoria cannabis*. Its severity is greater in regions where a wet, humid environment is prolonged for periods of time.

Septoria was noticed on two farms in New York State, in Ontario and Monroe counties, where the disease severity averaged 15% and 8%, respectively. As expected in disease ecology, the severity varied between C. *sativa* varieties, supporting the notion of growing diverse varieties to minimize the likelihood of losing an entire crop from the disease.

To avoid Septoria leaf spot:

- Remove infected plant debris as soon as possible, particularly at the end of the season.
- If growing outdoors, tilling may help break up plant remains from the previous season.
- Organic mulch over the solid surface with a 2-4 inch layer (5-10 cm) may act as a barrier protecting against fungal spores left in the ground.
- Reduce humidity and leave space between plants to increase air flow.
- To avoid splashing from affected leaves or from affected debris, abstain from watering overhead.

Hemp Rust

Leaf affected by hemp rust. *Photo: Marion Zuefle, NYS IPM Program*

Hemp rust is a disease caused by the fungus *Uredo kriegeriana*. Not much is known about the fungus, including its life cycle and its overwintering mechanisms. The disease has been found in New York, Tennessee, and surrounding states.

Cristulariella

Leaf (left) and close-up of the underside of a leaf (right) affected by *Cristulariella*. *Photo: Marion Zuefle, NYS IPM Program, Cornell*

The fungus *Cristulariella* was commonly found in the 2021 season in NYS and may have affected up to 50% of some fields. *Cristulariella depraedans* affects maple trees in Europe and North America. Although the disease causes light to moderate defoliation, trees usually recover. In hemp, the species and consequences of the disease are not determined.

Bacterial Leaf Spot

Bacterial leaf spot (BLS) can be caused by *Pseudomonas* spp. and *Xanthamonas* spp. The pathgens are spread by water splashing and wind-blown rain. The pathogens will spread rapidly with overhead irrigation; BLS can move quickly through a transplant production greenhouse during overhead irrigation.

Bacterial leaf spot generates lesions that appear water-soaked and are limited to the leaf veins or margins. As the lesions become more numerous, the entire leaf may yellow, wither, and fall from the plant.

There is no cure for BLS. To prevent the onset of the disease:

- Avoid mechanical damage to the plant's leaves.
- Avoid excess moisture conditions on foliage.
- Avoid overhead watering.

Viruses and Viroids

Viruses are small agents that multiply in living cells, composed of a protein coat that encloses nucleic acid (DNA or RNA). Viroids on the other hand, lack the protein coat.

Given that some viruses enter the plant via insect vectors, controlling for insect pests is necessary to avoid further diseases.

Viruses may also be transmitted by propagation from infected mother plants. Therefore, avoid using infected mother plants and discard them if you notice disease.

To prevent viruses and viroid disease:

- Use virus-free mother plants and planting stocks.
- Discard infected plants.
- Control insect vectors.
- Remove weeds and other plants that may also harbor the virus or the insect vector.
- Assure proper disinfection and cleaning of equipment and tools.
    - Clean scissors and pruners in between plants. You can use a bleach solution 1 part bleach diluted into 4 parts of water applied for 5 minutes. Then rinse the bleach solution.
- Cover the land with mulch to avoid aphids and whiteflies which can be vectors.

Although there have been no reports so far of viruses or viroids in NYS and these are common in western states, it may be a matter of time for these to appear in the state.

List of *C. sativa* Viruses and Viroids

Virus	Acronym
Alfalfa mosaic virus	AMV
Arabis mosaic virus	ArM
Beet curly top virus	---
Cannabis sativa mitovirus 1	---
Cannabis cryptic virus	---
Citrus yellow-vein associated virus	---
Cucumber mosaic virus	CMV
Lettuce chlorosis virus	LCV
Tobacco ringspot virus	TRSV
Tomato ringspot virus	ToRSV
Tobacco streak virus	TSV
Tomato mosaic virus	ToMV
Viroid	
Hop latent viroid	HLVd

Information provided by Zachary Stansell and Anya Osatuke on the 'USDA Hemp Descriptor and Phenotyping Handbook' (https://www.ars.usda.gov/northeast-area/geneva-ny/plant-genetic-resources-unit-pgru/docs/hemp-descriptors/)

Plant affected with alfalfa mosaic virus (left) and a close-up of a leaf showing the mottling common with AMV (right). AMV is spread by aphids. *Photo: Anna-Liisa Fabritius and AL&L Crop Solutions, Inc*

Insects and Mites

A survey of insect pests of C. *sativa* was conducted at two outdoor farms in 2020 in which 20 different potential insect pests were observed. None of the insect pests reached levels high enough to cause an economic impact. There are several other insects and mites known to be pests of C. *sativa* that were not detected in this survey, although they could already be present in NY or arrive in the next few years. These include the Eurasian hemp borer, rice root aphid, and hemp russet mite.

The most common insect pest–and the one that caused the most amount of feeding damage–is the red headed flea beetle, *Systena frontalis*. Even though it caused a lot of visible feeding damage to leaves at the surveyed farms, the plants were able to grow out of the damage and, by early September, damage was very difficult to find. Red headed flea beetles peaked on July 28th in the 2020 survey. Plants at that point were large and did not show any signs of yield loss; however, smaller, later plantings would likely be at greater risk from damage at that time.

Based on observations from other states, there are several insects that should be monitored based on their potential to cause economic loss: corn earworm, cannabis aphid, European corn borer, potato leafhopper, Japanese beetle, flea beetles, and possibly the darker spotted straw moth.

C. sativa INSECTS in NEW YORK

Insect*	Scientific Name
Common stalk borer	*Papaipema nebris*
European corn borer	*Ostrinia nubilalis*
Corn earworm	*Helicoverpa zea*
Darker spotted straw moth	*Heliothis phloxiphaga*
Cannabis aphid	*Phorodon cannabis*
Brown marmorated stink bug	*Halyomorpha halys*
Red headed flea beetle	*Systena frontalis*
Yellow wooly bear	*Spilosoma virginica*
Potato leafhopper	*Empoasca fabae*
Grasshopper spp.	Order Orthoptera
Japanese beetle	*Popillia japonica*
Flea beetle spp.	*Alticini spp.*
Four-lined plant bug	*Poecilocapsus lineatus*
Twospotted spider mite	*Tetranychus urticae*
Fungus gnat	*Bradysia spp.*
Oblique banded leafroller	*Choristoneura rosaceana*
Ebony bugs	Family Thyreocoridae
Black plant bug	*Miridae*
Tarnished plant bug	*Lygus lineolaris*
Leaf miner	Various families and species

* List of hemp pests observed at two farms in Ontario and Monroe counties in 2020. Provided by Marion Zuefle, NYS IPM Program, Cornell

Common stalk borer. *Photo: Marion Zuefle, NYS IPM Program, Cornell*

European corn borer. *Photo: Marion Zuefle, NYS IPM Program, Cornell*

Corn earworm moth (adult). *Photo: Kadie Britt*

Corn earworm larva. *Photo: Marion Zuefle, NYS IPM Program, Cornell*

Darker spotted straw moth adult. *Photo: Marion Zuefle, NYS IPM Program, Cornell*

Darker spotted straw moth larva. *Photo: Marion Zuefle, NYS IPM Program, Cornell*


Cannabis aphids. *Photo: Marion Zuefle, NYS IPM Program, Cornell*


Brown marmorated stink bug. *Photo: Marion Zuefle, NYS IPM Program, Cornell*


Red headed flea beetle. *Photo: Marion Zuefle, NYS IPM Program, Cornell*


Yellow wooly bear. *Photo: Marion Zuefle, NYS IPM Program, Cornell*


Potato leafhopper. *Photo: Marion Zuefle, NYS IPM Program, Cornell*


Grasshopper. *Photo: Heather Grab, Cornell*

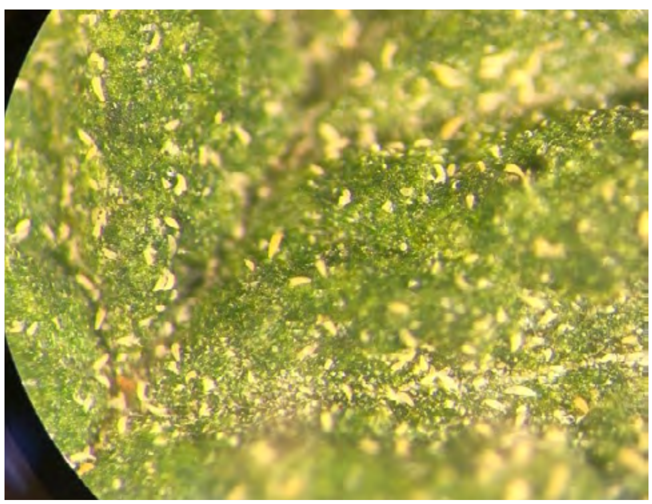
Japanese beetle. *Photo: Heather Grab, Cornell*

Japanese beetle damage. *Photo: Jamie Crawford, Cornell*

Flea beetle. *Photo: Cornell Hemp team*

Fourlined plant bug. *Photo: Marion Zuefle, NYS IPM Program, Cornell*

Twospotted spider mite (white circle) as seen under a microscope. *Photo: Kadie Britt*



Hemp russet mites as seen under a microscope. *Photo: Kadie Britt*

Insect Management

Recommendations for insect management when growing C. *sativa*:

- If using transplants, start with clean plants, carefully inspecting them prior to acceptance and consider quarantining new plant material. Infested plants are a common pest source.
- Manage irrigation carefully, as spider mites are attracted to plants that are too dry. Also monitor and remove potential weed hosts in the field, as spider mites often move into a field from surrounding weeds.
  - Ensure that greenhouse vents are properly screened, and use good order of operations when moving between clean and pest management areas.
- Provide adequate nutrition and maintain ideal soil pH to avoid plant stress.
- Although grasshoppers are more problematic in western states, avoid planting near small grain fields (wheat, rye, etc.) that will be harvested while C. *sativa* plants are in the field, as grain harvest can drive grasshoppers into nearby crops.
- Destroy crop residue as soon after harvest as feasible to eliminate any remaining pests. Certain insects, such as cannabis aphid, can continue a life cycle in the field if there is remaining plant material. European corn borer larvae can overwinter in crop debris.
- Prevent pests from becoming established by excluding them from plants, if possible, and maintaining plants in as healthy a condition as possible to resist infestation.
- If indoors, ensure that vents are properly screened and/or use floating row covers.
- Scout plants regularly for pests, at least once per week; ensure correct identification of insects or mites, and keep a written record of your observations.
  - Make sure to look at roots as well! Traps can be used to passively monitor certain outdoor pests such as adult males of both corn earworm and European corn borer, although their accuracy for alerting growers to larval infestations is not fine-tuned. Additionally, sticky cards can be used to passively monitor certain indoor and outdoor pests like aphids, thrips, fungus gnats, and others.
- If using insecticidal sprays, select the management materials that are most likely to be effective against target pests and the least likely to cause unintended consequences. Be sure to check with your state Department of Agriculture if unsure about pesticide use in C. *sativa*.
  - Some have used the biological insecticide DiPel with good results. These have not been tested in controlled experimental settings.
- Fungus gnats will feed on decaying matter in the soil as well as roots and both the adults and larvae can transmit diseases like *Fusarium* to other plants. To avoid fungus gnat population:
  - decrease watering,
  - apply beneficial nematodes, and
  - change old potting media for future seed starts.
  - Monitor for fungus gnats in the greenhouse by using yellow sticky cards.

- Consider using beneficial insects.
    - Beneficial mites can control spider mite populations.
    - Although adult and larval lady beetles are beneficial insects, adults are apt to wander away from the location in which they are released. As a result, lady beetles are often more effective in confined environments such as greenhouse settings. Lady beetles are usually sold in the overwintering stage and have a low reproductive status during this point in their life cycle, so females will not always lay eggs after release. Additionally, lady beetles for purchase are usually collected from native populations outside the desired range of where they are being released, which threatens wild lady beetle populations, and increases the possibility of interbreeding with local populations which can also bring problematic outcomes.
    - Some people have used *Trichogramma* parasitic wasps with good results to control moths.
    - Aphid parasitoid wasps can help control aphid populations.

Syrphid fly, also known as a hover fly, is a beneficial insect. Syrphid flies are pollinators as adults and predatory as maggot-like larvae. *Photo: Cornell Hemp team*

Mummified aphids from parasitic wasps. *Photo: Vince Dyer*

- For outdoor grows:
    - Chickens can be a way to deal with both Japanese beetles and grasshoppers, although this has not been studied in depth.
    - Plants that entice beneficial insects could be planted, assuring the cultivation of plants that produce nectar will attract syrphid flies as the adult stages feed on it, although this has not been studied in C. *sativa* on a field scale.
    - There are a few different insects that will bore into the stem including the common stalk borer, European corn borer, and hemp borer. Pheromone traps can be used to monitor for the European corn borer.
    - The common stalk borer lays eggs on weeds and grasses and usually moves in from the perimeter of the field. Therefore, control surrounding weeds to decrease common stalk borer. Also planting early allows plants to get larger before stalk borers move in thereby decreasing potential damage.
    - Young seedlings are most at risk from flea beetle feeding so you can protect them with row cover until they are large enough to withstand the feeding pressure. Plowing can reduce the overwintering population and beneficial nematodes can be used to control the larvae in the soil.

Herbivory

Rabbits and deer may eat C. *sativa* plants, particularly when they are young. People have reported that planting marigolds in the perimeter of the C. *sativa* grow helps keep these animals away. High fencing may be needed to exclude deer, if herbivory persists.

FIBER

Fiber Cultivation

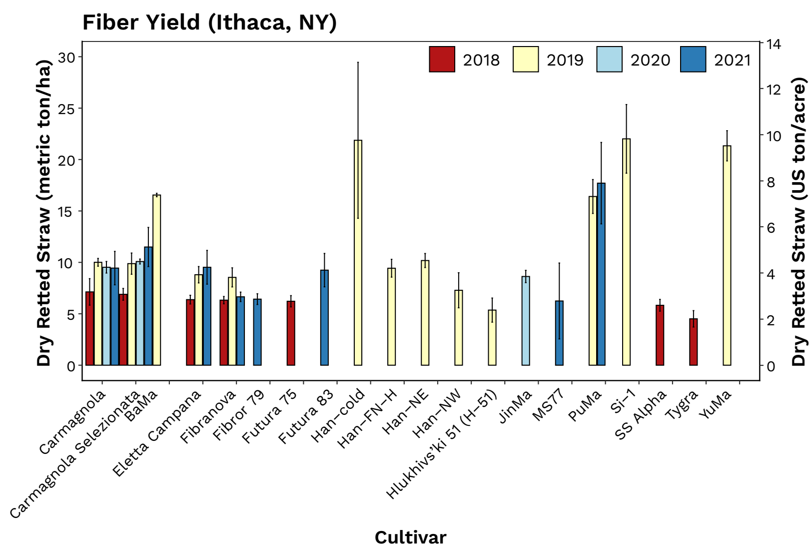
variety selection, open ground production and calendar, fiber processing, and market preparation

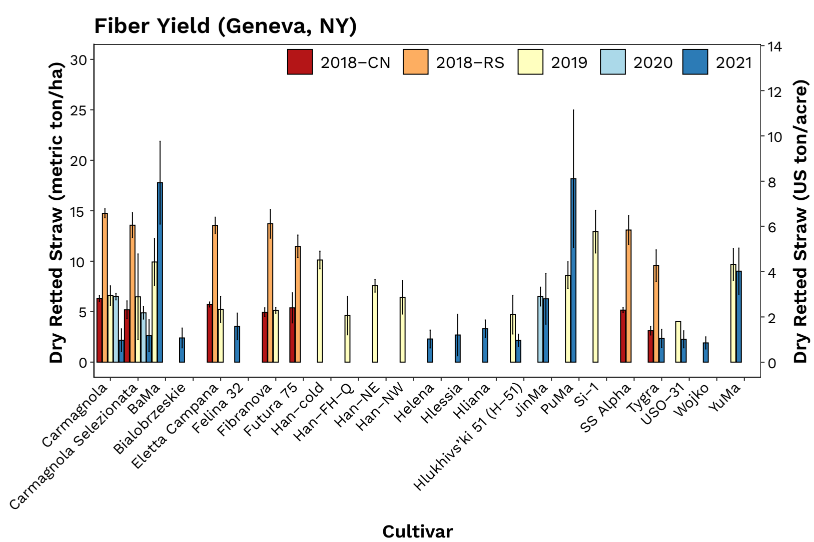
Variety Selection

Fiber growers plant from seed and variety selection is an important factor for farmers due to the difference in performance. Yield evaluations over time highlight the importance of variety selection and environmental conditions towards economically relevant traits.

Among the 28 fiber and dual-purpose cultivars evaluated by the Cornell hemp research program over the last four years in New York, there has been considerable fiber yield variability across cultivars and locations as shown in the figures. These results establish that some varieties perform better at particular locations and therefore variety selection must be made with location in mind.

- 'Si-1' and 'PuMa' were the highest-yielding cultivars in Ithaca for 2019 (9.82 tons/ac (22.01 metric ton/ha)) and Geneva for 2021 (7.28 tons/ac (18.17 metric ton/ha)), respectively.
- The lowest yield was observed from 'Tygra' in Ithaca in 2018 (1.83 tons/ac (4.51 metric tons/ha)) and 'Wojko' in Geneva in 2021 (0.77 tons/ac (1.90 metric ton/ha)).
- The varieties 'Carmagnola' and 'Carmagnola Selezionata' showed more yield consistency in Ithaca than in Geneva through a comparison across locations and years.
    - In Ithaca, the yield of these two cultivars was slightly lower in 2018.
    - Both performed worse when cultivated in Geneva in 2021, reaching less than 1.34 tons/ac (3 metric ton/ha).
    - In Geneva, their yield was the greatest in 2018 (6.05 tons/ac (13.57 metric ton/ha) and 6.58 tons/ac (14.75 metric ton/ha)) at one of the two testing sites.
- In 2018, the yield of 'Eletta Campana' and 'Fibranova' in the Geneva testing was about two times greater than in Ithaca.





Dry retted straw of 28 fiber and dual-purpose hemp cultivars evaluated in Ithaca, NY (top) and Geneva, NY (bottom) over the last four years. Two testing sites were cultivated in Geneva in 2018: Crittenden North (CN) and Research South (RS). Bars represent the mean and 95 confidence interval of four replications harvested.

Open Ground Production for Fiber Hemp

Land Preparation

When C. *sativa* hemp is grown for fiber, it is commonly produced in a conventionally tilled system. Following deep or shallow tillage, field cultivators are often used to smooth the soil surface. This practice is beneficial when pre-transplanting fertilizers are applied, and growers desire uniform incorporation.

A grain drill can properly set the seed at the proper depth and in-row spacing. No-till drills can be used if there is not too much crop residue. Air seeders are also effective if the seed bed is properly prepared.

Recommendations:

- When using a drill
    - Common plant spacing is 7-8 inches (~17.5-20.5 cm) for fiber hemp
    - Sowing depth of approximately 0.5-0.8 inch (~1.3-2 cm)
- Row spacing for fiber hemp ranges from 36-48 inches (91-122 cm).
    - Make sure that you can fit a tractor and walk between rows which may be helpful to manage weeds between rows.

Producers are strongly encouraged to utilize ripping shank to reduce in-row soil resistance.

Irrigation in an Open Ground System

Cannabis sativa has a reputation of being drought tolerant. When compared to similar crops such as cotton, hemp does use water more efficiently. This allows hemp to be a viable crop in climates that receive little to no rain during the growing season. Irrigation of hemp for fiber has shown to improve yields of biomass and stem mass by 7% and 9% respectively, however, effects of irrigation have been shown to be lower for hemp than in maize or kenaf. These findings suggest that the extra yields of irrigating hemp for fiber may not be worth the investment of resources that is seen with other crops.

Overhead irrigation during the vegetative stage of the crop is recommended at 0.5 inch (1.27 cm per week, increasing to 1 inch (2.54 cm) per week during times with high heat and humidity if there is no local rainfall to meet the crop need. It is also suggested for settling transplants following planting. It should be noted that use of irrigation systems that wet leaves can increase chances of fungal or bacterial infections occurring.

When using an open ground production system, it is recommended to use subsurface drip irrigation, dispensing 0.5 inch (1.27 cm) per week, during the flowering stage of crop development. Drip irrigation may also be used.

Recommendations:

- Reduce overhead irrigation during the flowering stage to avoid trichome damage. This will also reduce incidence of disease in the inflorescence.
- Avoid irrigating during the heat of the day or in windy conditions to maximize water efficiency. Early morning irrigation is best.
- Keep irrigation equipment well-maintained to prevent water loss due to leaks.
- Keep detailed records to understand water needs by variety.

Managing Nutrients for Hemp Cultivated for Fiber

Important nutrients for proper hemp growth include nitrogen (N), phosphorus (P), potassium (K), sulfur (S) and boron (B).

NOTE: The fiber hemp recommendations for fertilizer use provided are taken from the *Cornell Guide for Integrated Field Crop Management* since there are still no conclusive studies that provide this information for hemp production.

It is highly recommended to have a soil test before using any fertilizer to provide a more accurate guideline of the amount of fertilizer to use. To estimate the amount necessary of fertilizer, use the following information:

> *"Divide the recommended nutrient amounts by the fertilizer analysis using the same ratio. For example,* 30 + 60 + 30 *(a* 1-2-1 *ratio) divided by* 10-20-10 *(fertilizer analysis) is* 3*; thus,* 300 *pounds per acre of* 10-20-10 *will provide the recommended* 30 + 60 + 30."

See the fertilizer material and respective analysis (modified from Table 2.11.1 in the *Field Crops* guideline), demonstrating that these can be directly applied to the soil or blended with other fertilizers.

Fertilizer Materials

Common Name	Chemical Formula	Analysis (%)		
		N	P_2O_5	K_2O
Nitrogen materials				
Ammonium nitrate	NH_4NO_3	34	0	0
Ammonium sulfate	$(NH_4)_2SO4$	21	0	0
Ammonium nitrate-urea	$NH_4NO_3+(NH_2)_2CO$	32[A]	0	0
Anhydrous ammonia	NH_3	82	0	0
Aqua ammonia	NH_4OH	20[A]	0	0
Urea	$(NH_2)_2CO$	46	0	0
Phosphate materials				
Superphosphate	$Ca(H_2PO_4)_2$	0	20	0
Concentrated superphosphate	$Ca(H_2PO_4)_2$	1	44-46	0
Ammoniated superphosphate	$Ca(NH_4H_2PO_4)_2$	5[A]	40[A]	0
Monoammonium phosphate	$NH_4H_2PO_4$	13[A]	52[A]	0
Diammonium phosphate	$(NH_4)_2HPO_4$	18[A]	46[A]	0
Urea-ammonium phosphate	$(NH_2)_2CO+$ $(NH_4)_2HPO_4$	28	28	0
Potash materials				
Muriate of potash	KCl	0	0	60
Monopotassium phosphate	KH_2PO_4	0	50[A]	40
Sulfate of potash	K_2SO_4	0	0	50
Sulfate of potash-magnesia	$K_2SO_4MgSO_4$	0	0	22

[A] variable analysis
Key: calcium (Ca), chlorine (Cl), magnesium (Mg), nitrogen (N), phosphorus (P), potassium (K), sulfur (S)

Common Name	Chemical Formula	Analysis (%)	Nutrient
Other Nutrients			
Borate	Na_2BO_4	20[A]	B
Solubor	Na_2BO_4	20.5	B
Ferrous sulfate	$FeSO_4$	20[A]	Fe
Magnesium sulfate	$MgSO_4$	16[A]	Mg
Magnesium oxide	MgO	45[A]	Mg
Manganous sulfate	$MnSO_4$	28[A]	Mn
Zinc sulfate	$ZnSO_4$	36[A]	Zn
Zinc oxide	ZnO	50[A]	Zn
Zinc chelate	Zn chelate	14[A]	Zn
Superphosphate	$Ca(H_2PO_4)_2$	14[A]	S
Calcium sulfate (gypsum)	$CaSO_4$	15[A]	S

[A] variable analysis
Key: boron (B), calcium (Ca), iron (Fe), magnesium (Mg), manganese (Mn), sodium (Na), sulfur (S), zinc (Zn)

Take into account:

- Since N and K add ions to the soil, high concentration of these near the germination or seedling period may cause salt burn.
    - Salt burn negatively impacts germination and growth.
    - Dry conditions during planting time can make salt burn more pronounced.
    - Avoid salt burn by using a max amount of 80-100 lb/acre (~90-112 kg/ha) of N plus K.
- High ammonia, urea, or diammonium phosphate may also produce salt burn.
    - If ammonia is used pre-planting as a N source, apply it at a far distance from the seed location.

In general, these are the values used by the industry based on the requirements to achieve a yield of 4-5.5 tons/acre (9.8-13.5 tons/ha) of fiber or 600-1000 lbs/acre (~672-1,121 kg/ha):

- N: 60-90 lbs/acre (~67-100 kg/ha)
- P: 35-50 lbs/acre (~40-56 kg/ha)
- K: 75-135 lbs/acre (~84-151 kg/ha)
- Ca: 220 lbs/acre (~246 kg/ha)
- N:P:K ratio suggested for fiber: 1:0.7:1.5

Secondary macronutrients, which are required for plant growth are not required in large quantities and may be provided through other ways than fertilizers. These macronutrients are:

- Calcium (Ca)
- Magnesium (Mg)
- Sulfur (S)

Micronutrients, known as minor elements, are also necessary but required in small amounts. Soils in New York State contain suitable amounts of micronutrients except for a few exceptions. The micronutrients of importance in New York State are:

- Boron (B)
- Chlorine (Cl)
- Copper (Cu)
- Iron (Fe)
- Molybdenum (Mo)
- Sodium (Na)
- Zinc (Zn)

Further information:

Cornell University College of Agriculture and Life Sciences fertility and nutrient management guidelines for field crops at http://nmsp.cals.cornell.edu/guidelines/

Fertilization Techniques

Given that proper fertilization is necessary for hemp production–requiring appropriate usage to avoid environmental damage and reduce income–producers must be aware of proper fertilization techniques. This becomes particularly important if manure, which provides macro and micronutrient, is applied.

To help identify fields with elevated risk of leaching nutrients to groundwater, the Nitrate Leaching Index (NLI) and the New York Phosphorus Index (NY-PI) are used in New York State.

Nitrate Leaching Index (NLI)

Nitrogen (N) turns into water-soluble nitrate that can be lost by leaching, denitrification, runoff and/or erosion.

- Well-drained soils have a higher risk of leaching than less-drained soils.
- New York Nitrate Leaching Index (NLI)
    - Below 2 (NLI<2): low potential for nitrate leaching below the root zone
    - 2-10: intermediate potential
    - Greater than 10 (NLI>10): high potential for leaching below the root zone
- For intermediate and high potential LI soils:
    - Base fertilizer application rates on information provided in the Cornell guidelines.
    - Apply fertilizers close to the expected planting date (within a 3-day range).
    - Starter fertilizer N levels should be below 50 lb/acre (56 kg/ha).
    - If incorporating sod crops, do so in the fall.
    - Reduce manure application in the fall or winter. If applied, consider planting winter cover crops.

The New York Nitrate Leaching Index fact sheet provides more information on calculating the NLI and management implications: http://nmsp.cals.cornell.edu/publications/factsheets/factsheet11.pdf

New York Phosphorus Index (NY-PI)

Since phosphorus binds to soil particles, erosion is a common way to lose this compound, but can also be lost as runoff when dissolved. The NY-PI, which was adopted in 2001, estimates the potential for P to leave fields and uses records on farms, erosion, and manure and fertilization plans.

NY-PI has four risk levels (low, medium, high, very high) and the highest level indicates that no additional phosphorus is needed.

Take into account:

- Evaluating NY-PI yearly to consider crop rotation.
- NY-PI score can be lowered with practices like application rate and timing.
- Areas with high P Fields with a history of high P applications may need management changes.

If fertilizing with manure, consider the following guidelines that include **12 important factors** divided into three groups:

1. Field Conditions
   - Soil moisture/saturation, frozen or not
   - Snow, ice, and frozen soil
   - Ground cover
   - Slope and slope length
   - Drain tile, surface inlets, ditches
   - Nearby surface water
   - Nearby wells
2. Weather Conditions
   - Precipitation, amount, and duration
   - Expected warm fronts causing snow melts
3. Manure Application Management
   - Manure consistency
   - Application method
   - Application rate and total volume

Further considerations:

- Consult the guidelines for proper manure application to lessen nutrient runoff possibility.
- Highly recommended: Refer to the Cornell University Guidelines for Comprehensive Nutrient Management Plans
- Keep in mind that some practices contradict each other:
  - protocols for reduction of runoff or erosion may not be consistent with those for diminishing leaching potential

Further information:

Cornell University Guidelines for Comprehensive Nutrient Management Plans

The New York Nitrate Leaching Index rates based on soil type and township precipitation data

Nitrogen Guidelines for Field Crops in New York

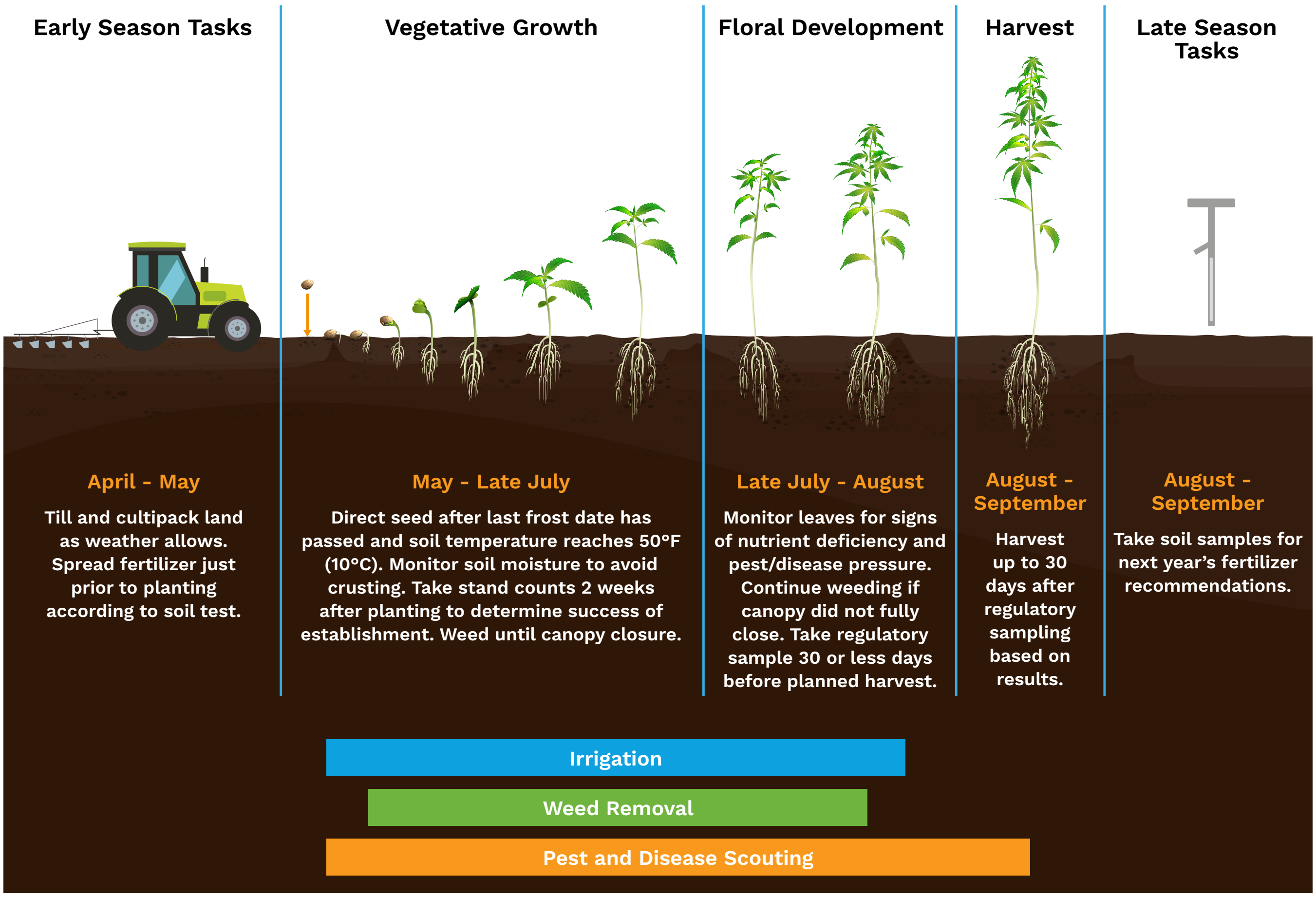
The New York Phosphorus Runoff Index (2003)

The New York Phosphorus Runoff Index: Version 2.0 (2021)

The New York Phosphorus Index 2.0

Revised Winter and Wet Weather Manure Spreading Guidelines to Reduce Water Contamination Risk

Fiber Hemp Production Calendar



Fiber Production Tasks by Month

January-March

Equipment and Facilities
- Repair and perform maintenance on planters, sprayers, and fertilizer application equipment.
- Clean harvesters and other equipment.

Crop Management
- Research varieties and make relationships with seed providers.
- Secure seed.
- Attend grower meeting(s).

Nutrient and Soil Management
- Make sure that soil has been tested.
- Order fertilizer for upcoming season.

Pest and Disease Management
- Inventory chemicals to determine needs for upcoming season.

April

Equipment and Facilities

- Calibrate planter and sprayers.

Crop Management

- Ensure that all seed and fertilizer has been received.
- Create planting plan and field maps.
- Begin field cultivation for weed suppression and bed preparation after terminating cover crop.
- Make a plan for crop irrigation.

Nutrient and Soil Management

- Apply phosphorus and potassium based on soil test.

Pest, Disease, and Weed Management

- Terminate cover crop.
- Burn down weeds persisting after cultivation.

May

Equipment and Facilities

- Final check to ensure that all equipment has been fully serviced and is ready for the season.
- Perform maintenance on weather station and place in field.

Crop Management

- Continue field cultivation for weed suppression and bed preparation, as weather allows.
- Plant after soil temperature is maintained above 50°F (10°C).
- Monitor soil moisture levels to avoid soil crusting during seedling establishment.
- Take stand counts two weeks after planting and reseed, as needed.

Nutrient and Soil Management

- Apply phosphorus and potassium based on soil test if not done previously prior to planting or at planting.
- Apply granular or liquid nitrogen at planting.

Pest, Disease, and Weed Management

- Burn down weeds persisting after cultivation.
- Apply pre-emergent and post-emergent herbicides as regulations allow.
- If applying pre-emergent herbicides, irrigate to activate if no rain is forecasted.
- Continuously monitor young plants for pests and diseases or signs of abiotic stress.

June

Equipment and Facilities

- Perform maintenance, as needed.

Nutrient and Soil Management

- Monitor leaves for signs of nutrient deficiency and supply supplemental fertilizer, as needed.

Pest, Disease, and Weed Management

- Continuously monitor plants for pests, diseases, or signs of abiotic stress, and treat issues as they arise.

July

Equipment and Facilities
- Perform maintenance, as needed.
- Ensure that storage facilities have been secured for baled fiber.

Crop Management
- Monitor plants for signs of flowering weekly and record flowering date.
- Schedule regulatory tests for 30 days prior to planned harvest date.

Nutrient and Soil Management
- Monitor leaves for signs of nutrient deficiency and supply fertilizer, as needed.

Pest, Disease, and Weed Management
- Continuously monitor plants for pests, diseases, or signs of abiotic stress, and treat issues as they arise.

August

Equipment and Facilities
- Perform maintenance, as needed.
- Ensure that harvest equipment is in working order.
- Ensure that storage facilities have been secured for baled fiber.

Crop Management
- Monitor soil moisture levels and irrigate, as needed.
- Monitor plants for signs of flowering weekly and record flowering date.
- Schedule regulatory tests for 30 days prior to planned harvest date.
- Mow plants with a sickle bar mower at the end of flowering before seed set.
- Leave swaths of stems on the ground for 10 to 20 days to ret.
- Turn the swaths (ted) at least once to ensure even retting.
- Bale fiber after it reaches 14% or less humidity.
- Attend Cornell Hemp Field Day.

September

Equipment and Facilities
- Perform maintenance, as needed.

Crop Management
- Schedule regulatory tests for 30 days prior to planned harvest date.
- Mow plants with a sickle bar mower at the end of flowering before seed set.
- Leave swaths of stems on the ground for 10 to 20 days to ret.
- Turn the swaths (ted) at least once to ensure even retting.
- Bale fiber after it reaches 14% or less humidity.

Nutrient and Soil Management
- Monitor leaves for signs of nutrient deficiency and supply supplemental fertilizer, as needed.

Pest, Disease, and Weed Management
- Continuously monitor plants for pests, diseases, or signs of abiotic stress, and treat issues as they arise.

October

Equipment and Facilities

- Perform maintenance, as needed.

Crop Management

- Harvest any extremely late flowering cultivars.

Nutrient and Soil Management

- Mow plants with a sickle bar mower at the end of flowering before seed set.
- Leave swaths of stems on the ground for 10 to 20 days to ret.
- Turn the swaths (ted) at least once to ensure even retting.
- Bale fiber after it reaches 14% or less humidity.
- Consider cover crop options, crop rotation, and site selection for the next growing season.
- Take soil samples for next year.
- Apply lime required for the next year with cultivation.
- Plant cover crop.

Pest, Disease, and Weed Management

- Remove and burn residual crop material if diseases that overwinter on residual appeared in your planting this year (i.e. downy mildew).

November-December

Equipment and Facilities

- Repair and clean harvest equipment.
- Winterize equipment, as needed.
- Make a list of necessary equipment/materials for upcoming year and begin placing orders.

Crop Management

- Review the season to evaluate what went well and what needs adjusting for next year.
- Ensure that cover crop is well established.
- Begin researching varieties and making relationships with plant and/or seed providers.

Nutrient and Soil Management

- Apply lime required for the next year with cultivation.
- Evaluate which products are needed for next year and place orders.

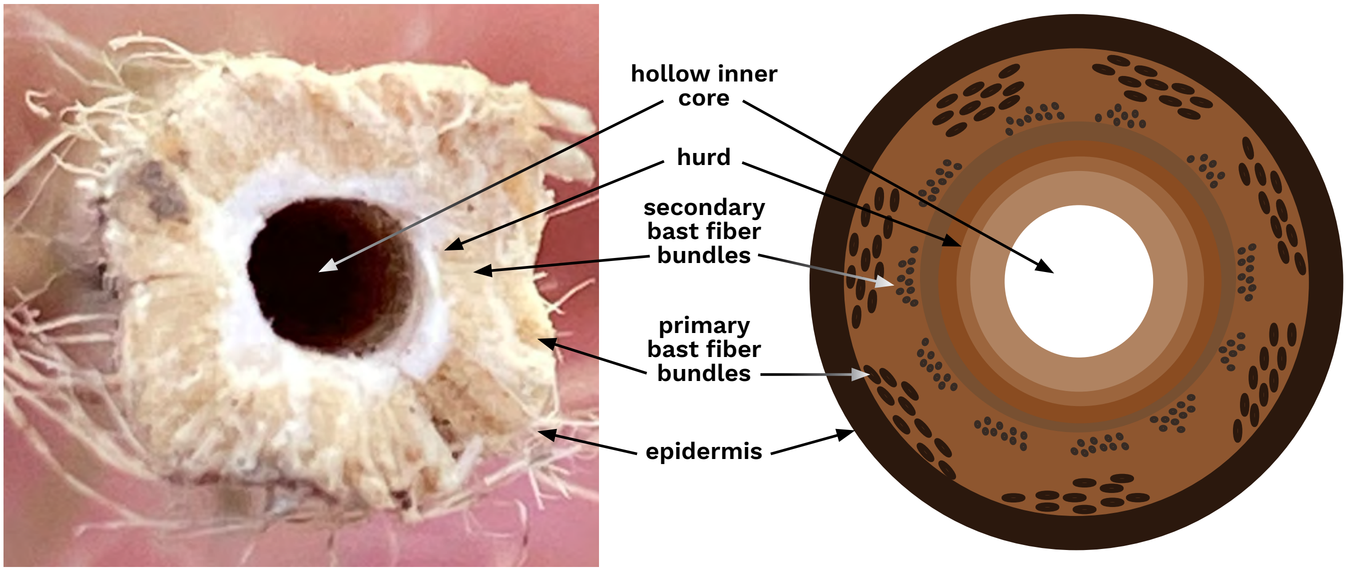
Pest, Disease, and Weed Management:

- Determine which management practices worked well this year and decide which should be reevaluated.
- Inventory chemicals.

Fiber harvest using a sickle bar mower, Geneva, NY. *Photo: Anthony Barraco III*

Fiber Harvest, Retting, and Processing

Hemp stalks are mainly composed of chemical components such as cellulose, hemicelluloses, lignin, and pectin. These components are bound by a lignin-rich middle lamella.



Cross section (left) and diagram of the cross section (right) of a hemp stem. *Photo and diagram by Daniela Vergara, CCE*

Harvest

Fiber hemp is usually mechanically harvested using a sickle bar mower by cutting the stem a few inches above the soil surface. In dual or triple harvest arrangements, a combine with a "double-cut" system can be used to harvest the top flower heads from the stalk to recover grain and potentially also threshing residues.

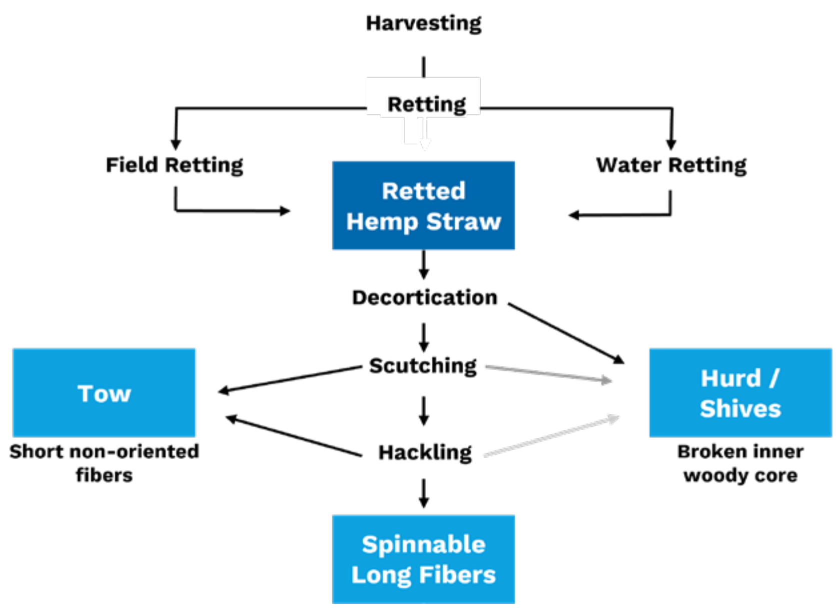
Fiber hemp should be harvested at the onset of male flowering, as males typically flower earlier than females. Plants harvested at seed maturity are significantly lignified making them tougher to cut and process compared to those harvested at the beginning of flowering. Some suggest that harvest should be performed when flowering has ended but before seed set.

Plant maturity, location of the fibers on the stem, and post-harvest practices can have significant influence on fiber chemical composition. Generally, the upper portion of the stem produces higher quality bast fibers and a lower proportion of secondary bast fibers. It is also thought that females produce stronger fibers whereas males producer longer fibers. At present, more research is needed to resolve many of these questions.

Depending on harvest time, stems may still be immature and have high moisture content, potentially leading to rotting during the retting process. If plants are left in the field too long after flowering, fibers may become overly stiff.

Post-Harvest

Once hemp stalks are harvested, a process called retting degrades the middle lamella for easier separation of the fiber bundles. Retting occurs when stalks are degraded, separating the plant fiber from the rest of the stalk. Retting must happen immediately following harvest. Successful retting enables mechanical separation of the bast fiber and inner woody core or “hurd” during the decortication process. The process of retting can take on different forms.



The process fiber goes through to generate final products.
Graphic: Heather Grab from Hemp Processing course, modified from (Musio et al. 2018)

Types of Retting

Field or Dew Retting

One of the most common retting methods is field or dew retting where harvested stalks are heaped into piles in the field called windrows. Over time, microorganisms break down substrate in the middle lamella of cell walls which bind fiber bundles together. This process is mainly facilitated by species of fungi that produce pectinolytic enzymes.

Bundled cultivars retting in a microenvironment, Geneva NY. *Photo: Daniela Vergara, CCE*

Over-retted bundles. *Photo: Anthony Barraco III*

Field retting uses significantly less resources than the alternative method of water retting and is more economically feasible as it does not require much equipment. However, field retting is heavily reliant on precipitation for microorganism proliferation to facilitate stem breakdown. Dry climates, with little rain, are difficult for field retting.

Since field retting is dependent on the weather, there are difficulties when trying to standardize the process across different climates and seasons. Incomplete or under-retting hinders mechanical separation, while over-retting weakens the fiber. On average, bundled plants are left on the ground for approximately 10-20 days depending on the weather conditions.

Due to the highly variable nature of field retting, stalks are typically less uniform than those subjected to water retting.

Water Retting

Water retting produces higher quality fiber through a more demanding process in both labor and capital. Instead of remaining in the field after harvest, hemp stalks are submerged in tanks of water. This process reduces the retting period. Skilled personnel must carefully observe the entire process. Water retting has been mostly discontinued in western countries due to the large amount of consumption and contamination of freshwater; instead, field retting is prevalent due to the low economic cost and environmental friendliness .

Of the two primary agricultural retting practices, water retting generally produces higher quality fiber than those produced by field retting. Hemp fiber for textiles and more delicate uses requires water retting.

A color scale has been developed to establish the retting degree in hemp. By comparing the color of the hemp in the field to the scale, an appropriate degree of retting can be achieved.

For more information, please visit: https://renewable-carbon.eu/news/nova-institute-presents-hemp-straw-color-scale-for-the-destination-of-the-degree-of-retting/


Fiber separation of cultivar Fibror 79 after two weeks of retting in Geneva, NY. *Photo: Anthony Barraco III*

Baling

Once the stalks have been successfully retted, they can be baled. Dry weather is necessary to bale stalks, which is contrary to the conditions necessary for field retting. The ideal humidity to bale the produced straw is under 14%.

Stalks can be baled with either a square or round baler.

- Round bales can shed water and may be stored outside for a short period of time without significant material loss.
- Square bales are more easily stored compared to round bales.

NOTE: Indoor storage is preferred and should be sought out whenever possible to prevent molding and protect the quality of the raw material.


Hemp stalks after drying. *Photo: Daniela Vergara, CCE*

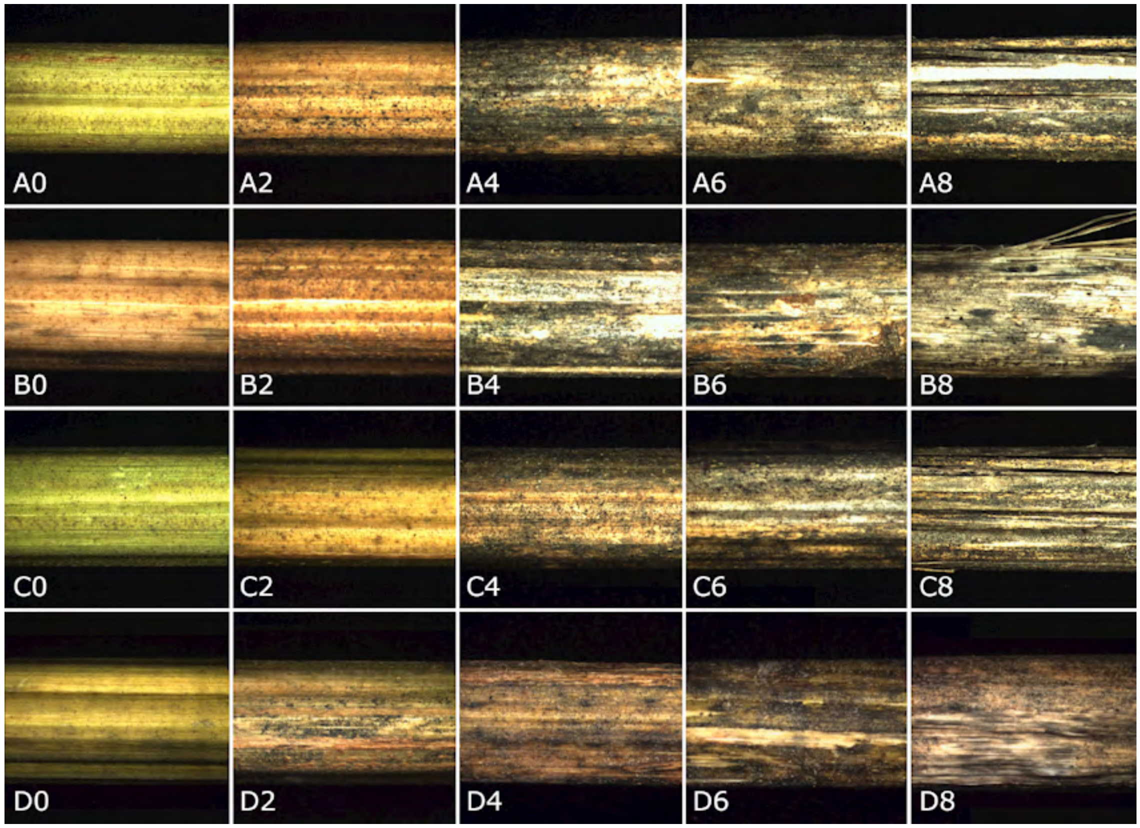
Fiber Hemp Varieties

A. Futura 85

B. Fibror 79

C. Carmagnola Selezionata

D. Carmagnola

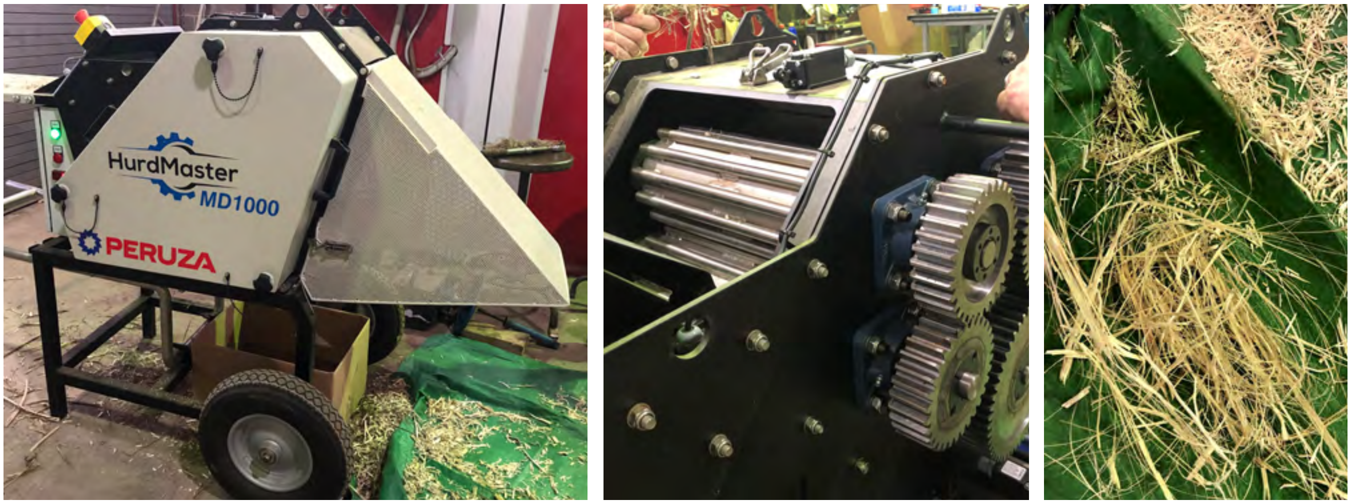


Stem microscopic photos of fiber hemp with the Infinity Lumenera 3 microscope and GIMP software from different hemp varieties: A) Futura 85; B) Fibror 79; C) Carmagnola Selezionata; and D) Carmagnola. The numbers in the figure represent the amount of weeks retted. For example B4 equals variety Fibror 79 at 4 weeks. *Photo: Anthony Barraco III*

Milled fiber from the variety Carmagnola Selezionata at different time points (from left to right): unretted, 2 weeks retted, 4 weeks, 6 weeks, and 8 weeks retted. *Photo: Anthony Barraco III*

Fiber Processing

Through further processing, the fiber can be used in multiple products including fabric, insulation material, carpeting, cordage, paper, plastics, and bagging. Similarly, the hurd which is derived from the inner woody core can be used in products such as bedding, insulation, absorbent materials, and hempcrete. The hurd is broken into smaller pieces, also referred to as shives, through the process of decortication, which employs a series of crushing rollers to separate the bast fibers and the hurd. Hurd pieces that remain attached to the bast fibers are removed in an additional series of steps including scutching in which the bast fibers are scraped to remove hurd fragments along with tow (short fibers and secondary fiber bundles). The next step is hackling in which the individual fibers are separated and aligned.



Decorticator at Cornell's campus and resulting hurd. *Photo: Heather Grab, Cornell*

- Traditionally, decortication machines use stalks that have been retted, but some can also be used with green stalks with positive results.
- Although there are hemp varieties specifically bred for bast and hurd, many hemp producers are also processing the stalks of high cannabinoid varieties with positive results. Processors are using the stalks in building materials like the insulation hempcrete products.
- Another advantageous use of hemp stalks is for the production of biochar. Biochar is the carbon-rich material remaining after pyrolysis of hemp stems. Application of biochar to the soil sequesters carbon and supports the soil microbial community by providing labile carbon and a suitable habitat.

Product Integrity and Contamination

Since hemp cultivation for fiber is emerging and information about the crop is still being developed, the requirements for the enhancement of fiber production are in progress.

General practices by the industry:

- Keep moisture content of harvested stems at 16% or below to avoid mold.
- Baling hemp below 10% moisture can break the fiber.
- Avoid:
  - weed contamination–baling hemp fiber with weeds can't be processed
  - rocks and stones that can break equipment
  - plastic fragments (although plastic wrap can be used to tie bales)

Grading and Market Preparation

Due to the infancy of hemp as a fiber crop, grading metrics are still being developed. Important grading parameters include:

Agronomic Traits

- Stalk height
- Diameter (max., mean, min.)
- Mass
- Internode number and length (max., mean, min.)
- Time to reach full height
- Moisture content
- Cellulose: lignin content ratio

Fiber and Hurd Characteristics

- Fiber length
- Tensile strength
- Crystallization
- Cross linking
- Ease of decortication (mechanical vs microbial retting)
  - degree of retting (color)
- Bast:Hurd ratio
- Cleanliness
- Visual appearance

The number of hemp fiber buyers continues to grow, creating promising conditions for the generation of a supply chain. At present, uses for hemp straw include animal bedding, hempcrete, insulation material, and materials for car products.

Prospective purchasers may have specific quality requirements. Therefore, it is recommended for hemp producers to establish relationships with their buyers and understand their needs.

Because transportation is costly, it is recommended for growers and processors to be in close distance to avoid long-distance transportation.

GRAIN

Grain Cultivation

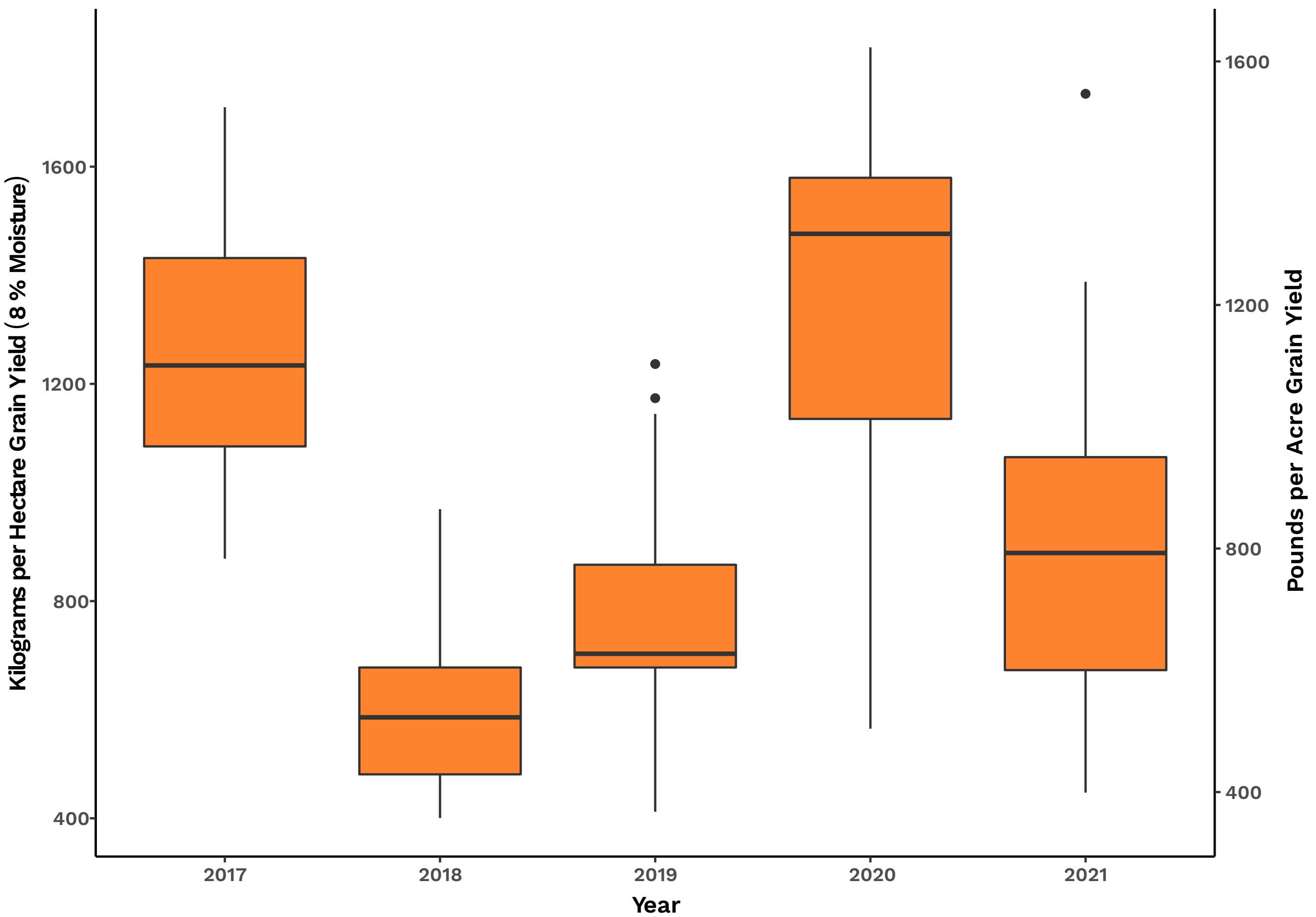
variety selection, open ground production and calendar, grain harvest and processing, and market preparation

Variety Selection

Like fiber, hemp grain is planted from seed and cultivar selection is an important factor in performance.

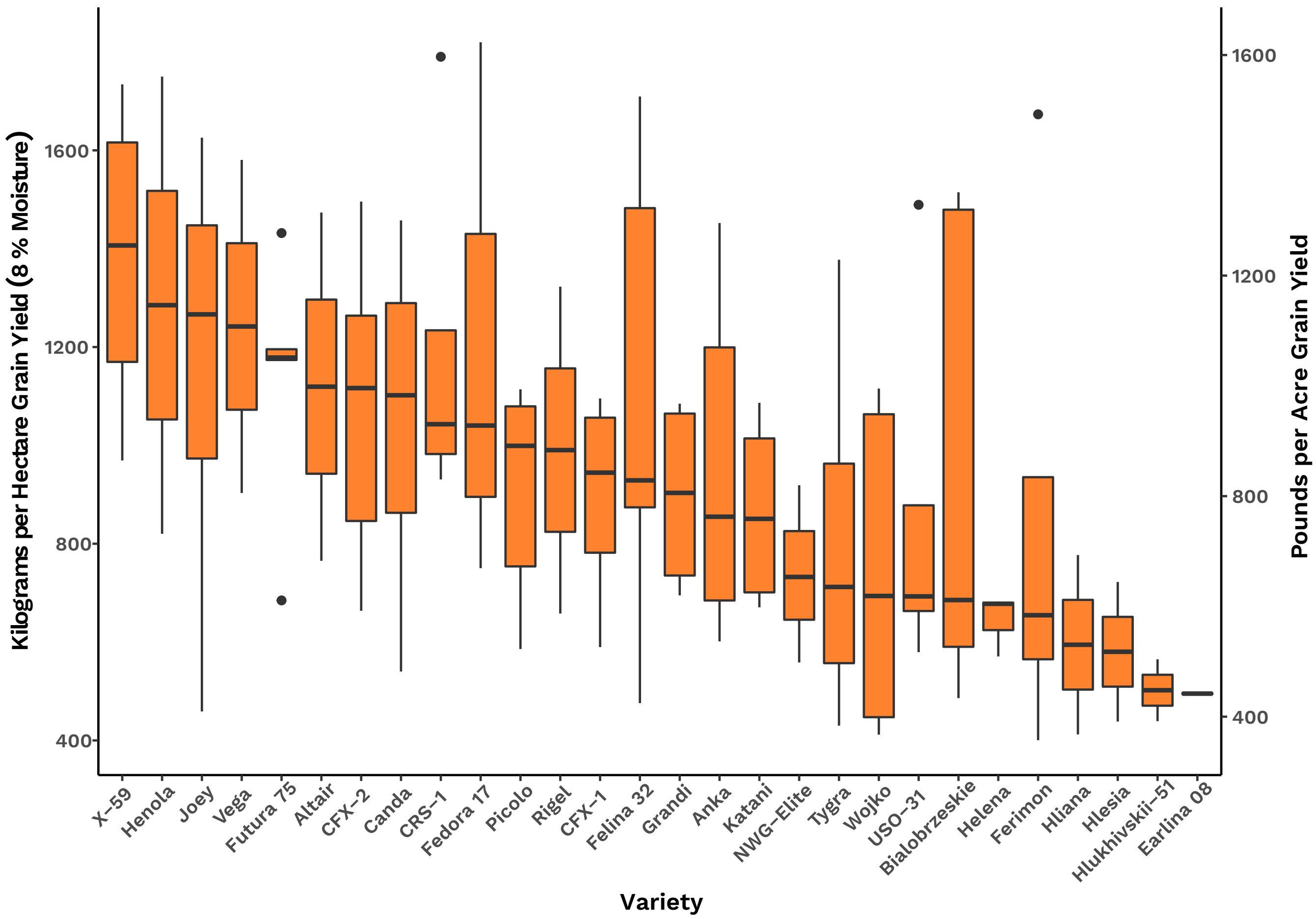
Yield

In 2017, the average grain yields were approximately 552 lbs/acre (~619 kg/ha) and 1,026 lbs/acre (~1,150 kg/ha), respectively, in two different field trials conducted by Cornell in their field research stations. Trials conducted in 2018 yielded less grain whereas 2020 saw high grain yields (see chart). 2021 was an outlier year in precipitation. Therefore, grain yields vary in time, possibly due to the environmental conditions.



Mean (dark horizontal line) and total distribution of grain yield across years in New York trials.

Grain yield varies by variety. The highest producing variety in the highest yielding trial generated 2,341 lbs per acre (~2,624 kg/ha) in 2017. In 2018, the highest yielding variety in the most productive trial generated 1,450 lbs per acre.



Mean (dark horizontal line) and total distribution of grain yield across varieties trialed in New York, 2018.

Some varieties (e.g., Bialobrezkie) have a great amount of yield variance. Other varieties, such as Vega, Futura 75, Helena, Hlukhivski 51, and Erlina 08, are more consistent in the yield—with Vega and Futura 75 on the higher end of production, and Helena, Hlukhivski 51, and Erlina 08 on the lower end. NOTE: This consistent variation in these varieties may be due to low numbers of plants grown.

Other Considerations

Seed size, oil content, and other attributes must be considered when choosing varieties for seed. In 2018, in Ithaca and Geneva, NY, harvested grain had an oil content of 29, a fiber content of 35.1, and a protein content of 28.

Seed size comparison. *Photo: Luis A. Monserrate*

Open Ground Production for Grain

Land Preparation

When C. *sativa* hemp is grown for grain, it is commonly produced in a conventionally tilled system. Following deep or shallow tillage, field cultivators are often used to smooth the soil surface. This practice is beneficial when pre-transplanting fertilizers are applied, and growers desire uniform incorporation.

A grain drill can properly set the seed at the proper depth and in-row spacing. No-till drills can be used if there is not too much crop residue. Air seeders are also effective if the seed bed is properly prepared.

Recommendations:

- When using a drill
    - Common plant spacing is 7-8 inches (~17.5-20.5 cm) for grain
    - Sowing depth of approximately 0.5-0.8 inch (~1.3-2 cm)
- Row spacing for fiber or grain hemp ranges from 36-48 inches (91-122 cm).
    - Make sure that you can fit a tractor and walk between rows which may be helpful to manage weeds between rows.

Producers are strongly encouraged to utilize ripping shank to reduce in-row soil resistance.

Irrigation in an Open Ground System

Cannabis sativa has a reputation of being drought tolerant. When compared to similar crops such as cotton, hemp does use water more efficiently. This allows hemp to be a viable crop in climates that receive little to no rain during the growing season.

Overhead irrigation during the vegetative stage of the crop is recommended at 0.5 inch (1.27 cm per week, increasing to 1 inch (2.54 cm) per week during times with high heat and humidity if there is no local rainfall to meet the crop need. It is also suggested for settling transplants following planting. It should be noted that use of irrigation systems that wet leaves can increase chances of fungal or bacterial infections occurring.

When using an open ground production system, it is recommended to use subsurface drip irrigation, dispensing 0.5 inch (1.27 cm) per week, during the flowering stage of crop development. Drip irrigation may also be used.

Recommendations:

- Reduce overhead irrigation during the flowering stage to avoid trichome damage. This will also reduce incidence of disease in the inflorescence.
- Avoid irrigating during the heat of the day or in windy conditions to maximize water efficiency. Early morning irrigation is best.
- Keep irrigation equipment well-maintained to prevent water loss due to leaks.
- Keep detailed records to understand water needs by variety.

Managing Nutrients for Hemp Cultivated for Grain

Important nutrients for proper hemp growth include nitrogen (N), phosphorus (P), potassium (K), sulfur (S) and boron (B). The N:P:K ratio suggested for grain is 1:0.8:1.

NOTE: The grain hemp recommendations for fertilizer use provided are taken from the *Cornell Guide for Integrated Field Crop Management* since there are still no conclusive studies that provide this information for hemp production.

It is highly recommended to have a soil test before using any fertilizer to provide a more accurate guideline of the amount of fertilizer to use. To estimate the amount necessary of fertilizer, use the following information:

> *"Divide the recommended nutrient amounts by the fertilizer analysis using the same ratio. For example,* 30 + 60 + 30 *(a 1-2-1 ratio) divided by 10-20-10 (fertilizer analysis) is 3; thus, 300 pounds per acre of 10-20-10 will provide the recommended* 30 + 60 + 30."

See the fertilizer material and respective analysis (modified from Table 2.11.1 in the *Field Crops* guideline), demonstrating that these can be directly applied to the soil or blended with other fertilizers.

Fertilizer Materials

Common Name	Chemical Formula	Analysis (%)		
		N	P_2O_5	K_2O
Nitrogen materials				
Ammonium nitrate	NH_4NO_3	34	0	0
Ammonium sulfate	$(NH_4)_2SO4$	21	0	0
Ammonium nitrate-urea	$NH_4NO_3+(NH_2)_2CO$	32[A]	0	0
Anhydrous ammonia	NH_3	82	0	0
Aqua ammonia	NH_4OH	20[A]	0	0
Urea	$(NH_2)_2CO$	46	0	0
Phosphate materials				
Superphosphate	$Ca(H_2PO_4)_2$	0	20	0
Concentrated superphosphate	$Ca(H_2PO_4)_2$	1	44-46	0
Ammoniated superphosphate	$Ca(NH_4H_2PO_4)_2$	5[A]	40[A]	0
Monoammonium phosphate	$NH_4H_2PO_4$	13[A]	52[A]	0
Diammonium phosphate	$(NH_4)_2HPO_4$	18[A]	46[A]	0
Urea-ammonium phosphate	$(NH_2)_2CO+$ $(NH_4)_2HPO_4$	28	28	0
Potash materials				
Muriate of potash	KCl	0	0	60
Monopotassium phosphate	KH_2PO_4	0	50[A]	40
Sulfate of potash	K_2SO_4	0	0	50
Sulfate of potash-magnesia	$K_2SO_4MgSO_4$	0	0	22

[A] variable analysis
Key: calcium (Ca), chlorine (Cl), magnesium (Mg), nitrogen (N), phosphorus (P), potassium (K), sulfur (S)

Common Name	Chemical Formula	Analysis (%)	Nutrient
Other Nutrients			
Borate	Na_2BO_4	20[A]	B
Solubor	Na_2BO_4	20.5	B
Ferrous sulfate	$FeSO_4$	20[A]	Fe
Magnesium sulfate	$MgSO_4$	16[A]	Mg
Magnesium oxide	MgO	45[A]	Mg
Manganous sulfate	$MnSO_4$	28[A]	Mn
Zinc sulfate	$ZnSO_4$	36[A]	Zn
Zinc oxide	ZnO	50[A]	Zn
Zinc chelate	Zn chelate	14[A]	Zn
Superphosphate	$Ca(H_2PO_4)_2$	14[A]	S
Calcium sulfate (gypsum)	$CaSO_4$	15[A]	S

[A] variable analysis
Key: boron (B), calcium (Ca), iron (Fe), magnesium (Mg), manganese (Mn), sodium (Na), sulfur (S), zinc (Zn)

Take into account:

- Since N and K add ions to the soil, high concentration of these near the germination or seedling period may cause salt burn.
  - Salt burn negatively impacts germination and growth.
  - Dry conditions during planting time can make salt burn more pronounced.
  - Avoid salt burn by using a max amount of 80-100 lb/acre (~90-112 kg/ha) of N plus K.
- High ammonia, urea, or diammonium phosphate may also produce salt burn.
  - If ammonia is used pre-planting as a N source, apply it at a far distance from the seed location.

Secondary macronutrients, which are required for plant growth are not required in large quantities and may be provided through other ways than fertilizers. These macronutrients are:

- Calcium (Ca)
- Magnesium (Mg)
- Sulfur (S)

Micronutrients, known as minor elements, are also necessary but required in small amounts. Soils in New York State contain suitable amounts of micronutrients except for a few exceptions. The micronutrients of importance in New York State are:

- Boron (B)
- Chlorine (Cl)
- Copper (Cu)
- Iron (Fe)
- Molybdenum (Mo)
- Sodium (Na)
- Zinc (Zn)

Further information:

Cornell University College of Agriculture and Life Sciences fertility and nutrient management guidelines for field crops at http://nmsp.cals.cornell.edu/guidelines/

Fertilization Techniques

Given that proper fertilization is necessary for hemp production–requiring appropriate usage to avoid environmental damage and reduce income–producers must be aware of proper fertilization techniques. This becomes particularly important if manure, which provides macro and micronutrient, is applied.

To help identify fields with elevated risk of leaching nutrients to groundwater, the Nitrate Leaching Index (NLI) and the New York Phosphorus Index (NY-PI) are used in New York State.

Nitrate Leaching Index (NLI)

Nitrogen (N) turns into water-soluble nitrate that can be lost by leaching, denitrification, runoff and/or erosion.

- Well-drained soils have a higher risk of leaching than less-drained soils.
- New York Nitrate Leaching Index (NLI)
    - Below 2 (NLI<2): low potential for nitrate leaching below the root zone
    - 2-10: intermediate potential
    - Greater than 10 (NLI>10): high potential for leaching below the root zone
- For intermediate and high potential LI soils:
    - Base fertilizer application rates on information provided in the Cornell guidelines. (See link below.)
    - Apply fertilizers close to the expected planting date (within a 3-day range).
    - Starter fertilizer N levels should be below 50 lb/acre (56 kg/ha).
    - If incorporating sod crops, do so in the fall.
    - Reduce manure application in the fall or winter. If applied, consider planting winter cover crops.

The New York Nitrate Leaching Index fact sheet provides more information on calculating the NLI and management implications: http://nmsp.cals.cornell.edu/publications/factsheets/factsheet11.pdf

New York Phosphorus Index (NY-PI)

Since phosphorus binds to soil particles, erosion is a common way to lose this compound, but can also be lost as runoff when dissolved. The NY-PI, which was adopted in 2001, estimates the potential for P to leave fields and uses records on farms, erosion, and manure and fertilization plans.

NY-PI has four risk levels (low, medium, high, very high) and the highest level indicates that no additional phosphorus is needed.

Take into account:

- Evaluating NY-PI yearly to consider crop rotation.
- NY-PI score can be lowered with practices like application rate and timing.
- Areas with high P Fields with a history of high P applications may need management changes.

If fertilizing with manure, consider the following guidelines that include **12 important factors** divided into three groups:

1. Field Conditions
    - Soil moisture/saturation, frozen or not
    - Snow, ice, and frozen soil
    - Ground cover
    - Slope and slope length
    - Drain tile, surface inlets, ditches
    - Nearby surface water
    - Nearby wells
2. Weather Conditions
    - Precipitation, amount, and duration
    - Expected warm fronts causing snow melts
3. Manure Application Management
    - Manure consistency
    - Application method
    - Application rate and total volume

Further considerations:

- Consult the guidelines for proper manure application to lessen nutrient runoff possibility.
- Highly recommended: Refer to the Cornell University Guidelines for Comprehensive Nutrient Management Plans
- Keep in mind that some practices contradict each other:
    - protocols for reduction of runoff or erosion may not be consistent with those for diminishing leaching potential

Further information:

Cornell University Guidelines for Comprehensive Nutrient Management Plans

The New York Nitrate Leaching Index rates based on soil type and township precipitation data

Nitrogen Guidelines for Field Crops in New York

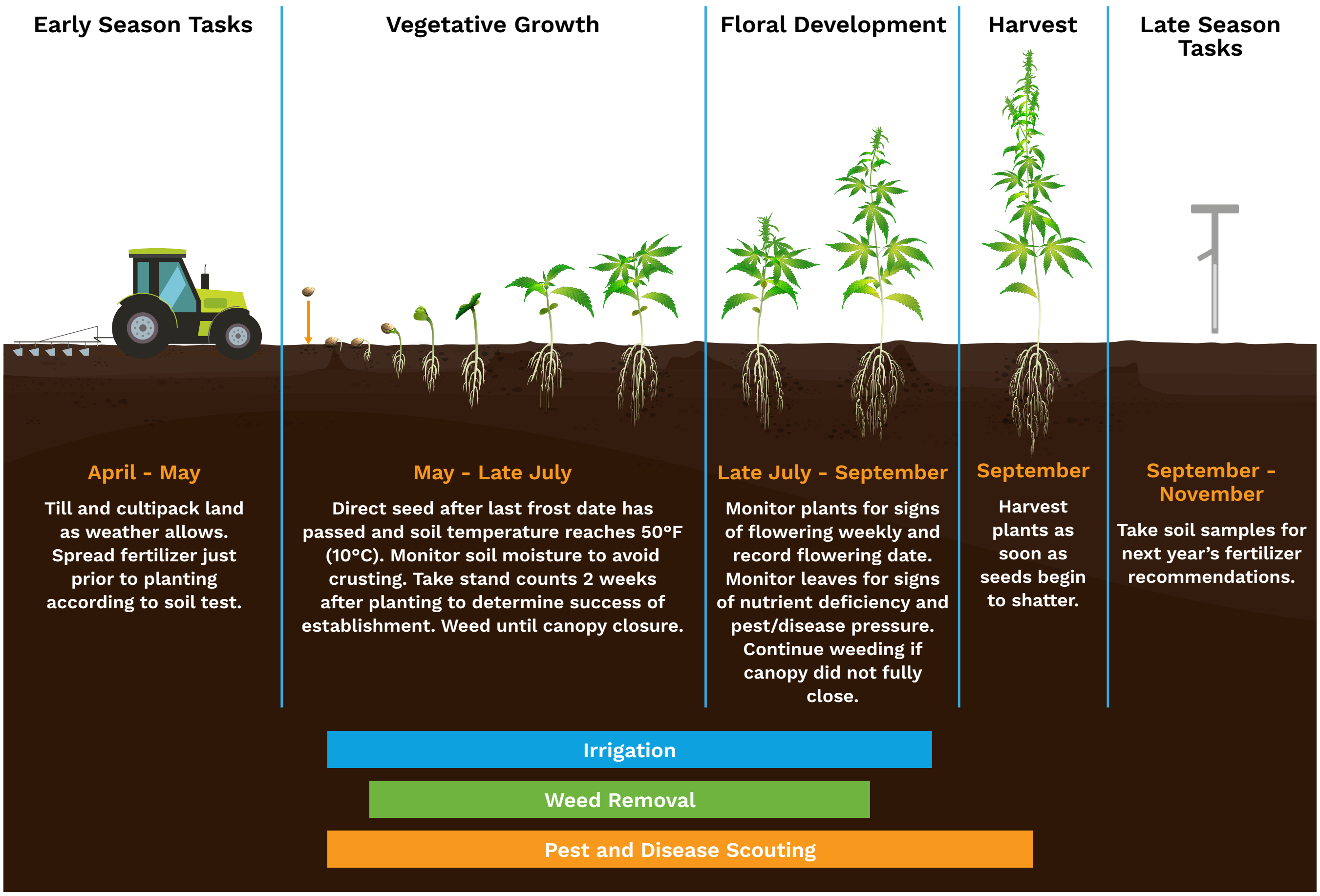
The New York Phosphorus Runoff Index (2003)

The New York Phosphorus Runoff Index: Version 2.0 (2021)

The New York Phosphorus Index 2.0

Revised Winter and Wet Weather Manure Spreading Guidelines to Reduce Water Contamination Risk

Grain Hemp Production Calendar



Grain Production Tasks by Month

January-March

Equipment and Facilities

- Repair and perform maintenance on planters, sprayers, and fertilizer application equipment.
- Clean harvesters and other equipment.

Crop Management

- Research varieties and make relationships with seed providers.
- Secure seed.
- Attend grower meeting(s).

Nutrient and Soil Management

- Make sure that soil has been tested.
- Order fertilizer for upcoming season.

Pest and Disease Management

- Inventory chemicals to determine needs for upcoming season.

April

Equipment and Facilities
- Calibrate planter and sprayers.

Crop Management
- Ensure that all seed and fertilizer has been received.
- Create planting plan and field maps.
- Begin field cultivation for weed suppression and bed preparation after terminating cover crop.
- Make a plan for crop irrigation.

Nutrient and Soil Management
- Apply phosphorus and potassium based on soil test.

Pest, Disease, and Weed Management
- Terminate cover crop.
- Burn down weeds persisting after cultivation.

May

Equipment and Facilities
- Final check to ensure that all equipment has been fully serviced and is ready for the season.
- Perform maintenance on weather station and place in field.
- Place soil moisture meters in field 10 cm deep after planting.

Crop Management
- Continue field cultivation for weed suppression and bed preparation, as weather allows.
- Plant after soil temperature is maintained above 50°F (10°C).
- Monitor soil moisture levels to avoid soil crusting during seedling establishment.
- Take stand counts two weeks after planting and reseed, as needed.

Nutrient and Soil Management
- Apply phosphorus and potassium based on soil test, if not done previously.
- Apply granular or liquid nitrogen at planting.

Pest, Disease, and Weed Management
- Burn down weeds persisting after cultivation.
- Apply pre-emergent and post-emergent herbicides, as regulations allow.
- If applying pre-emergent herbicides, irrigate to activate if no rain is forecasted.
- Continuously monitor young plants for pests and diseases or signs of abiotic stress.

June

Equipment and Facilities
- Perform maintenance, as needed.

Nutrient and Soil Management
- Monitor leaves for signs of nutrient deficiency and supply supplemental fertilizer, as needed.

Pest, Disease, and Weed Management
- Continuously monitor plants for pests, diseases, or signs of abiotic stress, and treat issues as they arise.

July

Equipment and Facilities

- Perform maintenance, as needed.

Crop Management

- Monitor plants for signs of flowering weekly and record flowering date.

Nutrient and Soil Management

- Monitor leaves for signs of nutrient deficiency and supply supplemental fertilizer, as needed.

Pest, Disease, and Weed Management

- Continuously monitor plants for pests, diseases, or signs of abiotic stress, and treat issues as they arise.

August-September

Equipment and Facilities

- Perform maintenance, as needed.
- Ensure that harvest equipment is in working order.

Crop Management

- Harvest plants as soon as seeds begin to shatter.

October

Equipment and Facilities

- Perform maintenance, as needed.

Crop Management

- Harvest any extremely late flowering varieties.

Nutrient and Soil Management

- Consider cover crop options, crop rotation, and site selection for the next growing season.
- Take soil samples for next year.
- Apply lime required for the next year with cultivation.
- Plant cover crop.

Pest, Disease, and Weed Management

- Remove and burn residual crop material if diseases that overwinter on residual appeared in your planting this year (i.e., downy mildew).

November-December

Equipment and Facilities

- Repair and clean harvest equipment.
- Winterize equipment, as needed.
- Make a list of necessary equipment/materials for upcoming year and begin placing orders.

Crop Management

- Review the season to evaluate what went well and what needs adjusting for next year.
- Ensure that cover crop is well established.
- Begin researching varieties and making relationships with plant and/or seed providers.

Nutrient and Soil Management

- Apply lime required for the next year with cultivation.
- Evaluate which products are needed for next year and place orders.

Pest, Disease, and Weed Management:

- Determine which management practices worked well this year and decide which should be reevaluated.
- Inventory chemicals.

Grain Harvest and Processing

Harvest

Hemp flowers are indeterminate, continuously producing new flowers and setting grain. The grains at the bottom of the inflorescence are more mature than those at the top. Hemp is also very prone to shattering as mature seeds are not held tightly into the bracts and will easily fall to the ground. High winds near harvest time can result in large crop losses. Hemp left in the field after an early killing frost will likely lose a large portion of grain due to shatter.

Harvest date is variety-determined, typically 4-6 weeks after full flowering. Seeds have different maturation times on the same plant so consider harvesting when the seeds begin to fall to the ground. Songbirds and doves will also begin to eat grain when its is mature and can cause significant crop losses. There will always be a compromise between weather conditions degrading seed and the amount of mature hemp seeds. However, high quality hemp seed oil is better a late than early harvest.

To maximize yields, hemp is harvested at ~70-80% maturity. Immature seeds are smaller and green in color compared to mature grain. Although a portion of the crop will be immature, there is no difference in oil content at 50% versus 100% mature.

Hemp is generally harvested when green and at a higher moisture content (10-12%) than other grain crops. Because harvest occurs early when seed has a relatively high moisture content:

- It is critical to quickly dry the grain for safe storage conditions at 8-9% moisture content.
- Lignification of stems is low, reducing the likelihood and fiber tangles and wrapping in harvest equipment.

Grain is harvested with a combine which could be used to harvest other grain crops such as wheat. However, a wheat combine should be avoided if the hemp seed will be marketed as gluten free. Common practices in the industry include keeping the header high to minimize stem passage through the combine and using a cylinder speed between 450-600 rpm.

Hemp seeds from Cornell's field trials stored in a fabric bag. *Photo: Daniela Vergara, CCE*

Birds are a major pest of hemp grain crops. *Photo: Heather Grab, Cornell*

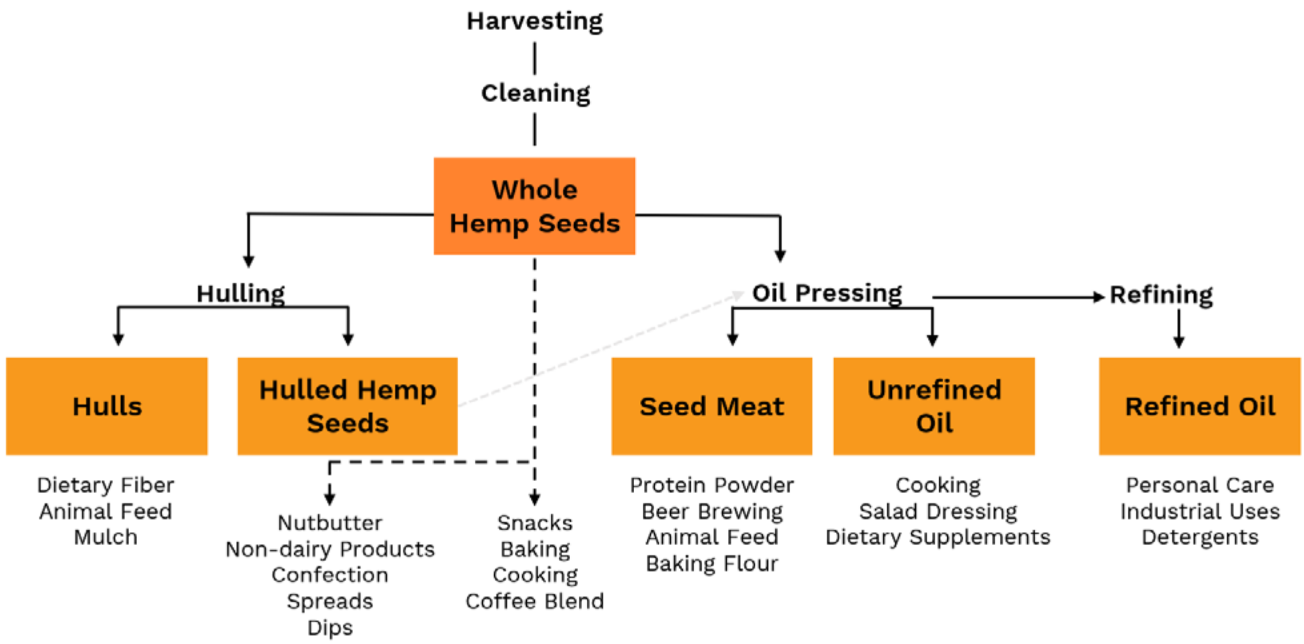
Harvest Reminders:

- Because hemp grain is generally marketed as a gluten free crop, it is critical to thoroughly clean harvest equipment when switching between wheat crops and hemp.
- Draper headers with conveyor systems are less prone to wrapping issues compared to auger style headers.
- Inconsistency in crop height might need varying header height or setting at a height leaving the lower grain heads and avoiding long sections of stem from the tallest heads that could present a wrapping hazard.
- To ensure an efficient separation of grain from chaff, handle with care:
    - Ground speed
    - Distance between the threshing drum and concave
    - Fan speeds
    - If augers are used to move grain, they should be used at a low speed to avoid damaging grain which could result in oxidation or microbial contamination.

- Rotating shafts should be covered to avoid hemp stems wrapping around them. Bearings should be cleaned immediately after harvest or they will be impossible to clean later. Any sign of smoke should trigger a halt to harvesting before fire starts.

Post-Harvest

After the harvest, the grain is quickly dried down and then cleaned before storing the grain in bins. If the grain is not immediately processed at a crushing plant or dehulling facility, then proper post harvest storage, under controlled environment with insect and rodent control, is essential. The oil in hempseed will go rancid over time, so refrigerated and dry storage is best.



Grain processing steps to generate final products. *Graphic: Heather Grab from Hemp Processing course (modified from Wrangham 2019)*

The seeds can be hulled to separate the hull (the outer shell of the seed) from the 'hearts'. Hemp hearts are edible and can be used in cereals or granola bars.

A shaker table separates seeds using mesh screens (left), a destoner for separating based on weight (center), and hulled hemp hearts (right). *Photos: Daniela Vergara, CCE*

Whole seeds can be cold pressed to produce oil and press cake. A screw press used for oil extraction from other seed crops, such as sunflower or canola, can also be used to process hemp seeds. Common practice is to have a seed moisture content of 5-7%, never below 4% or above 12%.

NOTE: Remember to lubricate all threads heavily on the grain press with food grade grease.

Screw press to process hemp seed oil at Cornell's AgriTech Food Science Pilot Processing Plant. *Photo: Daniela Vergara, CCE*

Recommended Press Parameters (provided by George Howick, Cornell AgriTech Food Science)

Press Parameters	Whole Hemp Seed (with shell)	Hemp Heart (without shell)
Gap (mm)	1.5	1
Nozzle #	11	7
Speed (rpm)	20-36*	11
Temperature of press head	105°C	105°C

* Start at 20 rpm for 5-10 minutes, then go up to 25 rpm, then up to 36 rpm—depending on performance and temperature. (Oil yield is higher when rpm is lower.)

The extracted oil can be used in personal hygiene products such as lip balms, body lotions, and hair products or it can be further refined to produce oil for salads (see process diagram on previous page). The press cake that is extruded after oil extraction is edible with high levels of amino acids.

Seed oil extracted using a screw press (left). After the oil is extracted from the hemp seeds, a press cake is extruded from the screw press (right). *Photos: Daniela Vergara, CCE*

Product Integrity and Contamination

Because there are currently few secondary market options for hemp grain crops, avoiding contamination and spoilage is a priority.

- Consider a drying facility with temperatures between 100-122°F (37-50°C).
- A high level of chaff or dockage remaining in the grain at storage can result in reduced storage times before spoilage as well as an increase in post-harvest storage pests.

As with fiber, hemp cultivation for grain is relatively novel. New information about the crop is still being developed.

General practices by the industry:

- Assure combines and other equipment is clean and free of weeds.
    - Establish cleaning procedures for all grain harvest equipment.
- Aspects that determine cleaning:
    - Harvest method
    - Required cleanliness
    - Seed characteristics
- Store the seeds properly to assure viability and to avoid vermin.
    - A dry, cool place is recommended.
    - Containers should be clean and should close properly.

Grading and Market Preparation

Due to the infancy of hemp as a grain crop, grading metrics are still being developed, however, there are important factors to consider:

- seed number
- seed weight
- seed size
- digestibility
- amino acid and oil content
- shell (hull) hardness
- maturation time

Current grain buyers include food product companies producing snack products, hemp milk, hemp butter, culinary oil, flour, or protein powder. These prospective purchasers may have specific requirements, and therefore it is recommended for grain hemp producers to establish relationships with their buyers and understand their needs. To avoid costs in transportation, it is recommended for growers and processors to be in close proximity to avoid long-distance transportation.

CANNABINOIDS

Cannabinoid Cultivation

variety selection, production calendars, plant propagation and cloning, controlled environment cultivation, harvest and processing

Variety Selection

Growers cultivating C. *sativa* for cannabinoids may plant from clones or seed. States may require approved varieties, so consider cannabinoid varieties carefully.

- New York State requires growers to submit their list of varieties and source.

Plant varieties should be chosen based on cannabinoid percentage potential (e.g., CBD, CBG, CBC).

Other requirements to keep in mind are:

- Photoperiod
  - The difference in the photoperiod requirement within varieties will dictate the amount of time the plant needs in the flowering stage to achieve peak maturity.
- Disease/pest resistance
- Floral structure
- Yield

Cornell's field trials for high-cannabidiol Cannabis varieties showed significant variation in cannabinoid content both within and among varieties. For example, CBD yield per plant varied and some varieties had high total CBD yields due to biomass while others had a high concentration of CBD but produced little biomass. Therefore, when choosing high-cannabinoid Cannabis varieties consider both cannabinoid production and yield.

Additionally, cannabinoids and terpenes ratios vary between and among varieties. Be sure that your variety choice is approved by your buyer for CBD or CBG content and terpene profile.

Preliminary results from a NYS field trial indicated that 24 of 32 varieties exceeded the legal limit of 0.3% THC at the time of harvest, so proper timing of regulatory testing prior to harvest is key. Make sure that your final harvest date THC content will be approved by your buyer. Additionally:

- CBD:THC ratios averaged 26:1 and do not vary much.
- The variety with the highest CBD and total cannabinoid content was 'FL 70'.
- Three varieties averaged over 1.5% total CBC.
  - The Cornell line GVA-H- 19-1067 had more than 3%.
- Some individuals from Cornell's variety GVA-H-19-1091 produced more than 1% of the varin cannabinoids (CBDV, THCV, and CBCV).

Cannabinoid Analysis of Biomass Samples, Preliminary Results from Cornell's 2020 Field Trials.

Cultivar/ID	Percent								CBD:THC
	THC	CBD	CBC	CBG	THCV	CBDV	CBL	Cannabinoids	
GVA-H-19-1064-003	0.26	8.41	1.38	0.20	0.00	0.02	0.00	11.67	32.23
GVA-H-19-1066-001	0.40	11.97	2.36	0.22	0.00	0.03	0.01	16.98	29.70
GVA-H-19-1067-001	0.34	11.31	3.19	0.24	0.00	0.03	0.00	17.13	32.85
GVA-H-19-1068-003	0.17	5.07	0.56	0.17	0.00	0.02	0.03	6.83	30.59
GVA-H-19-1077-008	0.36	10.49	0.46	0.47	0.00	0.03	0.01	13.42	28.92
GVA-H-19-1091	0.24	4.10	0.21	0.15	0.08	0.36	0.04	5.88	24.19
GVA-H-19-1191	0.17	4.29	0.20	0.22	0.00	0.06	0.04	5.66	25.69
GVA-H-20-1030	0.27	8.18	0.93	0.32	0.00	0.09	0.03	11.14	30.79
BaOx	0.37	10.52	0.76	0.39	0.00	0.09	0.00	13.78	28.69
Carolina Dream	0.28	7.30	0.56	0.20	0.01	0.23	0.04	9.69	25.68
CJ 2	0.41	11.19	0.47	0.52	0.00	0.04	0.07	14.41	27.28
CSG Berry Blossom	0.33	9.31	0.52	0.39	0.00	0.02	0.00	12.01	28.46
CW EM-18	0.39	10.43	0.98	0.35	0.01	0.21	0.03	14.06	27.01
CW EM-28	0.36	9.03	0.38	0.28	0.00	0.03	0.06	11.49	25.04
CW EM-31	0.49	12.65	0.62	0.33	0.00	0.05	0.07	16.10	26.04
CW EM-73	0.46	11.97	0.64	0.30	0.00	0.05	0.05	15.28	25.91
Early Pearly	0.24	6.65	0.41	0.15	0.00	0.18	0.00	8.67	27.15
FL 49	0.37	10.81	0.56	0.28	0.00	0.02	0.01	13.64	28.93
FL 58	0.36	10.95	0.59	0.32	0.00	0.03	0.02	13.89	30.10
FL 70	0.50	14.31	0.74	0.47	0.00	0.07	0.03	18.26	28.83
Hybrid #5	0.40	11.32	0.57	0.28	0.00	0.05	0.02	14.31	28.61
Hybrid #9	0.33	9.50	1.55	0.21	0.00	0.02	0.01	13.12	29.15
Lindorea	0.34	9.79	0.58	0.26	0.00	0.14	0.00	12.61	28.91
NS52	0.45	11.27	0.63	0.42	0.00	0.03	0.03	14.51	25.48
Rogue	0.37	9.81	0.68	0.41	0.01	0.10	0.01	12.92	26.24
SB 1	0.40	10.25	0.49	0.32	0.00	0.04	0.06	13.12	25.48
SR-1	0.44	10.52	0.50	0.30	0.00	0.03	0.05	13.44	23.85
Sweetened	0.25	7.29	0.80	0.27	0.00	0.06	0.06	9.90	29.12
The Grand	0.34	9.36	0.58	0.25	0.00	0.02	0.00	11.95	27.83
TJs CBD	0.37	9.27	0.49	0.25	0.00	0.08	0.03	11.92	25.09
Umpqua	0.54	14.01	0.59	0.40	0.00	0.04	0.06	17.71	26.10
Z 25	0.52	13.78	0.63	0.31	0.00	0.03	0.05	17.35	26.63
Mean	**0.36**	**9.90**	**0.77**	**0.30**	**0.00**	**0.07**	**0.03**	**12.97**	**27.71**

Production of High-Cannabinoid Cannabis Transplants

The production of a transplant typically takes 20-30 days depending on the desired end size of the transplant. Plants need to be transplanted near the 21-day timeframe because the likelihood for root bound plants increases significantly beyond that point.

Starting Plants from Seed

Soilless media, often in 72- or 96-cell trays, are used to start seeds. Once liners get rootbound in a tray, the plants do not recover and the root system becomes susceptible to mid-season disease or drought stress. It can be beneficial to use ridged deep trays to avoid root bound seedlings. Through this methodology, the seedling can grow for several weeks until transplanted into larger pots or directly into the ground. A transplanter can be used to plant into the ground.

Cloning

Cloning is a process where vegetative cuttings are taken off a 'mother' or stock plant. This method produces genetically identical plants. Mother plants should be kept in vegetative stage and not allowed to flower. This method is costly, so it is mostly used for high-cannabinoid Cannabis plants (flower production).

Rooting can be distinguished between rooting success and root quality. Rooting success refers to the presence/absence of adventitious roots, while root quality refers not only to root formation, but also considers their amount and length. Good root quality helps plants to establish quickly, grow healthier and faster.

Rooting success is dependent on:

- Cultivar/variety
- Hormone treatment
- Humidity
- Light
- Root zone temperature

Factors that can influence rooting success and quality:

- Number of leaves left on the cutting and the position of the cutting on the mother plant
- Wounding the base of the cuttings can decrease the number of days until stem cuttings produce roots, however it does not increase rooting success.

Making cuttings (top) and using rooting hormones (bottom) for *C. sativa*. *Photos: Daniela Vergara, CCE*

Cloning recommendations:

- Clean all areas with a bleach solution before cloning.
- Choose a tip of the plant that has at least 3 nodes above the cut.
- Use a sharp razor blade or sheers to make a single fine cut to avoid tissue damage.
  - The cut can be made 1 inch (2.5 cm) below a node.
- Make sure to sterilize the blade to avoid disease transmission between plants.
- Consider removing large leaves so that the plant uses energy in rooting, not in photosynthesis.
  - Having more leaves implies having more area to lose water.
  - Fewer leaves allows for airflow through the tray.
- When producing hemp transplants, moisture management is critical to avoid mold contamination.
- Apply rooting hormone on the end of the cutting to improve rooting success
  - If you are growing in a certified organic system, check with your certifier about which synthetic hormones are exempt for use as some are not approved for organic production.
- Place the cuttings firmly into rooting cubes/substrate so that the cut end is fully implanted in the cube.
  - There are many substrate options available on the market such as Rockwool, Oasis, and peat/perlite-based rooting cubes.
- When temperatures are lower than optimal, using a heating pad under the propagation domes can improve rooting success.

Current evidence does not support the use of these practices to enhance rooting success:

- Leaf tip cutting
- Stem wounding

Representative cutting bearing four fully expanded leaves, three leaves were removed but no leaf tips. *Photo: Lucía Vignale*

After cuttings are produced, they should be placed in a high humidity environment such as an Ebb and Flow Table which allows plant trays to saturate and then drain. Alternatively, watering can be performed overhead to control irrigation and ensure trays do not remain saturated. Cloning domes are also very effective and popular; however, they may be more prone to mold. Although new cuttings need the warm and humid environment until roots are established, mold also thrives under these conditions.

Recommendations to avoid mold:

- Proper ventilation
- Avoid water to dwell directly on plants

Choosing a tray with an open bottom that allows roots to air prune is critical to prevent root girdling. Once roots begin to spiral, it is very difficult for the plant to overcome this issue.

New clones placed on rockwool (left), a water-system method (right). *Photos: Daniela Vergara, CCE*

Cuttings propagated in three different substrates: rockwool, peat/perlite-based, and oasis. *Photo: Heather Grab, Cornell*

The production of a transplant typically takes 20-30 days, depending on the size of the plant suited best for different styles of transplanters. Plants need to be transplanted near the 21-day timeframe, because the likelihood for root bound plants increases significantly beyond that point.

Increased air movement in the facility will help to prevent disease and to strengthen the main stem of a transplant. The use of oscillating fans increases airflow and strengthens seedlings via mechanical stimulation of young shoots.

May or June should provide ideal conditions for propagating plants in terms of optimal day-length and temperature, although shade cloths and supplemental lighting could be required.

Grow dome with cuttings and open ventilation (left and center). *Photos: Lucía Vignale;* Set of grow domes (right). *Photo: Heather Grab, Cornell*

Overall considerations/recommendations:

There is no universal method that assures a 100% rooting success ("one size fits all" method) and ease of rooting can be variety specific. Therefore, it may be helpful to try different combinations of the recommended methods/treatments (e.g. substrates, hormone treatments, humidity, light intensity) when starting a new operation or growing a new variety. Also, some common practices, such as leaf tip cutting, may be detrimental to the plant and decrease rooting success.

High-Cannabinoid Cannabis Cultivated Outdoors

Plasticulture

Plasticulture employs a layer of plastic mulch over the plant bed to control weed pressure within the row, as well as drip irrigation for efficient and directed water and fertilizer application.

Land Preparation

Bed Size: Once the field is tilled, growers using the plasticulture method will need to determine bed size, the type of plastic to be used, and then prepare the soil. Bedding machines are available to bed, lay plastic and drip tape all at once in both single and multi-row configurations.

The typical bed dimensions for C. *sativa* plastic beds range from 20 inches (51 cm) wide x 6 inches (16 cm) tall up to 30 inches (76 cm) wide x 8 inches (21 cm) tall. Single-row bedders can be used to space beds as far apart as desired.

Row Spacing: Typically, C. *sativa*, on plastic systems, is grown on 4-8 feet (1.2-2.5 m) center row spacing. Skipping rows is typical of plasticulture operations—providing growers with a way to enter the fields with spray equipment later in the season, as well as easy access for harvesting. Many growers will lay fields out with 4-to-6 plastic rows between skip rows and spray each side of a skip row with a pull-type boom sprayer.

Plastic Options: When selecting a plastic type, it is common for growers to use black thick plastic (48-60 inches wide (122-153 cm) by 4,000 feet (122 m) by 1.25 mm).

Soil: Soil moisture is very important when laying plastic and is critical for forming a smooth tight bed free of clods. If the soil is too dry when laying plastic, it will be challenging to completely moisten the beds throughout the growing season with only drip tape irrigation.

Irrigation in a Plasticulture System

To irrigate plastic C. *sativa* beds, water should be applied by drip tape under the plastic mulch film. Drip tape sizing is usually 5/8 inches or 7/8 inches (15-22 mm) 8-10 mm thickness with emitter spacing of 12 inches or 18 inches (30-46 cm). Typically, C. *sativa* will need 1-2 inches (2.5-5 cm) of water per week. The type of plant and amount of rain determine how often and for how long the irrigation is turned on. Flow rates on 5 or 6 ft (1.5-1.8 m) row spacing average 19-to-33 gallons per minute per acre, depending on emitter spacing and size.

Transplanting

One day prior to transplanting, the producer should irrigate to ensure that soil moisture is sufficient to facilitate planting. Producers may opt to plant either by hand or water wheel transplanter depending on acreage. It is recommended to irrigate 0.5 inch (1.27 cm) per week for two weeks following transplanting, increasing to 1-2 inches (2.5-5 cm) per week for the remainder of the growing season if there is no local rainfall to meet the crop need. Soil type and weather conditions can alter this recommendation.

Direct Seeded High-Cannabinoid Cannabis

Seeding using a manual seeder for high-cannabinoid Cannabis. *Photo: Savanna Shelnutt, Cornell*

Cannabis sativa plants emerging from the soil. *Photo: Savanna Shelnutt, Cornell*

Direct seeding high-cannabinoid Cannabis in high density is a novel production system in much of the United States. Some producers in Western states have implemented this system successfully on large acreage for cannabinoid extraction. Direct seeding is advantageous as it enables mechanized planting, maintenance, and harvest of large acreage, reducing dependence on manual labor. Autoflower cultivars are particularly well suited to this system as direct seeding avoids transplant shock that often stunts these cultivars. Producers looking to reduce their plastic waste may also be interested in this system as no horticultural plastic or drip tape is generally used.

Traditional Horticultural Style (Plasticulture)
4 ft x 6 ft spacing = 2,178 plants per acre

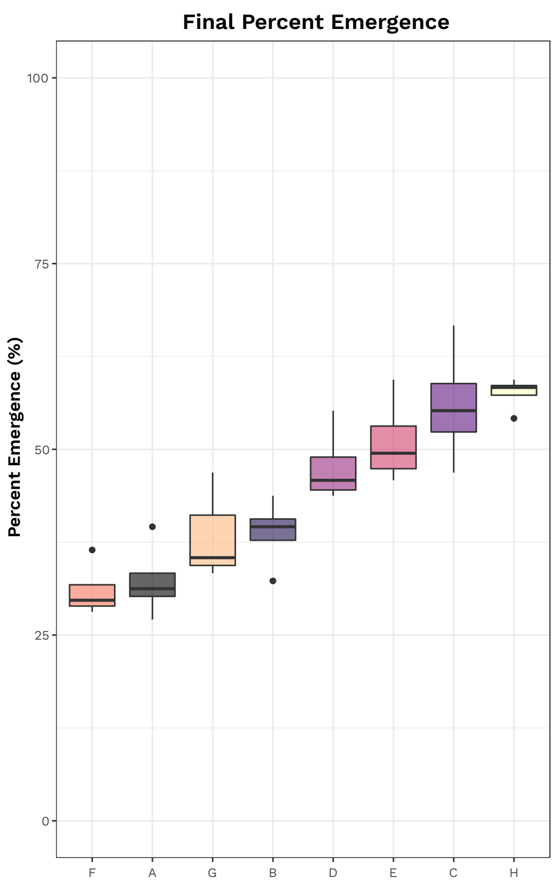
High Density Direct Seeded
1.5 ft x 2.5 ft spacing = 11,616 plants per acre

Different methods of planting high-cannabinoid Cannabis: traditional horticultural style (left) or a high density direct seeded (right). *Photos: Savanna Shelnutt, Cornell*

Plantings can be established by hand with a push-behind seeder or by a tractor with a cone seeder or vacuum seeder, such as a Monasem. Bed preparation is similar to that for grain or fiber planting, involving several rounds of tillage followed by grooming with a cultipacker.

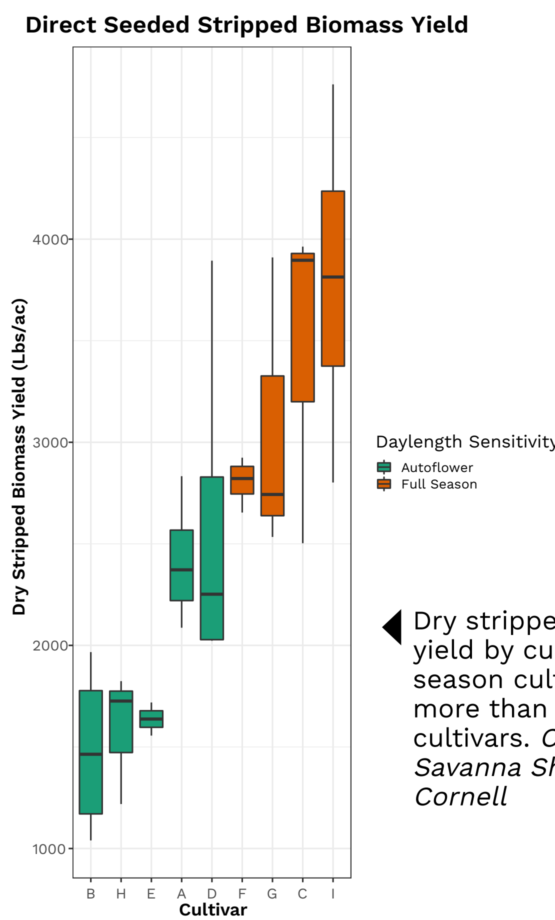
At present, stand establishment is generally poor due to a lack of fungicidal seed coatings, herbivory by insects and animals, and destruction of seed by birds shortly after planting (see Final Percent Emergence chart). To ensure a healthy stand, it is necessary to seed at approximately three times the desired planting density and then thin to requisite spacing. Final plant spacing should be 1 foot (~30 cm) between plants for daylength insensitive cultivars and 1.5 feet (~46 cm) between plants for daylength sensitive cultivars on 30-inch (~76 cm) rows. Irrigating shortly after planting will optimize seed germination.

Weed management by hand hoeing or tractor-pulled cultivator should be intensive until canopy closure to mitigate yield loss. Regular scouting should occur throughout the season so that any disease or insect pests may be dealt with in a timely manner. Sprinkler irrigation after canopy development is not recommended as it increases leaf wetness and increases the incidence of disease.



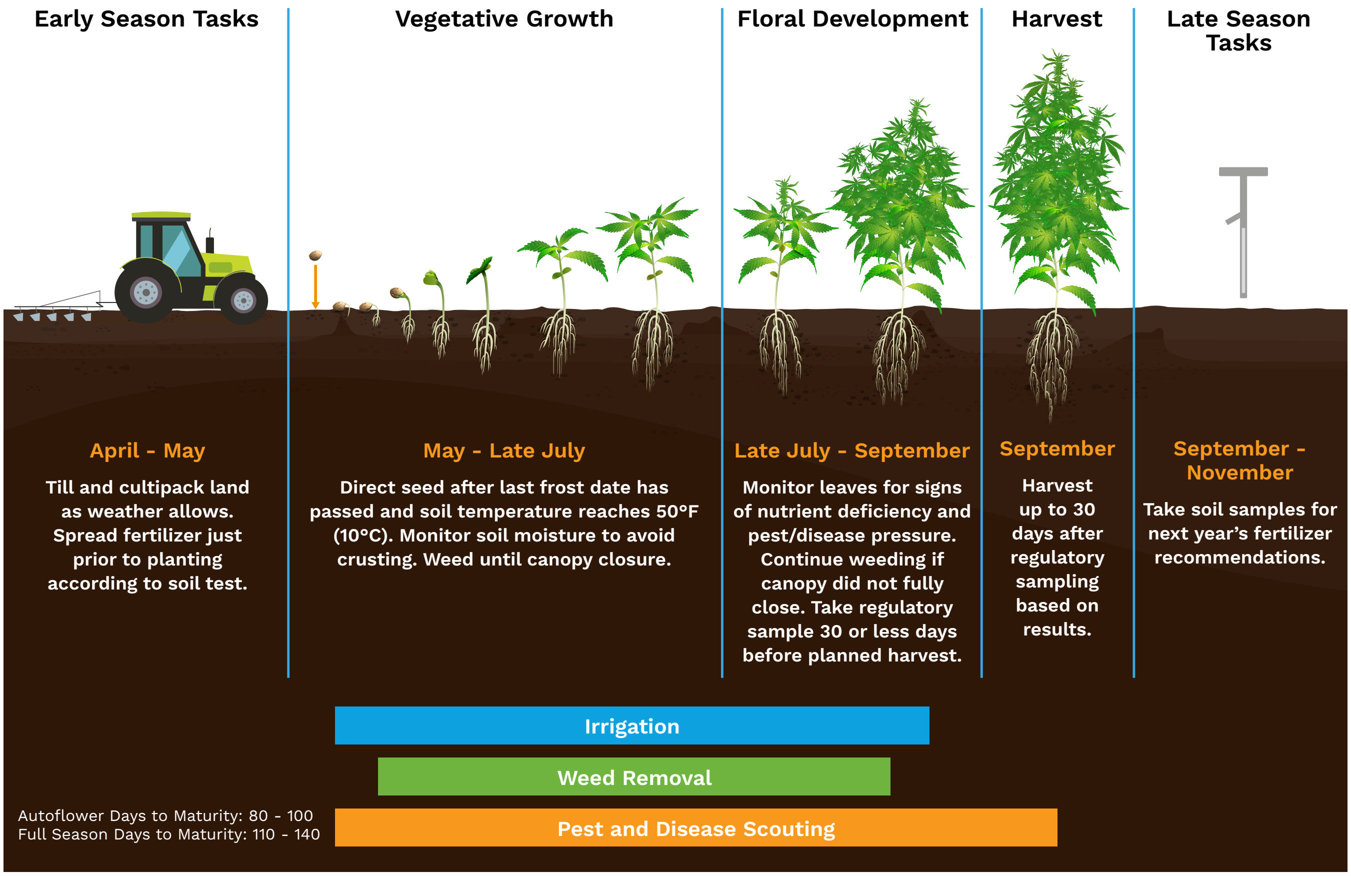
Percent emergence in high density direct seeded plantings by cultivar. Emergence is measured by counting the number of plants established within a given length of row two weeks after planting and comparing that number to the expected number of plants. Emergence is generally low, ranging from about 30%-55%. *Chart: Savanna Shelnutt, Cornell*

Harvest should occur approximately five weeks after flowering or 30 days or less after regulatory sampling. Harvest can be completed by hand, but this system is optimized for mechanical harvest with a stripper header. Material may be dried for later extraction or extracted wet immediately after.



Dry stripped biomass yield by cultivar. Full season cultivars yielded more than "autoflower" cultivars. *Chart: Savanna Shelnutt, Cornell*

Direct Seeded High-Cannabinoid Cannabis Production Tasks by Month



January-March

Equipment and Facilities

- Repair and perform maintenance on planters, sprayers, and fertilizer application equipment.
- Clean harvesters and harvest paraphernalia.
- Sharpen pruners and loppers.
- Clean and organize drying facilities.

Crop Management

- Research varieties and make relationships with seed providers.
- Secure seed.
- Make list of necessary equipment/materials for upcoming year and begin placing orders.
- Attend grower meeting(s).

Nutrient and Soil Management

- Make sure that soil has been tested.
- Order fertilizer for upcoming season.

Pest and Disease Management

- Inventory chemicals to determine needs for upcoming season.

April

Equipment and Facilities

- Calibrate planter and sprayers.

Crop Management

- Ensure that all seed has been received.
- Create planting plan and field maps.
- Begin field cultivation for weed suppression and bed preparation after terminating cover crop.
- Make a plan for crop irrigation.

Nutrient and Soil Management

- Apply phosphorus and potassium based on soil test.

Pest, Disease, and Weed Management

- Terminate cover crop.
- Burn down weeds persisting after cultivation.

May

Equipment and Facilities

- Final check to ensure that all equipment has been fully serviced and is ready for the season.
- Perform maintenance on weather station and soil moisture sensors and place weather station in field.

Crop Management

- Continue field cultivation for weed suppression and bed preparation, as weather allows.

Nutrient and Soil Management

- Apply phosphorus and potassium based on soil test, if not done previously.

Pest, Disease, and Weed Management

- Burn down weeds persisting after cultivation.

June

Equipment and Facilities

- Perform maintenance, as needed.
- Place soil moisture meters in field 10 cm deep after planting.

Crop Management

- Plant after soil temperature is maintained above 50°F.
- Install irrigation and ensure that soil moisture is sufficient to support plants prior to planting.
- Monitor soil moisture levels and irrigate, as needed, to avoid soil crusting during seedling establishment.
- Take stand counts two weeks after planting and reseed, as needed.

Nutrient and Soil Management

- Apply granular or liquid nitrogen at planting.

Pest, Disease, and Weed Management

- Apply pre-emergent and post-emergent herbicides, as regulations allow.
- If applying pre-emergent herbicides, irrigate to activate if no rain is forecasted.
- Cultivate and hand weed, as needed.
- Continuously monitor young plants for pests and diseases or signs of abiotic stress.

July

Equipment and Facilities

- Perform maintenance, as needed.

Crop Management

- Monitor soil moisture levels and irrigate, as needed.
- Check early and autoflower cultivars for signs of flowering at very end of month and record flowering date.

Nutrient and Soil Management

- Monitor leaves for signs of nutrient deficiency and supply supplemental fertilizer, as needed.

Pest, Disease, and Weed Management

- Cultivate and hand weed, as needed or until canopy closure.
- Continuously monitor plants for pests and diseases or signs of abiotic stress.
- Treat issues as they arise by spraying pesticides or releasing beneficial insects.

August

Equipment and Facilities

- Perform maintenance, as needed.
- Ensure that harvest equipment is in working order.
- Ensure that drying facilities are secured and in working order.

Crop Management

- Monitor soil moisture levels and irrigate, as needed.
- Monitor plants for signs of flowering weekly and record flowering date.
- Schedule regulatory tests for 30 days prior to planned harvest date.
- Attend Cornell Hemp Field Day.

Nutrient and Soil Management

- Monitor leaves for signs of nutrient deficiency and supply supplemental fertilizer, as needed.

Pest, Disease, and Weed Management

- Hand weed, as needed.
- Continuously monitor plants for pests and diseases or signs of abiotic stress.
- Treat issues as they arise by spraying pesticides or releasing beneficial insects.

September

Equipment and Facilities

- Perform maintenance, as needed.

Crop Management
- Monitor soil moisture levels and irrigate, as needed.
- Monitor late flowering plants for signs of flowering weekly and record flowering date.
- Schedule regulatory tests for 30 days prior to planned harvest date.
- Harvest early and mid-flowering cultivars.

Nutrient and Soil Management
- Monitor leaves for signs of nutrient deficiency and supply supplemental fertilizer, as needed.

Pest, Disease, and Weed Management
- If planting into bare soil, cultivate and hand weed, as needed.
- Continuously monitor plants for pests and diseases or signs of abiotic stress.
- Treat issues as they arise by spraying pesticides or releasing beneficial insects.

October

Equipment and Facilities
- Perform maintenance, as needed.

Crop Management
- Harvest mid- and late-flowering varieties.

Nutrient and Soil Management
- Consider cover crop options, crop rotation, and site selection for the next growing season.
- Take soil samples for next year.
- Apply lime required for the next year with cultivation.
- Plant cover crop.

Pest, Disease, and Weed Management
- Remove and burn residual crop material if diseases that overwinter on residual appeared in your planting this year (i.e., Downy Mildew).

November-December

Equipment and Facilities
- Repair and clean harvest equipment.
- Winterize equipment, as needed.

Crop Management
- Review the season to evaluate what went well and what needs adjusting for next year.
- Ensure that cover crop is well established.
- Begin researching varieties and making relationships with plant and/or seed providers.

Nutrient and Soil Management
- Apply lime required for the next year with cultivation.
- Evaluate which products are needed for next year and place orders.

Pest, Disease, and Weed Management:
- Determine which management practices worked well this year and decide which should be reevaluated.
- Inventory chemicals.

Transplanting High-Cannabinoid Cannabis

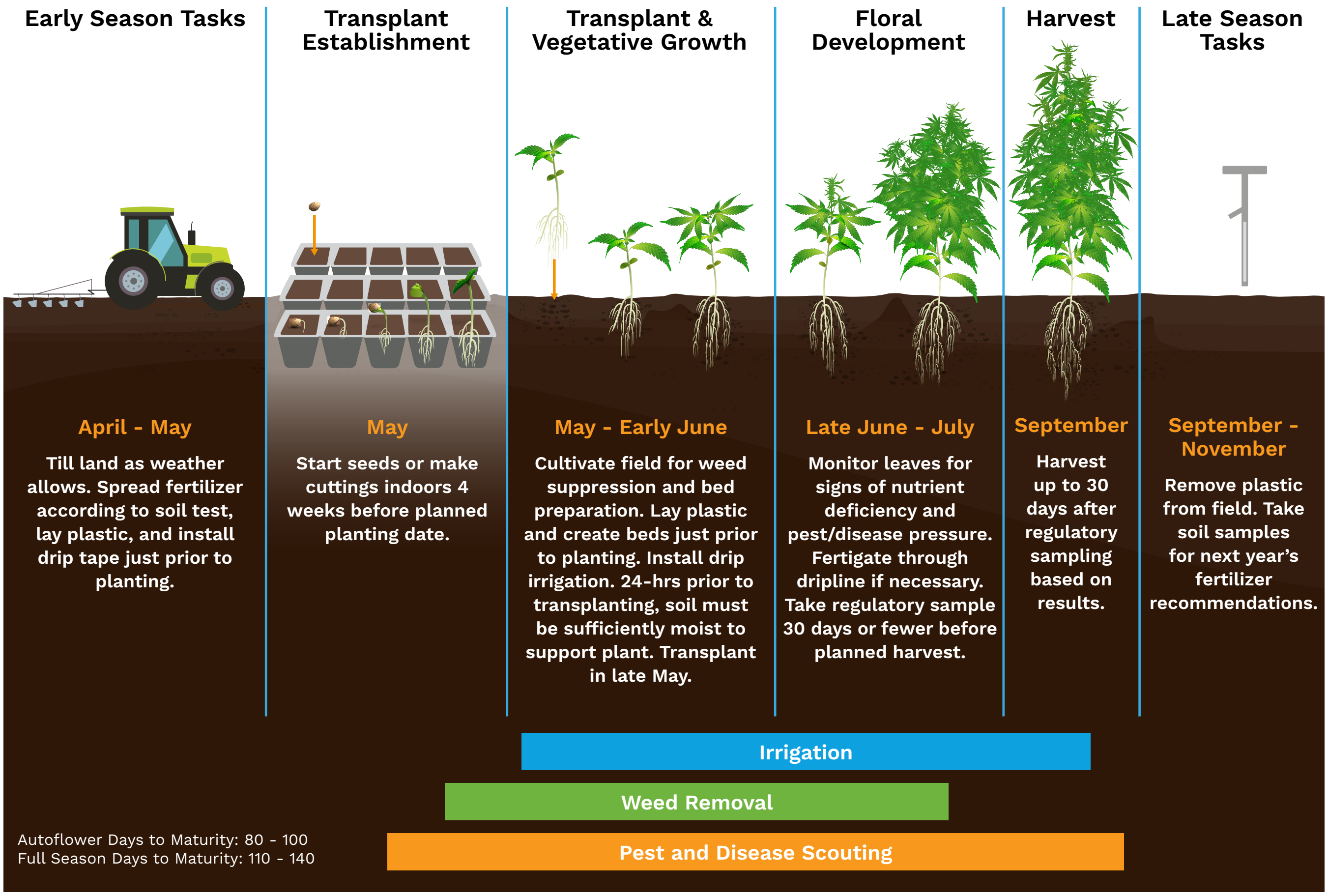
After transplant beds are established, growers should begin to transplant into the field. Timing is dependent upon the weather, soil conditions and acreage. Transplants should have well-established roots (which occurs after approximately 3-5 weeks). One day prior to transplanting, the producer should run irrigation to ensure that soil moisture is sufficient to facilitate planting. (See Irrigation section.) Producers may opt to plant into bare soil by hand or water wheel transplanter depending on acreage.

Plants should be set 2-3 inches (5-8 cm) deep for optimum growth and performance. It is important to monitor soil moisture closely in the weeks after planting to ensure that plants are not droughted or flooded as they establish themselves in the field. The row spacing for high-cannabinoid Cannabis production ranges from 36-48 inches (91-122 cm).

Transplanter machine allowing consistent space between plants and a better packing. *Photo: Larry Smart, Cornell*

Manual transplanting of hemp plants into the field. *Photo: Cornell Hemp team*

Transplanted High-Cannabinoid Cannabis Production Tasks by Month



January-March

Equipment and Facilities

- Repair and perform maintenance on planters, sprayers, and fertilizer application equipment.
- Clean harvesters and harvest paraphernalia.
- Sharpen pruners and loppers.
- Clean and organize drying facilities.

Crop Management

- Research varieties and make relationships with seed providers.
- Secure seed and/or plans for rooted cuttings.
- Make list of necessary equipment/materials for upcoming year and begin placing orders.
- Attend grower meeting(s).

Nutrient and Soil Management

- Make sure that soil has been tested.
- Order fertilizer for upcoming season.

Pest and Disease Management

- Inventory chemicals to determine needs for upcoming season.

April

Equipment and Facilities

- Calibrate planter and sprayers.

Crop Management

- Ensure that all seed has been received.
- Create planting plan and field maps.
- Begin field cultivation for weed suppression and bed preparation after terminating cover crop.

Nutrient and Soil Management

- Apply phosphorus and potassium based on soil test.

Pest, Disease, and Weed Management

- Terminate cover crop.
- Burn down weeds persisting after cultivation.

May

Equipment and Facilities

- Final check to ensure that all equipment has been fully serviced and is ready for the season.
- Perform maintenance on weather station and soil moisture sensors and place weather station in field.

Crop Management

- Start seeds and take cuttings approximately four weeks prior to planned planting date.
- Continue field cultivation for weed suppression and bed preparation, as weather allows.
- Lay plastic and create beds just prior to planting.
- Install drip irrigation and ensure that soil moisture is sufficient to support plants prior to transplant (at minimum 24 hours before).
- Transplant, as weather allows, in late May.

Nutrient and Soil Management

- Apply granular or liquid nitrogen just prior to or at planting. (If using plastic, apply when building beds)

Pest, Disease, and Weed Management

- Burn down weeds persisting after cultivation.
- Continuously monitor young plants for pests and diseases or signs of abiotic stress.

June

Equipment and Facilities

- Perform maintenance, as needed.
- Place soil moisture meters in field 10 cm deep after planting.

Crop Management

- Monitor soil moisture levels and irrigate, as needed.
- Evaluate success of transplant establishment two weeks after planting and replace plants, as needed.

New York grown CBD transplants ready to go. *Photo: J. Reid, CCE*

Nutrient and Soil Management

- Monitor leaves for signs of nutrient deficiency and supply supplemental fertilizer, as needed.

Pest, Disease, and Weed Management

- If planting into bare soil, cultivate and hand weed, as needed.
- Continuously monitor young plants for pests and diseases or signs of abiotic stress.

July

Equipment and Facilities

- Perform maintenance, as needed.

Crop Management

- Monitor soil moisture levels and irrigate, as needed.
- Check early cultivars for signs of flowering at very end of month.

Nutrient and Soil Management

- Monitor leaves for signs of nutrient deficiency and supply supplemental fertilizer, as needed.

Pest, Disease, and Weed Management

- If planting into bare soil, cultivate and hand weed, as needed.
- Continuously monitor plants for pests and diseases or signs of abiotic stress.
- Treat issues as they arise by spraying pesticides or releasing beneficial insects.

August

Equipment and Facilities

- Perform maintenance, as needed.
- Ensure that harvest equipment is in working order.
- Ensure that drying facilities are secured and in working order.

Crop Management

- Monitor soil moisture levels and irrigate, as needed.
- Monitor plants for signs of flowering weekly and record flowering date.
- Schedule regulatory tests for 30 days prior to planned harvest date.
- Attend Cornell Hemp Field Day.

Nutrient and Soil Management

- Monitor leaves for signs of nutrient deficiency and supply supplemental fertilizer, as needed.

Pest, Disease, and Weed Management

- If planted into bare soil, cultivate and hand weed, as needed.
- Continuously monitor plants for pests and diseases or signs of abiotic stress.
- Treat issues as they arise by spraying pesticides or releasing beneficial insects.

September

Equipment and Facilities

- Perform maintenance, as needed.

Crop Management

- Monitor soil moisture levels and irrigate, as needed.
- Monitor late flowering plants for signs of flowering weekly and record flowering date.
- Schedule regulatory tests for 30 days prior to planned harvest date.
- Harvest early and mid-flowering cultivars.

Nutrient and Soil Management

- Monitor leaves for signs of nutrient deficiency and supply supplemental fertilizer, as needed.

Pest, Disease, and Weed Management

- If planting into bare soil, cultivate and hand weed, as needed.
- Continuously monitor plants for pests and diseases or signs of abiotic stress.
- Treat issues as they arise by spraying pesticides or releasing beneficial insects.

October

Equipment and Facilities

- Perform maintenance, as needed.

Crop Management

- Harvest mid and late flowering cultivars.

Nutrient and Soil Management

- Consider cover crop options, crop rotation, and site selection for the next growing season.
- Take soil samples for next year.
- Apply lime required for the next year with cultivation.
- Plant cover crop.

Pest, Disease, and Weed Management

- Remove and burn residual crop material if diseases that overwinter on residual appeared in your planting this year (i.e., downy mildew).

November-December

Equipment and Facilities

- Repair and clean harvest equipment.
- Winterize equipment, as needed.

Crop Management

- Review the season to evaluate what went well and what needs adjusting for next year.
- Ensure that cover crop is well established.
- Begin researching varieties and making relationships with plant and/or seed providers.

Nutrient and Soil Management

- Apply lime required for the next year with cultivation.
- Evaluate which products are needed for next year and place orders.

Pest, Disease, and Weed Management:

- Determine which management practices worked well this year and decide which should be reevaluated.
- Inventory chemicals.

Managing Nutrients for High-Cannabinoid Cannabis Cultivated Outdoors

NOTE: The following recommendations are taken from the *Cornell Integrated Crop and Pest Management Guidelines for Commercial Vegetable Production* due to a lack of conclusive studies on high-cannabinoid Cannabis.

Consider the following recommendations if growing high-cannabinoid Cannabis in soil in pots or bags:

> In general, for vegetable crops, most of the recommendations are established on the plant needs based on synthetic fertilizers. These recommendations can change based on the growing condition. For example:
>
> - Nitrogen (N) levels change due to soil temperature and moisture content
>   - Reduce the N levels if growing with plastic mulch. Warmer temperatures and uniform conditions under the mulch allow for higher decomposition rates of organic matter increasing the N levels.
> - Many of the nutrients should come from cover crops (if used), and compost.

Nutrient source is dependent on the soil type and previous soil management. For example, some soils naturally have high potassium (K) and sodium (Na) which may happen if these have had previous manure application.

If your farm and grow are managed organically, many plant nutrients can be supplied by decomposed organic matter or through nutrient amendments which could be used during the growing season.

In the long term, N mineralization rate increases and therefore more N will be available due to increased soil microbial activity. These soil microorganisms need different types of organic matter that will assure diversity and long-lasting organic soil which will increase crop productivity.

It is recommended to get your soil tested at Cornell Soil Health Testing Lab (http://soilhealth.cals.cornell. edu). Base the amount of phosphorus (P) and potassium (K) on the table below (Table 11.7.3 for Cucurbits in the *Commercial Vegetable Production* guideline).

Recommended Amounts of Phosphorus (P) and Potassium (K) Based on Soil Tests

Level in Soil Test	Soil Phosphorus Level (P_2O_5 lbs/A)			Soil Potassium Level (K_2O lbs/A)		
	low	medium	high	low	medium	high
Nutrient recommendation	120	80	40	120	80	40

Below is an example to calculate nutrient credits and needs based on soil sample recommendation for vegetables (modified from Table 11.7.8 in the *Commercial Vegetable Production* guideline). However, consider that most high-cannabinoid Cannabis will likely not use manure for nutrients.

Example: Calculating Nutrient Credits and Needs Based on Soil Sample Recommendations

Conditions	Nitrogen (N) (lbs/acre)	Phosphate (P_2O_5) (lbs/acre)	Potash (K_2O) (lbs/acre)
A. Total crop nutrient needs			
B. Recommendations based on soil test			
C. Credits			
Soil organic matter – 2%			
Manure – 1000 gal hog			
Compost – none			
Cover crop – red clover			
D. Total credits			
Additional nutrients needed (B minus D)			

Other nutrients to consider for high-cannabinoid Cannabis production are:

- Sulfur (S)
  - found in low levels typically in sandy soils
  - highly leachable and important for N uptake
- Boron (B)
  - consider applying 1 pound in dry fertilizer (0.3-to-0.5% in blend)
  - 2-to-3 applications recommended at ¼ pound each when plants start flowering

Commonly in the industry, compost has been used as a fertilizer source by some producers in NYS, which usually has high nitrogen levels. However, some of them have also used tomato fertilizer, horse manure, biochar, chicken poop, and organic fish emulsion.

Plant Tissue Analysis

Plant tissue analysis is necessary to understand the compounds present in plant tissues to understand plant health, whether the plant is capturing the necessary nutrients from the soil, and nutrient deficiency. This may give an idea of possible fertilization regimes. Foliar nutrient sampling can be considered maintenance of the crop to prevent yield loss before deficiency symptoms become visible.

Example of tissue collection. *Photo: Daniela Vergara, CCE*

Since plant nutrient levels can differ based on the location, it is important to sample the correct tissues. For example, old leaves at the bottom of the plant may not provide as good a sample as the plant may have scavenged nutrients from these tissues. On the other hand, very new shoots may also provide biased information.

Recommendations (guidance based on tissue collected in tomatoes):

- Find a testing lab that is reliable and has a fast turnaround.
- Proper tissue collection is crucial.
  - Collect a young, fully mature leaf (which is generally found 6 leaves down from the growing point). This should <u>not</u> be an inflorescence leaf but a young, fully mature fan leaf.
  - Collect sample from multiple plants.

Location in the plant for tissue collected for nutrient analysis.

Below the range of nutrient sufficiency in foliar tissue for *C. sativa* taken from North Carolina State Extension, and for tomatoes which can be extrapolated for high-cannabinoid Cannabis.

Foliar Tissue Nutrient Sufficiency Range

Element	Range	
	C. sativa	Tomatoes
Nitrogen (N) (%)	3.3 to 5.0	3.5 to 5.0
Phosphorus (P) (%)	0.27 to 0.48	0.3 to 0.65
Potassium (K) (%)	1.8 to 2.7	2.5 to 4.0
Calcium (Ca) (%)	1.5 to 2.9	1.0 to 3.0
Magnesium (Mg) (%)	0.30 to 0.65	0.35 to 1.0
Sulfur (S) (%)	0.25 to 0.36	0.2 to 1.0
Iron (Fe) (ppm)	70 to 150	50 to 300
Manganese (Mn) (ppm)	40 to 158	25 to 200
Zinc (Zn) (ppm)	33 to 60	18 to 80
Copper (Cu) (ppm)	5 to 11	5 to 35
Boron (B) (ppm)	30 to 90	30 to 75

Example tissue analysis (courtesy of Tap Root Fields).

Element	DM Basis	Satisfactory Range	Deficient	Low	In Range	High	Excessive
Nitrogen	4.83 %						
Potassium	2.35 %						
Phosphorus	.638 %						
Calcium	2.14 %						
Magnesium	.367 %						
Manganese	19 ppm						
Iron	85.2 ppm						
Copper	6.35 ppm						
Boron	44 ppm						
Zinc	34.3 ppm						

Additional Elements	As Sampled Basis	Dry Matter Basis
% Sulfur	.11	.39

For assistance interpreting your report, contact your local Cooperative Extension office.

Cornell Cooperative Extension

Recommendation:

Despite high Potassium levels, the grower should plant as normal and later send a leaf for tissue analysis to see how the plants was absorbing nutrients.

Controlled Environment Cultivation of High-Cannabinoid *Cannabis sativa*

Controlled Environment Agriculture (CEA) is an advanced form of agriculture in which a broad range of parameters can be manipulated for growth optimization such as, sanitation, lighting, CO_2 supplementation, temperature, among many others (https://cea.cals.cornell.edu/). Physical and technological barriers reduce rates of contamination from a diversity of sources and pest species. CEA growing structures include greenhouses and warehouse farms. High tunnel production provides some protection and can be thought of as Modified Environment Agriculture.

Why are indoor cultivation sites often referred to as "warehouses"?

During prohibition, *C. sativa* growers used fully controlled environments in the form of tents, warehouses, basements, closets, and bathrooms, spawning the generic term "warehouses" to refer to these growing locations.

Today, indoor cultivation and other enclosed environments without sunlight that depend on electricity to produce a lighting source–such as tents and growth chambers–are still commonly referred to as "warehouses".

Since the passing of the Farm Bill in 2014, hemp growers are starting to explore different methods of cultivation. There are numerous ways to cultivate this crop that come with advantages and disadvantages.

Photo: Andrew Demetri

Indoor vs Greenhouse Production

A major difference between indoor and greenhouse operation styles is that greenhouses utilize sunlight as a source of plant active radiation, making use of light and heat from outside. Greenhouses need daily temperature monitoring and adjustment for appropriate light intake (intensity and daylength) from the sun. Greenhouses make use of various glazing materials (coverings) which allow the transmission of sunlight and help to retain heat from the sun. Multi-layer glazing or additional thermal curtains can be used provide additional insulation and reduction in heating costs, in exchange for a decrease in sunlight transmissivity.

In addition to glass, there are several other materials that can be utilized as greenhouse glazing. Information modified from University of Arkansas Extension (https://greenhouse.hosted.uark.edu/Unit03/Section02.html):

- **Polyethylene Film** – Commonly used for its flexibility, low cost, light weight, and ease of installation. A single layer has an average light transmittance of 86% (~75% for double) and has a relatively high thermal conductance for capturing heat.
    - Downsides: Short lifespan (~3 years), and some include infrared inhibitor lining which reduces heat loss, but has been shown to cause condensation.
- **Fiberglass Reinforced Polyester** – A light transmittance of up to 90% (double ~70%) while being rigid, light weight, and low in cost.
    - Downsides: This type of paneling has been shown to degrade over time due to U.V. emittance from the sun, causing yellowing and reduction in light transmittance. Highly flammable but can be treated with U.V. inhibitors and fire-retardant sprays. Lifespan of about 2-3 years.
- **Acrylic** – This type of paneling comes in various layers (single: Plexiglass; double: Exolite (87-93% transmissivity)) and thickness, including the actual panels themselves and the distance between them. Strong, lightweight, resistant to U.V. degradation, and Exolite may have a lifespan of 20-25 years.
    - Downside: Flammable, easily scratched, have a high degree of thermal expansion and contraction from weather, high initial cost and requires special support anchors.
- **Polycarbonate** – Available in single (dynaglass), double (Macrolux), triwalls, and panels with crossing supports. Single and double/bi-walls are the most common in this type of paneling and with adjustable sizes in thickness of material, overall panel, and distance between the flutes; one can curate specific paneling for their operation and needs. Bi-wall panels have approximately 83% transmissivity, where single panels have about 94%; these panels are strong and lightweight with an average lifespan of 20-25 years. These panels also offer U.V. resistance and condensation reduction.

Indoor growing allows greater temperature and humidity control if properly installed, particularly with sufficient HVAC capacity, which leads to better control over diseases.

Mixture of sunlight and LED *C. sativa* inflorescence.
Photo: Andrew Demetri

However, indoor growing ultimately requires greater energy use and carbon emissions than greenhouses. With the right glazing coupled with some other energy saving techniques, a greenhouse can be a better option than indoor growing for those who want to reduce their environmental footprint, while also reducing inputs.

Although there is not a reliable glass panel with 100% transmissivity, the light spectrum of our sun cannot simply be replicated from a stand-alone light source, and for many, this is the reason greenhouses present economic and horticultural advantages over total indoor cultivation. The quality of light provided to the plant can result in different growth responses from the plant, which can lead to more vigorous crop growth (see the Artifical Lighting section).

Irrigation and Water Quality

The type of irrigation system used depends on the production style in the facility. The type of substrate and its physicochemical attributes (see the Potting Media section) will influence irrigation quantity and timing. Water quality plays a fundamental part in optimizing plant health and nutrient uptake, although unfiltered/tap water can supply additional nutrients, however, it can also foster unwanted disease and other detrimental chemicals for the plant's health. Unfiltered water can also hold properties such as extreme variation in pH, alkalinity, and electrical conductivity (dissolved salts) that can drastically alter the growing environment. A grower can manage increased concentrations of salts—high electrical conductivity (EC)—in the media by raising the leaching fraction and regulating the amount of fertilizer added.

Leaching fraction* is the proportion of water drained from a container/pot after irrigation.

* defined by North Carolina State University Extension

It is possible to blend water sources to achieve a desired composition of purity as an alternative to total water treatment. Such water sources can be municipal sources, a well, pond water, rainwater, and reverse osmosis water. Reverse osmosis is a form of water treatment that utilizes a semipermeable membrane and pressure to push water through to purge it of any contaminants.

A closed loop irrigation treatment system captures unused water from irrigation and recycles it to be filtered through and used again effectively lowering water costs. This can be used in tandem with a rainwater capturing system for a more sustainable approach. The filtration system works by having a series of filters with decreasing pore sizes that can have an additional carbon filter and UV light to further treat the water prior to irrigating. In both soil and soilless substrates, irrigation scheduling should match the daily course of evapotranspiration given the respective environmental parameters and that water/fertilizer use efficiency is largely governed by the farmer themselves.

Since C. *sativa* grows best in a pH of 6-6.5, using this (or a slightly lower) target pH for irrigation water can help calculate acid injection requirements. An alkalinity calculator is available online from the University of New Hampshire. To use this calculator, growers must have their irrigation water pH and alkalinity data. These can be obtained from water treatment plants in the case of municipal water, or for wells and surface water, multiple commercial labs will test for irrigation water suitability.

Alkalinity in water can systematically and consistently alter the pH by neutralizing acids with the presence of dissolved alkalis. The ideal irrigation water has minimal concentrations of dissolved salts and is suitable for irrigating when each parameter can be managed without negatively impacting plant health.

Recommendation:

- Regularly test and monitor your water supply; it's an essential step in the upkeep of your facility and crop well-being.
    - Water testing can help identify if an on-premise water treatment system is necessary.

The elevated levels of pH and calcium bicarbonate in most NYS irrigation wells indicates the need for injection of acids particularly to high tunnel irrigation systems. Although sulfuric acid is the most common conventional source, citric acid is the choice for organic growers.

The introduction of acids and other nutrients into the irrigation system is possible with a proportional injector. The amount required will depend on the pH and calcium bicarbonate of the untreated irrigation water. Common proportional injector brands include Chemalizer and Dosatron (https://www.dosatronusa.com).

Suggested Water Quality Guidelines for CEA Crop Production in Soilless Substrates

Parameter	Manageable Range
Soluble salts (EC)[1]	< 0.75 mS/cm for plugs < 1.5 mS/cm for general production
pH	4.5 to 7.0
Alkalinity ($CaCO_3$ equivalent)[2]	< 300 ppm
Sodium (Na)	< 70 ppm
Chloride (Cl)	< 70 ppm
Nitrogen Nitrate (NO_3) Ammonium (NH_4)	10 ppm
Phosphorus (P) Phosphate (H_2PO_4)	5 ppm
Potassium (K)	< 20 ppm
Calcium (Ca)	< 150 ppm
Sulfates (SO_4)	< 45 ppm
Magnesium (Mg)	< 75 ppm
Manganese (Mn)	< 1 ppm
Iron (Fe)	< 2 ppm
Boron (B)	< 0.5 ppm
Copper (Cu)	< 1.0 ppm
Zinc (Zn)	5 ppm
Aluminum (Al)	5 ppm
Fluoride (F)	1 ppm

1 1mS/cm = 1000µS/cm = 640 ppm TDS (Total Dissolved Solids)
2 250 ppm CaCO3 = 1 meq/L CaCO3
Source: Raudales et al. 2021.

Irrigation water quality is of heightened importance in high tunnels compared to both open field and hydroponic production. The soil-based nature of high tunnels in the absence of precipitation (compared to open field), allows any problematic aspects of irrigation water to accumulate in the root zone as no leaching occurs. Whereas in hydroponics, a reset of root zone nutrients and pH is possible through flushing the growing media, soils retain and buffer the presence of cations and salts. These interfere with nutrient uptake and crop root health. Therefore, for appropriate high tunnel irrigation:

- An irrigation water sample analysis is critically important.
- Important parameters are pH, bicarbonate, soluble salts, and other nutrients.
- Consider soil parameters such as pH and calcium levels.

There are online irrigation and water quality tools to help:

- Greenhouse Production Calculators from the University of New Hampshire, https://extension.unh.edu/resource/greenhouse-production-calculators
- Irrigation Water Analysis from Waters Agricultural Laboratories, Inc., https://watersag.com/service/water-analysis-2/
- Water Analysis by Cornell Nutrient Analysis Laboratory, https://www.css.cornell.edu/cnal-forms/CNAL_Form_L.pdf

High Tunnels for *Cannabis sativa* Production

High tunnels are soil-based greenhouses that benefit from CEA technology, while keeping soil as the plant growth substrate. High tunnels are an effective technology for farmers that desire to extend their growing season, protect their crops from weather, and enhance the productivity and quality of specialty crops. In the case of C. *sativa*, the extended growing season and decreased field stress may lead to higher yields of floral biomass as well as higher concentrations of cannabinoids.

The unique growing conditions in high tunnels present challenges for long-term soil management. Excess tillage, fertility, and continuous cropping without rotation or precipitation results in a number of soil health and fertility issues that require intervention. The dry, but humid, enclosed nature of high tunnels can also accentuate particular pests and diseases.

What are high tunnels?

A high tunnel is a soil-based greenhouse, often with lower technology than hydroponic greenhouses. Common structural features include roll-up sides for passive ventilation and single- or double-layer polyethylene covering. Some high tunnel models incorporate thermostatic control heat and ventilation systems (fans and louvres). The commonality and defining feature of a high tunnel is the use of soil for a growing medium versus container or hydroponic production.


Photo: Cornell University

Soils

The soil is therefore the most important material resource in a high tunnel. To properly manage a high tunnel soil take into account:

- A complete soil analysis
    - include all macro, secondary, and micronutrients
- Soil pH
- Organic matter analysis
- Soluble salts or electrical conductivity (EC)

In New York State, high tunnel soil management requires attention to limiting calcium, phosphorus, and magnesium inputs from both conventional and organic nutrient sources. In our experience, these nutrients reach excessive levels and then limit the uptake of other key nutrients such as potassium and manganese. Excess nutrient applications occur when general use fertilizers such as 20-20-20 are applied in pursuit of adequate nitrogen without attention to the levels of phosphorus and potassium.

In New York State, high tunnel nutrient management will focus on nitrogen and potassium, as they are extracted from the soils in higher levels than other elements, while maintaining pH levels low enough to permit the availability of secondary and micronutrients. Exact amounts of any crop nutrient will depend on soil test results. For conventional fertility, the entirety of crop nutrient budgets can be applied via drip irrigation.

For organic high tunnels, bulk amendments such as alfalfa meal and composts are applied pre-transplant and incorporated, often with a target of at least 50% of the total nitrogen budget. Soluble certified organic nutrients are available for fertigation to achieve the balance of the nutrient requirements. Nutrient injection can occur daily or 3 times per week, alternated with clear water.

Foliar Nutrient Sampling

Foliar nutrient sampling (see the Plant Tissue Analysis section) is crucial to understand the general health and nutrient uptake of the plants. After soil and water testing, high tunnel growers can develop a nutrient management plan to deliver adequate nutrients at corresponding crop stages to maximize floral mass and cannabinoid concentrations. The quantity and source of nutrients will be specific to each high tunnel based on the soil and water tests. Foliar nutrient sampling can then be used to monitor uptake and utilization of nutrients by the crop. A small (< 1 quart) representative sample (multiple plants throughout the high tunnel) of the youngest, fully expanded leaf is submitted to a commercial agriculture lab for analysis. Growers can then adjust levels of these nutrients in the injection system to correct deficiencies or excesses.

Pest Management

High tunnel pest management is characterized by the warm, higher humidity environment, free of rain and soil splashing. This reduces foliar diseases found in wet conditions such as Downy Mildew and Septoria Leaf Spot, however diseases such as Powdery Mildew are accentuated in high tunnels. Arthropod pests (see the Insects and Mites section) can thrive in the dry environment of high tunnels, particularly thrips and twospotted spider mites.

Since high tunnels are a combination of field and greenhouse production techniques, pest management is also combines tools from both settings. Fungicide and insecticide applications can occur in high tunnels, however in New York State, the Department of Environmental Conservation interprets prohibitions on greenhouse applications to include high tunnels. For example, a label that states 'NOT FOR USE IN GREENHOUSES' is prohibited from high tunnels in New York.

The use of beneficial insects and mites, commonly known as biocontrols, can be a successful management technique in high tunnels. Predatory and parasitoids species can be released preventatively in high tunnels to control thrips, mites and aphid species.

Common suppliers of these biocontrols:

- Koppert, https://www.koppert.com/
- Biobest, https://www.biobestgroup.com/

Plasticulture Beds

High tunnels often use mulched, raised bed techniques, common to outdoor annual horticultural crops (see Open Ground Production for Grain section or Open Ground Production for Fiber Hemp section). Within the high tunnel spacing of mulched beds must factor in height restrictions along greenhouse walls (for equipment passage), as well as increased canopy of the crop.

Raised, plastic mulch beds in a high tunnel warm the root zone, control weeds, and conserve irrigation water. *Photo: Judson Reid, CCE*

Ventilation

High tunnel ventilation is an important tool to manage temperature, relative humidity, and carbon dioxide levels. Roll up sides along tunnel side walls can be adjusted manually or thermostatically, with temperature management the primary decision influence. In the spring and fall, sidewalls can be opened partially to reduce cold and wind damage to the plants. In warmer months, these sidewalls may be open constantly.

High tunnels often have a single layer of polyethylene glazing, which can result in dramatic heat loss, particularly on still, clear nights. To protect the crop from temperature swings and potential cold/freezing damage, a double layer of poly, or supplemental heat is recommended. The use of low tunnels with floating row covers is also a low input method to retain heat in a young crop. Row covers are applied over a crop at sunset, and removed shortly after sunrise in high tunnels, to allow heat from the sun to be adsorbed by the soil. Common brands of row cover include Remay, AgriBon, and Novagryl. These lightweight fabrics are suspended above the crop with wire hoops to prevent physical damage to young plants.

For further information on high tunnel films:

- Gas vs Cold Damage in High Tunnel Tomatoes (page 1), https://rvpadmin.cce.cornell.edu/pdf/veg_edge/pdf187_pdf.pdf
- High Tunnel and Greenhouse Film: Is it Time to Change? (page 12), https://rvpadmin.cce.cornell.edu/pdf/enych_newsletter/pdf211_pdf.pdf

Sustainability

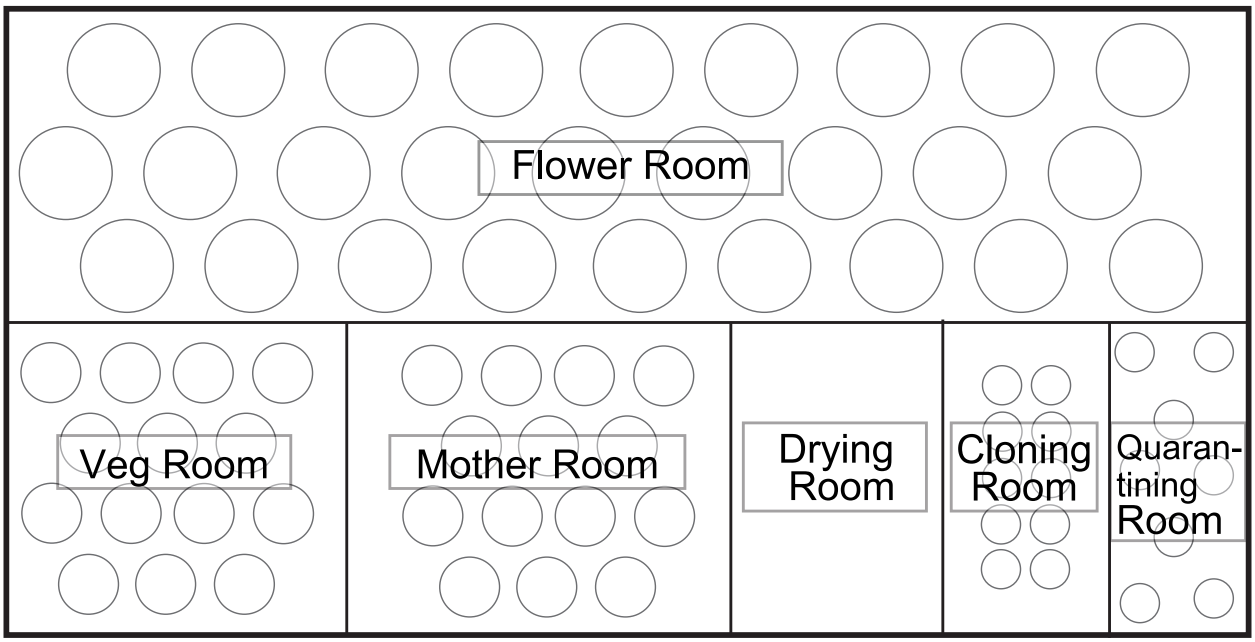
High tunnels can offer an increase in sustainability, or decreased carbon footprint when comparing yield to energy inputs. As the C. *sativa* industry seeks to improve sustainability measures, high tunnels can balance economic objectives by producing larger flowers with higher cannabinoids concentrations when compared to field level yields without the high energy inputs of full technology greenhouses. In New York, the Office of Cannabis Management highly encourages organic farming methods, which preclude hydroponics. As high tunnels are soil based, growers can realize the benefits of a greenhouse, while meeting organic production standards.

Indoor Production Layout

Although the following layouts do not consider important areas in C. *sativa* grows such as a manufacturing zone, storage, trimming area, or waste management area, these outlines describe the approximate sizes to consider when designing an indoor production facility.

REMEMBER: C. *sativa* is a light sensitive crop; therefore the transition between the vegetative to flowering stages depend on the hours of light. Therefore, to ensure that mother plants and those in vegetative will not flower prematurely, a longer daylength is needed. On the other hand, during the flower stage a short day is needed, or, technically, a long night period.

Indoor Production Layout (no breeding)



Cloning Room: Place in the facility where vegetative propagation is performed.

Drying Room: Location where flowers are hanging after harvesting.

Flower Room: Space in the facility where plants start their flowering stage.

- Short "days" (usually around 12 hours of light)

Mother Room: Place where mother plants—those used to take cuttings for propagation—are located.

Quarantining Room: Location where new plants are isolated before introducing them into the facility.

Veg Room: Location where plants are in vegetative growth stage after propagation and before inducing flowering.

- Long "days" (usually around 18 hours of light) to build up plant size

Recommendations:

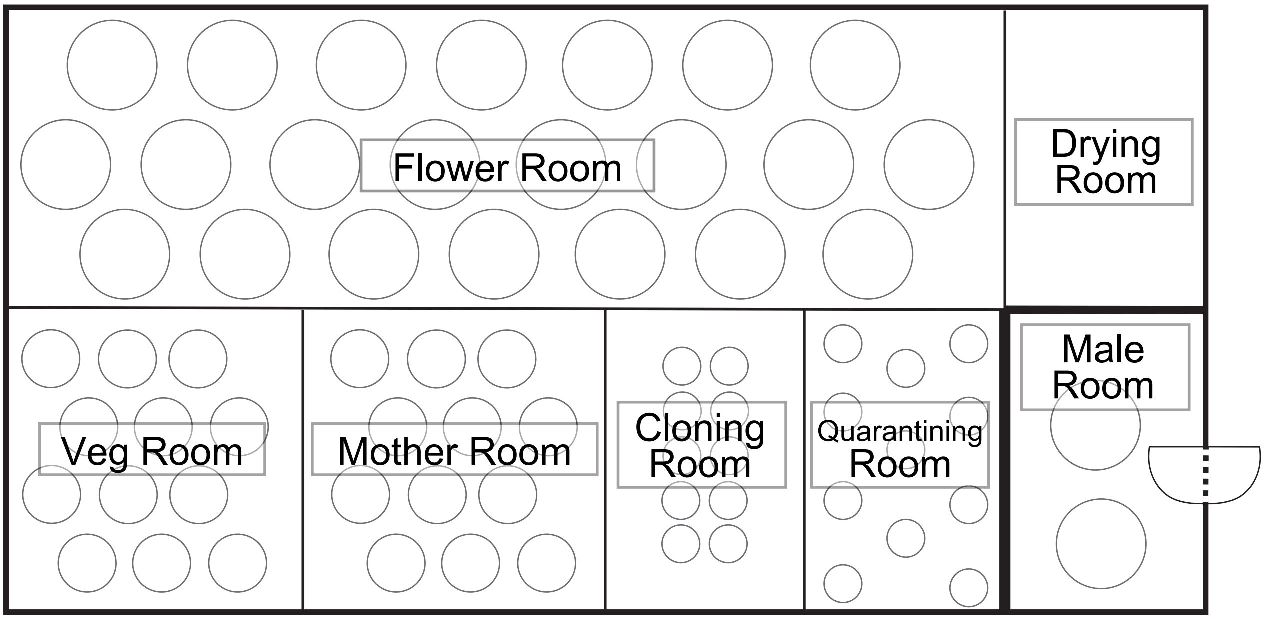
- All rooms should have access to electricity (for lights and fans/AC/heat), a water faucet, and a drain.
- Consider having a mother room and a veg room about 1/4 to 1/3 of the size of your flower room.
- A veg/flower room can be used if the light time will be changed between plant stages.
    - Changing the light regime in a room instead of having different veg and flower rooms avoids having to move plants from one location to the next, reducing plant stress and damage and personnel costs. Dispersal of disease or pests to multiple rooms (if plants are sick, maybe unknowingly) is minimized too.
    - The disadvantage of a veg/flower room is the waste of space and resources while plants are growing into full mature size (because during the vegetative propagation stage the plants are smaller, they can be placed at a closer density).
- The cloning rooms should be small with multiple shelves to hold the cloning domes.
- The quarantining room is useful if you are bringing plant material from elsewhere. This room should also be small with at least two tents to make sure plants are isolated before moving them to your grow
- The drying room should be 1/4 to 1/3 of the size of the flower room. It's not necessary for this room to have a water faucet and a drain (although these are always helpful), but it must have electricity for the HVAC system.
- People that visit the facility should have hair caps and shoe covers. Lab coats are also highly recommended.

If there will be breeding and pollen produced by either males, monoecious individuals, or reversed females (see the Sex Reversal section), it is important to have extra care to avoid unwanted pollination. Besides the recommendations above, these are further suggestions if breeding will take place at your facility.

- Restrict the number of people that go into the male room, designate one or two people maximum.
    - Once these people go into the male room, they should not visit any other rooms in the facility.
    - These designated individuals should change clothes before and after visiting the male room, including shoes.
- Consider having the access doors to the male room outside of the facility so that the designated individuals can't go to any other room after visiting the male room.
    - Designate specific times to enter this room, perhaps at the end of a shift so that no other room is visited afterwards.
- Consider having a double door to enter the male room.
    - These double doors should not be open simultaneously; one must be closed while the other is open to avoid pollen leaving the male room.
- Assure that the male room has a separate ventilation system to avoid pollen traveling through the air ducts into other rooms.
    - Consider having a suction air system in the space between the double doors, to extract any pollen particle before it leaves the room.

- Pollinate in tents to avoid transferring pollen to the other rooms.
  - If pollinating in the quarantine room, there may be risk of disease (if the new plants are sick).

Indoor Production Layout (with breeding)



Production Calendar

High Tunnel

Production should generally follow the calendar for outdoor spaced plantings. (See the High Tunnels for Cannabis sativa Production section.) Growers may choose to adjust spacing based on desired plant density within the tunnel. Planting date should be adjusted based on desired final size of plants.

For example, a full season cultivar planted in late April or early May could reach heights of 10 plus feet by the end of the season. Planting in late May or early June may be best as growth will be limited by the plant's flowering time.

Autoflower varieties may be planted as soon as soil temperatures are consistently above 50°F (10°C) and should flower four to five weeks later, although some varieties are fully mature at 7-8 weeks.

High tunnels usually have drip tape installed, making fertigation an option for nutrient management. Special attention must be paid to pest and disease management, particularly the management of powdery mildew, as this environment is ideal for some pests. (See Diseases, and Insects and Mites.)

Greenhouse

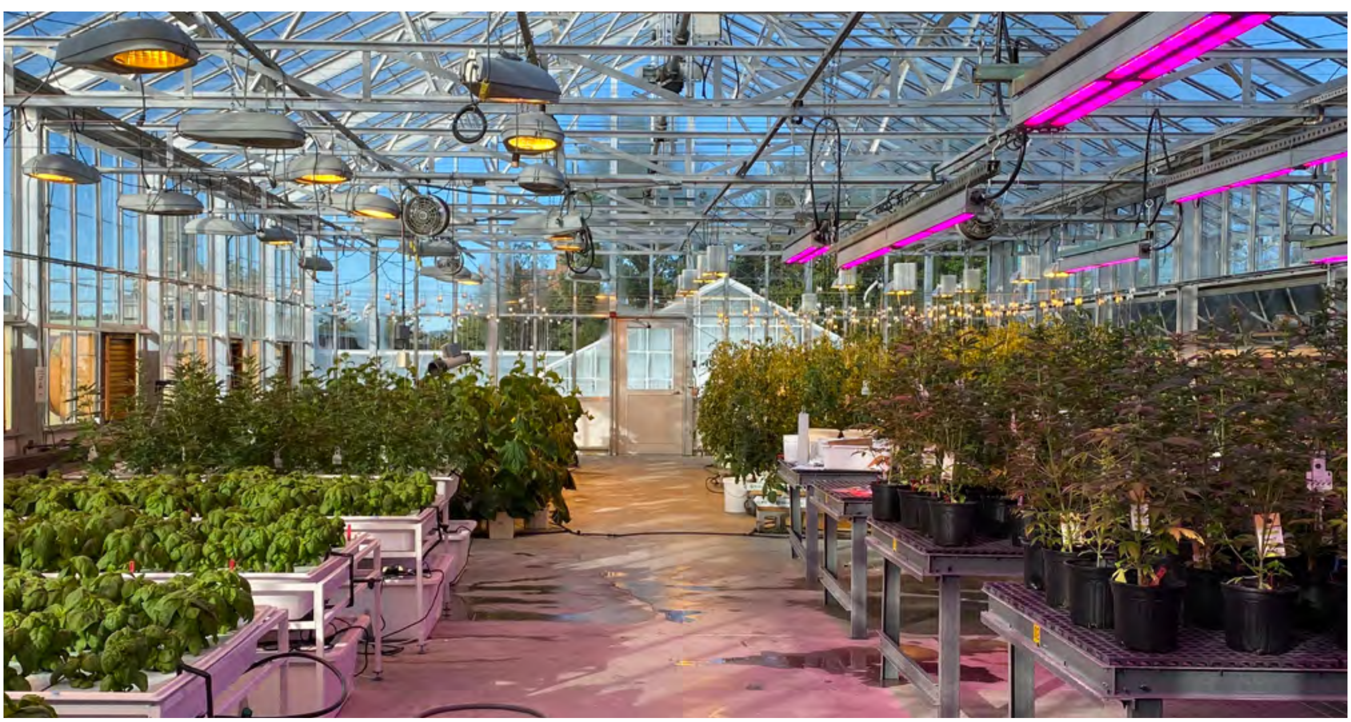
Production calendar should be based on availability of labor and drying space for harvest and grow room set up, which may vary widely between producers. Producers should generally expect to have 3-4 growth cycles per grow room per year.

General production schedule for photoperiod C. *sativa* in CEA (greenhouse/indoors):

- Propagation 2-4 weeks (in a separate propagation/cloning room)
    - long day photoperiod (13+ hours, but often longer to ensure vegetative growth and add additional light)
- Vegetative growth stage 2+ weeks
    - 2 weeks for high density plant production (1 plant per square foot); longer vegetative stage to build up the plant for lower density production.
    - long day photoperiod (13+ hours, but often longer to ensure vegetative growth and add additional light). 18-hour photoperiod common.
- Flowering/generative stage
    - short day photoperiod (12 hours lighting, 12 hours uninterrupted night)
    - 8-9 weeks from start of short days until harvest for many cultivars

Controlled Environment Production

Multiple production systems and styles work well in controlled environments. The two broad categories of production styles are soil and soilless, in reference to the type of medium/substrate used to grow the plant. A potting medium is the material or mixture of materials which help the plant in various ways, such as keeping its posture, providing substrate for beneficial microbes, increasing nutrient/water availability, among other uses. Potting mix selection relies on the broader growing system as some are made from inert material that does not have an effect other than to hold up the plant. Soil is a complex and biochemically active medium that can be fine-tuned in CEA to produce certain favorable micro-environments that can further aid in nutrient uptake, pest/disease resistance, create buffers (i.e.: electroconductivity, pH, nutrients), drought/water toxicity, and more. Whereas soilless systems rely less on the medium and prioritize actions from the grower that directly affect the plant's wellbeing. The soilless medium category is broad, so not all statements apply to all.



Fully functioning Cornell hydroponics greenhouse. *Photo: Andrew Demetri*

Potting Media

Soilless media comes with more uniform and, in some cases, inert properties. However, soilless media and soil can be customized with attributes termed: water holding capacity, air filled porosity, total porosity, bulk density, and cation exchange capacity. These attributes will help choose a substrate to provide a beneficial environment for plant growth and development.

Particle size of soilless potting mixes are chosen to balance water holding capacity and air-filled porosity. The general recommendation is a potting mix should have a total porosity of 50% or greater. Total porosity is the sum of air-filled porosity and moisture holding capacity. Air filled porosity should be 10% or greater (values less than this can limit oxygen available to roots leading to poor rooting or sensitivity to root diseases). Water holding capacity should be 40% or greater (values less than these require a substrate to be irrigated more frequently).

Water Holding Capacity (P_v)
Percent pore space that is filled with water in a given substrate at container capacity. A higher water holding capacity will provide longer sustained water in your media, but too much could be detrimental by holding large amounts of water.

Air Filled Porosity (E_a)
Percent of pore space in a given substrate filled by air at container capacity. Having adequate air-filled porosity gives the plant some breathing room along with niches to extend roots to acquire additional nutrients.

Total Porosity (E)
Percent pore space by volume of a given substrate at container capacity: $E = P_v + E_a$

Bulk Density (p_b, g/cm^3)
Dry weight of a substrate per unit of volume. As bulk density increases a heavier/more reliable container is necessary. The particle size of the media can be manipulated in some instances to alter bulk density in a given container.

Cation Exchange Capacity (CEC)
Ability of a substrate to hold positively charged fertilizer salts, more is better. This can allow an extended time for the plant to uptake these cation nutrients while making sure they do not get wasted by leaching out of the substrate. Common cations: H^+, K^+, NH_4^+, Na^+, Ca^{2+}, Mg^{2+}

Modified from Professor Neil Mattson's class on Hydroponics, Cornell University

Photo: Andrew Demetri

Type of Soilless Potting Media

Soilless media come in many different shapes and sizes made from various plant- and mineral-derived sources.

Plant-derived Soilless Potting Media

Type	Description	Properties
Peat Moss	Types of mosses used for their water retention, ease of use, and affordability properties.	
Sphagnum Peat	Slow decomposition, low nitrogen depletion	Total pore space of 82-84%, water holding capacity of 60-68%, air-filled pore space of 10-15%, bulk density of approximately 0.1 $g \cdot cm^{-3}$, CEC of 15 meq/100 cm^3, general pH of 3.0-4.5
Hypnum Peat	Darker in color, fine texture	Total air porosity ~80-82%, air-filled pore space of 6-7%, water holding capacity of 70-75%, CEC of 32 meq/100 cm^3, general pH of about 5.0-6.5
Reed-sedge Peat	Composed of various plant martial, tends to be further decomposed than other peats	Average total pore space of 80%, air-filled pore space of 10-14%, water holding capacity of 65-67%, bulk density of 0.14 to 0.16 $g \cdot cm^{-3}$, variable pH
Coco Coir 	Derived from the husks of coconut, and often a byproduct of other industries, this organic alternative has properties that can add nutrients, a buffer for pH/ nutrients, and increased water retention.	~80% total porosity, 40% water holding capacity, a bulk density of 0.08g/cm^3, and CEC of 20-80 meq/100 cm^3, average pH of 7.0
Wood Chips/Dust 	Generally made from pine and hardwood bark that is decomposed to an extent or composted, that allows and tends to have microorganisms within while deteriorating over time. The wood can maintain its porosity for a long time, is relatively cheap, and can be composted further to add additional benefits.	The pH may decrease over time but has a general range of 5.0-6.0 and a CEC range of 3.2-3.8 meq/100 cm^3.
Rice Hulls 	Used primarily as an additive to increase aeration in other mixes. Can help improve water holding capacity, acting as a reservoir, and aeration which in turn improves drainage and breathability of the medium. Environmentally sustainable way to improve media quality.	Low CEC, typically neutral in pH

Modified from Dr. Evans, University of Arkansas Extension, https://greenhouse.hosted.uark.edu/Unit07/Section05.html
Actual properties may vary based on source and processing/storage methods.

Mineral-derived Soilless Potting Media

Type	Description	Properties
Stone Wool (Rockwool) 	A combination of coke, basalt, and limestone that is then heated to 1600°C and spun into fibers similar to fiberglass (Mattson et al., 2015).	These fibers are inert and can be organized in a variety of ways that impact physical properties including both high water holding capacity and aeration.
Perlite 	Spherical white pellets that are crushed volcanic rock and heated at temperatures near 1800°F (982°C). A good medium to mix with others or used as a stand-alone medium in specialized production systems.	Has large pores and is lightweight, therefore has a low bulk density. Inert material has negligible influence on CEC and pH.
Vermiculite 	Made from crushed mica crystals and heated to 1400°F (760°C). Allows for high water holding capacity and low weight properties, making it another great option for adding to a mix to increase the benefits from multiple media.	Inert, lightweight substrate with a CEC of 2-3 and pH of 6.0-8.9
Expanded Clay Aggregates 	Clay pellets are heated to a temperature of 2100°F (1148°C) thus allowing the small clay pellets to expand and increase in surface area, granting increased pore space and can be reused after sanitation.	The pH of this media is negligible with a CEC of 3-12 meq/100 cm^3.
Sand 	Comes in various sizes that will have differing effects on media preparations and is typically used in mixes and in nursery settings; can increase pore space within mixes.	It has negligible pH and CEC effects, has a high bulk density.
Oasis 	An inert, cubed-foam like suberate that is made using proprietary materials, popular for their affordability and inertness.	Negligible effects on pH, CEC, and other media physicochemical properties.

Modified from Professor Neil Mattson's class on Hydroponics, Cornell University

The compositions of these plant- and mineral-derived substrates can be used as additives to each other to combine benefits. The choice of soilless substrate or media mixture is crucial in providing adequate physical and chemical properties needed for a specific plant species and its ideal growing conditions.

Growing Cannabinoid *Cannabis sativa* Indoors Using Coco Coir

Because coco coir is widely used, we will provide recommendations for this medium.

Fertigation

Since coco coir does not provide any nutrients to the plant, it must be continually fertilized, and many do it through a water irrigation system known as fertigation. Some recommend fertigation between 3-5 times a day depending on the size of the plant and the size of the growing container, which is easy on automatic watering systems. Some people in the industry mix coco with perlite, to give extra air to the plant's roots.

Recommendations:

- Do not let your coco medium dry.
- Maintain pH at 5.5-6.0.
- Measure the water's electrical conductivity (EC)–a measure of fertilizer strength–to determine the ions (nutrients).
- Add the fertilizer to the water system. Use a complete fertilizer, maintaining EC based on the table below.

Fertilizer Rate and Target EC by Plant Development Stage

Development Stage	Fertilizer Rate (ppm N)	Target EC	
		Top Irrigation (mS/cm)	Sub Irrigation or Capillary Mat (mS/cm)
Early Vegetative	100 to 125	1.0 to 1.5	0.67 to 1
Late Vegetative	150 to 200	1.5 to 2.0	1.0 to 1.3
Peak Flowering	200 to 225	2.0 to 2.5	1.3 to 1.7
Pre-Harvest	100 to 150	1.5 to 2.0	1.0 to 1.3

Modified from Professor Neil Mattson, Cornell University

Nutrient Injectors

These tools help an operation fertilize with irrigation water and provide automation. This helpful tool allows a grower to mix up liquid soluble fertilizers in a concentrated form. The injector takes and the concentrated nutrients injects them into a water solution to provide calculated doses for plant nutrition, typically indicated in fertilizer to water ratios.

Common ratios in commercial agriculture greenhouse facilities are:

- 1:200, 1:100 (the most common), 1:64, and 1:50.

Certified greenhouse grade fertilizers should be used to reduce clogging/contaminants, increase purity and solubility. Nutrient injectors allow fertilizer stock tanks to be readily available for the grower to use and store. Some fertilizer salts are incompatible in a concentrated form and cause a precipitation (sludge). Therefore 2-3 stock tanks each with their own associated injector may be used.

- Contact your fertilizer supplier to determine if precipitation is an issue with their fertilizers and if multiple stock tanks/injectors are required. Calcium nitrate is a commonly used fertilizer ingredient but it is not compatible with fertilizer salts that contain sulfates or phosphates.

- Typically:
  - One stock tank is reserved for calcium nitrate and compatible fertilizer salts.
  - A second stock tank contains fertilizer salts not compatible with calcium nitrate (such as sulfate and phosphates).
  - A third fertilizer tank may contain acid, if pH needs to be decreased.

Recommendation:

- Do not mix calcium with sulfates or phosphates.
- Contact the fertilizer supplier to determine which fertilizers are compatible/incompatible.
- Test a nutrient mix prior to scale.
  - Mix the same ratios in a closed jar and notice the interactions with the fertilizers.

Nutrient injector.

Multiple stock tank set up. *Photos: Andrew Demetri*

Hydroponics

Hydroponics is a broad category of production styles that use soilless potting mixes. It is an all-inclusive term for multiple styles of cultivating plants in non-organic media (sometimes), water, aggregate culture, and absorbed nutrient technique. Hydroponic systems can be divided in two groups based on nutrient delivery method:

1. **Open irrigation (also know as drip to drain):** Provides a fresh nutrient solution each irrigation cycle, such as in drip systems and hand watering. Excess nutrient solution is typically not captured and reused.
2. **Closed irrigation:** The same nutrient solution recirculates while being monitored and adjusted accordingly. Systems include aeroponics, nutrient film technique, and deep-water culture.

In hydroponic systems, maintaining adequate pH levels are of high priority to allow for optimal growth and nutrient uptake for the plant.

Recommendation:

- Keep pH between 5.5-6.0. Acid or bases are used to adjust pH as needed.
- Consider liquid oxygen or an air pump to ensure the plants are getting supplemental oxygen which is important to support root system health. (Roots need oxygen to respire.)
    - Keep the nutrient solution at saturated dissolved oxygen concentration (about 8 ppm at room temperature) as it provides greater availability to the plant.

Drip irrigation tubing. *Photos: Nicholas Kaczmar*

Ebb and Flow

Ebb and flow hydroponics involves a table with sides that has pots filled with inert media, such as stone wool or clay aggregate. The table is linked to a water reservoir and pumped to periodically add water + nutrient solution into the growing bed of the table. The table is generally a few inches deep, ~1-2 inches of nutrient solution is pumped in, enough to flood the entire bottom portion of the potted growing medium that will then be absorbed through capillary reaction until the water holding capacity of the medium is met and then slowly drains back into the reservoir. This cycle happens several times throughout the day depending on watering/fertilizer regime and substrate water/nutrient holding capacity. For commercial use, the recaptured nutrient solution will typically go through a treatment process to reduce the chances of disease and viruses. Ebb and flow systems scale well, supply sufficient water for water-craving plants, and are also energy efficient when compared to other hydroponic production styles.

Advantages

- Provides an abundance of water and nutrients to the plant at once
- Can be scheduled
- Low maintenance

Disadvantages

- Susceptible to power outages and timer failures
- Large water reservoir required
- High volumes of nutrients
- Can spread root borne diseases if water is not sanitized between irrigation cycles

Aeroponics

System where the roots of the plant are suspended in air and are intermittently sprayed with oxygen-rich nutrient solution. Often plants are supported with netted pots and the use of an inert and porous substrate such as expanded clay aggregates. Components of an aeroponic system include a nutrient solution reservoir with an oxygen pump that is then propelled through PVC pipe and delivered to the plant via misting nozzles. These nozzles can range from small to larger for different spray patterns, measured in microns. Once the nutrient mist is done spraying, the plant will uptake as much nutrients as it needs, and the rest will drip down and be drained back into the nutrient reservoir to be reused. This system can be automated once the correct procedure and calculations have been dialed in. Although aeroponics can be efficient, these systems are more sensitive to fluctuations compared to other hydroponic or soil-based systems. Whereas soil and some soilless media provide a buffer for pH, nutrients, water, cations, etc., aeroponics provides no buffer, and the slightest changes in power or miscalculation in nutrient dose could potentially damage the entire crop or drastically reduce yields. Aeroponics is used some hobby scale systems but not common in commercial production facilities for the veg or flowering stage. Aeroponics is often used for vegetative propagation of cuttings.

Advantages

- Water and fertilizer use efficiency
- Can be scheduled
- Space efficient
- Easy to move plants if needed

Disadvantages

- Susceptible to power outages and timer failures
- Requires increased monitoring of plants
- Requires knowledgeable grower
- Requires fairly high maintenance (unclogging of mist nozzles, adjusting pH/EC)
- Quick change in root-zone conditions (pH, EC, temperature) if not properly maintained

Nutrient Film Technique

In nutrient film technique (NFT) plants are transplanted into inclined channels/gullies using an inert substrate such as stone wool or oasis. In this technique the seedlings are started in these inert substrates and then placed into the channels soon after germinating. The channels themselves do not have any type of substrate to support the plants. Although channels can be lined with a film. Extruded food-grade PVC channels are an example material that have no film lining to them. Oxygenated nutrient solution is passed through these channels to provide adequate resources for the roots and plants that are then drained to be treated and reused. The importance of proper channel slope in relation to volume and flow of nutrient solution are key aspects for optimizing a successful seed to harvest crop rotation. These channels are usually covered to maintain high humidity and protection from light (to reduce algae growth). Because C. *sativa* plants have large root systems which can clog channels, NFT is not a common commercial technique.

Advantages

- Good water use efficiency
- Lightweight: easy to clean and move
- Comfortable when placed at waist height
- Provides the ability for space-use efficiency by creating a small but dense environment
- Can be scheduled

Disadvantages

- Susceptible to power outages and timing failures
- Potential for biofilms and algal growth
- Irrigation tubes can clog
- Volume of water per plant is low meaning pH, EC, and temperature can fluctuate greatly

Nutrient film technique (NFT) grown lettuce. *Photos: Andrew Demetri*

Deep Water Culture

Deep water culture (DWC) utilizes polystyrene rafts with drilled holes that float on top of a bed of water mixed with nutrients and oxygen, so that the roots are always submerged in solution. Like aeroponics and NFT systems, an inert substrate, such as stone wool, is used to start seedlings/cuttings and when transplanted into the system helps support the plant. A large reservoir of nutrient filled water is used and can be tens to hundreds of gallons depending on the scale of operation. This water could also be treated, adjusted, and recirculated with an external reservoir. The bed should be filled so that the polystyrene rafts are floating above with space below for root growth. In DWC systems the roots of the plants do not get as tangled with adjacent plants in the same system, unlike in nutrient film technique.

DWC has the advantage of respacing plants if needed during the crop cycle to give more growing room. Since there is a large volume of aerated, nutrient filled water DWC systems are more sustaining in an electrical outage. Challenges in DWC systems include algal growth in the reservoir and rips/tears in the reservoir lining which can cause crop loss and major water loss.

Advantages

- Efficient water use, if no leaks and kept clean
- Stability in power outages
- Less susceptible to biofilms
- Can be cheaper initial investment
- Water temperature manipulation
- Respacing, if necessary

Disadvantages

- If a big enough leak occurs, a complete drainage would be needed to repair
- Heavy due to large volume of water
- Large initial quantities of water and fertilizer needed
- Requires additional support for taller plants which could be top heavy and tip over
- Requires knowledgeable grower

Individual root mass of deep water culture (DWC) basil.

DWC *C. sativa. Photos: A. Demetri*

Vertical Farming

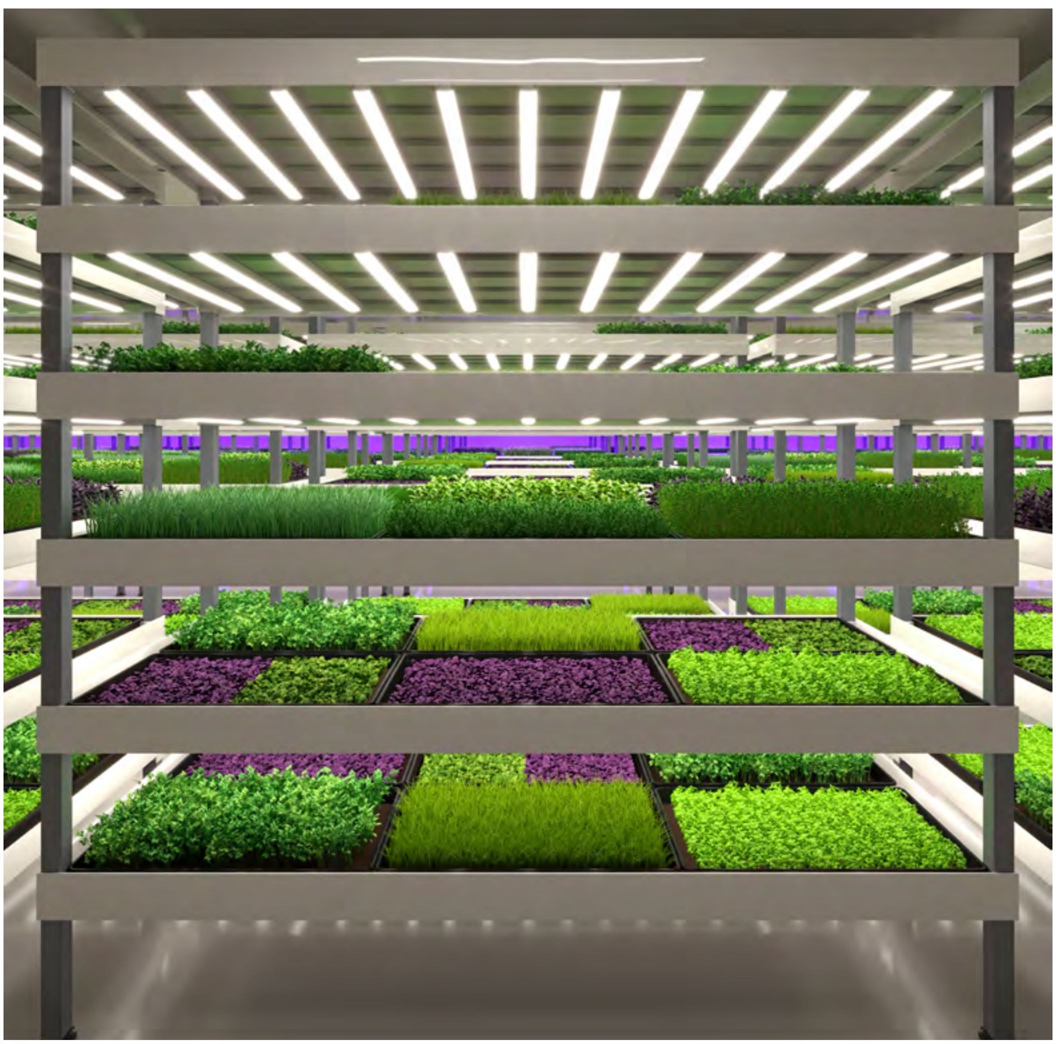
This technique aims to maximize space-use efficiency and is designed so that units are stacked on top of one another, like shelves. Fertigation (irrigating while fertilizing) is typically through drip emitters, and lighting is provided for each level; this style can be stacked as tall as needed for a given facility's infrastructure and production demand. Vertical systems can be implemented for different growth stages of the plant–such as clone rooting, vegetative growth, or flowering–or can be used from seed/clone to harvest in the same vertical grow. There is an increase in land-use efficiency in vertical farming at scale in agriculture due to its vertical stacking, but as is the case with single-layer indoor production, vertical technology must catch up to provide a more sustainable approach to vertical farming due to its large energy requirements.

Advantages

- Space use efficiency, multi-layer production
- Can be scheduled
- Typically, at waist height or taller
- Water-use efficient

Disadvantages

- Energy intensive
- Requires knowledgeable grower
- Can be harder to monitor
- Dripping water can be unsanitary/unhealthy for plants below
- May create additional labor to reach higher level



Microgreens growing in a vertical hydroponics system.

Controlled Environment Agriculture Equipment and Technology

Benches and Tables

There are various benches and tables that can be used to facilitate easier cultivation practices and observations; they basically lift the crops up off the ground to approximately waist height. These tables/ benches come in a variety of shapes, sizes, and materials that can be specified to a facility's needs.

A popular bench amongst industry professionals are the slotted benches that can come in a variety of materials. These benches are slotted in different patterns to facilitate adequate air flow and drainage along with physical support for the crop load. The height increase from benches also plays a role as a type of cultural pest control, as the crops do not reside directly on the floor where pathogens, insects, and weeds can more easily access the plant. Rolling benches which have only one aisle-way at a time to access the plants improve overall space use efficiency. Considerations when thinking of what bench to purchase for your operation:

Bench Height
For handling plants in various life stages and operation styles

Air Spaces in Surface
Proper drainage and air circulation to reduce disease

Dimensions and Mobility
Fits the grow room infrastructure and cultivating strategy

Strength
How many plants can be held at once, including pot size, media bulk density, water capacity, and plant weight

Compatibility
Irrigation and production system compatibility

Cost
Consider type of material, longevity, and logistics of operation

Modified from John Kumpf, Cornell University https://courses.cit.cornell.edu/hort494/greenhouse/bench/bench.html

Photo: Andrew Demetri

Slotted rolling bench. *Photo: Andrew Demetri*

Container Pots and Plant Density

Containers come in a variety of sizes and materials from plastic to organic and recycle based. Depending on the size and scale of the operation, 1–5-gallon pots are used for increased plant density, but if there is a limit to plant count, it is thought that increasing container size to 10+ gallons can provide a larger root biomass and potentially larger individual plants. In Canada common spacing is 1 to 2 square feet per plant during the flowering cycle and can be denser during the vegetative stage.

It is important to note that with different containers come different water drainage and maneuverability. Plastic is a popular cost-effective choice for pots, but more sustainable alternatives are available. Plastic pots can be reused between crop cycles if they are not physical damaged and if they are properly sanitized to kill root diseases. Plastic and some alternative pots can be 'netted' meaning there are slits on the bottom surface of the pot to allow for persistent root growth and improved drainage; these pots are mostly used in hydroponic systems.

Netted pots with expanded clay aggregate.
Photo: Nicholas Kaczmar

Alternative Containers to Increase Sustainable Greenhouse Crop Production

Container Type	Description
Recycled 	Typically made from recycled plastic bottles and other post-consumer waste streams. The material is processed into a liquid and can be combined with natural fibers and other organic/plant materials. It is heated then processed to produce a geotextile fabric that has a much-reduced carbon footprint but cannot be composted and is not biodegradable.
Compostable 	Intended for post-harvest composting since they are not quickly decomposing or completely biodegradable. Utilizes mostly bioplastics coupled with rice hull and thick-walled fiber/paper containers. These containers are not suitable for 'backyard' compost piles due to their inconsistencies in temperatures, moisture, pH, aeration, and microbial populations.
Plantable	These pots are aimed for planting your crop directly into potting mixes to reduce transplanting shock while saving time and potential costs. To assure these attributes, the material is readily decomposable with easy penetration of root mass. Decomposition speed of the material is dependent on potting mix, nitrogen, moisture, temperature, pH, microbial activity, and more. These containers can come from a variety of organic sources.

Modified from University of Kansas Extension: https://www.uky.edu/hort/sites/www.uky.edu.hort/files/documents/alternativecontainers.pdf

Alternative pots seem to have no significant difference to plastic. Additionally, higher plant density results in an increased overall yield, but reduced plant density results in higher individual plant yields.

Artifical Lighting

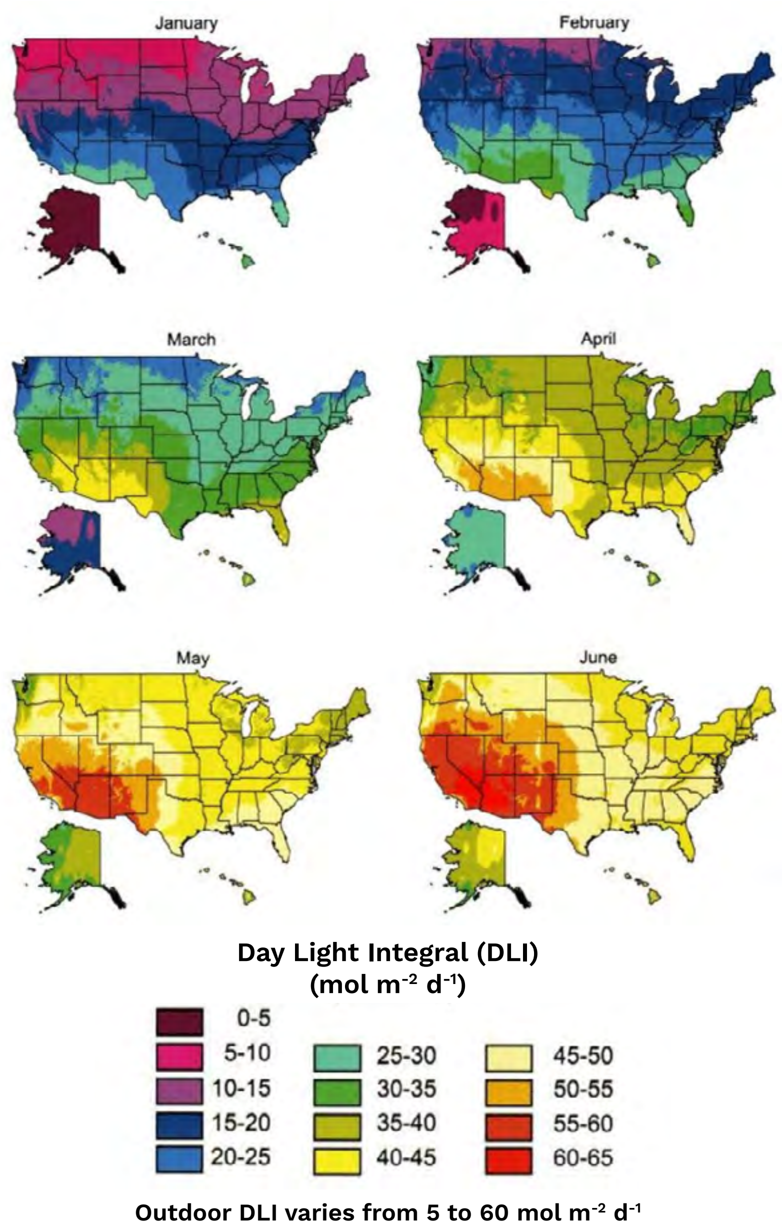
When choosing supplemental/artificial lighting for a controlled environment it is important to understand which type of controlled environment you plan to grow in. This decision will significantly impact the type of lights for purchase, the intensity at which they should run, along with the number of lights that are needed. Plants in a greenhouse environment will receive light from the sun and thus may not need as many supplemental lighting fixtures as indoor facilities.

For greenhouses, another important factor to consider for implementing supplemental lighting is geographical location. Weather patterns affects the amount of natural light entering the greenhouse during certain seasons. For example, a greenhouse in southern California will receive more natural light during the winter months than a greenhouse in Upstate New York. The commonly accepted way to measure the intensity of the sun's lighting for a given day or the delivery of supplemental lighting to a plant can be quantified using daily light integrals (DLI). DLI may be defined as "the number of light particles, or photons, received during one day in a particular location and area" (Erik Runkle from Michigan State University extension). Average location specific DLI maps can be found online.

Further lighting resources:

- https://www.hortlamp.org/outreach/fact-sheets/
- https://glase.org/

How much sunlight do you have?



Outdoor daily light integral varies seasonally. Note that about 50 to 70% of outdoor light enters the greenhouse. *Source: Faust and Logan (2018) HortScience 53(9(:1250-1257)*

Type of Lighting: HPS vs. LED vs. CMH

LED lights are becoming one of the most popular types of artificial lighting on the market overtaking Ceramic Metal Halide (CMH) and High-Pressure Sodium (HPS) lights. This can be attributed to the rapid advances in technology.

White LEDs provide a full spectrum of photon wavelengths that coincide with photosynthetically active radiation (PAR) which include photons between 400-700 nm. While white LEDs generally lack far-red wavelengths (701-750 nm) which have been shown to affect photosynthesis when coupled with shorter wavelengths. Although the interest in the extended photosynthetically active (ePAR) wavelengths between 701-750 nm are being investigated, they have shown promising results for increased efficiency. When looked at in isolation, photosynthetic drive decreased with wavelengths above 685 nm, but have shown synergistic effects when combined with red:blue and warm-white LED lighting correlating with an enhancement in net photosynthesis.

The following are important terms that describe the quality or quantity of light. (For meters to help quantify light fixtures, see Detectors & Sensors section.)

Instantaneous Light to Light Integral

Photosynthetically Active Radiation (PAR), this is measured in the range of 400-700 nm.

- The unit for measuring instantaneous light incident upon a surface is micromoles per square meter per second (or **$\mu mol \cdot m^{-2} \cdot s^{-1}$**). Photosynthetic photon flux density (PPFD) is the amount of energy (photons or particles of light) hitting a square meter every second. (The term mole is a really large number, 6.02x1023 photons; a micromole (μmol) is one-millionth of a mole.)
- Daily light integral (DLI) is the accumulation of all the PAR received during a day. The unit for cumulative light or daily light integral (DLI) is moles per square meter per day (or **$mol \cdot m^{-2} \cdot d^{-1}$**)

Example:

A fixture provides 500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD. How many **$mol \cdot m^{-2}$** does it provide when lit for 1 hour?

500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ x 1 hour x 3,600 seconds/hour) / 1,000,000 μmol/mol = **1.8 $mol \cdot m^{-2} \cdot hour^{-1}$**

If the same fixture is on hour 18 hours a day, how many **$mol \cdot m^{-2} \cdot d^{-1}$** DLI is provided by the light?

500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ x 18 hrs/day x 3,600 sec/hr / 1,000,000 μmol/mol = **32.4 $mol \cdot m^{-2} \cdot d^{-1}$ PAR**

C. *sativa* is a high light crop requiring a minimum DLI of 30 mol·m^{-2}·d^{-1} for moderate yield, with increased yield at higher DLI.

Light quantity (DLI) is the primary driver of plant photosynthesis and yield. There are effects from specific wavebands of light which are more prominent in indoor growing rather than greenhouses which have a background of sunlight (broad spectrum light). The role of light spectrum on plant development is described in the following list:

UV Photons (100 to 400 nm)
Has shown promise to induce photoprotective compounds in plants along with antimicrobial properties; in excess UV photons can be harmful to plant and human health.

Blue Photons (450 to 495 nm)
Plays a role in the development of chlorophyll and can reduce height development in the plant.

Green Photons (520 to 560 nm)
Although mostly reflected from green plant foliage it can still be utilized. Used to aid in humans' vision of the grow room. (Can also use LED protective glasses).

Red Photons (635 to 700 nm)
Helps flowering, increased height of plant, and has synergistic effects with blue wavelengths.

Far-Red Photons (701 to 750 nm)
Deeper penetration into foliage, synergistic effects with other wavelengths, energy efficient, and cell expansion.

White Light
A combination of red, blue, and green spectra. Can have different effects based on the percent of each wavelength present.

Modified from Erik Runkle, Michigan State University Extension (2015)
https://www.canr.msu.edu/uploads/resources/pdfs/light-wavebands.pdf

When used in a greenhouse environment, plants receive most UV and far-red light from the sun, making white LEDs a good choice for supplemental lighting in greenhouses. White LEDs seem to produce similar results of plant height and flower biomass compared to less energy efficient types such as HPS or Metal Halide. There are no definitive studies that point to certain spectra significantly increasing cannabinoid biosynthesis based on light spectrum. Thus, the energy efficiency of a fixture and its initial cost are more important for return on investment than the spectral distribution at high photon flux. The efficacy of a fixture is the light output (PPFD) per unit electricity with a unit of μmol/J. A higher number is better meaning there is greater light output per unit energy (joule). The best HPS fixtures (double-ended bulbs with electronic ballasts) have a reported efficacy of 2.1 μmol/J, while some LEDs have a reported efficacy of 3.0 to 3.7 μmol/J (meaning they may use 30 to 40% less electricity for the same light output). The design lights consortium (DLC) maintains a list of third-party certified horticultural LEDs that meet efficacy and operational criteria (hours operated to 10% loss in light output, 5-year warranty, etc.) While LED's will save energy and thus have lower cost of operation, the initial price for

LED fixtures is high. Overall, the economic decision about which lighting system to adopt is complicated and based in part on the months of the year lighting is needed, number of hours fixtures will be operated per year, number of years they will be used, upfront cost, maintenance, and installation costs. It is recommended to contact several lighting manufacturers and compare their quotes and technical specifications.

Carbon Dioxide (CO_2)

Carbon dioxide is an essential reagent for photosynthesis, and supplementing CO_2 to about 1,000 ppm (ambient air is about 400 ppm) can lead to increased plant growth and yield. *Cannabis sativa* has demonstrated enhanced water use efficiency and net photosynthesis with supplemental CO_2, although the increase varied among cultivars. Levels can be measured using CO_2 monitors and detectors.

NOTE: Increased levels of CO_2 in enclosed environments can have negative effects on human health. OSHA requires that CO_2 concentrations are less than an average concentration of 5,000 ppm.

Several systems can be used to add supplemental CO_2:

Compressed Tanks

Also known as liquid carbon dioxide, this popular method delivers vaporized CO_2 and distributes it through holes running throughout the growing space. Due to precision and ease of use this is typically a more expensive form of delivery that comes by the truckload to fill up large tanks for commercial growers but can also be supplied in individual tanks for smaller grows.

Compressed tanks can be explosive and cause other danger. For hazard reduction, the tanks are required to have a pressure regulator, flow meter, solenoid valve, CO_2 sensor, and timers.

Combustion Sources

Utilizes combustion of fossil fuel (ex. natural gas) to generate carbon dioxide, energy, water, and heat. The rate of combustion, efficiency, and amount needed depends on the purity and type of fuel used. Distribution is usually done in a downward fashion from above the plant coupled with sufficient air circulation. Typically, one large gas engine is utilized and processed through multiple filters to provide pure CO_2.

This is as a more sustainable practice since it can provide heat and energy, in addition to CO_2. The heat is captured from the combustion reaction and stored in a reservoir of water to be later used for environmental control. Issues with combustion CO_2 sources are that if a flame is not firing properly there can be off-gases such as carbon monoxide (with corresponding human risks), nitric oxide and ethylene (which can damage plants).

Decomposition and Fermentation

The natural microbial decomposition of organic materials can produce adequate levels of carbon dioxide. A simple breakdown of organic waste in a container that can capture and distribute it would suffice. Depending on the operation type and size, this method can take up large amounts of space and can vary in the cost of total input (depending on your source of organic waste material). These methods are typically not considered viable at a commercial scale.

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Dry Ice
Dry ice is a solid form of CO_2 and since it cannot readily transition into a liquid state, the solid form sublimates right into the gaseous state. This is one of the cheapest methods of administration. Depending on size of operation this can be used as an environmental coolant as well (typically for small scale/hobby grows).

Utilized with special cylinders integrated with a gas flowmeter to control/monitor sublimation rates of the dry ice. Approximately one pound of dry ice can supply up to 1,300 ppm in a 100 ft^2 area/day. Larger scaled operations typically distribute the CO_2 by placing broken up pieces of dry ice in insulated containers with release holes throughout the greenhouse that can last the entire day.

Chemical Method
An expensive alternative but can be adapted to both small and large scale grows. The reaction between baking soda and an acid (typically acetic acid) produces CO_2. To obtain necessary levels, a large amount of materials is involved; about 10-12 liters of 5%-acetic acid combined with two pounds of baking soda can generate one pound of CO_2. The acid is slowly released or dripped onto the baking soda which will extend the length of the reaction but is time intensive and can have variable resulting concentrations. (Typically for small scale/hobby grows).

Modified from Oklahoma State University Extension (2017)
https://extension.okstate.edu/fact-sheets/greenhouse-carbon-dioxide-supplementation.html

Temperature

Temperature controls plant biochemical processes such as photosynthesis and developmental processes such as leaf unfolding rate. Different C. *sativa* varieties may differ, but in general 25-30°C (77-86°F) day temperature is optimal.

Relative Humidity and Vapor Pressure Deficit

Relative humidity (RH) is another vital environmental control, which measures the amount of moisture in the air and is described by the percent of water being held in the air. Vapor pressure deficit (VPD) is a more accurate way of describing the environmental moisture content and the driving factor for transpiration rate of the plant. VPD is the difference in the amount of water in the air in relation to the amount of water that can be held at a specific temperature and is generally measured in kilopascals (kPa). Warmer air holds more water compared to colder air.

RH and VPD are inversely related meaning that when there is a high percent of RH in the air, the VPD is low; therefore, low RH equates to high VPD. One can functionally affect transpiration rates of the plant with adequate modification to VPD. A hydrated leaf has near 100% RH and lower water content in the air creates a gradient in which is favorable for water to evaporate from the leaf and enter the atmosphere.

Air with low RH has greater driving transpiration forces than air at high RH. Transpiration rate is important to measure as the driving force of water loss in the plant and plays a key role in nutrient and water uptake/distribution, net photosynthesis, regulating internal temperature, and various other metabolic activities throughout the plant.

Plants are more sensitive to leaves and inflorescences disease infections (such as botrytis and powdery mildew) at high RH (low VPD).

Recommendations:

- During juvenile, vegetative, and flowering life stages (Jin et al., 2019)
  - 25°C (77°F)
  - RH/VPD
    - RH 75% VPD of 0.8 kPa for juvenile plants
    - 55-60% RH for vegetative & flowering 1.3-1.4 kPa

High VPD and low RH may result in stunted growth, rapid transpiration, potential drought stress (leading to other stresses), and increased pest and nutrient sensitivity in the seedling/propagation stage.

Low VPD or high RH are reduced transpiration rates, decrease in nutrient uptake, condensation production on leaf tissue, and a favorable environment for disease.

Indoor Temperature and Humidity Control

In indoor growing the HVAC system (heating, ventilation, and air conditioning) is used to control temperature, airflow and relative humidity/VPD. An HVAC system must be sized appropriately to the facility by an engineering professional familiar with plant applications. Typically, a much larger HVAC capacity is required than traditional warehouse applications (such as shipping and receiving centers, industrial manufacturing) which is due to the high lighting capacity (meaning there is much waste heat to remove regardless of whether HPS or LED fixtures are used) and a large need for dehumidification due to plant transpiration of water.

Air Flow

Air movement is important regardless of whether an operation is using greenhouse or indoor growing. Air flow leads to uniform distribution of environmental conditions (temperature, relative humidity, and carbon dioxide) and reduces surface moisture which can exacerbate disease issues. Forced air systems such as horizontal air flow (HAF) or fan-jets are ways to help prevent/reduce problems that come with inconsistent relative humidity and provide uniform distribution of carbon dioxide and continuous wiping of the leaf surface. For HAF, for each 50 ft of greenhouse space there should be another row of fans.

HAF is optimized with a slight tilt downward. Other types of air distribution approaches consist of convection tubing above or below canopy and vertical air flow fans.

Greenhouse Heating and Cooling

Greenhouses must have either unit heaters or centralized boilers sized sufficiently for their greenhouse structure by a greenhouse engineering professional. There are many options available for the type of fuel that can be used and fuel choice such as: electric, propane, natural gasses, fuel oil, and biomass (ex. wood). Fuel selection generally depends on what is available and least expensive to the producer.

For more information, please visit: https://ag.umass.edu/greenhouse-floriculture/fact-sheets/fuels-alternate-heat-sources-for-commercial-greenhouses

Because greenhouses trap solar radiation during the day, the greenhouse environment can heat up excessively requiring cooling.

To properly manage heat, implement passive and/or active cooling systems.

Passive cooling:

- Shading (physical or chemical)
  - curtains
  - seasonal shading compound (applied to the greenhouse paneled ceiling)
- Ventilation (eg. opening side walls and roof vents)

Active cooling:

- Forced air ventilation/fans
  - vents open on one side of a greenhouse to let cooler outdoor air in while fans on the other side blow hot/humid air out of the greenhouse
- Evaporative cooling pads
  - utilizes cooling pads and a form of exhaust fan/vacuum to pull warmer air from outside
  - often coupled with an algaecide to reduce the buildup of unwanted organisms

Evaporative cooling system. *Photo: Andrew Demetri*

Control Systems

These are the various environmental control systems that can be integrated for improved accuracy, precision, and potential autonomy. The four main categories of control systems are given below. Typically, small/seasonal greenhouse operations may use thermostats (on/off) switches or staged controllers while larger operations will use integrated controls for which there are a handful of commonly used greenhouse climate control systems.

Manual Controls
Manual initiation: physically adjusting a thermostat to a different temperature or manual irrigation. Generally, for smaller scale operations, more labor involved and less initial investment. Can also be used as an emergency control for other systems.

On/Off Switches
Similar to manual control, but with a digital interface allowing for changes based on a timed schedule and temperature ques. Can improve labor costs and margin for human error but are limited to one controller per environmental control.

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Staged/Step Controllers
May have capability to control multiple environmental parameters and to establish threshold values for change. Includes staged heating/cooling for seasonal changes and has sensory recognition capabilities for temperature and relative humidity. Programming features available. Most systems do not offer control over carbon dioxide, lighting, or irrigation. Avoids having multiple on/off switches while saving energy.

Integrated Controls
Controlled by a main computer system that uses more accurate sensors and makes decisions based on multiple environmental cues integrating to provide optimal environment adjustments. For example, manipulating ventilation and cooling to provide adequate VPD. Can keep data records and primarily depend on threshold values while saving energy and providing an autonomous and accurate way of cultivating.

Modified from Professor Neil Mattson's class on Hydroponics, Cornell University

Detectors & Sensors

pH/EC Meter
pH and EC (Electrical Conductivity) can be monitored directly through the irrigation/fertigation system. A substate lab test may be necessary for direct measurements about what the plant is receiving. A way to get this information is by using the pour-thru method, where plain water (without fertilizer) is poured through the substrate of the plant until it comes out the bottom of the pot/medium and is captured for measurements of pH and EC.

Measuring probes can come separately or in tandem. Electrical conductivity can be referred to in decisiemens per meter (dS/m) or parts per million (ppm).

Light Meters
A quantum sensor will measure light quantity through the total sum of photons hitting a specific area in a given time (units: umol/m^2/s).

Measuring the quality of light received can be done using a spectroradiometer, which measures the total sum of photons at specific wavelengths in an area (units: nm).

Pyranometers measure total solar radiation from the sun's intensity outside of a greenhouse (units: W/m). Different quantity and quality of light can alter a plant's growing strategies and proficiency. See the Artifical Lighting section for more information on quality and quantity of light affecting plant growth.

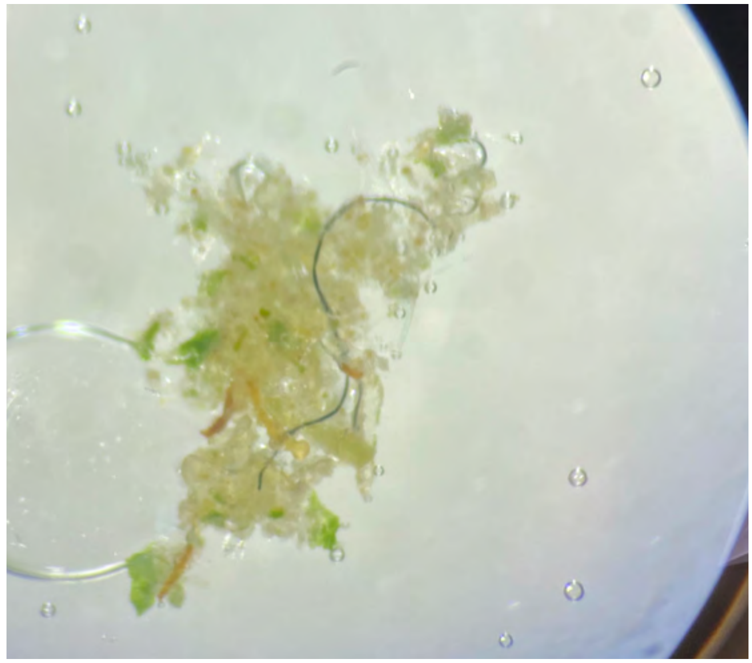
Modified from Professor Neil Mattson's class on Hydroponics, Cornell University

Worker Hygiene

Sanitation is a primary interest when working with a high value crop like high-cannabinoid C. *sativa*. Sanitation is also a cornerstone for most integrative pest management practices, to reduce damaging pests, diseases, or weeds. To reduce outside contamination such as microfibers, insects, pollen, hair, among others, consider:

- Laboratory coats
- Disposable clothing (or specific clothes to wear in certain rooms of the facility)
- Hair covers
- Sanitizing mats to step in
- Shoe covers
- Sanitizing mixtures to wash hands

Additional sanitation measures include air purification, UV-C lights, discarding of old plant/facility materials, and cleaning the rooms of plants once a rotation is done (i.e., vegetative rooms and flowering rooms).



Microfibers in processed *C. sativa* sample.
Photo: Andrew Demetri

Cultivation Practices

Cultivation practices such as stress training and super cropping (pinching and bending branches) are common but lack rigorous studies. Some practices are for ease of growing and may not increase plant yields. Stress training and super cropping describe cultivation techniques thought to alter the plant's growth forcing the production of higher floral or secondary metabolites. These techniques may play a role in total floral and secondary metabolite yields and may help induce increased efficiencies.

Photo: Andrew Demetri

Suggested Cultivation Practices

Cultivation Type	Description
Topping  *Photo: Faith Ann Sparks*	The apical meristem is cut forcing secondary branches to become more prominent, leading to a more uniform canopy with multiple primary inflorescences. Topping may provide increased cannabinoids due to a possible increase in overall yield, wet/dry biomass yield, and number of secondary branches. Some report a negligible difference between topping and other pruning strategies.
Lolli-popping  *Photo: Faith Ann Sparks*	Pruning off secondary branches and leaves to maintain/enhance prime floral producing branches. Typically applied prior to the flowering stage and results in a grow room with reduced foliage which may reduce pest pressure and improve pest monitoring. Total CBD production is significantly higher in the top-fraction of the plant's inflorescences compared to the lower half.
Environmental Manipulation	The application of stress to plants including, end of production drought, salt, light deprivation, etc... are practices that attempt to increase cannabinoid/inflorescence production. However, few studies have evaluated these approaches and they may reduce overall plant yield.
Trellising  *Photo: Nicholas Kaczmar*	Uses a net or trellis to provide support for floral biomass while increasing canopy uniformity. Some growers use multiple layers as the plant grows and matures. This practice requires physical manipulation of the plant growing through the netting that can lead to physical support, air flow, and light penetration. Trellising may make sampling, moving, or removing plants more challenging.
Crop Schedule & Harvest Timing	Some facilities have plants grown from seedling/clone to harvest in the same room, whereas others have different rooms specifically suited for each growth stage of the plant. (Separate rooms for each growth stage can be useful for year-round growing, sanitation, and product producing efficiency). It ultimately falls upon the practicality of your operation to do either. In a one room grow style it can be easier for the plants to acclimate to the new environmental changes. A crop rotation schedule could be as follows: • Seedling/clone room into a vegetative growth room into a flowering growth room via rolling benches or physical replacement. • After each replacement, sanitation and a new batch of crops can then restore the space in the prior room ◦ optimizes space-use efficiency and crop scheduling

Cannabinoid Harvest and Processing

The flowering stage under natural light in northern latitudes, as previously noted, generally occurs from late August through September. The timing is dependent on daylight hours and the photoperiod requirement of the varieties being grown.

Harvest Timing

Harvest of a high-cannabinoid Cannabis crop is dictated by its THC amounts in order to remain compliant with regulations. The concentration of CBD and CBC increases at a fixed ratio with THC (26:1 CBD:THC), meaning peak maturity occurs as the THC approaches the legal limit of 0.3%. When ready, the whole plant should be harvested and transported immediately into the drying process.

Harvesting for cannabinoids is a very intensive labor as is mostly done by hand. Supplies needed:

- trimmers and pruners
- gloves
- hanging clips or ropes for drying

There are some mechanized harvest options that include mechanical trimmers which offer a better option to clean the flowers. However, hand labor is still required to cut the plants and the branches and put them into the trimmer.

Drying

Drying flower branches after harvesting. *Photos: Daniela Vergara, CCE*

It is important that the humidity and temperature are controlled during the drying process. It is common to use barns for this process, though it is not the only drying option. These barns allow for a controlled environment where heat can be applied to the crop to limit humidity, while also pushing a significant amount of air through the crop to dry the material.

The typical drying time using a barn is 3-to-4 days from 60-70% field moisture to 8-12% in the floral material in a tobacco barn. If using a sweet potato curing facility, expect the drying time to range from 6-to-10 days. Regardless of infrastructure, it is important to encourage maximum airflow and removal of humidity and moisture from the plant material. Continuous airflow and quick drying are key to mold prevention.

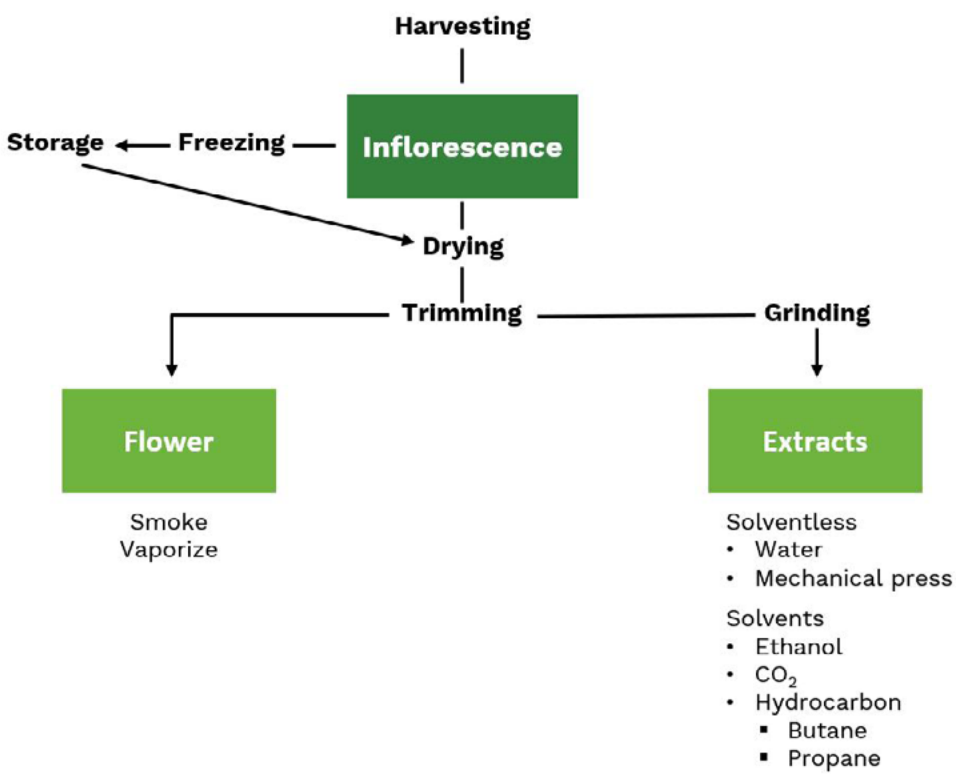
Consider that your drying space area must be approximately 1/4 of your flower canopy area. So, in a hypothetical example, if you have 100 ft^2 of flowering area, you will need approximately 25 ft^2 of drying space. Consider drying vertically to make use of the space, and a staggered harvest to have multiple turnovers in the drying space.

When drying in a barn, consider the following:

- Maintain drying temperatures below 120°F (48°C)
- Push as much air as possible during the drying process
- Maintain relative humidity inside the barn below 40%
- Bulk boxes can be utilized, or plants can be placed directly into the barn without boxes or racks

Trimming and Stripping

After drying, it is recommended to strip the plant's floral material from the stalk which can be done by hand or using mechanical buckers. This allows for only the flower and leaf material to be collected. The more stalk/fan leaf material in the finished product, the lower the quality. During this process, the moisture level should be maintained at 8% or lower for storage before purchasing to prevent mold from forming.



Cannabinoid processing, from harvest to final products.

There is also an opportunity to trim the flower prior to drying and then use a forage dryer or to freeze the crop. Freezing may be a good way to store the crop long-term. However, freezing comes with potential problems during the thawing process.



Collected flower after drying and trimming (left and right). *Photos: Daniela Vergara, CCE*

Once the flower is dry, it can be sold as a smokable flower, or can be processed for cannabinoid and terpene extracts.

Cannabinoid Processing

There are multiple ways in which cannabinoids and terpenes can be extracted from the flower to produce different types of resins and extracts. These multiple ways include solvent-based methods such as ethanol, other hydrocarbons like propane and butane, oil (such as common butter), and CO_2. Since cannabinoid and terpenes are lipophilic, which means that they dissolve in lipids (fats), the extraction methods include lipophilic solvents. Other ways to extract cannabinoids and terpenes include solventless methods, which are more physical instead of chemical based, and are therefore solvent free. These methods include heat presses as well as ice water washing and dry sifting.

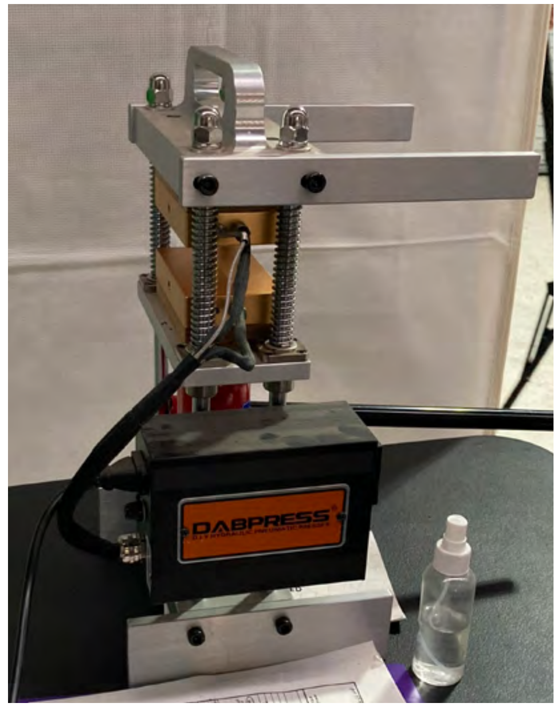
Hydrocarbon extractions can be dangerous due to the combustibility of compounds such as butane. These extractions, when carefully performed, allow for both the terpenes and cannabinoids to remain in the final product. Many companies use these methods to preserve the terpenes that are highly volatile. To implement these extraction practices, make sure to abide by the specific laws and regulations, and that they are performed by adequately trained personnel.

- New York State processors should visit the Office of Cannabis Management website to understand the appropriate regulations: https://cannabis.ny.gov/processors

In ethanol and butane reactions, to extract the ethanol and butane, these must evaporate which is usually done through heating. Since cannabinoids have a higher boiling point than either ethanol or butane which have a lower boiling point, ethanol and butane evaporate quicker leaving a residual-free resin.

In a CO_2 supercritical extraction, the flower is placed in a container where the CO_2 is forced under both high temperature and pressure into a super critical phase which has properties of both a liquid and a gas. As a supercritical fluid, CO_2 is a highly tunable solvent and by changing the density through temperature and pressure terpenes, cannabinoids, and other plant compounds such as flavonoids can be selectively solubilized.

Solvent-based extraction methods. Top: ethanol extraction with decarboxylation reactors. Bottom: CO_2 extraction machine. *Photos: Daniela Vergara*



Solventless press machine with heat.
Photo: Daniela Vergara

Different kinds of concentrates through various methodologies. Left: Badder (concentrate whipped under heat). Center: Resin (ethanol-based). Right: Shatter (solvent-based). *Photos: Daniela Vergara*

Product Integrity and Contamination (Cannabinoids)

Cannabinoid products have high standards of integrity, and the criteria varies by state or jurisdiction. However, general guidelines include:

- No mold contamination (particularly important during the drying stage post-harvest)
- Testing for:
  - THC (and the acidic form THCA) are mandatory to remain compliant under the federal law
  - heavy metals
  - mycotoxins
  - bacteria presence

Refer to the Testing section for more information on specific tests.

Grading and Market Preparation

Plant material that does not contain trichomes (resin on the floral material) will decrease quality, therefore the cleaner the floral material after post-harvest handling, the higher quality. This also ensures that the products made from the flowers will also have high quality. Avoid stems, leaves, stalks, and other non-flower materials that will decrease the overall cannabinoid percentage.

The price of cannabinoid flowers and products usually depends on cannabinoid and terpene concentration, which is determined by the variety of C. *sativa* but also on the growing conditions. If grown indoors, light is a critical factor for secondary-metabolite production.

Important Lab Techniques

triploid varieties, sex reversal, micropropagation, and genetic testing

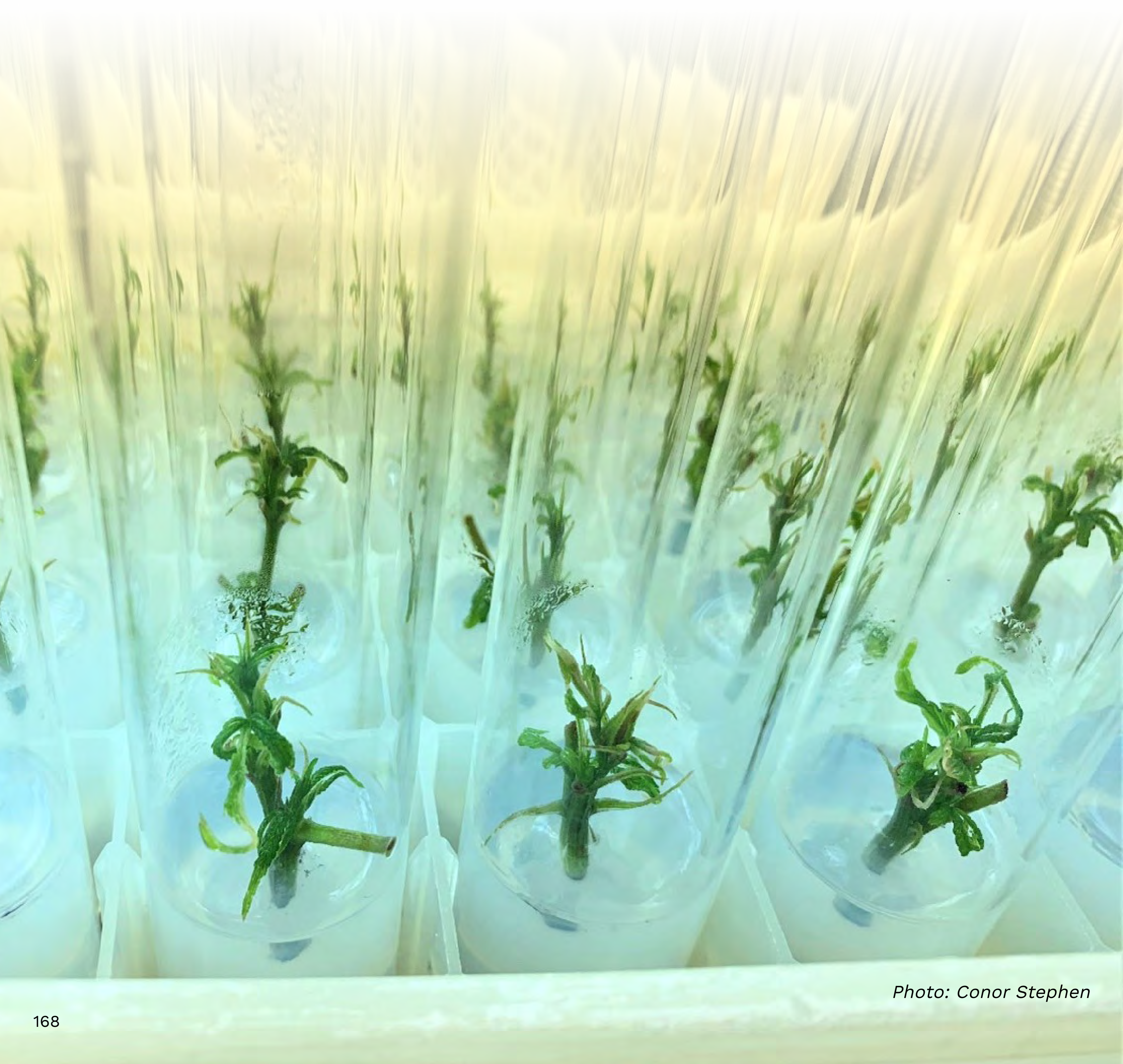


Photo: Conor Stephen

Triploid Varieties

Cannabis sativa, as humans, is naturally a diploid organism. This means that one set of chromosomes containing half of the genetic material comes from one of the parents (eg. mother), while the other set of chromosomes containing the other half of the genetic material comes from the other parent (eg. father). The prefix 'di' comes from the Greek 'two', in this case, two sets of chromosomes.

Polyploidy is a state in which an organism contains more than a pair of homologous chromosomes in its cells. Polyploidy is common in plants, in angiosperms as well as other higher taxa, and it's associated to domesticated plants because multiple agronomically favorable traits are found in polyploid plants, perhaps due to the increase in genome size. This increase in genome size also increases genetic diversity and therefore the possibility of bearing favorable traits such as disease resistance, or the ability of adapting to different environments. Additionally, because natural and artificial selection have more material in which they can act on, they can be more effective. Polyploid individuals may display gigantism, which may be appealing for domestication. In strawberries, for example, polyploids are larger and therefore more desirable. Additionally, polyploidy is found in approximately 30% of cultivated crops, including strawberries, bananas, and mustards.


Inflorescence from a triploid *C. sativa* variety that may display a rare example of fasciation.
Photo: Daniela Vergara, CCE

Triploid plants are one example of polyploidy, where there are three copies of each chromosome. Since the gametes formed by these plants have an unequal number of chromosomes, these triploid embryos differ in their levels of fertility and in their phenotypic characteristics. Additionally, because of the errors in meiosis in polyploid individuals particularly in triploids, many of these efforts result in seedless varieties, which could be highly advantageous. For example, in watermelon, the abnormal meiotic pairing in triploid individuals resulted in seedless varieties which are highly sought, as well as triploid sugar beets with larger roots important for commercial purposes. Because of the uneven sets of chromosomes, triploid C. *sativa* individuals should be sterile and should not produce any seeds even in the presence of nearby pollen.

Despite the low sample sizes, polyploid high THC Cannabis plants have been developed. These projects have descriptions of the production of tetraploid plants which had larger fan leaves, an increase in trichome density, and larger but more sparse stomata. These tetraploid individuals had tendencies of higher yields, but there were no differences in whole plant weight, weight of trimmed bud, or in the final dry weight of buds, indicating that chromosome doubling had little effects on plant growth, maturity, or yield. Additionally, these individuals had a slight increase in CBD and sesquiterpenes, but no significant increase in THC. Overall, terpene content was more variable in the tetraploids compared to diploids. Another characteristic of these tetraploid individuals was reduced rooting. This research concluded that tetraploid C. *sativa* plants grow normally despite the reduced rooting with comparable chemotypes to diploids.

A big caveat of this investigation is that only two varieties were used, and only one of them was successful at rooting and at developing mature tetraploid plants. Therefore, all measurements and conclusions are based on a single variety. With this extremely low sample size it's inconclusive whether there is within and between variety variation in the ability to produce tetraploids.

The triploid varieties tested in the field trials at Cornell were produced by the company Oregon CBD. The height of the triploid varieties was not significantly different from the height of the diploid varieties.

Variety:
- Lifter Seedless
- Pine Walker Seedless
- Sour Lifter Seedless
- Sour RNA Seedless
- Sour Suver Haze Seedless
- Suver Haze Seedless
- White CBG Seedless

Sex Reversal

Cannabis sativa has monoecious and dioecious lineages. Dioecious lineages have males and females in different plants, while monoecious individuals produce male and female flowers in different locations on the plant. In dioecious lineages, sex is primarily determined by sex chromosomes with males carrying an XY pair, and females an XX pair. Monoecious lineages lack a Y chromosome. Refer to the Female, Male, and Monoecious Plants section.

Flowers of the opposite sex in C. *sativa* can be induced with feminizing or masculinizing chemical agents even in mature plants that have already been sexually differentiated, commonly referred to as 'sex reversal'. Therefore, using this technique female plants can be induced to produce male flowers and therefore pollen. Similarly, males can also be induced to produce female flowers.

This technique is mostly used for female plants to self-pollinate or to pollinate other females, and therefore the offspring will lack a Y chromosome. This is the way in which feminized seeds are produced, which lack a Y chromosome. Therefore, these feminized seeds guarantee the absence of a Y chromosome, however, monoecy could still happen in low ratios (and therefore the production of male flowers and pollen) and some of these feminized individuals could still be sex reversed to produce male flowers and pollen.

Ethylene is a hormone that has been found to be an important modulator of plant growth and development. In plants such as melons and corn, sexual identity is due to hormone-mediated gene expression apparently by ethylene levels. Chemical compounds such as silver nitrate, colloidal silver, or silver-thiosulphate are widely used by breeders in the C. *sativa* industry to induce sex reversal in female plants, producing male flowers. Silver nitrate is a known inhibitor of ethylene action.

On the other hand, ethephon is an ethylene-releasing agent, which has been used to reverse the sex of males to produce female flowers. These two chemical compounds which have successfully been used to reverse the sex of inflorescences on male and female individuals.

Plants undergoing sex reversal to produce male flowers for self-pollination. *Photos: Akio Lloyd*

The moment to start the sex reversal is right after the plants are transferred from the vegetative stage into the flower stage and the lights are diminished for 17:7 for one week, and then to 16:8 until pre-flowers appear. Plants should then be placed into a 12:12 light regime to induce full flowering. Treatments with ethephon and silver nitrate should continue every day for the next three weeks.

Cannabis sativa Micropropagation

Plant tissue culture is the growth of plants on a sterile, nutrient medium *in vitro* under controlled environmental conditions. More simply, it is the act of sustaining living plant material in a sterile environment. Tissue culture is a powerful *in vitro* technique that can be used for propagation, germplasm storage, breeding, crop preservation and improvement, and much more. It is a process that requires a high degree of cleanliness, special equipment, and technical expertise. There are many uses for tissue culture, but the most commercially important use is for asexual micropropagation, or clonal propagation, of plants *in vitro*. Plant micropropagatioin began to become commercialized in the 1960's and has been an important tool for the agricultural industry ever since.

Asexual propagation is commonly used to produce and maintain entirely female clones of C. *sativa*. Growing C. *sativa* directly from seed poses a potential risk for growers because the segregation of traits often causes inconsistent vegetative growth and flowering. Although, in certain circumstances germinating valuable genotypes *in vitro* may be necessary to restore a highly valuable genetic line, it is not necessary for most breeders. There are several advantages when micropropagating C. *sativa* in tissue culture. It is a clonal (asexual) propagation system, the plant material is clean and vigorous, it is an efficient use of space, the plants require less maintenance than if grown in the field or greenhouse, and it offers year-round production with proper planning and execution.

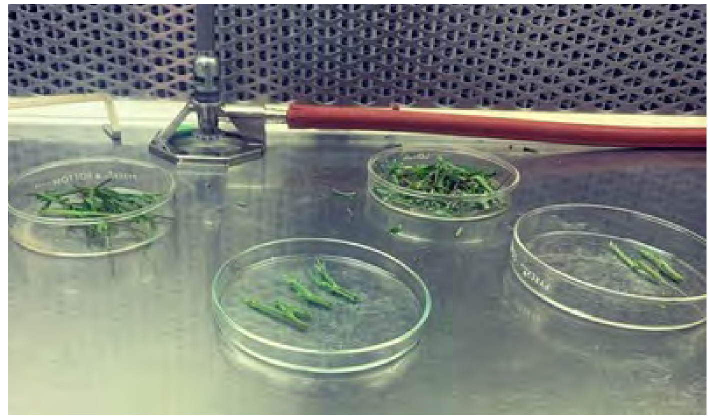
Tissue culture is a technique that allows scientists to preserve their best C. *sativa* plants for future cultivation. By employing tissue culture, a producer may create a 'library of plants' to rotate into the production system or breeding program. One of the biggest advantages offered by tissue culture is the possibility of producing disease-free plants on a large scale. Furthermore, if there is a particular plant of a cultivar with important phenotypic (physical) or chemotypic (phytochemical) characteristics that a grower wishes to conserve for future breeding applications, tissue culture is a great way to assure that the grower has clones of that plant.

Tissue culture is not a replacement for traditional breeding, but a valuable asset in a traditional breeding program. It does not generate new sexual combinations in mass quantity, but rather it preserves valuable phenotypes that are already established. There are *in vitro* techniques that can be used for the generation of new plants, but micropropagation is not one of them. This is a technique that requires highly *skilled* personnel that understand *aseptic technique* and *laboratory* safety protocols. This approach requires a well-equipped laboratory with specific equipment and supplies such as a *HEPA-filtered* flow hood, chemical compounds, artificial media, an autoclave, and other expensive equipment. Sterile environment is crucial when working *in vitro*, as micropropagation is a meticulous process in a tidy, organized setting.

Micropropagation consists of five stages. Stage 0 is the initial step in micropropagation and involves the proper selection and growth of stock plants. Stage I is the establishment of aseptic cultures. This is often achieved using a disinfecting agent to achieve explant surface sterility. Stage II is the multiplication phase in which plantlets are grown for weeks at a time and shoots are subdivided until the desired number of propagules are attained. Stage III is the period in which root induction occurs, and Stage IV is when plants are acclimatized and finally transitioned to the environment in which they will be grown. Often, Stages III and IV are combined into one step to save time and money.

Stage I of tissue culture can be performed with seeds or nodal cuttings as the starting plant material, called an explant. Explants can be disinfected with ethanol and/or bleach followed by a thorough rinse with deionized distilled water (ddH_2O) while working in a sterile environment. Concentrations of 70-75% ethanol and up to 20% sodium hypochlorite (the active ingredient in common household bleach) are adequate to sterilize the surface of a wide range of C. *sativa* tissue without killing it. The concentration of ethanol and bleach will vary depending on the health and type of explant tissue. If the explant is herbaceous tissue, the desired tissue should be excised with a sharp razor or blade before sterilization, taken to the flow hood, sterilized with ethanol and/or bleach, and rinsed with sterile ddH_2O. After sterilization, the explant should have injured tissue aseptically removed. Once the tissue has been trimmed and the basal region recut, the explant should be placed immediately into sterile medium for tissue regeneration and growth. Generally, the explants will require subculturing onto fresh medium once every three or four weeks until the cultures are advanced through stage IV and ready to enter the production pipeline.

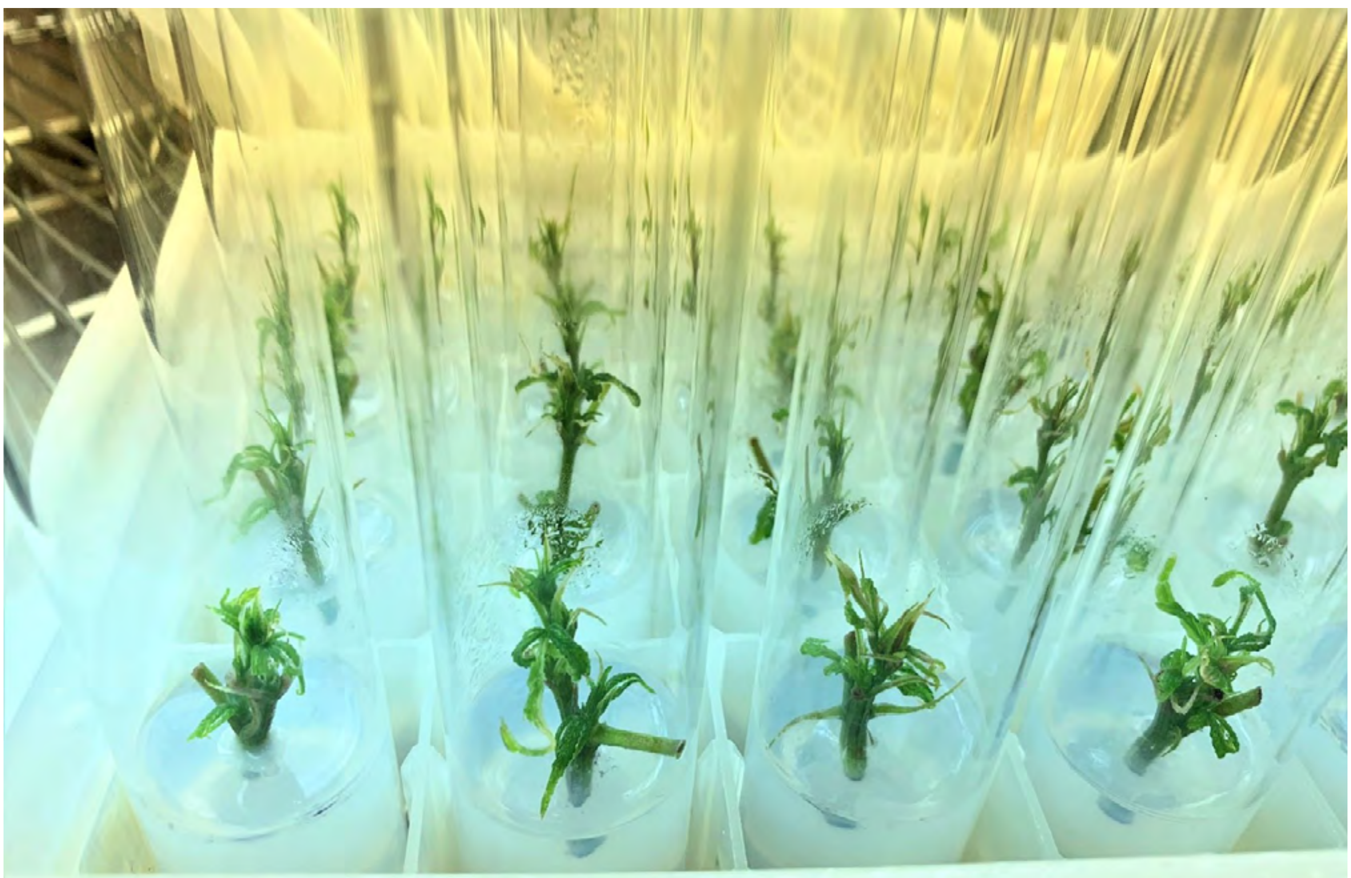
Supplies sterilized by autoclave at 250°F (121°C) 15 psi are used to incorporate filter-sterilized additives to semisolid media while the media is still liquid before dispensing into sterile culture vessels. All steps in media preparation are recommended to be performed on a sterile work bench like a laminar flow hood (pictured above). *Photo: Faith Ann Sparks*



The choice of *C. sativa* explant depends largely on the desired outcome as well as the genotype of the tissue. Here, the desired outcome of the tissue culture system is a healthy and strong replacement for the original mother plant from which the cultures were derived. The technician experiments with apical nodes and axillary nodes to understand more the impact of vegetative bud positional differences on *in vitro* growth and tissue development. *Photo: Faith Ann Sparks*

Healthy *C. sativa* cultures will develop a dark green hue and crisp fresh scent similar to healthy, *ex vitro* vegetative *C. sativa* plants. *Photo: Faith Ann Sparks*

Newly initiated *C. sativa* explants in Stage 1 of micropropagation. *Photo: Faith Ann Sparks*


Each *C. sativa* genotype has a unique demand for nutrients. Analyzing the growth response of the tissues in vitro provides clues to toxicities or deficits in the growth medium. Other environmental factors like low light levels and excessive humidity can have negative consequences to the health and vigor of micropropagated plant. *Photo: Conor Stephen*

In the later stages of micropropagation roots are encouraged and plants are hardened for transplant into soil in a process called, acclimatization. Pictured above is a micropropagated *C. sativa* plant with roots. *Photo: Andrew Demetri*

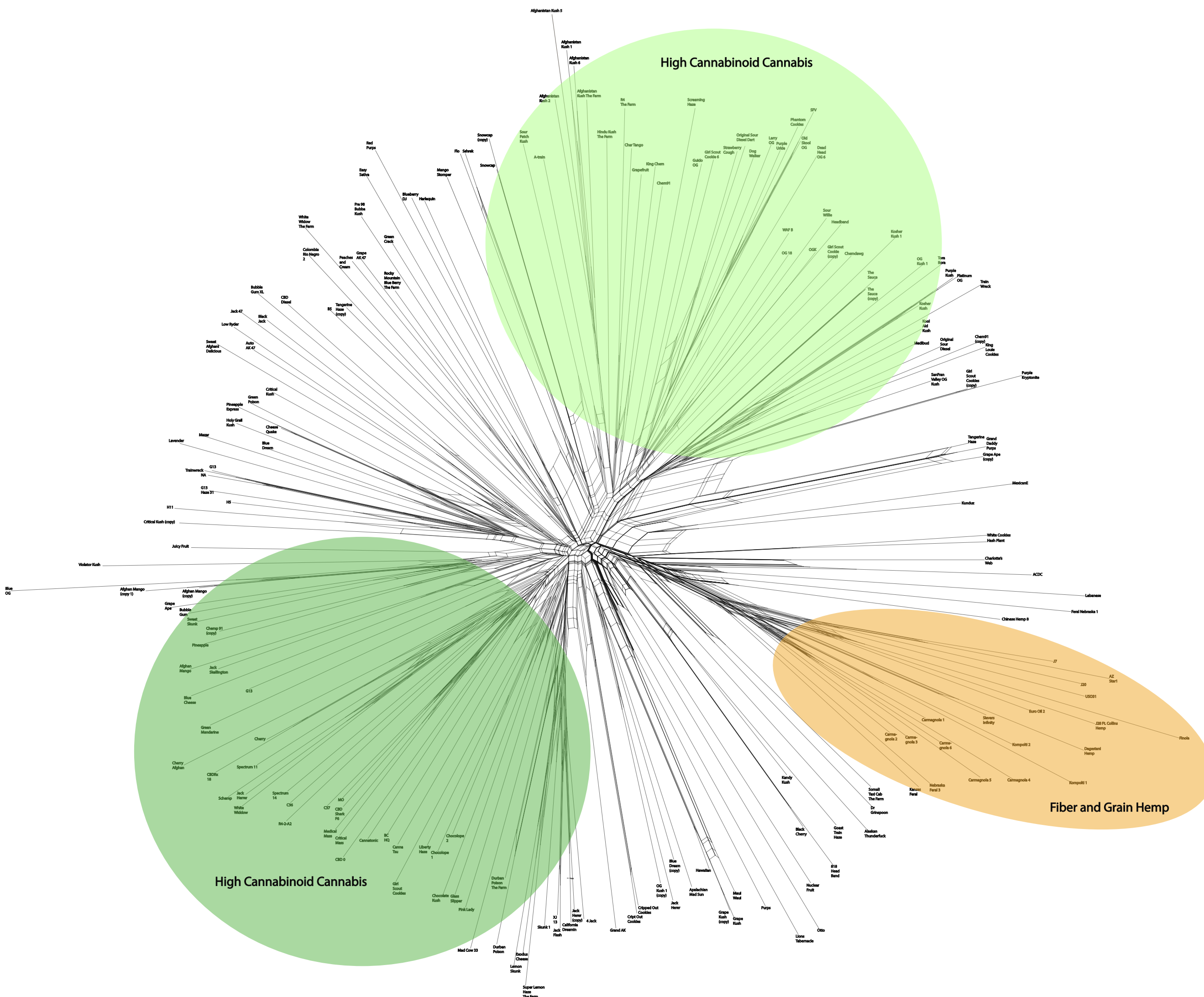
Genetic Testing

There are multiple genetic tests available for C. *sativa* varieties. These tests rely on either sequencing parts of the genome or assaying single nucleotide polymorphisms at known locations in the genome.

The genome is the entire collection of DNA, the genetic material from an organism. *Cannabis sativa* individuals have 9 autosomes (chromosomes not related to sex) and X or Y sex chromosome. The Y chromosome is absent in monoecious lineages.

There are different ways of sequencing a genome. Some sequencing methodologies transcribe all the letters in the genome (Whole Genome Shotgun; WGS), other methodologies only sequence some of the genomic regions (eg. Genotyping by Sequencing; GBS). There are advantages and disadvantages of these different methodologies, but since WGS sequences the entire genome, all (or most) genes will be sequenced.

When analyzing the genome of multiple C. *sativa* varieties, there are multiple genetic clusters in but a consensus point to at least two high cannabinoid lineages and a lineage of hemp bred for fiber and grain. Some studies suggest another lineage of hemp from China. The regulatory definition of hemp as containing <0.3 THC and descriptions of sativa or indica groupings do not correspond well with this genetic relationship.



Splits tree graph showing the relationship between approximately 300 *C. sativa* varieties, and the different lineages within the species. *Figure modified from Lynch et al. 2016*

The figure above, called a Splits Tree graph, shows the relationship between approximately 300 different C. *sativa* varieties. Each of the lines is a variety and the closer the lines, the more related they are sharing a greater portion of the genome. Two lines (varieties) that are very close together share a lot of their genome. Therefore, varieties that come from clones should be very close together as they should share all (or most) of their genome. The threadlike structure in the middle of the figure represents the region of the genome that is shared between all individuals, in other words, the ancestral part of the genome. Depending on how the graph is divided we can see between 3-7 different groups. The hemp individuals used for fiber or oil form a lineage, with varieties such as 'Finola, 'Carmagnola', or 'USO-31' among others (orange lineage). There are at least two high cannabinoid Cannabis groups with varieties traditionally found at dispensaries used for medical or recreational purposes.

These genome analyses, which have been extremely useful to identify clones, have shown that varieties with the same epithet (eg. 'Girl Scout Cookies') may not be related to each other and are scattered throughout the graph. Although this is not the case for all individuals as there are some varieties that do cluster together (eg. 'Chocolope'). Genome analyses are extremely useful to understand relationships between individuals, which could be achieved through either GBS or WGS. However, in addition to identifying whether individuals are related to each other, WGS also provides the opportunity of analyzing genes of interest, and other genomic regions such as the repetitive content (also known as the 'junk DNA'). GBS generates a big amount of missing data that must be imputed and using actual genetic data rather than imputation provides an accuracy as high as 30%.

These genetic tests can be also used to identify whether individual plants have the potential to be male or to produce high THCA or CBDA. These tests are usually done via PCR (Polymerase Chain Reaction), a molecular biology technique that amplifies a targeted DNA sequence. In other words, PCR allows to generate millions of copies of a specific genomic region.

Male Genetic Tests

In the case of testing for males, we know of particular genomic regions that may help to identify the presence of the Y chromosome, called MADC (Male-associated DNA sequences). Although these MADC markers may be useful to detect the Y chromosome, they do not report monoecy. They only give information on the presence of the Y chromosome and no information as whether a particular female has the ability of producing male flowers.

Cannabinoid Genetic Tests

Another widely used genetic test in the industry detects the genes that synthesize THCA and CBDA. Although originally it was thought that THCA and CBDA were two different alleles (form of a gene) at the same gene, now we know that these are different genes in close proximity in the genome. In other words, until 2015 we thought THCA and CBDA were the same gene, and that this gene had two different forms (alleles): THCA and CBDA which were codominant—they could both be expressed and one was not recessive or dominant to the other. These were called the BD and BT alleles, and this locus was called the B locus. BD/BD individuals produced high CBDA, BT/BT individuals produced high THCA, and BD/BT individuals produced both CBDA and THCA. Therefore, plants could have high THCA (Type I), both compounds (Type II) or high CBDA (Type III).

In 2015 it was found that CBDA and THCA were not two alleles from the same gene but were different genes in close proximity. Even though the phenotypes may still hold and there are plants that produce one, the other, or both compounds, we now know that these are multiple genes that vary in number and are in the same genomic region. These different genes can have multiple alleles of their own. It has been found that individuals that produce high THCA usually have a truncated (incomplete) CBDA locus, and those that produce high CBDA have a truncated THCA locus.

Additionally, it is also common in the industry to refer to Type IV C. *sativa* to those plants that produce high CBGA (Cannabigerolic acid), and Type V C. *sativa* to those that produce little to no cannabinoids at all.

Therefore, the various PCR tests allow to amplify particular cannabinoid genes from the different varieties. For example, if a variety has a CBDA gene, there are PCR tests that allow to identify these genes, as well as THCA.

Post-Production

testing, product integrity and contamination, budget, equipment, risk management recommendations, and crop insurance

Testing

Equipment to measure cannabinoids, terpenes, and other compounds from the *C. sativa* plant. Left: High performance liquid chromatography (HPLC). Right: gas chromatography mass spectrometer (GC-MS). *Photos: Daniela Vergara*

Due to the nature of C. *sativa*, there are a number of tests that must be conducted on the crop throughout production and post-production. It is important to note that testing protocols may vary by state. These protocols are typically available on state Department of Agriculture websites.

Testing for THC (and the acidic form THCA) is mandatory to remain compliant under the federal law of 0.3% or less. Tests for other cannabinoids such as CBD, CBG, CBN or THCV may vary on a state-by-state basis.

Testing for heavy metals is mandatory and highly recommended, as well as for mycotoxins, bacteria presence, and pesticides. A whole panel analysis usually includes microbial, residual solvent analysis (if you are producing concentrates), mycotoxins, pesticides, THC, and heavy metals.

Heavy Metal Testing Requirements in NYS

Metal	Ingestion Limit	Inhalation Limit
Antimony (Sb)	---	---
Arsenic (As)	1.5 µg/gram	0.2 µg/gram
Cadmium (Cd)	0.5 µg/gram	0.2 µg/gram
Chromium (Cr)	---	---
Copper (Cu)	---	---
Lead (Pb)	1.0 µg/gram	0.5 µg/gram
Mercury (Hg)	1.5 µg/gram	0.1 µg/gram
Nickel (Ni)	---	---
Zinc (Zn)	---	---

The first column includes the heavy metals that need to be tested according to the NY Department of Health for medical Cannabis; however, the NY Department of Health does not include the limits for these metals. The NYS Department of Agriculture and Markets has the limits for certain heavy metals which are found in columns two and three. Note: Copper (Cu) and Zinc (Zn) are essential for plant growth.

Microorganism Testing Requirements in NYS

Microorganism	Limit
Bacteria	
Clostridium botulinum	---
Escherichia coli	None
Klebsiella spp.	---
Pseudomonas sp.	---
Salmonella sp.	None
Bile tolerant gram negative bacteria	---
Fungi	
Aspergillus sp.	<103 CFUs/gram
Mucor sp.	<103 CFUs/gram
Peniccillium sp.	<103 CFUs/gram
Thermophilic Actinomycetes species	<103 CFUs/gram

Microorganisms listed are those that need to be tested according to the NYS Department of Health for medical high THC Cannabis. Limits listed are from NYS Department of Agriculture and Markets.

Recommended Cannabinoids to be Tested in NYS

- Δ-9-Tetrahydrocannabinol (Δ9-THC)
- Δ-9-Tetrahydrocannabinolic Acid (THCA)
- Tetrahydrocannabivarin (THCV)
- Cannabidiol (CBD)
- Cannabidiolic Acid (CBDA)
- Cannabidivarine (CBDV)
- Cannabinol (CBN)
- Cannabigerol (CBG)
- Cannabichromene (CBC)
- Δ-8-Tetrahydrocannabinol (Δ8-THC) *
- Cannabichromevarin (CBCV) **
- Cannabigerovarin (CBGV) **
- Cannabigerol monomethyl ether (CBGM) **
- Cannabielsoin (CBE) **
- Cannabicitran (CBT) **

The cannabinoids without an asterisks are those recommended for testing by both the NYS Departments of Health and Agriculture and Markets. The cannabinoids with one asterisk (*) are those that are recommended for testing by the NY Department of Health, and the ones with two asterisks (**) are those recommended for testing by the Department of Agriculture and Markets.

Testing of processed material or products for cannabinoids is usually done via HPLC (High-performance liquid chromatography) or GC (Gas Chromatography). In general, both methodologies rely on chromatography which is an analytical chemistry technique that separates, identifies, and quantifies components in a mixture.

The advantage of HPLC is that it can test for both the acidic and the neutral forms of the cannabinoids, while GC, which requires heating, converts the acidic forms into neutral and therefore the total cannabinoids are quantified. Therefore, the results when using GC equipment yield total cannabinoids and not the acidic or neutral forms independently. Due to the volatile nature of terpenes, GC is best at quantifying them.

Another technique used to quantify the components of C. *sativa* products is Mass Spectrometry (MS) which measures the mass changes of compounds. This methodology may be more sensitive and precise than chromatography as it gives more specific results when measuring the mass of a molecule. Although THCA and CBDA have the same mass and cannot be distinguished by MS, when coupled with GC in a GC/MS both techniques add confidence to the compound identification.

The equipment mentioned in this section can also detect the presence of toxins from either bacteria or fungi. However, other methodologies to test for the presence of microorganisms is via traditional culture methods, antibody assays such as ELISA (Enzyme-linked Immunoassay), and DNA methodologies such as PCR (Polymerase Chain Reaction).

For heavy metals labs may use ICP (Inductively Coupled Plasma) equipment, which is a type of mass spectrometry that detects atoms and ions (atom or molecule with an electric charge).

Cannabis sativa testing requires highly skilled personnel that understand chemistry and follow safety protocols carefully. These techniques require a well-equipped lab with the above-mentioned equipment plus multiple chemical compounds.

Recommendations:

- Find a testing lab that is reliable and has a fast turnout.
- Ideally this testing lab will have ISO 17025 accreditation and DEA registration as a Schedule 1 analytical lab and is accredited by NYS.
- Testing for heavy metals is crucial since, as aforementioned, *C. sativa* is a bioaccumulator of certain elements, such as Cd and Cu.

Recommended Toxin Testing in NYS

Toxins	Limit
Aflatoxins B1, B2, G1, G2	20 parts per billion
Ochratoxin A	20 parts per billion

Recommended by the NYS Departments of Health and Agriculture and Markets.

Recommended Organics to be Tested in NYS

- Fungicide/Herbicide/Insecticide/Pesticide
- Growth Regulator
- Myclobutanil
- Piperonyl butoxide
- Indole-3-butyric acid
- Azadirachtin
- Cinerin I
- Cinerin II
- Jasmolin I
- Jasmolin II
- Pyrethrin I
- Pyrethrin II

Recommended by the NYS Departments of Health and Agriculture and Markets.

- Ask the lab about their equipment to understand how they are testing for compounds.
  - For example, if the lab provides results of total THC or CBD amounts (neutral cannabinoids), it is because they are either:
    - testing via GC, or
    - they are measuring the acidic and neutral forms–THCA and THC, or CBDA and CBD (with a HPLC, for example)–and adding the values together.
- If you use a lab outside of NYS make sure that the lab provides results and performs the analysis required by NYS.

Example Certificate of Analysis. *Courtesy of Certainty Analytical Labs*

CERTAINTY ANALYTICAL LABS

Hemp Compliance & Quality Assurance Testing

CERTIFICATE OF ANALYSIS

ABC Processing Center
Canandaigua, NY

Cannabis sativa flower

Batch ID:	20220108.1	**Sample ID:**	20220108.1.023
Type:	Flower	**Submitted:**	01/08/2022
Instrument:	Hippolyta	**Started:**	01/08/2022 @ 9:18 PM
Method:	QP/22/Potency	**Reported:**	01/09/2022

15 Panel Cannabinoid Profile

COMPOUND	LOQ (PPM)	MEASUREMENT UNCERTAINTY (%RSD ‡)	RESULT (mg/g)	RESULT (%w/w)
Δ8THC	0.5	0.18	ND	ND
Δ9THC	0.5	0.14	0.8	0.08
THCa	0.5	0.39	BLOQ	BLOQ
THCV	0.5	0.37	ND	ND
THCVa	0.5	0.21	ND	ND
CBD	0.5	0.18	57.7	5.77
CBDa	0.5	0.19	19.7	1.97
CBDV	0.5	0.39	ND	ND
CBDVa	0.5	0.97	ND	ND
CBN	0.5	0.09	BLOQ	BLOQ
CBG	0.5	0.21	BLOQ	BLOQ
CBGa	0.5	1.98	ND	ND
CBC	0.5	0.48	ND	ND
CBCa	0.5	1.31	ND	ND
CBL	0.5	1.49	ND	ND
TOTAL CANNABINOIDS *			78.1 mg/g	7.81%
TOTAL POTENTIAL THC **			0.7 mg/g	0.07%
TOTAL POTENTIAL CBD **			70.2 mg/g	7.0%

‡Based on the low, mid, & high average levels, as determined from the method validation

% (w/w) = Percent (Weight of Analyte / Weight of Product)

* Total Cannabinoids result reflects the absolute sum of all cannabinoids detected.

** Total Potential THC/CBD is calculated using the following formulas to take into account the loss of a carboxyl group during decarboxylation step.

Total THC = THC + (THCa *(0.877)) and

Total CBD = CBD + (CBDa *(0.877))

ND = None Detected (as defined by the dynamic range of the method or not included in the test)

BLOQ = below the limit of quantitation

NOTES:

None

FINAL APPROVAL

Brandy Young-Ggamana	09Jan2022
MANAGED BY	DATE

Testing results are based solely upon the sample submitted to the lab and in the condition it was received. Certainty Analytical Labs, Corp. warrants that all analytical work is conducted professionally in accordance with all applicable standard laboratory practices. Data was generated using an unbroken chain of comparison to NIST traceable Reference Standards and Certified Reference Materials. Some services get subcontracted out to accredited 3rd party compliance testing firms. In those instances, reports can be traced back to the original compliance data. Customers will be notified about subcontracted services.

Certainty Analytical Labs | 260 East Main St., Suite 6411, Rochester, NY 14604 | 585-237-8497 | www.certainsciencescom

Product Integrity and Contamination

Soil Quality

A large factor in the production of a high quality C. *sativa* crop is the identification of potential contaminants and prevention of contamination that have been mentioned throughout this manual. Soil quality, as previously mentioned, is a very important factor. Therefore, when selecting a site for C. *sativa* cultivation:

- Have soil tests available to ensure the absence of heavy metals.

Sanitation

Sanitation practices are crucial, particularly the thorough cleaning of all tanks, lines, pumps, screens, and nozzles on all spray equipment used for C. *sativa* after the application of a conventional pesticide in other cropping systems. Consider the following guidelines when cleaning sprayers and transplanting equipment:

- Drain the tank and thoroughly rinse with clean water.
    - After draining, spray fresh water through the spray boom for 5 to 10 minutes.
- Fill the sprayer tank with clean water and add a cleaning solution (recommended per the label of the target pesticide being removed).
    - Running the sprayer and pressurizing the boom, hoses, and nozzles for 15 minutes.
- Allow the sprayer to sit for 8 to 10 hours while full of cleaning solution.
- Spray the cleaning solution, allowing the cleaning agents to move through the entire spray system.
- Clean all nozzles, screens, and filters; rinse the sprayer to remove cleaning solution, then spray rinsate through the booms.
- Rinse the entire system with clean water.

Budget

Item	$ per Acre			
	Fiber Production and Harvest	Grain (Seed) Production and Harvest	Dual (Fiber and Grain) Production and Harvest	High Cannabinoid Cannabis for CBD Production, Horticulture Production, and Harvest
Value of Production				
Fiber	516.10	NA	161.20	NA
Grain (seed)	NA	600.00	600.00	NA
Total Value (A)	**516.10**	**600.00**	**761.20**	**NA**
Cost of Production				
Variable Inputs				
Fertilizers and Lime	78.40	78.40	78.40	349.33
Seeds and Plants	209.47	104.73	48.49	4,530.80
Sprays and Other Crop Inputs	18.93	66.78	42.43	2,850.56
Labor	38.91	15.84	47.90	4,472.44
Repair and Maintenance				
Tractors	3.73	19.38	21.37	23.56
Equipment	14.10	13.70	24.15	6.24
Fuel and Lube	17.32	17.57	29.02	100.70
Interest on Operating Capital	9.74	8.09	7.46	308.34
Variable Costs Total (B)	**390.60**	**324.49**	**299.22**	**12,641.97**
Fixed Inputs				
Tractors	24.65	42.76	56.22	168.78
Equipment	32.63	23.84	43.50	107.39
Land Charge	104.18	104.18	104.18	191.67
Value of Operator and Family Management				
Fixed Costs Total (C)	**161.46**	**170.78**	**203.90**	**467.84**
TOTAL COSTS (B+C)	**552.06**	**495.27**	**503.12**	**13,109.81**
Returns				
Returns above Variable Costs (A-B)	125.50	275.50	461.98	NA
Returns above Total Costs (A-(B+C))	-35.96	104.72	258.06	NA

Budget Notes

Fiber, Grain, and Dual-Purpose

- Fiber, grain, and dual-purpose values reflect 2021 budget estimates. For more complete details, see https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/a/7491/files/2020/04/economics-of-fiber-grain-dual-hemp-2019.pdf
- Expected value of hemp fiber production: $0.065 per pound; expected value of hemp seed (grain) production: $0.60 per pound

- Expected yields, hemp fiber production: fiber production and harvest only scenario: 3.97 tons per acre; dual purpose fiber and seed (grain) production and harvest scenario: 1.24 tons per acre. Expected yield, hemp seed (grain) production. All scenarios: 1,000 pounds per acre
- Revenues, costs and returns reflect expected 2020 price levels as of fall 2019.
- Fertilizers and Lime costs reflect Cornell University agronomists' recommendations regarding Nitrogen (N) and Purdue University regarding Phosphorus (P) and Potassium (K).
- Seeds and Plants costs vary by scenario with respect to seeding rates but are constant with respect to seed price per pound.
- Sprays and Other Crop Inputs include crop professional fees, machinery hire rent & lease, and others—estimates reflect no spray inputs for hemp production and harvest.

High Cannabinoid Cannabis for CBD

- High cannabinoid Cannabis for CBD values reflect 2019 costs of production estimates.
    - Reported totals may not equal the sum of individual items due to rounding.
    - Labor costs reflect labor from hired and, or family and, or owner/operator sources.
    - Machinery related variable and fixed costs per Lazarus. http://wlazarus.cfans.umn.edu/william-f-lazarus-farm-machinery-management
    - This analysis excludes a charge for management inputs.
- Analysis reflects costs incurred from application submission, establishment of a winter cover crop through placement of dried material in totes for shipping or storage.
- Tillage operations, bed shaping, plastic laying, drip tape installation, fertilizer applications, planting, cultivating between rows, transporting harvested plants to drying barn completed using a tractor and implement.
- Other tasks including pruning/thinning, removing male plants, staking, harvesting, hanging, stripping, and filling totes completed using hand labor.
- Transplants at 1,800 plants per acre, $2.50 per plant cost for purchased transplants or for value of on farm grown, 1,550 plants harvested per acre
- Sprays and Other Crop Inputs include crop professional fees; machinery hire, rent and lease; license and testing fees; drying expenses; and others—estimates reflect no spray inputs.
- Future work will incorporate total value of production, revenue estimates for the purpose of developing costs and returns analysis. Variability in revenue related factors and the resulting risks and uncertainties point to the importance of understanding the relationship between expected revenue, price and payment model, percent CBD, pounds of dry matter sold, THC levels, other quality factors etc.

Questions? Comments? Contact John Hanchar, Cornell Cooperative Extension, jjh6@cornell.edu

Recommendations:

- Please study and consider the various sources of risk and uncertainty that characterize hemp enterprises.
    - These include production, marketing (price and payment models, product sold, payment receipt), labor, legal, and financial – when making decisions regarding hemp's place in cropping systems.
    - Variability in outcomes requires considerable management input to develop and implement strategies for addressing risks and uncertainties.

Equipment

Purpose	Item	Description
Fiber	Chisel plow	23 ft
	Disk	21 ft
	Planter	20 ft conventional grain drill
	Sickle bar mower	9 ft
	Rake	22 ft
	Round baler	4x5, 20ft
	Round bale transport	
	Tractors, power units	40 to 200 hp
Dual-purpose	Chisel plow	23 ft
	Disk	21 ft
	Planter	20 ft conventional grain drill
	Combine with draper head	23 ft
	Transport, clean, dry grain	
	Sickle bar mower	9 ft
	Rake	22 ft
	Round baler	4x5, 20ft
	Round bale transport	
	Tractors, power units	40 to 275 hp
Grain	Chisel plow	23 ft
	Disk	21 ft
	Planter	20 ft conventional grain drill
	Combine with draper head	23 ft
	Transport, clean, dry grain	
	Tractors, power units	130 to 275 hp
High Cannabinoid Cannabis for CBD	Chisel plow with harrow	15 ft
	Prairie grass drill	10 ft
	Boom sprayer	30 ft
	Offset disk	12 ft
	Raised bed prep tool	7 ft working width
	Water wheel planter	7 ft working width
	Rotary tiller	5 ft
	Wagon, field to barn transport	
	Tractors, power units	40 to 130 hp

Risk Management Recommendations

To avoid risks, make sure to keep yourself informed and to establish an educated information network. The establishment of cooperatives assures that you have a structure to rely on especially if people are engaged. Cooperatives may help secures inputs, and for marketing purposes it helps to avoid financial risks.

Three main risks have been identified with the following characteristics:

1. **Marketing.** This occurs when the product is not harvested, harvested but unsold or has unacceptable levels and duration of inventories along the value chain, or when the product is sold but at economically non-viable prices.

   This marketing risk may happen due to difficulties on promoting the products or determining price points, because of unmet legal or quality standards. Another issue could be the lack of legal contracts.

2. **Legal.** There may be risks and uncertainties surrounding the legal environment within which value chain firms must operate. Currently, in some states laws and regulations can restrict and restrain value chain growth and efforts to improve and become more efficient. Additionally, there are difficulties at license renewal process, and at achieving clarity regarding laws, regulations, and standards.

3. **Financial.** This final issue is a risk due to two unknown aspects: the value chain and the desired financial results or profit expectations; and the availability and costs relative to margins for financial goods and services, such as, borrowed capital.

So far, high cannabinoid Cannabis for CBD production is where most risk exists due to the high investment per acre. However, these aspects may also be applicable to grain or fiber for processing.

This new market is attracting investors and interested parties from non-agricultural backgrounds. It is important to discuss all potential pitfalls that come with agriculture with these partners. Although farmers are aware of all potential difficulties and dangers that come with farming, it is important to reflect all these perils in the contract to protect the farm's investment.

Hemp Growing Permit

The first step to growing hemp, after researching the crops and markets thoroughly, is applying for a permit to grow and/or process. This is done through New York State Department of Agriculture and Markets. Make sure to read all the information on the website as rules keep changing.

Recommendation:

- The hemp business should be its own entity (LLC, S corp, non-profit) especially if processing will be involved.
    - Additional fees and possibly additional insurance may be involved.

Plant or Seed Acquisition

Obtaining high cannabinoid Cannabis seeds can be a complicated activity, as there are no commercial seed catalogues for variety selection. Varieties are privately owned and access to seed, transplants, or "mother" plants requires contacting an owner-breeder. Assure relationships with reputable breeders to ensure good seed or plant material, which along with good growing and production practices will help maximize viability.

Questions that should be reflected in a growing contract with processor/buyer:

- Who is providing the plants/seeds?
- Who owns the intellectual property of the seeds/plants and how will those use agreements be respected?
- Who is determining which variety will be grown?
- Who is transporting seeds/plants and when will they be acquired/delivered?
- What growth stage will they reach the farm?
- What happens if seed germination is low or transplants arrive damaged/infected/infested/dead/too big or small for transplanting equipment?
- Who is responsible for seed quality especially feminized* seed, ensuring there are very few males?
- What if many males (>10%) appear in the maturing plants? Who is financially responsible for removal?
- Who owns the crop and when?

** Due to feminized seeds, the resulting male to female ratios may differ in the field. When planting high cannabinoid Cannabis, assurance that there are very few males, optimally none in the field, is critical to reducing cost of production and maintaining cannabinoid quantity.*

If the processor provides transplants:

- At what point does the farm take ownership and responsibility for the crop?
    - When the plants are shipped from the greenhouse, or when they are planted in the ground?
- When does ownership of the plants change end of season?

Other duties that should have clear assignments, lines of ownership and timelines:

- harvesting
- drying
- stripping
- chopping / transportation
- storage until processed

Testing

NYS Department of Agriculture and Markets (DAM) will be sampling the crop to be sure it meets the <0.3% THC content.

Recommendations:

- Test the product a couple of weeks before DAM testing to avoid any "surprises" as to the utility of the product.
- Make sure that your contracts (see below) reflect the financially responsible party for testing, including cannabinoids and other qualities such as residues or contaminants. Due to the expensive nature of these tests, make sure that the contract reflects:
    - Frequency and number of tests (per field, per ton of product, per variety, etc.)
    - Which tests, and what method of testing would be employed that specifies THC limits that complies with the law

Contracts and Legal Recommendations

Contracts are a necessity but expensive to enforce in court and not an ideal situation. To avoid these stressful legal hurdles, try to develop a strong relationship with respectable businesses and ethical and reliable partners who are adept at negotiating expectations verbally and contractually.

In combination with a solid professional relationship, and a strong business plan, the contract should reflect the areas below, although every situation is different and may need additional considerations.

Because of the shifting legal regulatory environment, contracts may change and have differences. Due to the current nature of the industry, members must critically assess their entrance, exit, and size of enterprises.

Recommendations:

- Make sure to clearly state in your contract which party will be financially responsible for testing.
    - Tests can be expensive, and contracts should reflect frequency, type, and number of tests, and testing methodology
- Make sure to understand the characteristics of well written contracts to ensure compliance.

Clauses: Non-Compete, Indemnification, and Confidentiality

A processor may ask that a non-competition clause be included in the contract, which should be evaluated carefully by the farm's management and attorney. Further questions regarding these clauses should be considered are clear specifications in terms of duration, acreage, poundage, variety etc. Although it is common for buyers to secure their product if the farm/farmer needs to consider possible additional opportunities with other buyers or, the event of excess crop production that the buyer did not contract.

Recommendations:

- If the farm agrees to these restrictions assure ample compensation to balance the potential profits derived from additional sales relationships.
- The farm/grower should be indemnified or "held harmless" for all activities that occur once the product has changed ownership to the processor, likely at the farm-gate.
    - This relieves the farm of any liability in the processing, sales, or use of the product.
    - This is especially important with CBD products as they are supplements that consumers will ingest. The farm insurance agent should be included in the conversation.
- Ensure that policies are up-to date, and the insurance carrier is aware of this contract and agrees with its terms.
- Not having the insurance carrier agree to contracts runs the risk of loss of coverage.

Confidentiality clauses are also commonly found in contracts for high cannabinoid Cannabis for CBD production. There are many areas where proprietary information and/or intellectual property may be utilized but ensure the contract clearly explains out what is "secret". The contract should also reflect that the farm and permit holder have some responsibility to report to NYSDAM and possibly cooperate with a Land Grant or other University on research.

Recommendations:

- Make sure that the contract is two sided and that the processor will not share any of your proprietary information/IP
    - Farms may have production practices that have been honed through trial and error for decades throughout generations
- Confidentiality applies to the contract itself as well. Terms should be held confidential.

Force Majeure – A Superior Force

Most contracts have a *force majeure clause* which translates to situation that is both unforeseeable and uncontrollable making completion of the contract impossible. Examples are war, labor strike, or weather/geological events. In agriculture, some weather events are expected while others, resulting in total devastation, should be considered in the contract. Although the 2018 Farm Bill instructs USDA to develop a policy, please see below about the crop insurance availabilities for hemp.

Recommendation:

- Clearly state what party is assuming financial risk for costs should a major weather impact production
    - Is it a shared costs-to-date for both parties to avoid the farm bearing all seasonal risks?

An additional force majeure risk is a regulatory one, since the FDA has stated that, because there is an FDA-approved drug based on CBD, interstate sales are under their prevue and future oversight may become stricter. The result would mean significant risk to the future distribution of CBD products. Further questions to keep in mind, if the FDA were to enforce interstate trade regulations is who would own the crop and product and bear the risk. Keep in mind timing: if federal regulations were to change in October, most of the crop costs are already invested at farm level.

Attorneys

Ask your current attorney if they are comfortable with C. *sativa*, or if they can suggest an attorney for legal advice drafting negotiations. Keep in mind that C. *sativa* is a unique agricultural and legal area, and, in some cases, attorneys have specialized in medical or adult-use Cannabis in other states, but are not aware of NYS regulations.

Recommendations:

- Do not to accept legal assistance or recommendations from those you are contracting with (the other party) .
- Assure that the attorney who is advising you is admitted to the NY Bar Association (or the Bar Association of the state you are farming in).
  - Admission to any state Bar does not necessarily permit them to appear in federal court.
- If the processor's business is located outside of NY select an attorney also qualified to practice in that other state.
  - Ask them to provide documentation of their work and/or recommendation from clients as to their experience.

Payments

Payment for the product is usually the primary focus of a contract. Typically, for CBD crop, growers are paid by poundage and quality. Quality depends on CBD amount, on the lack of contaminants and residues and on the legal compliance regarding THC amounts. Percent of CBD is the primary measurement of quality that is in direct relationship to payment.

Buyers may want to include deductions for loss of quality such as contaminants.

Recommendations:

- The contract should include a timeline for payment.
- Due to the upfront investment required by CBD crops, it is wise to negotiate with processor an upfront payment.
  - If not, the contract should state when the crop will be paid for (upon transportation off the farm/change of ownership) and by what means.
- Interest or penalties should also be included if payment timelines are not met.
  - The contract should reflect the responsible party for fees in the unfortunate event that enforcement becomes necessary.

Crop Insurance

The USDA Risk Management Agency (RMA) and Farm Service Agency (FSA) administers crop insurance. The current options for C. *sativa* crop insurance are Whole-Farm Revenue Projection and Multi-Peril Crop Insurance coverage under RMA and Noninsured Crop Disaster Assistance Program (NAP) covered FSA.

- **Whole-Farm Revenue Projection**: This insurance covers multiple crops on your property.
- **Multi-Peril Crop Insurance**: This crop insurance is only available for C. *sativa* in certain states and counties. Information on which locations are eligible can be found on the RMA Actuarial Information Browser: https://webapp.rma.usda.gov/apps/actuarialinformationbrowser/CropCriteria.aspx.
- **Noninsured Crop Disaster Assistance Program**: This program provides financial assistance to crops that are uninsurable when there are low yields, loss of inventory, or unable to prevent due to a natural disaster.

More information can be found at your local USDA office or online:

Risk Management Agency: https://www.rma.usda.gov/

Farm Service Agency: https://www.fsa.usda.gov/programs-and-services/disaster-assistance-program/noninsured-crop-disaster-assistance/index

Other Information

Registered Permit Information

Colorado: Colo. Rev. Stat. §§ 35-61-101-109; 8 Colo. Code Regs. § 1203-23 and https://www.colorado.gov/pacific/agplants/industrial-hemp

North Carolina: N.C. Gen. Stat. §§ 106-568.50-.57; 2 N.C. Admin. Code 62.0101-.0109 and https://www.ncagr.gov/hemp/

South Carolina: S.C. Code § 46-55-10-40 and https://agriculture.sc.gov/divisions/consumer-protection/industrial-hemp/

Virginia: Va. Code §§ 3.2-4112-3.2-4120 and https://www.vdacs.virginia.gov/plant-industry-services-hemp.shtml

Hemp Production eGuide
https://www.hemptrade.ca/content.aspx?page_id=22&club_id=950211&module_id=402335

USDA Hemp Descriptor and Phenotyping Handbook
https://www.ars.usda.gov/northeast-area/geneva-ny/plant-genetic-resources-unit-pgru/docs/hemp-descriptors/

Transpiration - Water Movement through Plants Tracy M. Sterling, Department of Entomology, Plant Pathology and Weed Science, New Mexico State University https://passel2.unl.edu/view/lesson/c242ac4fbaaf

Future Directions

Since C. *sativa* cultivation was forbidden until the appearance of the Farm Bills, the advancement of scientific research for the improvement of C. *sativa* for industrial, agricultural, medical, and biological purposes has been stunted. Although hemp legalization through the Farm Bill allows for cultivation at a federal level, it depends on state and local jurisdictions particularly due to the risk that high cannabinoid Cannabis production may reach undesired THC levels. Due to states legalizing medical, and high cannabinoid Cannabis, and high THC Cannabis, laws and regulations are constantly changing contributing to an unstable legal landscape. Uncertainty has led to ambiguity in cultivation, restraining help that could be provided by governmental, medical, and academic institutions, and could be especially detrimental for small producers with limited funding.

Due to this legal instability and because C. *sativa* is a new emerging crop in the US, the supply chain, particularly dealing with manufacturing, distributors, and retail, is not yet well established. Although C. *sativa* does offer new possibilities for business and new employment opportunities, these uncertain sceneries do not offer assurance to farmers and producers.

Because of the lack of research, C. *sativa* breeding in the public domain has not been robust and inbreeding to stabilize phenotypic traits is still lacking. Thus, many available varieties have variable characteristics between plants, including plant form, flowering time, and cannabinoid profile. Despite these unstable phenotypes, multiple companies in the hemp and high THC Cannabis industries sell products assuring specific phenotypic traits (eg. no males, no seeds, specific cannabinoid amounts) which has led to distrust between producers and seed companies, resulting in legal disputes in some cases. Given the lack of knowledge on how traits are inherited in C. *sativa* and how much of phenotype s affected by environmental effects, it is recommended to avoid promises of attaining specific phenotypes, particularly when seeds or clones will be grown in different environments.

The high versatility of C. *sativa* and its multiple uses derived from either flower, stalk, or seeds, necessitate different harvest processes depending on end use. For example, high cannabinoid Cannabis is grown for the flower without the presence of males and must be hung to dry and stripped of leaves, twigs, and stems. Hemp for seed on the other hand must be collected from the female inflorescences, while the stalk from the fiber hemp must be dried before processed. These differences in processing and handling must be considered depending on the final use and cultivation purpose.

To standardize C. *sativa* as a crop in New York State, farmers must be willing to grow it. Taking on a new crop is not an easy task, especially when it comes to C. *sativa*. Due to its long period of prohibition, information regarding its production has taken time to become commonplace in the farming community. Farmers should not be replacing their current crops with C. *sativa*. Instead, farmers should trial on a small area with proper consulting to familiarize with the crop. Adding C. *sativa* as a rotational crop not only increases the diversity of a farmer's income, but it also increases the biodiversity of their agro ecological landscape. Monocropping often results in increased pest and disease pressure. Rotating C. *sativa* with other crops such as corn, wheat, and legumes can reduce disease and insect pressure. In China, fiber hemp has been shown to be useful in a wheat intercropping system. *Cannabis sativa* has come under public scrutiny recently due to findings that show indoor production leads to significant levels of greenhouse gas emissions. When it comes to the sustainability of C. *sativa* production, it should also be recognized that hemp cultivation for fiber offers a much different production style, one that can potentially be viewed as carbon negative and environmentally friendly. Determining the realistic environmental impact of producing fiber hemp products should be a focus for the future of the industry.

A big challenge that will arise soon, will be to avoid unwanted pollination by those growing high cannabinoid Cannabis from those growing hemp for fiber or grain. This will become a major challenge with federal legalization when regulations allow for more flexible outdoor production of high cannabinoid Cannabis for medical and recreational purposes as these types should not be pollinated. One possible way to avoid unwanted pollination could be to grow all plants intended for cannabinoid production indoors. Another long-term possibility to avoid unwanted pollination is to produce genetically modified plants with sterile pollen or to plant triploid varieties. This alternative may also pose a problem for those who need seed production (eg. grain varieties), however, this could also open the possibilities for the emergence of companies that specialize in producing seeds in house so that farmers do not need to worry about fertilization.

Finally, regarding laws and regulations, there is hopeful progress and promising steps being taken by congress. For example, the Marijuana Opportunity Reinvestment and Expungement Act (MORE), recently passed through the House (but stuck in the Senate), would abolish federally criminal penalties for individuals that possess, cultivate, or distribute high THC Cannabis. The act would expunge criminal records for nonviolent high THC Cannabis convictions and imposes a tax to assist communities that were previously impacted by policing practices related to nonviolent high THC Cannabis use.

Other examples of federal legislation that would further establish a regulated high THC Cannabis industry include The Cannabis Administration and Opportunity Act (CAOA) and The Secure and Fair Enforcement Banking Act (SAFE Banking Act). The CAOA is another high THC Cannabis legalization bill drafted by the senate and lead by Senators Chuck Schumer, Ron Wyden, and Cory Booker that would end federal prohibition of cannabis and reinvest in communities that were unfairly targeted in the War on Drugs. The SAFE Banking Act allows state licensed high THC Cannabis businesses with much needed access to banking and financial services. The goal of these acts in reforming cannabis laws, is to "safely and responsibly regulate cannabis sales, possession, and use in a way that balances individual liberty with public health and safety."

Glossary

Adult-use: *Cannabis sativa* with more than 0.3% THC used for recreational purposes.

Aeroponics: Type of hydroponic cultivation where plants are grown without a soil medium using air or a mist environment.

Angiosperm: Plants that produce flowers

Anther: Male organ where the pollen is produced

Autoflower: *Cannabis sativa* plants that do not need light cues to flower.

Bioaccumulator: Organism that gradually accumulates substances, usually toxic chemicals, or radioactivity.

Bract: Modified leaf found beneath the inflorescence

Branch: Woody structure connected to the main stalk that bear stems and leaves

Candelabra: *Cannabis sativa* plant architecture with multiple branches that hold inflorescences.

Cannabinoid: Organic compound that characterizes the *Cannabis sativa* plants similar to terpenoid compounds and interacts with the mammalian endocannabinoid system. Secondary metabolite: it is not crucial for growth or reproduction but may confer an advantage.

Carbon sequestration: The capturing and storing of atmospheric carbon dioxide (CO_2)

Carolus Linnaeus: Swedish botanist who described Cannabis sativa in 1753

CBD/A: One of the main cannabinoids produced by the *Cannabis sativa* plant with medicinal properties. Although the plant produces the compound in acidic form (CBDA, Cannabidiolic Acid), when heated it loses a carboxyl group (COOH) and turns in to the neutral form (CBD, Cannabidiol)

CEA - Controlled Environment Agriculture: Form of hydroponic agriculture including indoor and vertical farming

Cloning: Technique where plants are propagated via cuttings

Cola: Main inflorescence in *Cannabis sativa* plants usually cultivated for cannabinoid production

Columnar: *Cannabis sativa* plant architecture with a column shape where most branches are the same size.

Deep water culture: Hydroponic method of cultivation where plants are grown in a liquid medium instead of a soil medium

Diploid: That contains two sets of chromosomes each of them coming from one parent (like in humans).

Direct seeding: Planting methodology where seeds are directly placed into the ground.

Disease: Illness that produces specific symptoms and is usually caused by another organism such as bacteria or fungi.

Drying: Process of dehydrating and desiccating branches usually those with flowers when *Cannabis sativa* is cultivated for cannabinoid production.

Ebb and flow: Hydroponic methodology comprising of flooding and draining nutrient solutions.

Emergence: Appearance of seedlings through the soil

Fan leaves: *Cannabis sativa* leaves which are big and carry photosynthesis

Farm Bill: Regulation that governs several agricultural and food programs

Female: Individual that bears the ovaries with ovules that when fertilized develop into seeds

Glossary

Fiber: *Cannabis sativ*a tissue forming threadlike structures that can be used in products such as paper, clothing, or rope.

Filament: Part of the male reproductive organ that holds the anther

Flowering stage: Phase in the *Cannabis sativa* life cycle where the plant produces inflorescences.

Full season: *Cannabis sativa* plants that are not autoflower and respond to light cues to produce flowers

Fungi: Eukaryotic organism (has a nucleus) that produces spores and feeds on organic matter. Some fungi cause disease in the *Cannabis sativa* plants

Genetic testing: Procedure to understand, using DNA (genetic material) the characteristics of a plant such as sex, or relationship to other individuals

Grain: Harvested seed of the *Cannabis sativa* plant

Grain drill: Machine used to plant seeds at a consistent rate into the soil

Greenhouse: Structure with walls and roof made of translucid material such as glass that allows a regulated environment where plants are grown

Harvest: Period when the useful parts of the plant are collected

Heavy metals: Metallic chemicals with high density usually toxic. These include mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), thallium (Tl), and lead (Pb)

Hemp: Under the legal definition hemp are *Cannabis sativa* plants that produce less than 0.3% THC. Under the genetic definition these are *Cannabis sativa* plants that cluster in a lineage of those individuals traditionally bred for industrial purposes such as fiber or grain production.

Herbicide: Chemicals used to control or kill unwanted plants or weeds.

Herbivory: Using plants as food

High tunnel; Hoop house: Structure that protects plants and prolongs the season where the plants are planted in the soil.

Hurd: Woody part of the stem from the *Cannabis sativa* plants cultivated for fiber

Hydroponic: Process of growing plants in mediums other than soil including water, air, or coco coir among others.

Indoor: Growing plants inside a greenhouse, tunnel, or warehouse.

Insect: Arthropod animal with six legs. Some insects affect the *Cannabis sativa* plants

Insurance: The possibility of having protection against eventuality when cultivating *Cannabis sativa* plants

Irrigation: Process by which water is supplied to the plants usually involving pipes or hoses.

Jean Baptiste Lamarck: French biologist who in 1785 described what he thought was a different species of Cannabis that he called *Cannabis indica*. As of today, only one species in the genus Cannabis is accepted: C. *sativa*.

LED - light emitting diode: A more efficient light system that emits light using current (electrons) flow

License: Authorization for cultivating specific types of *Cannabis sativa* plants

Male: Individual that produces the male gametes, in plants the pollen, which fertilizes the female

Glossary

plant to produce seeds.

Marijuana: *Cannabis sativa* plants that produce more than 0.3% THC

Micropropagation: Growth or Propagation of plants in closed environments in culture media using sterile conditions to develop adult plants, also known as tissue culture.

Monoecious: Plants that bear both male and female reproductive organs

Mother plant: Adult plants where cuttings are taken for propagation.

MRTA - Marijuana Regulation and Taxation Act: Law that was signed on 2021 legalizing marijuana in New York State

OCM - Office of Cannabis Management: Agency established after the MRTA came into effect that implements the regulations for medical and recreational (adult-use) cannabis.

Oomycete: Eukaryotic organism (has a nucleus) of fungi-like organisms that form a distinct lineage. Some of these organisms are harsh plant pathogens.

Pistil: Female reproductive organ containing the stigma and the bract where the ovules are produced

Plasticulture: Agricultural practice that employs the use of plastic materials

Pollen: Substance produced by the male plants resembling powder that carry the male gamete

Pyramidal: *Cannabis sativa* plant architecture with a pyramid shape similar to that of a Christmas tree.

Sex reversal: The act of using chemical agents to express genes in biochemical pathways related to sex expression so that individual plants express flowers of the opposite sex.

Shives: Woodchips like biproduct of hemp fiber after decortication

Sickle bar mower: Equipment used to mow during harvesting that holds a heavy bar that supports the cutting blades.

Soil: Substrate consisting of mixture organic and inorganic matter; remains, clay, and rock particles that forms a dark brown material used to grow plants

Soilless: Substates that do not contain soil but other forms of media that support the plant

Solvent less: Extraction methodologies that do not use chemical solvents

Stalk: Main stem of the plant, structural woody part that supports branches, twigs and at the basal end the roots.

Stamen: Male organ that holds the tepal, filaments, and anthers where the pollen is produced.

Stem: Main structural part of vascular plants that supports branches, twigs and at the basal end the roots and transports water and nutrients between the roots and the leaves, flowers, and fruits.

Stigma: Part of the female reproductive organ where the pollen is received. In *Cannabis sativa* plants these look like hairlike structures that sometimes vary in color, from purple, pink, to white.

Sugar leaves: Leaves in the *Cannabis sativa* plants that are found within the inflorescences and are usually covered with trichomes

Tepal: Outer part of the flowers that is not a sepal or a petal.

THC/A: One of the main cannabinoids produced by the *Cannabis sativa* plant that is psychoactive and highly governmentally regulated. The plant produces the cannabinoid in its acidic form

Glossary

(Tetrahydrocannabinolic acid - THCA) which when heated is converted to the neutral form (Tetrahydrocannabinol – THC) which is the form that mostly interact with the mammalian endocannabinoid system.

Tissue: Set of specialized cells that perform an organized function in the plant

Tissue analysis: Examination of a specific plant tissue to understand the nutrient content and evaluate the need for fertilizers

Tissue culture: Micropropagation

Transplanter: Equipment used to transplant seedlings into the field.

Trichomes: From the Greek hair, structures in the *Cannabis sativa* plants where the secondary metabolites are produced and are most abundant in the female inflorescences.

Triploid: That contain three sets of chromosomes.

USDA - United States Department of Agriculture: the governmental institution providing leadership in food, agriculture, and related issues.

Vegetative stage: Not in the flowering stage, when the *Cannabis sativa* plants grow in size and mass before starting to flower

Vertical farming: Indoor grows of plants using hydroponic and/or lighting technologies (ie. LED).

Viroid: Infectious agent that contains genetic material, usually RNA but lacks a protein coat and like viruses, need of a living cell to replicate.

Virus: Infective agent consisting of genetic material (RNA or DNA) embedded in a protein coat.

Weed: An unwanted plant growing where it competes or harms the cultivated plant.

Yield: The amount of product harvested.

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