Organic Seed Alliance
Supporting the ethical development and stewardship of seed
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Principles and Practices of Organic Beet Seed Production in the Pacific Northwest

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Crop History, Lifecycle, and Basic Biology

The humble vegetable known simply as the beet (*Beta vulgaris* L.) in North America is a member of the Chenopodiaceae or goosefoot family. It is also called garden beet, red beet, table beet, or beetroot to distinguish it from both sugar beets and fodder beets. The sugar beet is grown for its high sugar content and the fodder beet, also called mangold, mangel, or mangel-wurzel, is grown for its nutritious tops and roots that are used as animal fodder. These three root crops along with the leafy vegetable, Swiss chard, are all members of the same species, *Beta vulgaris*. Despite being distinguished by various subspecies designations by taxonomists, these four crops are all fully sexually compatible and will readily cross when flowering in proximity to one another.

The garden beet is thought to have originated in the western reaches of the Mediterranean region in southwestern Asia and was introduced into Europe during the Middle Ages. The earliest cultivated beets were probably used as a leafy green vegetable. There is some indication that the roots of this ancestral form of the crop were used for medicinal purposes. Its use as a root crop was first documented by Roman epicures in the 2nd century. It wasn't until the 16th century in Germany that its root was described as having a shape like a turnip. It has been speculated that the original form of the crop was an annual, probably a winter annual. It is thought that through selection as a food plant that could be stored through the winter that as the crop spread northward the beet developed an enlarged storage root and become a biennial.

The garden beet is a biennial, normally requiring two growing seasons to produce seed. During the first year of growth it produces a rosette of leaves and a fleshy taproot. During the second year it develops a seed stem that is 3 to 5ft (0.9 to 1.5m) tall with extensive branching and can cover a diameter of more than 3ft (0.9m) on the ground. Flowering is initiated by a cold treatment of the roots, or vernalization, after the first season's vegetative growth coupled with lengthening daylight in spring.

Due to a decline in the use of fresh beets in North America from the 1960s through the 1980s seed production for this crop saw a decline. Fortunately, because of a steady increase in the consumption of fresh vegetables since the 1980s beets have made a dramatic comeback as one of the most popular vegetables at farmer's markets, in community supported agriculture (CSA) style boxes, and in restaurants that treat vegetables with the respect that they deserve. Fresh market beets are most commonly sold in bunches of 4 to 6 plants with attached tops. Tops must be 10 – 14in (25 – 35cm) tall to meet market demands. Beets are now also grown extensively for their immature greens which are used as an ingredient in prepared, bagged salad mixes. Plantings for this use are at a much higher density than the plantings for traditional fresh market crops. This can be planted in several 3 – 4in (8 – 10cm) bands or as a solid "blanket" on top of a raised bed. This has been a real boom for beet seed producers as some organic salad mix growers may use upwards of 1.5 - 3 million seeds/ac (3.75 – 7.5 million seeds/ha).

Climatic requirements

The garden beet is a cool season crop that thrives when grown at moderate temperatures between 60 - 78F (15.5 – 25C), which encourages steady, vigorous growth. When grown as a spring planted vegetable, beets can tolerate hot temperatures at or above 86F (30C) after they have produced their initial vegetative growth during cooler spring weather. At the end of the first season of vegetative growth the beet seed crop requires a vernalization period where roots are exposed to temperatures at or below 50F (10C) for at least 8 weeks without being exposed to extensive hard freezes below 28F (-2C).

In the second year of growth the beet seed crop can be more sensitive to heat, especially during the early stages of seed development, from anthesis (the period of flower opening to fruit set)

until the embryo and endosperm have fully formed. During this period of rapid cell division heat, drought, or other environmental stresses can result in inferior seed quality. In order to produce high quality yields of vigorous seed with high germination rates beet seed crops should be grown in regions where temperatures during this crucial seed development stage of early spring don't usually exceed 75 – 80F (25 – 28C). The best beet seed production locales have cool, wet spring weather to establish a sturdy frame of vegetative growth, followed by cool, relatively dry summer weather to support optimum pollination, fertilization and seed development. An extended dry period in late summer and into early fall are ideal for the maturation of beet seed crops and to help to minimize the onset of seed borne diseases. Beet seed that avoids most precipitation as it matures also retains a healthy mahogany brown color at harvest. Important production areas include the Skagit Valley and greater Puget Sound of Washington, southern France, central Denmark, and northern Italy. While most of the Olympic Peninsula and the San Juan Islands do not have larger expanses of crop land they do hold great promise as areas for production of smaller, specialty beet seed crops that are well isolated from the larger commercial acreage of Skagit and Snohomish counties. Another excellent production area on the Pacific coast is the southern Gulf Islands, Vancouver Island, and the lower mainland of British Columbia, Canada.

Soil and fertility requirements

Beets grown as a vegetable crop are best suited to a fairly deep, well-drained sandy loam. Growing the first year roots on a friable soil of this quality will enable the seed grower to select for the shape of the roots before using them as planting stock the following season if using the root-to-seed method (see Planting the Crop). Roots can be replanted in heavier soils in the second year for seed production. In fact many growers claim that a somewhat heavier soil with a higher clay fraction will produce a higher seed yield. The optimum soil pH for beets is a narrow range, between 5.8 and 6.2. Beets are also salt tolerant and cropping is possible on soils too saline for many other crops. They are also very sensitive to boron deficiency in the soil, which can cause crown rot, blackening of leaf margins, or heart rot within the roots. Boron deficiency is most prevalent in alkaline soils. In seed crops, the amount of available nitrogen should not be too high in order to avoid excessive vegetative growth before bolting, as this promotes lodging of the plants during seed set. Well-maintained agricultural soils high in humus and microbial populations will supply adequate nutrients and water over the long seed production season.

Planting and Cultivation

Beet seed is produced using one of two basic methods, "seed-to-seed" or "root-to-seed" depending on your goals. Details of each method are described below. The seed-to-seed method is the easier and more efficient of the two as the crop is planted from seed in the first growing season, left in the field through winter and allowed to grow and flower in situ during the second growing season through to harvest. With both methods the crop is sown in mid-June to mid-July, depending on location, in rows 16 – 22in (40 – 55cm) apart, often with 2 rows on top of a 30 – 40in (76 – 103cm) bed. Seed should be planted at a density that is lower than normal for a vegetable crop, with a desired stand of 8 – 12 plants/ft (8 – 12/30cm). Roots should be somewhat smaller than is often used for vegetable production, between 2.25 - 3.0in (5.5 – 7.5cm) at the end of the season as they are often somewhat hardier to winter low temperatures when they are smaller. The crop is grown as if a vegetable and then left as is in the field for winter. This can be a drawback in many locations in the western USA as temperatures that drop below 24 to 28F (-4 to -2C) can easily damage the exposed growing point depending on the duration of the cold and the number of the freezing/thawing events that occur through the winter

Seed-to-Seed Method of Planting

Some growers using the seed-to-seed method will mechanically "throw" a shallow layer of soil ("soil mulch") up onto the row of beets to protect the roots from cold, especially from repeated cycles of freezing and thawing. There is much debate as to whether this soil mulch should cover the growing point which may get wet repeatedly during the winter. Caution should be used in heavy or frequently water logged soils as excessive moisture can cause rot at the growing point. However if the soil doesn't adequately cover the growing point it is debatable whether this method will actually protect the roots from temperatures below 24 to 27F (-4 to -2C).

As warm spring weather returns the beets put on a flush of new vegetative growth. At this stage it is possible to rogue out any plants that growing poorly or have foliage that is noticeably different in color, shape or height than the norm. If any foliage is exhibiting signs of disease it is also a good time to identify any disease causing organisms that might be present and rogue out any infected plants. Thin to the proper spacing for seed production with the healthiest roots at this time. The second drawback of the seed to seed method is the inability of the grower to perform selection on the crop's roots to maintain varietal integrity. While it may be possible to inspect the beet crowns for obvious flaws, like excessive crown size or roughness, when using this method the whole root is never pulled or "lifted" from the ground and evaluated for flaws, i.e. shape, color, excessively large tap root, etc. Because of this it is very important to start with seed that is known to have a high degree of genetic purity and therefore guaranteed to produce a high percentage of roots that are "true to type" for the particular variety being grown.

The seed to seed method has not been as successful in the beet seed growing region of the Pacific Northwest as it has been for other biennial seed crops. This method was used in the Skagit Valley of the Washington (the largest garden beet seed production area in the USA) until the 1940s. The practice of overwintering beets in the field to produce seed in the same field proved disastrous. The Skagit Valley beet seed growers were experiencing increasing losses of seed yield over a short number of years from beet mosaic virus (BtMV) (see Diseases of Beet Seed Crops.) The BtMV was being harbored from one season to the next on live plants overwintering in the field. These plants acted as a "green bridge" spreading BtMV from the second year seed bearing beet fields to the new, first year root crops in nearby fields. The insect vectors responsible were both the green peach aphid (*Myzus persicae*) and the black bean aphid (*Aphis fabae*). The solution was for all of the beet growers to agree to discontinue the use of the seed-to-seed method and to produce their roots outside of the valley. The lesson to remember is that disease problems due to overwintering crops which create a "green bridge" can occur with beets or other seed crops, even in areas with relatively small amounts of seed production if certain environmental conditions coincide with the presence of the pathogen.

Beets grown for roots the first year may be planted as they would for a beet vegetable crop.

The Root-to-Seed Method of Planting

The root-to-seed method requires that the beet roots are "lifted" and selected, then they are either replanted within hours or stored in a cooler, root cellar, or in a pit in the ground ("pitting") and are

replanted the following spring. The advantage of this method is that it affords the grower a chance to evaluate each root and decide if it is worthy of contributing its traits to the next generation. Additionally, it enables growers to produce beet seed in climates that are too cold for the seed-to-seed method to be used. Very importantly, it also allows the farmer to avoid transmitting diseases via a "green bridge" that could seriously jeopardize the seed crop.

Producing the roots during the first season is done essentially in the same way as described for the seed-to seed method above, using the same planting dates, plant densities, and width between rows. Roots are harvested and prepared for storage in the fall when the roots have achieved an adequate size (3.0 – 3.75in/7.5-9.5cm diameter). When using the root-to-seed method the roots should be; 1) free of any physical damage, disease, insect infestation, 2) true to type for all major traits inherent in the particular variety, and 3) prepared for storage by trimming off most of the tops while retaining the apical growing point of the shoot. It is important to remember the old adage "one rotten apple spoils the whole barrel," making sure that all roots that you store are sound and free of any rot.

Selecting roots for storage.

The first step for harvesting and preparing the roots for storage is usually to pull the plants and make an initial selection, eliminating any obviously poor quality plants based on both the quality of the root and the top before the tops are trimmed. It is always wise to make this initial selection as storing only the selected roots conserves space in a root cellar or cooler. It also gives you a sense of the true size of the population that you have available for planting in the second year.

Preparing roots for storage: For long term storage in a cooler or root cellar the beet roots need to be properly prepared for storage. Roots that are stored for replanting to produce a seed crop are called "stecklings." Stecklings are much more likely to rot in these simulated storage environments than they are when stored in pits in the field. Therefore, there are several methods used in preparing the stecklings for storage in a controlled environment. First the roots should be cleaned of most of the soil that is still attached to them, but without the use of water. Water may be useful in removing the soil but getting the roots wet before storing them may only encourage decay organisms to grow. In fact, some researchers believe that the balanced microbial community that exists in healthy soil may act as a deterrent to many destructive pathogens that may otherwise grow in storage. Soil that is not easily removed by hand or shaking should not be removed by vigorous rubbing as it can damage the root making it more prone to disease in storage.

The next step is to remove any portion of the taproot that is longer than 2.5 to 3in (6.5 to 7.5cm) long and also remove most of the petioles (leaf stems), as both of these tissues are the most susceptible portions of the root to rot. It should be remembered that both the taproot and the apical shoot enclosed in the deepest layers of the petioles are where the active growth will emanate in the spring. The taproot and lowest portion of the bulb is where the roots will emerge during the second year, hence the need to retain the 2.5 to 3in (6.5 to 7.5cm) taproot. The petioles will slowly rot away in storage and as they also serve to protect the apical bud for next year's shoot growth this rotting, if excessive, can infect and destroy the bud before the root is replanted. A preventative measure is to trim away as much of the petiole as possible at the beginning of the storage process

without damaging the apical bud. This requires deft hand work, a sharp knife, and knowledge of where the apical bud resides. Essentially you will cut much of the petioles off, starting very close to the crown of the root, near the base of the petioles, and cut *upwards*, so that the center of the petiole mass is about 0.5in (1.3cm) above the base of the crown (see photograph/diagram). In essence you are eliminating as much of the petiole as possible without damaging the apical bud.

Beet crowns are tripped to prepare for storage.

On a smaller scale beet roots can be stored in a root cellar or cooler. The temperature of the storage space should be between 34 – 37F (1 – 2.5C) before roots are placed in storage. Roots must also be stored at a relative humidity of at least 95%. Root cellars or other ground storage can supply this level of humidity, but if you are unsure of the ability of the storage environment to supply humidity constantly then it is judicious to place the roots in some type of medium or container that holds the roots at constant relative humidity. In root cellars beet roots are traditionally stored in moist, clean sand or clean, undecayed deciduous leaves, where the roots are laid carefully between layers of this material so as not to touch each other. Alternately large plastic produce bags (25lb/10kg) with several rows of small circular holes may be used with about two large handfuls of clean, dry wood shavings added to each bag to prevent condensation build-up. Both of these measures prevent the formation of free moisture on any surfaces within the bag. The holes allow some moisture to escape the bags and the wood shavings will soak up some moisture in the bag. If the storage facility is equipped with a reliable humidifier capable of producing >95%RH then the roots can be stored without putting them into plastic or a damp medium and placed in open bins with a light layer of clean wood shavings placed over them.

Large scale production methods for root-to-seed; A more mechanized system in the harvesting and storage of the roots for the root-to-seed method is used in the larger scale commercial beet seed operations in the Maritime Northwest. The tops are first cut with a flail, which is set high enough to avoid damaging the roots or the vegetative growing point right above the crown of the root. The roots are then lifted by undercutting and placed into shallow pits and covered with soil or are placed in windrows 12 to 18in (30 to 45cm) high *on top of the ground* and covered with soil. Both versions of this method are called “pitting,” even though the roots in the latter version are not truly placed in a pit. This above ground version of “pitting” is used in the beet seed production areas of Western Washington and was probably developed as a way to keep the roots as dry as possible during the wet winters that are common to the area. With both of these methods there should be a minimum of 12 – 18in (30 to 45cm) of soil covering the roots in milder temperate climates like the Maritime Northwest where winter temperatures don’t go much below 16 to 20F (-9 to -6.5C). Pitting roots in colder locales is done below ground, usually below the frost line and requires considerably more soil to cover the crop. All methods of pitting require very well drained soil to be effective.

Flowering and Pollination

The garden beet is predominantly wind pollinated and has extremely light pollen that is easily carried long distances by the wind. Perfect flowers are borne in most of the leaf axils of the large branching plant. They usually occur in clusters of two to five, with one bearing an extended bract that encircles the cluster. As this single bract dries it forms a corky, irregularly

shaped multi-seeded fruit. This is what is commonly called the “seed ball” or “multi-germ seed” in the seed trade. As this seed ball is capable of producing 2, 3, 4, and even 5 seedlings it is hard to achieve a well-spaced stand even with precision planting. Monogerm varieties have single flowers borne in bract axils, therefore no fusing of multi-germ seed balls. Many vegetable growers have avoided monogerm cultivars, complaining of poor seedling vigor. If true, this is a serious hurdle for monogerm seed to cross in gaining acceptance by organic farmers.

Beet flowers

The perfect flowers are protandrous, with the anthers of a particular flower maturing and shedding pollen for 2-3 days before the gynoecium of that flower matures and the stigma becomes fully receptive for up to two weeks. The small, greenish flowers are compact as the anthers have very short styles. They are not showy, as is normal for wind pollinated species. Nectar is produced and insect pollination is common, although the wind accounts for most pollination events. Beets are self-incompatible and therefore any individual beet plant will not receive its own pollen to fertilize its ovules and produce seeds. Each individual plant must have pollen from a genetically different individual in the population (or another population) to produce viable seed. This encourages almost complete cross-pollination between individuals in a population, although rare individuals capable of self-pollination have been found and used in hybrid breeding programs.

Isolation Requirements

Isolation requirements can vary depending on location and size of production. Beets are a wind pollinated crop with pollen that is very light and well adapted to travelling long distances. For this reason it requires a larger distance for pollen isolation than most crops. It is also important to remember that the table beet is only one of several crops that belong to the species *Beta vulgaris*, and therefore it is fully sexually compatible, and will readily cross with sugar beet, fodder beet (mangel), and Swiss chard. The minimal isolation required in level terrain with few physical barriers or obstructions to pollen flow with the wind is 3 miles (4.8 km) if the two crops being separated are distinctly different in type or color. Examples of different types can simply be two different crops, e.g. table beets versus Swiss chard, or it can be two different crop types of the same crop, e.g. cylindrical versus round in red table beets. Color in table beets and mangels include red, yellow, and white which need to be properly isolated from one another. Swiss chard displays these same colors and has many subtle shades of them that can be easily altered when two varieties with similar color are crossed. If there are distinct physical barriers like sections of forest, orchards, mountains, hills or even major tracts of buildings with mixed vegetation then it is possible to cut the isolation distance needed for these different types of *B. vulgaris* species crops to 1.5 miles (2.4 km).

The minimum isolation distance that is necessary between two different varieties of the same crop type, e.g. two round red beets or two yellow Swiss

chard varieties, can be grown as close as 2 miles (3.2 km) apart if there are no major physical barriers on the landscape, and 1 mile (1.6 km) apart if there are appreciable barriers.

It must be noted with these recommendations on isolation requirements that there is ultimately no isolation distance in seed production that guarantees that no crossing will occur between crops. Cross pollination can always occur due to some condition of the environment, biological interaction or human mistake. Pollen will occasionally travel further than these published isolation distances and seed growers and seed companies that have established these minimum distances do it with full knowledge that a small percentage of crosses may occur in any given year at these distances, but that greater distances would indeed be economically and practically prohibitive, especially in favorable seed growing environments where there are a number of farmers growing seed commercially. This is why there is a strong emphasis on monitoring of all seed stocks used to plant seed fields in order to rogue (eliminate) any outcrosses that may have occurred in a previous production cycle.

There has been much speculation among organic seed growers and seed companies on determining adequate isolation distances to virtually eliminate any chance of pollen contamination from a genetically modified (GM) version of a *B. vulgaris* crop with an organic seed crop of beets, chard, mangels, or sugar beets. As some level of crossing is inevitable even at the strictest isolation distances normally used, we recommend that the isolation used between GM *B. vulgaris* crops and any non-GM crops of this species should be doubled to at least 6 miles (9.6 km) to significantly reduce the chance of pollen contamination from the GM crop. Even at this distance the crop should also be tested for presence of GM contamination. It is also prudent for any organic beet (or other *B. vulgaris*) seed production fields to avoid any areas where seed production of any GM versions of these crops has occurred in recent seasons as volunteers and/or weedy escapes could be potential sources of pollen contamination for organic seed crops.

Genetic Maintenance and Improvement

Population Size

Beets are a cross-pollinated species with lots of inherent genetic variation. In order to maintain adequate genetic diversity and elasticity in any open-pollinated beet variety it is important to harvest seed from a minimum of 120 to 200 plants each time that you reproduce a variety. This will help insure that you do not severely shift the genetic frequency of any important traits that may not be obvious in your environment of selection and that the variety will maintain vigor and avoid inbreeding depression. The initial population size should reflect the intensity of selection activities. For instance, if a variety has been well-maintained and requires very little selection to keep it “true to type,” then beginning with a population of 250 plants before selection will easily yield 200 selected plants. On the other hand, if a variety has a large percentage of “off type” plants that need to be eliminated, it might require an initial population of 400 or more plants to derive a final population of 200 selected plants at a selection intensity of 50%.

Selection Criteria

The practice of trait selection of any crop is related to the needs of the farmer in a particular area, the environmental pressures of the production region, cultural practices utilized, and market demands. While vegetable breeders normally concentrate on traits for farmers that grow the crop as a vegetable, it is also important to remember that it is possible to select for traits important in the reproductive stage of the plant’s life cycle. Therefore, when someone is developing and maintaining varieties for organic systems the selection criteria should include selection for traits that are necessary for both the organic vegetable farmer and the organic seed producer. Selection should be done at several points in the life cycle when possible, including at the seedling stage, at

the market or eating stage, and during flowering to maximize reproductive health and seed yield.

To select for root qualities, when approximately 80% of the beet roots in the first year root nursery are of marketable size, the roots should be pulled and placed neatly on the beds for evaluation. Once the roots are pulled for selection it is best to keep them out of direct sun until they are replanted. Root selection on a cloudy, cool day is ideal. Selecting roots is best done with good knowledge of what "the norm" is for the phenotype (appearance) of each variety. Selection to a standard varietal type is the major objective in commercial production of established varieties. If a variety is adequately uniform at the outset of your seed production endeavor, then you can expect to discard approximately 10 – 20% of the roots, simply to maintain varietal integrity. If the variety is not uniform due to lack of prior selection (or poor selection), then expect to select out as much as 50% of the roots as off-types (see pictures below). Selection for improvements of market characteristics is always best done at the market stage. Beets are commonly selected on the following traits in genetic maintenance.

Seedling vigor: Seedling vigor and early robust growth are important to organic farmers as these traits affect the plant's ability to compete against weeds, resist seedling diseases, and contribute to overall plant health. Vigor can be improved over several cycles of selection. Selecting for the quickest, earliest seedlings to emerge is the first step, but seedling selection should also include recognition of shape, size, color, and ability of the seedlings to grow under less than optimum conditions. This selection should occur soon after emergence and may be coupled with the initial weeding and thinning of the plot.

Leaf size, shape and color: While many seed growers do not pay attention to the leaf characteristics of beets these traits are very important to vegetable growers that market bunch beets. Beets are generally classified as either short top types with tops that are often 6-8 inches (15-20 cm) tall, or tall top types with tops that are 10-14 inches (25 – 36 cm) tall. Selection of the tops for height within each of these categories is best done before the roots are pulled. Tops also vary in shape from the narrower strap leaf types to the wider heart shaped leaf types and require regular selection which is best done while the crop is standing. Leaf color can be deep green to medium green to a largely red hue (e.g. 'Bull's Blood'). For bunching types the darker green color is desirable as the lighter shades and reddish coloration is often associated with a product that isn't as fresh as the darker green type. Also cooler fall weather will often promote a blotchy reddening of the leaves that many people associate with leaf diseases or decline of the plant. This trait is more prevalent in some beet cultivars than others and selection for darker green leaves that resist reddening into the fall has been successful when practiced.

Beet tops are selected for size, shape and color.

Petioles: Beet petioles may be selected for color and strength. Dark petioles are desired as they are more attractive in a bunch. Striped petioles are also linked to "zoning" in the roots which is generally not desired as a deep red beet color is prefered. Zoning refers to the concentric rings of dark and light color. This trait is accentuated in the variety 'Chioggia'. Strong petioles that are not brittle are also desired and may additionally be selected for.

Striped petioles are commonly selected of of the population.

"Zoning" in the roots is linked to striped petioles.

Root shape: Table beets come in an array of shapes from long cylinders to rounded spheres, flattened globes, and roots that look like a toy top.

Beet roots are commonly selected for round shape

flattened globes, and roots that are shaped like a toy top. The size and width of the taproot at the bottom of the beet will also affect the shape of the beet, e.g. a top shaped beet often has a pronounced thick taproot. If the shape is not regularly selected then the unique shape of a variety can be lost within a couple of generations. When selecting for shape don't be overly concerned trying to get the perfect shape in each root, as no two roots will be the same and the shape will be an approximation of the ideal shape for the variety.

Odd shaped roots are selected out of the population.

Root color: The color of table beets includes red, pink, yellow, and white. There can be differences in the shades of these colors and the intensity of the pigmentation. The color is somewhat apparent from viewing the exterior of the root and the initial selection can be done in this way. However, if significant improvement in root color is desired then you may select more precisely for the intensity of color the roots by cutting them open to see the interior of the root. In order to do this and still be able to replant the beet it is imperative that you do not cut into (or near) the apical growing points of the crown or the root. However, cutting a slice of the root off of the side of the beet (a "cheek") you will be able to observe the interior color with no damage to the root. The piece of the root that is cut off can also be used for tasting (see flavor selection).

Beet cheek is cut to check internal color.

The beet root can then be left out in a cool, dry, shady spot for several hours to let the cut surface suberize or heal before it is planted. Suberin is a waxy substance that forms fairly quickly in damaged plant cells to prevent water from penetrating the tissue. The roots can then be replanted or stored for a short time before replanting. This evaluation for color of the cut roots should always be done at the end of the storage cycle soon before replanting the roots as long term storage of any damaged tissue is more risky than sound tissue.

Root crown and smoothness: The size and rough appearance of the crown of a beet can contribute greatly to its overall appearance and marketability. A large crown that does not have good definition and has rough outer margins that extend across much of the top of the root is not desirable in a fresh market beet. This characteristic also reduces the amount of harvestable tissue in the beet root for fresh market or processing. The outer tissue of the entire root may also have an unappealing roughness for the fresh market. This may be due in part to one or more of the common diseases of beets (see Rhizoctonia and Scab in the Common Diseases section), but also appears to be a heritable trait of some beet varieties. Selecting for a smoother root surface has been effective in some beet varieties.

Seed maturation, Harvesting and Cleaning

Seed maturation

Beet seed crops from second year roots mature in approximately 140 – 160 days depending on variety, climate, and planting date. Beet seed formation usually starts anywhere from six to ten weeks after flower stalk initiation. As the flowering habit is indeterminate, flowering and subsequent seed maturation will continue until harvest or frost. Because beet seed matures sequentially the percentage of beet seed reaching full maturity at the time of harvest will usually not exceed 75% of the total seed crop. The earliest seed to set will often mature several weeks before the bulk of the seed on any given plant has matured. This first seed set is usually of a high quality and has a high germination rate, but it may readily shatter as the bulk of the crop is maturing. The seed grower must determine when the maximum overall maturation has occurred, without losing a significant amount of the earliest maturing seed. Cool, wet weather can often occur during the late season, seed maturation period for beets in the Pacific Northwest making it even more important for growers to closely monitor the seed maturity and not harvest too early or too late. Early harvest may result in a percentage of seed that is not fully mature. Harvesting seed past the optimum time period may result in reduced yield and seed quality due to seed shattering and an increased incidence of seed borne diseases.

A standard method used to judge maturity of the beet seed crop is a visual assessment of the color of the seed ball (a multiple-seeded fruit resulting from the fused dry corky bracts of two or more flowers that occur at the same node). Harvest should occur when between 60 and 80% of the seed balls on at least 90% of the plants in the field have turned a tannish-brown shade, typical of mature beet seed. Unfortunately this method may sometimes be inaccurate due to the potential effects of the environment or the genetic variation of the particular beet variety being produced. In a number of environments the beet seed balls will turn a darker shade of brown, sometimes before

they reach full maturity. This often occurs with higher than usual levels of precipitation during the final weeks of seed maturation. This darkening may be due to saprophytic bacterial or fungal growth on the corky bract tissue of the seed balls. Depending on the pathogen it may not be harmful to the seed, but it seriously impedes visual assessment of beet seed maturity. There is also considerable variation between varieties for the degree of browning of the seed that occurs during the maturation process. Some beet varieties may retain greener hues than others, even when fully mature.

In order to make a more accurate assessment of the maturity of the seed it is best to check the relative maturity of the endosperm of the seed. The endosperm, which grows concurrently with the embryo, must be fully developed to produce viable, fully mature seed that will grow vigorously and maintain a high germination percentage through its expected storage life. The starchy endosperm can be monitored through the maturation process by cracking open any one of the several seeds that occur within each beet seed ball. The best way to determine the maturity is to squeeze a small amount of the endosperm out of the cracked seed and visually inspect it. If the endosperm is viscous and appears translucent or milky, it is not close to maturity and will require at least 3 to 4 weeks to mature. Sometime after this the endosperm will start to appear grayish and waxy, what is often called “flinty,” but it is still not close to maturity. When the endosperm becomes “starchy” with a true solid white color and has a firm texture then the seed is very close to maturity. A majority of the seed, at least 70 to 75% of the seeds on a given plant, must be at this advanced starchy stage before considering harvest.

Seed Harvest

Beet plants in full flower can have a stature of 3 to 6 ft (0.9 to 1.8 m) in height and can often cover a diameter of more than 3 ft (0.9 m) on the ground. The commercial beet seed crop is rarely staked so there is a tendency for the crop to lean in all directions, thereby making mechanical cutting or swathing without causing excessive amounts of seed shattering nearly impossible. Because of this many growers elect to perform the initial harvesting of the crop by hand. Crews walk through the field pulling plants by hand and laying them into several windrows across the field. In some cases the harvesters use machetes to cut the remaining beet root and root mass from the plant to minimize the chance of getting soil in the seed during the subsequent threshing. Some growers choose to leave the root mass attached as the root may still supply some energy in the final ripening that takes place in the windrow. This initial harvesting process is ideally timed to coincide with a subsequent period of fair weather for the “after ripening” of the seed in the windrow.

Beet seed drying in field on a tarp.

The seed plants should be placed in the windrows in such a way that they receive sufficient airflow to allow even drying even with heavy dew or light rains that may occur during this after ripening. This is important as beet windrows are not commonly turned as seed easily shatters during turning. Depending on the importance or value of a particular beet crop it may be worthwhile for the grower to place the crop onto landscape fabric or some other comparable porous material in order to catch any seed that may shatter during this period. The use of porous material is important to insure that any precipitation or moisture accumulation will quickly draw away from the seed.

The plants should remain in the windrows for a week to 10 days. After this drying period threshing can be done either by a belt thresher, stationary rotating thresher, or a self-propelled combine that is manually fed. Threshing should be done early in the day, mid morning in most climates, as light dew on the plants will prevent much of the potential shattering that can occur when the plants are picked up for threshing. The moisture can also lessen the amount of stems that break and lessen the size of the broken pieces that occur during threshing, thereby saving much time in subsequent seed cleaning steps to remove them. Threshed seed should then go through an initial screen cleaning or "scalping" to remove large leaf tissue, stems, and soil clods that can hold moisture. Further drying of the seed crop should occur at this point in a well-ventilated warm space with additional heat added as necessary.

Seed cleaning

Once the beet seed has been threshed and scalped the remaining chaff and light seed can be separated using winnowing or screening of the seed. These techniques are often used alternately as the larger pieces of stem and small pieces of leaf tissue can often be blown off through the use of an air stream or traditional winnowing with fans. Seed cleaning screen sizes are measured in 64ths of an inch and commercial beet seed will usually grade out at sizes between 6 and 10. Beet seed that is smaller than this will germinate poorly and larger seed is usually a minor fraction of the grade and is considered too large for the planting systems used by most farmers that grow beets. The use of a size 5 or 6 screen will remove most of the small debris and a size 11 will eliminate many sticks. If there are a significant number of smaller sticks that are difficult to remove with screens or winnowing they can often be caught on a seed cleaning "drape." A drape is literally a piece of textured felt (old theatre curtains have been used as a source) that is stretched on a flat surface (a piece of plywood works) and positioned at an angle somewhere between 20 – 35 degrees. The seed lot with problematic sticks is then slowly run across this surface with some fraction of the sticks getting snagged on the felt and almost all of the seed running down into a bin.

Beet seed ready to be cleaned.

Diseases

The following is a list of common diseases in beet seed crops. Some of these are seedborne, i.e. they can be transmitted via infected seed. Seed producers should become familiar with the seedborne pathogens associated with their seed crops. Producers should routinely monitor crops for symptoms of these diseases and have plant samples tested to confirm presence or absence of the disease when symptoms are present. If the disease is present then the seed crop should also be tested.

Fungal Pathogens:

Cercospora leaf spot (*Cercospora beticola*)
Seedborne – monitor and test as needed.

Cercospora leaf spot is caused by the fungus *Cercospora beticola*. Symptoms first appear on older leaves as small circular or oval lesions with purplish brown borders. A characteristic of these leaf spots is the presence of a black dot in the center of the lesion. As the disease increases in severity, leaves will turn yellow and wither.

Cercospora leaf spot may overwinter on other members of the Chenopodiaceae family, such as spinach (*Spinacea oleracea*), Swiss chard (*Beta*

vulgaris), or common lambsquarters (*Chenopodium album*). Cercospora leaf spot thrives when relative humidity is above 90%, and air temperatures are above 60° F (15.5° C) at night and 80 - 90° F (26.6 – 32.2° C) during the day. This disease often appears in protected areas, such as near windbreaks.

Cercospora leaf spot can be controlled 1) by rotating crops so that land is not planted to Chenopodiaceae family members for multiple years, 2) by increasing airflow through increased row spacing or decreased plant populations, and 3) by choosing varieties with horizontal resistance to Cercospera leaf spot.

Downy mildew (*Peronospora farinose)*

Downy mildew is caused by *Peronospora farinose*. It can be seed borne and should be monitored and test as needed. Downy Mildew can be a serious problem for beet seed growers in the northwest, especially for stecklings in storage. Initial symptoms appear as light green, large spots on the upper leaves. As the disease progresses, leaves will develop a white or grey mold and wilt. Flower and seed heads may also become infected, reducing yield. Infected stecklings can develop greyish mycelium in the crown which can spread to the flowering parts of the plant after transplanting and flower initiation in the spring.

Downy mildew can overwinter on volunteer beets, other *Beta* species, or in crop residue. Downy mildew can also be transmitted via infected seed. High humidity or precipitation and cool (45 - 59° F, 7.2 – 15° C) temperatures encourage the spread of the pathogen.

To control downy mildew in beets: 1) increase airflow through increased row spacing or decreased plant populations, and 2) limit excess nitrogen to avoid weak, susceptible plants.

Fusarium wilt (*Peronospora farinose*)

Fusarium wilt is caused by *Fusarium oxysporum.* It is seed borne and should be monitored and tested as needed. Initial symptoms include yellowing of the leaves between the veins and browning of the leaf edges, progressing to complete yellowing of the plant, wilting, and premature death. When an infected beet root is sliced, a marked darkening of the rings may be visible.

Fusarium wilt can remain dormant in soils until conditions are favorable. When favorable it will then invade the plant via the roots. Infection will typically occur in hot weather (>80° F, 26.6° C), and when plants are experiencing stress.

To control Fusarium wilt: 1) practice crop rotations, 2) plant when soil temperatures are cool (<60° F, <15° C), 3) ensure good field drainage, 4) be careful during cultivation to avoid throwing soil onto plant crowns, and 5) choose varieties with horizontal resistance to Fusarium wilt.

Phoma leaf spot (*Pleospora betae*)

Phoma leaf spot is caused by the fungus *Pleospora betae*. It is seed borne and should be monitored and tested as needed. Phoma leaf spot can infect and damage beets at three life stages. In the seedling stage it can cause pre-emergence damping off; on developed plants, symptoms will be brown lesions with black rings along the edge; and in storage, it can rot roots beginning in the center of the crown and progressing down.

Phoma leaf spot can overwinter on plant debris. Wet weather and warm soils are conducive to infection and disease progression.

Phoma leaf spot can be controlled by: 1) rotating crops, 2) using disease-free seed, and 3) avoiding injury at root harvest to reduce infection during storage.

Rhizoctonia root and crown rot (RRCR)
RRCR is caused by the soilborne fungus *Rhizoctonia solani*. Symptoms of the crown rot are wilted leaves, progressing to the brown rosette. Symptoms of the root rot are dark colored lesions on the root surface.

RRCR can overwinter in the soil and cause infection will when optimum conditions occur. Optimum conditions include temperatures from 55 - 95° F (12 – 35° C) and wet soils.

Controls for RRCR include: 1) crop rotations with non-host crops (e.g. small grains), 2) promoting good soil drainage, 3) careful cultivation to avoid throwing soil onto plant crowns, and 4) choosing varieties with horizontal resistance.

Rhizoctonia causes lesions on the surface of the beet.

Viral Pathogens:

Beet Mosaic Virus (BtMV)

BtMV is a potyvirus. It is seed borne and should monitored and tested as needed. Initial symptoms of BtMV appear as mottled yellowing of the leaves. Leaves may become puckered and plants may be stunted in their growth relative to uninfected plants. BtMV can survive through the winter on infected crop plants or weeds from a number of families. BtMV is spread from plant to plant via aphids.

Controls for BtMV include: 1) Eliminating a "green bridge" by transplanting the vernalized steckling in separate location from where the steckling were grown from seed, 2) keeping fields and field edges clean of weeds and volunteers, and 3) controlling aphid populations to slow the spread of BtMV.

Beet Curly Top Virus (BCTV)

BCTV is a geminivirus. Young seedlings may die if infected. In older plants, symptoms may appear as thickened, curled leaves, often yellow in color with purple veins.

BCTV survives either in overwintering crops and weeds, or the beet leafhopper (*Circulifer tenellus*). BCTV is transmitted from plant to plant via beet leafhoppers. Warm temperatures and high leafhopper populations favor the spread of the virus.

Controls for BCTV include: 1) maintaining clean fields and field edges prior to planting, 2) planting early to avoid leafhopper pressure late in the season, and 3) planting genetically tolerant varieties.

Beet Western Yellows Virus (BWYV)

BWYV is a polerovirus. Symptoms of BWYV appear on older leaves. The leaves become yellow, brittle, and leathery. As the disease progresses, the entire plant may appear red or purple.

BWYV can overwinter on beet crops, as well as many weed species. BWYV is vectored from plant to plant by aphids.

As with BtMV, BWYV can be controlled by: 1) by growing the 1st and 2nd year stages of the biennial crop in different locations , 2) keeping fields and field edges clean of weeds and volunteers, and 3) controlling aphid populations.

Rhizomania - Beet Necrotic Yellow Vein Virus (BNYVV)

Rhizomania is caused by Beet Necrotic Yellow Vein Virus (BNYVV), a benyvirus. Above ground symptoms are yellow leaves, with a characteristic erectness. As the disease progresses, the leaf veins will become more yellow, and the leaves may ultimately become necrotic. Infected roots will often be stunted, with masses of lateral roots, giving the root a bottled-brush appearance.

BNYVV exists in the parasitic soil fungus *Polymyxa betae*. *P. betae* survives in soil and in plant debris. High soil moisture and warm soil conditions make *P. betae* more likely to infect plant roots, vectoring BNYVV.

To control BNYVV: 1) Plant early to avoid warm soil temperatures, 2) avoid saturating soils, 3) practice crop rotations, and 4) use varieties with horizontal resistance (current varieties with single gene resistance appear to be failing).

Nutrient deficiencies:

Crown or heart rot – boron deficiency
Boron is an immobile plant nutrient. When there is not a sufficient supply available for plant growth, deficiency symptoms will appear in fast growing tissues. These symptoms include young leaves with a black or brown appearance, and necrosis of the crown.

If soil tests indicate low boron status, boron may be added as an organically approved borax at least 1.8 lbs / acre (2 kg/ha). Deficiencies are more common in coarse-textured soils. Even if present, boron may not be plant-available if the soil is too alkaline.

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