Chapter 2

Growing Sugarbeet to Maximize Sucrose Yield

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Often it is said that sugarbeet growers are actually aiming to grow sugar (sucrose). Although that is true, it is not possible to grow maximum sugar per acre without careful consideration of what conditions enable sugarbeet to produce maximum sucrose yield. This section includes information on how the plant grows, critical periods in its growth, the factors that most affect sugar accumulation, and how to maximize sugar yield.

The Importance of Photosynthesis

Photosynthesis, the process in green leaves that uses the energy of sunlight to capture carbon dioxide from the air and convert it into carbon-containing compounds in the leaf, is the key to sucrose production in sugarbeet, as it is the basis of all plant growth. It is through photosynthesis and subsequent leaf biochemistry that sucrose is produced. Thus, the primary objective of sugarbeet cultivation must be to maximize photosynthesis through the entire growing season. Secondarily, factors under producer control affecting the distribution of the products of photosynthesis, the "photosynthate," should be identified and manipulated so that the maximum photosynthate is directed to root expansion and sucrose deposition.

Seasonal Variation in Sunlight

To understand sugarbeet growth it is necessary to consider how the availability of sunlight varies through the growing season, limiting the amount of photosynthesis possible. Solar radiation at the field varies with changing atmospheric conditions and daily and seasonal changes in sun position. In our relatively flat, open, low humidity growing area radiation tends to be fairly consistent from year to year. *Figure 2.1* is a plot, by month, of the 30-year (1961-1990) average and range for the daily amount of sun energy reaching the earth's surface at Scottsbluff, Nebraska. Other locations within the scope of this publication would be expected to be quite similar. In the discussion of each growth stage we will see that this seasonal variation in availability of solar energy affects sucrose accumulation and influences how the crop should be grown.

Growth Stages

For convenience, sugarbeet growth can be divided into six, easily recognizable stages (*Table 2.1*). Because sugarbeet is a biennial, requiring two growing seasons for completion of its life cycle, the last two stages — overwintering and regrowth (including stem elongation, flowering, and seed set) — are included in the full list of growth stages. While these stages are important when sugarbeet is grown for seed production, this guide will only review the four stages that occur when sugarbeet is grown as an annual for sugar production.

Table 2.1
Growth stages of sugarbeet and approximate duration of each stage.

Growth stage	Approximate weeks in stage
Germination and emergence	3-4
Canopy development predominates	6
Storage root growth predominates	9
Pre-harvest (preparation for winter)	5-6
Overwintering and vernalization	(through winter)
Stem elongation, flowering, and seed set	(second growing season)

Germination and Establishment

The importance of the first growth stage – germination and plant establishment – cannot be overemphasized because maximum photosynthesis on a given area is impossible without a uniform, suitably dense stand. Germination and establishment are very temperature and moisture sensitive. Typically, sugarbeet are planted as early in the spring as is feasible, based on long-term average and range in soil temperature, date of last freeze, precipitation pattern, etc., and modified by evaluation of the weather pattern and predictions for the planting year. Both soil temperature and soil moisture affect sugarbeet seed germination. Germination does not occur until soil temperature reaches 37^{o}F, and germination at such a low temperature requires the liberal presence of water. The importance of seedbed preparation, seed quality, seed placement, and early irrigation are discussed and recommendations for our growing area are presented in other sections of this publication. Recommended plant populations also are discussed later, and are of great importance. Too many plants per acre leads to mutual shading and crowding effects on root size, yet too few plants means less than maximum interception of sunlight throughout the growing season. In either case there will be less than maximum sucrose yield.

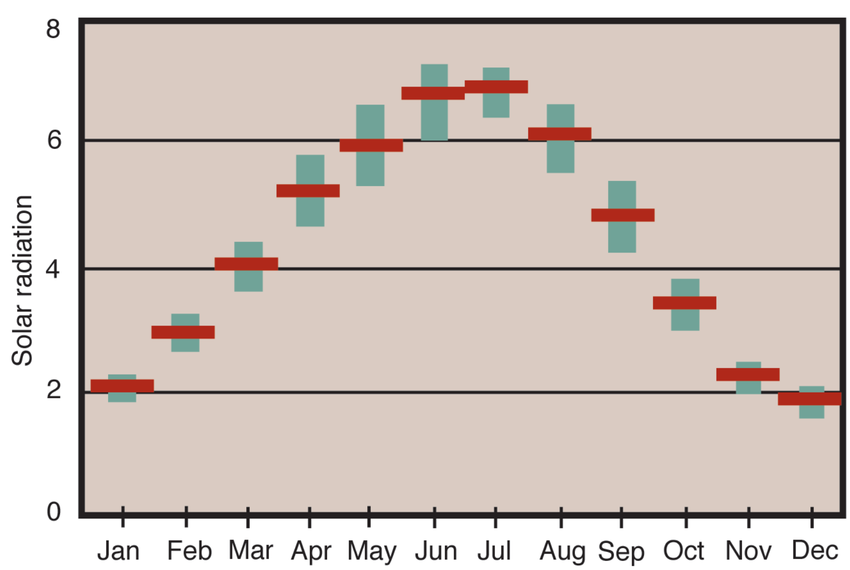

Figure 2.1
Average daily solar radiation, by month, at Scottsbluff, Nebraska. Data are 30-year averages (1961-1990) from Weather Bureau Army Navy (WBAN) database. Green bars show the 30-year range for the month, and the horizontal red line shows the 30-year average. Radiation is measured in kilowatt-hours per square meter per day.

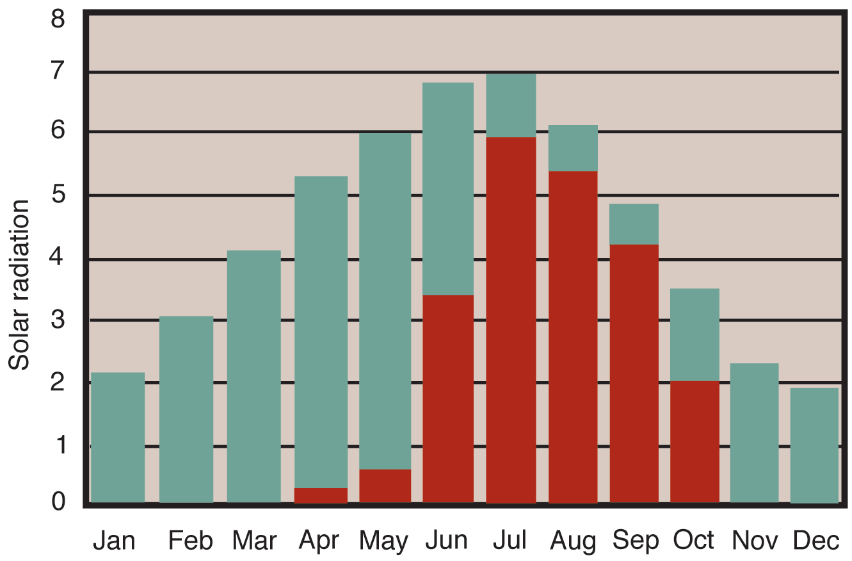

Figure 2.2
Daily average solar radiation, by month, at Scottsbluff, Nebraska. Data are 30-year averages (1961-1990) from Weather Bureau Army Navy (WBAN) database, in kilowatt-hours per square meter per day. Red bars show the approximate monthly proportion of available energy intercepted by sugarbeet.

After sugarbeet germinate and emerge, seedling growth typically is very slow, mainly because leaves appear slowly under cool temperatures. Only two or three small leaves per week appear at first. During the period of germination and establishment, usually mid-April through May, the amount of solar radiation reaching the field is high (*Figure 2.1*), yet there is very little sugarbeet leaf surface area available. As a result, most of the arriving solar energy is "wasted" from a sugarbeet growth perspective — that is, it is not intercepted for photosynthesis. *Figure 2.2* illustrates the amount of early-season solar radiation that is not captured because of insufficient leaf area. It is obvious why so much emphasis is placed on early planting and on managing the factors that affect early growth to canopy closure. The early part of the growing season provides one of the best opportunities for increasing light interception, and anything that contributes to a good, healthy, early stand will pay dividends at harvest.

Canopy Development

Both the rate of leaf appearance and leaf size increase as temperatures warm. Once sugarbeet plants are well-established and have produced four to six true leaves, they enter the canopy growth phase during which photosynthate is used mainly to produce the above-ground part of the plant, the leaves and petioles, collectively called the canopy. During this growth phase most of the dry weight gain of the plant occurs in the canopy (*Figure 2.3*). Leaves are produced throughout the season, and early leaves do not live as long as later leaves. At canopy closure there typically is about three times as much leaf upperside surface area as soil surface area. That is, at canopy closure the plants on an acre of land will have approximately three acres of upper leaf surface area. Light interception reaches a maximum at about this time. About 80-90 percent of the incident radiation can be captured if all other factors are optimal; some radiation always is lost through reflection, sunflecks that pass through the canopy without striking a leaf, stand gaps, etc. It may seem odd that about three times as much photosynthesizing leaf surface as soil surface is required to reach maximum light interception, but remember that the sugarbeet canopy is tightly packed, with much mutual shading and crowding of leaves along the crown (the plant's short stem). Thus, some areas of leaf overlap are not fully exposed to the sun and are relatively ineffective in photosynthesis.

The key to maximizing sucrose yield is to maximize light interception and photosynthesis throughout the life of the plant.

Storage Root Enlargement and Sugar Accumulation

Some root growth also is occurring during the canopy growth phase, but most of the plant's weight gain at that time is in the canopy. By about mid-season, canopy growth normally slows down and canopy dry weight becomes stable, eventually even decreasing in late season (*Figure 2.3*). At some point after canopy closure, under the influence of environmental cues, sugarbeet is genetically programmed to decrease leaf production and to begin increasing root size and sucrose storage in preparation for winter. Internal signals instruct the plant to divert much of the daily photosynthate from canopy formation to storage root enlargement and the storage of sucrose as an energy reserve. In the full life cycle, the stored sucrose later would be used to provide energy for cellular maintenance, for all the biochemical processes that must continue as the plant overwinters, and for initiation of regrowth and reproduction.

As the root growth phase progresses, the storage root rapidly enlarges and gains weight, both in the taproot structure itself and in the sucrose stored within that root (*Figure 2.3*). In other words, root growth becomes predominant. Canopy weight remains stable for a time as most photosynthate is diverted away from leaf formation, then eventually the canopy weight begins a gradual decline as more and larger leaves die than are produced to replace them. The dry weight curves in *Figure 2.3* illustrate ideal growth patterns for maximum sucrose production. It is during this growth stage that maximum daily rates of sucrose accumulation in the taproot occur. Earlier in the growing season daily solar radiation was greater, but insufficient leaf surface was available to intercept it fully, or the photosynthate produced was being used to produce more leaves and petioles rather than being stored.

Pre-Harvest Stage

During the pre-harvest period of September and October, decreasing light intensities and temperatures do not allow the higher rates of photosynthesis that occurred in mid-season. In September our daily solar radiation averages about 70 percent of the mid-season maximum, and in October the daily radiation average is only about 50 percent of the maximum (*Figure 2.2*). Once the full canopy is formed in mid-season, it is enough for maximum interception of the lower amount of arriving radiation in late summer and early fall. The photosynthate formed during this time is directed strongly to root structure and sucrose storage, but the amount of sucrose stored each day gradually decreases with time as photosynthesis decreases (*Figure 2.3*). There is no "sugaring up" or "ripening" period, as sometimes is believed, and no environmental cue that leads to a sudden surge in sucrose accumulation. It is true that sugar expressed as percent of root fresh weight continues to increase through the pre-harvest period, and some of that increase is real — an accumulation of sucrose resulting from photosynthesis. However, sucrose also may **appear** to increase when, in fact, fresh weight is decreasing with progressive soil and root dehydration in preparation for harvest. Other factors not discussed here also may contribute to an apparent, but not real, increase in percent sucrose as measured by polarimetry.

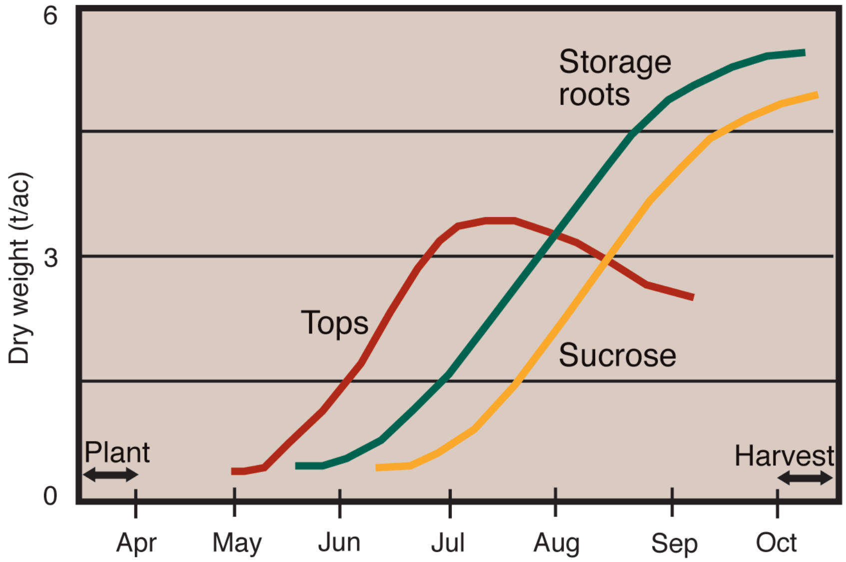

Figure 2.3
Seasonal growth curves (accumulation of dry weight) for the sugarbeet canopy, the storage root, and stored sucrose. The curves are typical of a crop grown for maximum sucrose yield.

Maximizing Sucrose Yield

The key to maximum sucrose yield is maximizing light interception throughout the life of the plant. With this in mind, it is easy to identify several important factors affecting light interception. Of course, environmental factors which can't be controlled are very important — temperature, precipitation quantity and type (rain/hail), seasonal variation in solar radiation, cloud cover reducing radiation intensity reaching the field, soil type and structure as it affects nutrient availability, etc. These factors alone cause considerable year-to-year variation in sugarbeet yield. The focus of this guide, however, is on those factors we can affect. Here we will simply enumerate the factors; each of them is discussed in greater detail in subsequent chapters.

First, anything that affects stand establishment is important in determining how quickly plants attain sufficient canopy to maximize light interception. Seedbed preparation, seed quality, seedling emergence, plant growth, row spacing, and arrangement all are important in the initial growth phase of sugarbeet. Because water is important throughout growth, it must be provided adequately until the pre-harvest stage when some drying of the soil and roots is acceptable. Irrigation method and quantity affect all aspects of plant growth and light interception. It is important to minimize wilting as much as possible; wilted plants are not photosynthesizing appreciably. Pathogens, pests, and weeds must be controlled because they also affect light interception. Diseases causing foliar symptoms can reduce light interception directly, and other types of diseases can affect various aspects of the health of the plant and decrease its ability to photosynthesize at a maximum rate. Weeds compete with the sugarbeet for light, water, and nutrients, all potentially affecting photosynthesis.

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The necessity for nutrient management is obvious, as leaves and all other tissues must be supplied with required nutrients that are not sufficiently present or available from the soil. The single most important nutrient is nitrogen and will be addressed in detail later (see *Chapter 8, Fertilizing Sugarbeet*). Nitrogen is essential for rapid expansion of leaves, so it must be available in the soil from sugarbeet germination to canopy closure. After that time, however, nitrogen in the soil should be depleted because "nitrogen drives canopy formation." As has been discussed above, sufficient canopy has already been formed by mid-season; after that, gradually decreasing light intensity and temperature limit photosynthesis. The canopy that already exists is sufficient for maximum photosynthesis under reduced light intensity, and the formation of more canopy cannot contribute to more photosynthesis. Of great concern is the production of large, late, dark green leaves, which will occur if nitrogen levels in the soil are not depleted or are maintained due to late mineralization. Such late leaf production uses photosynthate that otherwise would be used to increase root structure and stored sucrose.

Sugarbeet is unlike other crops, in which more nitrogen tends to result in more yield of the economic product. In sugarbeet, more nitrogen than needed for vigorous early season growth results in more tops, **not** more sucrose yield. Worse yet, excess late nitrogen has serious negative effects on root purity and therefore on sucrose extraction during sugarbeet processing. Producers should aim for a nitrogen management plan that drives canopy formation to mid-season closure, then keeps the canopy at a moderate size through the remainder of the growing season. This assures that late-season photosynthate has been devoted to root and sucrose yield, not to unnecessary canopy structure. It is quite acceptable for the canopy to become light green to yellow-green in color by September or October as nitrogen from the leaves is remobilized and returned to the root. The yellowed leaves still retain enough photosynthetic capacity to fully use the much decreased amount of sun energy that is available. Conversely, a large, dark-green late season canopy simply indicates that photosynthate has been used for too much above-ground production and maintenance, at the expense of root yield and sucrose storage. Maximum sucrose yield does not occur at maximum root yield, but at something less than maximum root yield. Thus, one should not aim for maximum tonnage, but for a healthy, properly fertilized crop that contains the most sugar and minimizes transportation costs.

Maximizing sucrose yield is a realistic goal for sugarbeet growers. Each chapter that follows will provide useful information about the most important growth factors that growers can control. As you read each chapter's recommendations, remember that they are experimentally derived for our area, and that the goal of each recommendation is to maximize plant growth so as to maximize light interception through the entire season. That is the secret to success in sugarbeet cultivation.