Crop Growth and Management Module

Certified Crop Advisor

State Performance Objectives

General New Mexico Crop Growth and Management Competency Areas:

1. Plant growth factors
2. Limitations on growth
3. Growth correlations
4. Growth dynamics
5. Growth analysis

Learning Objectives

The objectives for the New Mexico Crop Growth and Management Module are:
· To learn what external and internal factors affect crop growth
· To learn some of the theories on limiting crop factors
· To learn how crop geometry, even under changing environmental conditions, is influenced
· To learn how crop growth dynamics over the season influences plants and how plant parameters can indicate whether optimum yield conditions exist

Pre-Study Questions for Review

1. Generally, crop growth is expressed as a function of the genotype by the _____.
    a. genetics
    b. environment
    c. tillage used
    d. limiting factor
2. Crop growth is in the strictest sense simply cell division and _____.
    a. cell enlargement
    b. elasticity
    c. cell grouping
    d. immobilization
3. Some of the external factors that influence plants through the soil include texture, _____, organic matter, cation exchange capacity, pH, base saturation, and nutrient availability.
    a. percent blocky arrangement only
    b. structure
    c. number of tillage passes
    d. which state the soil is located in
4. Long-day plants are plants that respond to _____ or more hours of daylight for reproduction to initiate such as alfalfa or wheat.
    a. 3
    b. 6
    c. 12
    d. 13
5. _____ is a measurement that expresses the magnitude and persistence of leaf area (or leafiness) during the period of crop growth.
    a. leaf area duration
    b. night-time leaf opening
    c. stomata number
    d. growth rate

Check your answers before proceeding into the unit to find out how much you already know about the basic concepts on planting factors. Each correct answer is worth 20 points, based on a total of 100 points for the five questions. Answers: 1. b.; 2. a.; 3. b.; 4. d.; 5. a.

Crop Growth and Management

Plant Growth Factors

Plant growth and development are continuous during the crop life cycle, depending on availability of growth needs and the continued support of the environmental inputs. Generally, crop growth is expressed as a function of the genotype by the environment (internal growth factors X external growth factors). In crop production, one tries to maximize growth rate and yield through both genetic and environmental manipulation. Plant breeding and selection can modify the genetic traits while some manipulation of the microclimate (site selection, tillage, irrigation, drainage, fertilization, pest control, and cultural changes—planting date, stand density and spatial arrangement) can be implemented.

Crop growth is in the strictest sense simply cell division (increase in number) and cell enlargement (increase in size). The process of differenciation (cell specialization) is also required making plant development be both growth and differenciation. As agronomists, plant growth is frequently defined by the parameter from which measurements over time can be taken—dry matter increases. Dry weight accumulation is used as it generally has the greatest economic importance; however, height, volume, and leaf area are also often used.

The factors affecting growth can be broadly divided into external and internal factors. Factors under genetic control are numerous, thus these are only partial lists.

External Factors

1. climatic (light, temperature, water, day length, wind, gases)
2. soil—edaphic—(texture, structure, organic matter, cation exchange capacity, pH, base saturation, nutrient availability)
3. biological (weeds, insects, disease organisms, nematodes, various herbivores, soil microorganisms including nitrogen fixing/denitrifying bacteria and mycorrhiza contributing to symbiotic fungal associations)

Internal Factors

1. resistance to climatic, edaphic and biological stresses
2. photosynthetic rate
3. respiration
4. partitioning of assimilate and nitrogen
5. chlorophyll, carotene and other pigment contents
6. type and location of growing points (meristems)
7. capacity to store food reserves
8. enzyme activity
9. direct gene effects
10. differenciation

All of these factors, external and internal, will influence crop growth and development as well as the ultimate yield. Crops are most affected by stress during pollination and through to seed set during the growth stages in crop development. In general, the stages most affected by limitations to moisture as mentioned in an earlier unit are the same stages most affected by other stresses, also.

Growth Stages Most Affected by Stresses as Shown by Lowered Yields

Crop	Key Growth Period	Time when Stresses Should not be Limiting
Sorghum	boot-heading	boot-soft dough
Wheat	boot-flowering	jointing-soft dough
Corn	tassel-pollination	12 leaf-blister kernel
Cotton	first bloom-peak bloom	first bloom-bolls well formed
Beans, dry	flowering-early pod fill	axillary bud-pod fill
Potatoes	tuberization	tuberization-maturity
Soybean	flowering-early pod fill	axillary bud-pod fill
Sugarbeets	no critical stages	limit stresses during root assimilate fill
Alfalfa	no critical	limit stresses during regrowth-winter dormancy

As you can surmise, stress during pollination to beginning seed fill can severely limit yields on crops and it is this time, in particular, crops should have excellent growing conditions in order to optimize yields.

Limitations on Growth

Some of the first research studies on plant growth were on limitations and plant response. A knowledge of the theories derived can help in understanding plant responses and for planning management strategies.

The Liebig "law of the minimum" is the best known limiting factor theories and was simply stated as a deficiency or absence of one necessary constituent (all others being present), renders the soil barren for crops for which that nutrient is needed. The idea is that any growth factor in the lowest supply (climatic, edaphic, biological or genetic) sets the capacity for yield. This idea is usually illustrated as a "barrel concept" where the staves of the barrel are of different heights (the different growth factors) and the lowest one establishes the capacity of the barrel.

This early theory (1862) was improved upon once more about plant processes were understood. The Blackman theory of "optima and limiting factors" followed in 1905 by stating that a process is conditioned as to its rapidity by a number of separate factors with the rate of the process limited by the pace of the slowest factor. This theory suggests any abrupt cessation of a factor will immediately make that factor limiting; however, nature seldom is that abrupt. Thus, response lines to limiting factors such as photosynthesis (light and carbon dioxide inputs) or growth (many inputs) are usually curvilinear rather than sharp, abrupt changes to plant conditions.

Quickly after this knowledge, the Mitscherlich "law of diminishing returns" was hailed (1909) as explaining how the increase in any crop produced by a unit increment of a deficient factor is proportional to the decrement of that factor from the maximum (a curvilinear response rather than the linear response suggested by Blackman).

In 1936, Macy suggested that plants have a relationship between the sufficiency of nutrients and the plant response in terms of both yield and nutrient concentration of plant tissues. Thus, under the tissue-minimum-percentage range, an added increment may increase yield but not the overall nutrient percentage, while in the poverty-adjustment range, added increments could increase both yield and nutrient percentage and in the luxury-consumption range, added increments may have very little effect on yield, but may increase the composition percentage of the nutrient. This theory helped explain why the previous ideas were correct but not completely encompassing the concepts surrounding plant growth responses. This theory itself did not include new discoveries that found that biological reactions are complex and may proceed by more than one pathway, thus not necessarily slowing the process, some elements may substitute for others (sodium can partially substitute for potassium in some species), factors may modify or affect others (phosphorus can decrease zinc uptake, etc.), mixed plant factors and other conditions can change responses (additional nitrogen may increase plant growth and leaf area which in turn reduces light to lower leaves—soil temperature can be decreased from the shading and humidity increased), and more than one factor may be limiting at any one time.

In fact, because of this complex mix of factors and reactions, crop growth and development has been very difficult to define. This is especially true when defining the effect of day length and temperature on crop flowering. These stimuli, known as the photoperiodic effects, in plants are active on all plants. However, while all plants respond, they may react quite differently. In general, we group plant reaction to photoperiod in three categories.

1. long-day plants (plants that respond to 13 or more hours of daylight for reproduction to initiate such as alfalfa or wheat)
2. short-day plants (plants that require at least 12 hours of dark for reproduction to initiate such as soybeans or rice)
3. day-neutral plants (those plants that have reproduction initiated by environmental factors such as heat unit accumulation rather than being more strongly affected by length of the photoperiod such as some day neutral tomatoes, dandelion, strawberries—even though there are also some strawberries that are long-day and some that are short-day)

There are some plants that have a more complicated routine in photoperiodism such as short-long-day (SLDP) plants or long-short-day (LSDP) plants that have to have a sequence of exposures over time to initiate reproduction such as the temperature, perennial grasses like orchardgrass (SLDP) that requires vernalization between short and long days and jasmine (LSDP) that requires a sequence of long days prior to a spat of short days to flower.

Generally, it can be assumed that crop and wild species that flower and fruit in midsummer are long-day plants and those that flower and fruit in autumn are short-day plants.

With any plants, temperatures below those needed for normal growth activity will slow plant development regardless of the plants' general reaction toward day length. In fact, this is most apparent on species that require a period of cold or near freezing temperature in order to flower under long photoperiods of spring. This need for thermoperiodism, or vernalization in this case, may require several days to several weeks of cold temperatures. Winter cereal grains such as wheat and rye require vernalization. Vernalization, the promotion of flowering in response to the long days during spring, is different from seeds, bulbs or buds of temperate species that require only stratification (several weeks of cold, wet storage) to break dormancy and induce growth. In fact, modern cultivars of such biennial crops as sugarbeets and celery have been selected for high vernalization requirements so that first year bolting does not occur in commercial crops. Annual types of sugarbeets or sweet clover have also been selected that flower without vernalization at all.

In photoperiodism, it is the length of the night really, rather than the day length that operates the reaction of plants as was demonstrated by the original studies of Lang in 1952. The effect of photoperiod on floral induction is modified by temperature more than by any other environmental factor. Several other factors such as age or hormone levels in the plants such as auxins or gibberellins can also influence floral initiation.

The term photoperiodism was coined by two USDA scientists to define the plant response to day length. Flowering in plants occurs in response to exposure to a specific number of favorable photoinduction cycles. The minimum number of cycles required varies with plant species, cultivars, age and size. Photoperiodism is driven by light energy of the red (R) and far-red (FR) portion of the spectrum. Plants receive the stimulus by a pigment (phytochrome) in the buds or leaves which is then transmitted to other parts of the plant. Once the leaves receive the photoperiodic message, a substance is produced called florigen. This chemical message is transmitted to the growing point and up and down the plant stems to begin plant response.

Growth Correlations

Plants acquire a characteristic shape by component parts having a characteristic form that is repeatable in time and space. With favorable environment, growth can be enhanced quantitatively but the geometry of the parts and the whole is relatively constant.

Because agronomists like to measure plant growth progress, looking at the relationship of growth rates of individual parts over time is known as allometry. Allometry calculations can provide useful approximations over the season but they are not exact.

One of the most commonly used allometry is of plant top growth to root growth, usually expressed as shoot-root (S-R) ratio. It is often measured as an indication of plant tolerance to drought stress. Although genetically controlled, the S-R ratio is strongly influenced by environment. Besides water deficiency, fertilization, compaction and temperature as well as other variables influence the S-R ratio.

Because plants are symetical, another measurement is the apical and lateral bud growth. Light availability as well as adaptability in providing more growth from lateral buds will determine if and how much a plant can provide additional apical and lateral growth.

Measurements and timings of the vegetative versus the reproductive growth in plants is another means to quantify plant progress over the season. Since reproductive growth in annual plants appears to make virtually absolute demands on assimilate, timing and length of the reproductive process can document plant condition and efficiency. Perennials, however, appear to make only a partial commitment to reproduction and thus may not provide as keen an indication on plant condition.

Plant growth and differentiation is a complex of processes that lead to plant dry matter accumulation. Production of quality crops often requires production strategies that achieve a balance between growth and differentiation. In other words, growth is essential but should not be favored (by use of water and nitrogen as examples) to preclude differentiation. For example, cereal crops grown under high water and high nitrogen regimes, especially with low light, form plants with thin stem walls that tend to lodge. Limiting these external factors of water and nitrogen while maintaining or increasing light can lead to the formation of crop plants that will not lodge and can remain standing until mature and ready to harvest. Another example is how alfalfa accumulates starches in fleshy taproots in sunny, cool fall days. In fact, high irradiance during the day along with cool nights favor excess assimilate production (photosynthesis output exceeds growth/maintenance respiration requirements). This accumulation of excess carbohydrate food reserves in the alfalfa taproots also leads to hardening of the root protoplasm that protects the plants for overwintering.

Harvest index, a term to define the proportion of biological yield as represented by economic yield, is yet another way to describe seasonal partitioning of dry matter by the plant. Also known as the coefficient of effectiveness, the harvest index simply characterizes the movement of dry matter to the harvested part of the plant. Commonly defined as:

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

In grain crops, an increase in seed yield may primarily be due to increases in harvest index. The plants do not produce more total dry matter, but may partition more into the seed yield.

Growth Dynamics

Over a generation of plant growth, the pattern is usually represented as a sigmoid curve. This S-shaped curve of growth is a result of the differential rates of growth during the plant's life cycle. Indeed, seedling growth is slow but is followed by a period of exponential growth rate which later slows and tapers with the onset of grain formation and the mobilization/redistribution of food reserves to the seeds. When dry matter accumulation in crop plants is relatively constant for the season, it is expressed as a linear growth phase known as crop growth rate (CGR). When this growth declines due to mobilization/redistribution of food reserves to the seeds to a steady state, the crop plant is in physiological maturity. Many agronomists measure physiological parameters of plants during the linear phase or CGR as this phase best describes forecasts to yield.

Growth Analysis

In order to determine what influenced a crop plant during the season, one often needs to know more than just the end yield or the final dry matter accumulation. Looking at the yield-influencing factors and the plant development as net photosynthesis accumulation over time is one approach known as growth analysis. Only two measurements—made at frequent intervals—are required for growth analysis. These variables are leaf area and dry weight, with other quantities in the analysis derived by calculation. Growth analysis can be made of individual plants or of plant communities. Measurements on individual plants may include: relative and absolute growth rates; unit leaf rate or net assimilation rate; leaf area ratio; specific leaf area; and, specific leaf weight and allometry in growth (S-R ratio). Quantities used in plant community growth analysis include: leaf area index; leaf area duration; crop growth rate of total biomass and economic biomass; as well as net assimilation rate.

The relative growth rate (RGR) indicates the dry weight increase in plant matter over a time interval in relation to the initial weight. It is a commonly used parameter to measure crop plant growth over time.

Leaf area ratio (LAR) expresses the ratio between the leaf area (photosynthesizing tissue) and the total respiring plant tissues or total plant biomass. This measurement reflects the leafiness of a plant, but mean values are not precise. Plants like sunflower and sugarbeet have high LAR, while plants like pine do not but has a ten-fold greater RGR.

The net assimilation rate (NAR) is the net gain of assimilate by the plant per unit of leaf area and time. Age of the plant can distort this reading as this measurement assumes that the relationship between plant weight and leaf area is linear—and, later growth phases may have the growth rate of leaf area exceed that of dry matter or vice versa.

Leaf area index (LAI) expresses the ratio of leaf surface area to the ground area occupied by the crop. This measurement is an attempt to optimize crop production strategies to maximize light interception by using leaf density and spatial arrangement to cover ground area and promote rapid leaf expansion. Indeed, in a crop canopy, bare ground (where leaves do not fill the canopy space) does not trap and convert light energy. A LAI of 3 to 5 is usually necessary to maximize dry matter production in most cultivated crops. Forage crops may require a LAI of 8 to 10 to maximize light interception with grass forages that have a more upright leaf orientation.

Crop growth rate (CGR) is the gain in weight of a community of plants on a unit of land over a unit of time. Some plants are more efficient than others and the total crop growth weight can be compared to the economic crop growth weight to produce another useful quantity called the partitioning coefficient or index, an expression of the plant's efficiency in converting assimilate to economic yield.

Leaf area duration (LAD) is a measurement that expresses the magnitude and persistence of leaf area (or leafiness) during the period of crop growth. In wheat this measurement has been shown to correlate highly with yield.

Biomass duration (BMD) is analogous to LAD, but is less useful when used alone than along with the calculation of maintenance respiration losses over time, a function of live weight and temperature on the crop. It can be used in a model to construct plant responses over time and with the environmental factor of temperature influencing plant growth.

Growth and Management Summary

Limitations from growth factors will result in reductions in plant growth and development. Realizing the internal and external factors that affect crop growth will help in determining what management practices will benefit the crop. Crop growth is not only favored by inputs such as water and nitrogen but also by plant photoperiod, differentiation, photosynthesis optimization, temperature conditions, and other proper plant functioning. We can only peek into the plant processes during the season by using our knowledge of the plant growth curve and the whole-plant growth processes including constituent parts such as leaf area over time. Crop growth rate is of greatest interest as rate and duration ultimately express crop yield. Other classic growth analyses which can be used include leaf area index, relative growth rate and leaf area ratio. Growth analysis allows a better understanding of yield-influencing development of the crop during the growth cycle and may allow us to tweek the production systems to optimize plant growth and development as much as possible each season.

Post-Study Questions for Review

1. In crop production, one tries to maximize _____ and yield through both genetic and environmental manipulation.
    a. plant height
    b. plant girth
    c. growth rate
    d. root growth
2. Plant breeding and _____ can modify the genetic traits while some manipulation of the microclimate (site selection, tillage, irrigation, drainage, fertilization, pest control, and cultural changes—planting date, stand density and spatial arrangement) can be implemented.
    a. GMO pollen
    b. selection
    c. budding
    d. root stock manipulation
3. Some of the _____ factors (weeds, insects, disease organisms, nematodes, various herbivores, soil microorganisms including nitrogen fixing/denitrifying bacteria and mycorrhiza contributing to symbiotic fungal associations) are external factors that affect plant growth and development.
    a. physical
    b. chemical
    c. soil
    d. biological
4. In cotton, the key growth stage when you do not want stresses in the crop so that yield will not be limited is during _____.
    a. germination
    b. seedling
    c. first bloom
    d. physiological maturity
5. In the Liebig “law of the minimum” it is simply stated that a deficiency or absence of _____ necessary constituent (all others being present), renders the soil barren for crops for which that nutrient is needed.
    a. one
    b. two
    c. three

    d. four
6. Short-day plants are plants that require at least _____ hours of dark for reproduction to initiate such as soybeans or rice.
    a. 13
    b. 12
    c. 6
    d. 14
7. Species that require a period of cold or near freezing temperature in order to flower under long photoperiods of spring have a need for thermoperiodism, or _____.
    a. more moisture
    b. longer winters
    c. shorter springs
    d. vernalization
8. Because agronomists like to measure plant growth progress, looking at the relationship of growth rates of individual parts over time is known as _____.
    a. symmetry
    b. geometry
    c. allometry
    d. selection
9. Cereal crops grown under high water and high nitrogen regimes, especially with low light, form plants with thin stem walls that tend to _____.
    a. split
    b. lodge
    c. tiller
    d. grow more roots
10. _____ a term to define the proportion of biological yield as represented by economic yield, is yet another way to describe seasonal partitioning of dry matter by the plant.
    a. harvest rate
    b. growth rate
    c. assimilate rate
    d. harvest index

Check your answers before proceeding into the unit to find out how much you already know about the basic concepts on cropping systems. Each correct answer is worth 10 points, based on a total of 100 points for the ten questions. Answers: 1. c.; 2. b.; 3. d.; 4. c.; 5. a.; 6. b.; 7. d.; 8. c.; 9. b.; 10. d.