

Alfalfa Growth and Development

Shannon C. Mueller

Farm Advisor, University of California Cooperative Extension, Fresno, CA

Larry R. Teuber

Professor, Department of Plant Sciences, University of California, Davis

All aspects of alfalfa management require a thorough understanding of the growth and development of the crop. Basic knowledge of the botanical features of alfalfa, its growth patterns, and its developmental stages are keys to better management of a healthy, productive stand. Plant growth affects yield components, while plant morphology impacts many management decisions, including scheduling of herbicide treatments and harvest. This chapter describes the processes of alfalfa growth and defines precise stages of development.



Germination and Emergence

Alfalfa seeds begin germination shortly after planting, provided soil temperatures are approximately 65°F (18°C) and adequate moisture is present. Seeds will not germinate when soil temperatures are below about 35°F (1.7°C) or above 104°F (40°C). Absorption of water by the seed is the first step in the germination process and takes place when moisture is present in sufficient quantities to penetrate the seed coat. A small portion of alfalfa seed is highly resistant to water penetration; it is referred to as “hard seed.” Germination of hard seed is delayed many weeks or months after the majority of seed germinates. Seed produced in California typically has very little hard seed, whereas seed produced under different soil and climatic conditions can



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Corresponding Author:
Shannon C. Mueller
(scmueller@ucdavis.edu)



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have up to 60 percent hard seed. Seed lots with a high percentage of hard seed (>10%) may be scarified using specialized equipment to improve germination.

Mature seeds contain tiny immature leaves (cotyledons) and stored carbohydrates (endosperm), as well as the immature primary root (radicle). The first observable evidence of germination is the belowground elongation and penetration of the radicle into the soil to produce an unbranched taproot. After radicle emergence, the area below the cotyledons (hypocotyl) straightens and elongates, and the cotyledons are pulled above the soil surface (Fig. 3.1). The first true leaf produced is a unifoliolate (single leaflet) leaf. The seedling stem (primary shoot) continues to develop into a mature plant, producing alternately arranged trifoliolate (three leaflets per leaf) or multifoliolate (more than three leaflets per leaf) leaves. Subsequently produced stems are referred to as secondary stems.

Contractile Growth and Crown Development

A unique feature of early alfalfa development is contractile growth, or the formation of the crown during stand establishment. Contractile growth begins as early as 1 week after emergence and is usually complete within 16 weeks. As the primary and secondary shoots grow, the hypocotyl (portion of the stem below the cotyledonary node) shortens and thickens through a process known as contractile growth. This takes place when parenchyma cells in the hypocotyl simultaneously expand laterally and shorten longitudinally.

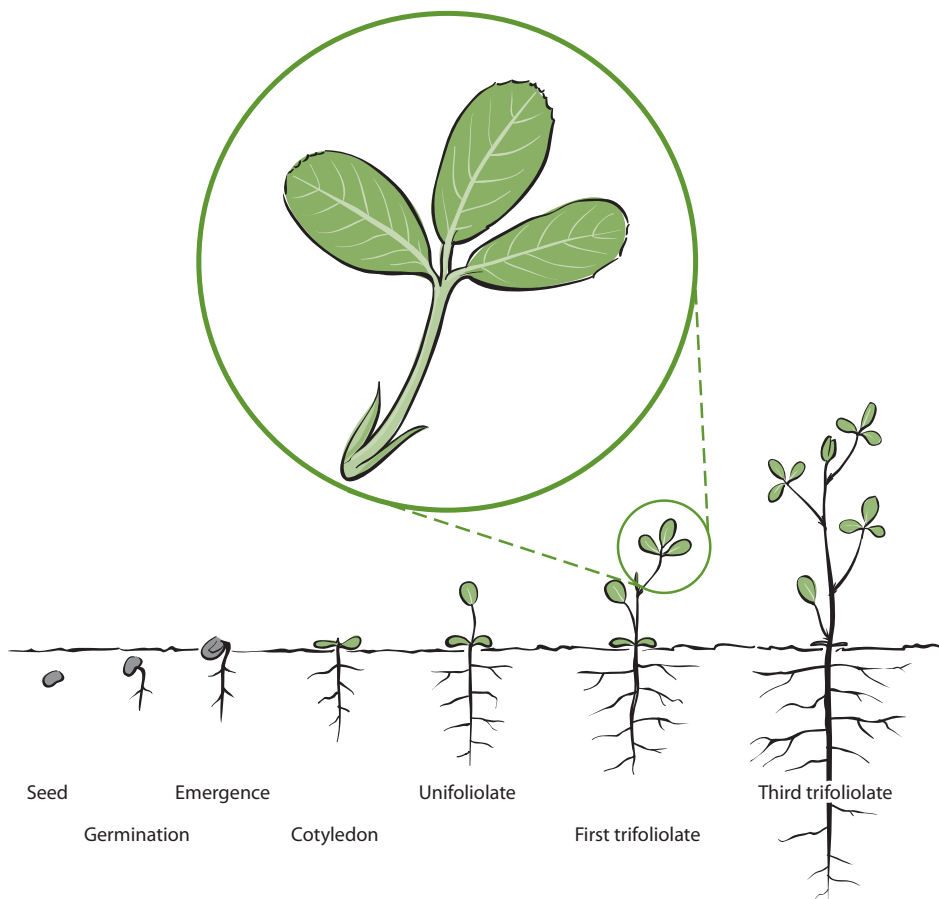
Outer tissues of the hypocotyl, which do not actively contract, are lifted in folds and wrinkles over the surface, producing the characteristic rough appearance of contracted roots and stems. As a consequence of contractile growth, both the cotyledonary node and the unifoliolate node may be pulled beneath the soil surface to form the *crown* of the mature plant (Fig. 3.2). All of these processes are influenced by soil temperature and, to a lesser extent, by photoperiod.

Importance of Crown Development

The adaptive value of contractile growth is to provide protection of growing points from desiccation, cold, or

FIGURE 3.1

Alfalfa seedling growth and development. The two leaves that first appear after emergence are called cotyledons or seed leaves. The next leaf to emerge is the first true leaf. It is unifoliolate. The second and subsequent leaves are usually trifoliolate, but may also be multifoliolate.



It is important to allow sufficient time for contractile growth to take place before field operations begin, especially harvest.

mechanical damage. Varieties with greater fall dormancy tend to have more pronounced contractile growth, resulting in the nodes being pulled further below the soil surface than they would be in less dormant varieties. It is important to give time for seedling crown formation to occur before beginning any farm-

ing practices that might disrupt the process, especially harvest operations. Protecting young seedlings from weed competition and insect damage is also critical to the long-term health of the developing crown. An argument in favor of fall planting is that it allows time for crown formation before the onset of cold weather. Well-developed crowns contain a large number of buds, which can lead to higher yields after cutting.

Root Development and N₂ Fixation

The radicle thickens and develops into the primary taproot. Smaller secondary roots begin to develop on the radicle as it grows deeper. Within 4 weeks after germination, root hairs on the radicle become infected with nitrogen-fixing bacteria, *Rhizobium meliloti* Dang., and begin to form nodules. It is within these nodules that nitrogen fixation occurs, converting atmospheric nitrogen into a form the plant can use. Estimates of N₂ (molecular nitrogen) fixation in alfalfa vary from about 40 to 400 pounds (18 to 181 kg) of N₂ fixed acre⁻¹ year⁻¹ with an average of about 175 pounds (79 kg) of N₂ fixed acre⁻¹ year⁻¹. Conditions ideal for alfalfa plant growth are also ideal for nitrogen fixation: neutral soil pH and adequate moisture are two of the most important.

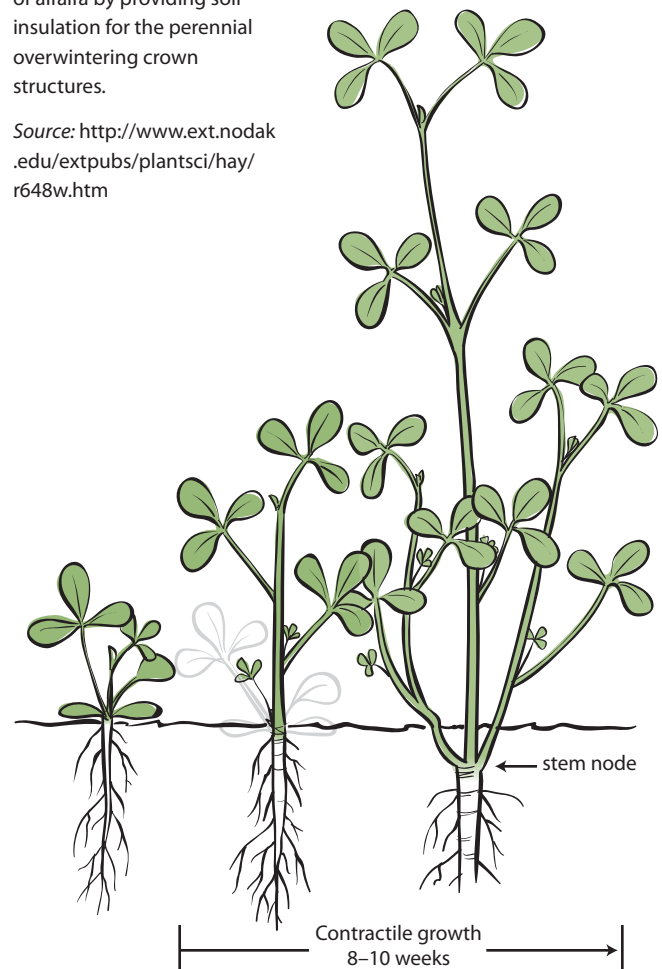
Populations of *Rhizobium* bacteria inhabit the soil naturally or as a result of previous alfalfa production on that site. However, it is recommended that *Rhizobium* strains specific to alfalfa be introduced at planting by the addition of inoculum to the seed.

During stand establishment, it is important to allow roots to penetrate deep into the soil, below areas where a restrictive soil compaction zone (plow pan) could potentially be created during initial harvest operations. Established alfalfa taproots have been known to extend more than 6 feet below the soil surface, provided there are no restricting layers. It is in these roots that the carbohydrates produced by photosynthesis are stored. Stored carbohydrates (root reserves) provide energy for regrowth after cutting, winter survival, and initial growth in the spring. Alfalfa plants use

FIGURE 3.2

The young alfalfa plant undergoes a growth phase known as contractile growth. This process in alfalfa involves a change in the shape of cells in the hypocotyl or seedling axis below the cotyledons and upper portion of the primary root from long and narrow to short and wide, as a result of carbohydrate or food storage. This shift pulls the lower stem nodes beneath the soil surface. Most winter-hardy alfalfa varieties have several nodes pulled well below the soil surface in the seeding year. Contractile growth greatly aids winter survival of alfalfa by providing soil insulation for the perennial overwintering crown structures.

Source: <http://www.ext.nodak.edu/extpubs/plantsci/hay/r648w.htm>



stored carbohydrates until leaf development is sufficient to provide energy for plant growth from photosynthesis. Once plants reach 8 to 12 inches in height (20 to 30 cm), enough energy is produced to maintain growth; at the same time, root reserves are replenished in preparation for the next cutting, or for winter survival.

Influence of Photoperiod and Soil Temperature on Alfalfa Seedling Development

Photoperiod (day length) and soil temperature both influence seedling development by affecting growth rate, stem initiation, and the allocation of photosynthetic products to the development of roots and stems. Not all cultivars respond equally to these environmental triggers. Seedling development of *dormant* cultivars is almost equally influenced by photoperiod and soil temperature, whereas seedling development of *nondormant* cultivars is essentially independent of photoperiod but is strongly influenced by soil temperature. Although the effect of photoperiod is less than that of temperature in cultivars grown throughout most of California, there are growth characteristics influenced by photoperiod that influence planting decisions. The importance of these considerations during stand estab-

lishment is covered in Chapter 4, “Alfalfa Stand Establishment.”

Optimum temperatures for alfalfa seedling development are in the range of 68° to 72°F (20°C to 22°C), depending on the dormancy of the cultivar. During the first 4 weeks following germination, the optimum soil temperature for root growth is slightly higher, between 69° and 76°F (21°C to 24°C). Dormant cultivars generally have

Seedling development of dormant cultivars is influenced by both day length and soil temperature, whereas non-dormant cultivars are influenced mostly by soil temperature.

lower optimum temperatures during this initial growth phase than do nondormant cultivars.

A photoperiod of approximately 12 hours stimulates the formation of initial crown buds and stems from the axils of the cotyledons and the unifoliolate leaf, forming the primary crown. Photoperiods shorter than 12 hours favor allocation of photosynthate (dry matter) to the development of roots. Therefore, with fall planting, seedlings develop under cooling temperatures and shortening day lengths. Under these conditions, seedlings might be expected to rapidly develop the initial crown and form plants with a stronger crown and larger root system than seedlings developing under the warmer conditions and increasing day lengths associated with spring and summer planting.

Plant Age and Stage of Development

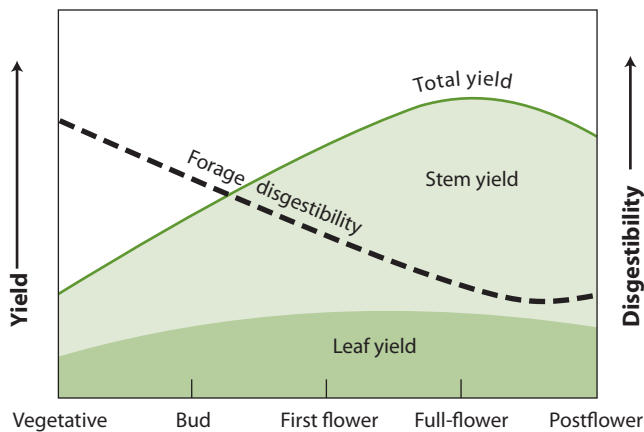
Alfalfa growth and development is controlled by the genetic potential of the plant interacting with the environment. It is important to make the distinction between plant *age* and *stage of development*. Alfalfa does not reach a specific stage of development at a given age. For example, if environmental conditions don't trigger changes in morphological development leading to the formation of reproductive structures, the plant will continue to grow vegetatively. On the other hand, specific environmental conditions (temperature, photoperiod, moisture status, salinity) can trigger the plant to transition into reproductive stages at a very young age. Most management decisions should be based on stage of development, not age.

Plant Maturity and Forage Quality

Forage quality changes over time as alfalfa plants grow and mature. It is well known that alfalfa yields increase as the crop matures, whereas the nutritional value of the forage declines significantly (Fig. 3.3). In young pre-bud alfalfa, the quality of the forage is high because of the high proportion of leaves to

FIGURE 3.3

Forage yield relative to quality (forage digestibility) at different alfalfa growth stages.



stems, but the yield is low. As the plant grows and matures, the proportion of leaves and stems changes. Stems lengthen and become more fibrous, increasing their total proportion in the forage. There is no concomitant increase in leaf percentage; thus, overall quality declines. To maximize yield, quality, and persistence, the grower must schedule management practices to maximize forage yield while achieving a level of quality to meet the nutritional requirements of the livestock that will consume it, without reducing desired stand life. The yield of high-quality forage is maximized in most cases by not harvesting until flower buds can be seen at the stem tips. During the vegetative period, before flower buds appear, yield generally increases faster than quality declines. However, during the flowering period, reduction in quality is very rapid, due primarily to increased fiber (cellulose and lignin) concentration in the stems. Within any regrowth interval, the trends in yield and quality can be modified by prevailing environmental conditions, such as changes in temperature.

The maturity of the alfalfa when it is harvested has the greatest impact on forage quality. It is also the variable most easily controlled by growers. Cutting according to the stage of development uses the plant as a harvest indicator and generally provides more consistent yield and quality among varieties and over years and locations compared to other harvest scheduling strategies. Improving the

understanding of alfalfa development and the changes that impact alfalfa quality will help growers balance the yield–quality tradeoff.

Although *quality* is often defined in terms of low fiber content (acid detergent fiber [ADF] and neutral detergent fiber [NDF] concentration), which results in high total digestible nutrients (TDN) or relative feed value (RFV), growers should be aware of the penalties resulting from attempts to minimize fiber concentrations by reducing the interval between cuttings. Shorter cutting intervals do not allow sufficient time for root reserves to accumulate; thus, alfalfa vigor and the yield of subsequent cuttings are reduced and effective stand life can be severely reduced. Furthermore, harvesting alfalfa at immature stages of development, especially in cool spring weather, can result in inadequate fiber levels for ruminants, which can be critical for animals used for reproduction and lactation. Other sources of fiber must then be added to the diet.

Predicting Alfalfa Quality

Historically, the stage of alfalfa development was estimated using the reproductive status of the most mature stems in the canopy. Thus, alfalfa was said to be at a “late bud” or “early bloom” stage of growth. Alfalfa maturity was also defined in terms of the presence and length of regrowth buds. These estimates of maturity were associated with various quality parameters. In the 1980s, researchers studied more precise methods to assess maturity and used them to more accurately predict the quality of the growing alfalfa crop. More recently, predictive equations for alfalfa quality based on the height of the most mature stem show promise as a rapid and inexpensive method of estimating alfalfa fiber components, but early efforts were not as successful in predicting crude protein. Modifications to these prediction systems continue to be evaluated. Overall, forage quality predictions based on the maturity of the crop work well, because the cumulative effect of environmental factors on crop growth and quality is expressed in large part by alfalfa’s morphological stage of development.

Determining Stage of Development of Alfalfa

As alfalfa develops, changes in the plant can be observed on individual stems (Fig. 3.4). The stems progressively pass through vegetative, bud, flower, and seed pod stages. Numerous stems at various stages of development are typically found on one plant and in any given field. Precise definition of the average (mean) stage of development is the first step in many quality prediction systems. The *Mean Stage* method averages a large number of individual stems and is a precise method used to relate maturity to forage quality in a field. The *Mean Stage of*

Development is determined by examining individual stems and classifying them according to the staging system defined by Kalu and Fick (1981). A detailed protocol for collecting a sample and calculating Mean Stage of Development can be found in Fick and Mueller (1989).

Descriptions of Alfalfa Developmental Stages

Vegetative Stages

At early stages of development, reproductive structures are not visible on alfalfa stems. Leaf and stem formation characterize vegetative growth. The three vegetative stages are distinguished by stem length.

Stage 0: Early Vegetative
Stem length ≤ 6 inches (15 cm); no visible buds, flowers or seed pods

Stage 1: Mid-Vegetative
Stem length 6–12 inches (16–30 cm); no visible buds, flowers, or seed pods

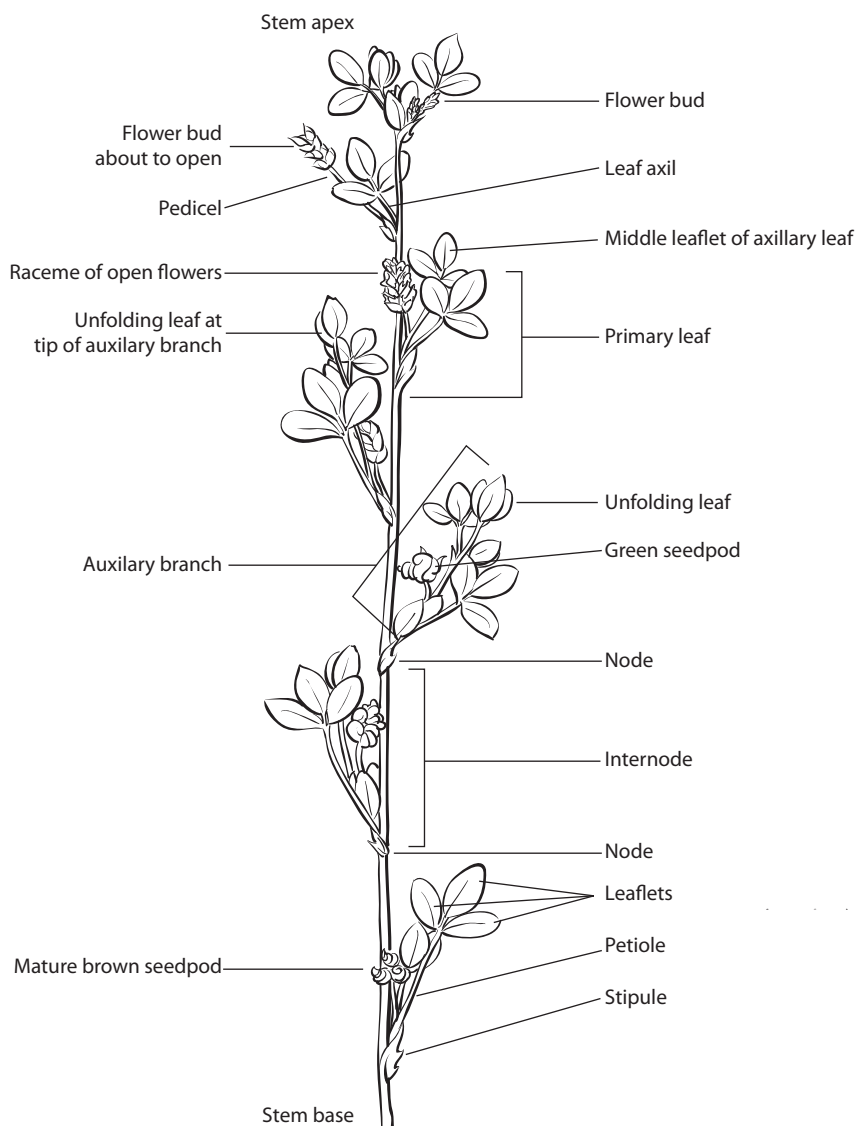
Stage 2: Late Vegetative
Stem length ≥ 12 inches (31 cm); no visible buds, flowers, or seed pods

Bud Stages

Flower buds first appear clustered near the tip of the stem or an axillary branch, because of the closely spaced nodes in that part of the shoot. At the transition from the vegetative stages to the bud stages, flower buds can be difficult to identify. At first, buds are small, distinctly round, and appear

FIGURE 3.4

Alfalfa stages of development as denoted on a single stem. After illustration by Lisa Richter.



hairy or fuzzy. In contrast, new leaves are flattened and oblong. As the nodes elongate, it becomes easier to distinguish individual nodes for the purposes of counting.

Stage 3: Early Bud

1–2 nodes with visible buds; no flowers or seed pods

Stage 4: Late Bud

≥ 3 nodes with visible buds; no flowers or seed pods

Flowering Stages

When environmental conditions meet specific requirements for temperature and photoperiod, flower buds develop into flowers. In fall, when there are fewer than 12 hours of daylight, buds may abort without forming flowers. Flowers may be purple, cream, yellow, white, or variegated combinations of those colors, depending on variety. Flowers may be open or closed. To be counted as an “open” flower, the standard petal (main large petal) of the flower must be unfolded. One or more flowers within the raceme (group of many flowers) may be open; however, the definition of stage 5 describes open flowers at only one node. Because one raceme arises from each node, the number of racemes with open flowers is actually what is counted. Flowering usually begins near the apex of the stem while buds are still developing rapidly above and below the point of initial flower opening.

Stage 5: Early Flower

One node with one open flower; no seed pods

Stage 6: Late Flower

≥ 2 nodes with open flowers; no seed pods

Seed Development Stages

If flowers are pollinated, they will ordinarily develop seed pods. In some environments, pollination is poor and only a few flowers form seed. Typically, alfalfa is harvested for forage well before the seed-bearing stages, which is when quality is lowest.

Stage 7: Early Seed Pod

1–3 nodes with green seed pods

Stage 8: Late Seed Pod

≥ 4 nodes with green seed pods

Stage 9: Ripe Seed Pod

Nodes with mostly brown, mature seed pods

Calculating the Mean Stage of Development

Two methods have been used to calculate the Mean Stage of Development for alfalfa forage. Mean Stage by Weight (MSW) is based on the dry weight of stems in each stage. Mean Stage by Count (MSC) uses the number of stems in each stage category to quantify maturity. Both procedures require a random sample of at least 40 alfalfa stems obtained from 5 to 6 places in a field, representing the natural range of growth patterns in that field. Individual stems are separated into the stages of development described above, based on their morphological characteristics. Most young samples have stems in only two or three categories. Older, more mature forage samples can have stems in each stage, from vegetative through seed pod.

Two methods have been used to precisely describe alfalfa growth stages: Mean Stage by Weight (MSW) and Mean Stage by Count (MSC).

Stems from each stage should be counted to determine the mean stage by the MSC procedure. For MSW, stems from each stage should be dried in a forced-air oven at approximately 140°F (60°C) in individual bags, then weighed.

MSC is calculated as the average of the individual stage categories present in the sample, weighted for the number of stems in each stage. MSW is calculated similarly, except the average of the individual stages is weighted for the dry weights of stems in each stage.

Example:

If an alfalfa sample had

- 4 stems in Stage 0
- 5 stems in Stage 1
- 5 stems in Stage 2
- 10 stems in Stage 3
- 15 stems in Stage 4
- 2 stems in Stage 5

MSC is calculated as

$$\frac{(4 \times 0) + (5 \times 1) + (5 \times 2) + (10 \times 3) + (15 \times 4) + (2 \times 5)}{(4 + 5 + 5 + 10 + 15 + 2)}$$

which equals

$$\frac{5 + 10 + 30 + 60 + 10}{41} \text{ or } \frac{115}{41} = 2.8$$

MSW would be calculated the same way, but instead of the *number* of stems in each stage, the *dry weight* of stems in each stage would be multiplied by the stage number, and the sum of the products would be divided by the total dry weight of all stems combined.

It is recommended that a decimal point be included with calculated mean stage values to distinguish a mean stage estimate from a rating of an individual stem.

Because stage of development and quality are closely associated in alfalfa, quality can be predicted by calculating mean stage. Predicting quality of the standing crop can help schedule when to harvest. Both MSW and MSC quantify morphological development of alfalfa. Most users prefer MSC because it is less tedious; however, only MSW is closely related to forage quality once crown buds start to elongate in an older canopy. Rapid, less complicated techniques for predicting quality have evolved from the Mean Stage system. For example, in 1998, Orloff and Putnam produced an *Alfalfa Quality Prediction Stick* with growth stages printed on three sides of the stick and corresponding percent ADF values associated with various

heights. Instructions printed on the fourth side of the stick guide growers through the process of predicting ADF using growth stage and height.

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