Factors Affecting the Nutritive Value of Range Forage

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Antoine Lavoisier (1743-1794), a great French chemist, is accredited as being the founder of the science of nutrition. His famous respiration experiments led him to state "La vie est une fonction chimique" or "Life is a function of chemistry." Since Lavoisier's time many advancements have been made in the field of animal nutrition.

The nutritive value of any forage is dependent upon its content of energy-producing nutrients as well as its content of nutrients essential to the body, namely, protein, minerals and vitamins.

Forages supply energy mostly in the form of carbohydrates. The carbohydrate fraction makes up from 60 to 80 percent of the dry matter. The higher carbohydrates may be broken up into three classes: (1) starch, readily and nearly completely digested by the animal; (2) cellulose, digested mostly by bacteria in the rumen of ruminants; and (3) hemicelluloses, intermediate between starches and cellulose and broken down by weak acids and alkalies. In chemical analyses, these higher carbohydrates are arbitrarily grouped into two classes, crude fiber and nitrogen-free extract. Crude fiber consists almost entirely of cellulose and lignin together with some resistant hemicellulose. Lignin is essentially nondigestible by most domestic animals. However, Utah studies have shown that deer are able to digest up to 42 percent of this constituent in birchleaf mahogany (*Cercocarpus montanus*) (Smith, *et al.*, 1956). Nitrogen-free extract consists mainly of starch and most of the hemicelluloses.

Protein commonly means nitrogen multiplied by the factor 6.25; however, 25 to 50 percent of the total nitrogen may be non-protein, essentially the amides and amino acids (Maynard, 1937). The value of protein is dependent principally upon its supply of certain amino acids which are required for the formation of body protein and which cannot be manufactured by the body. The amount of digestible protein furnished by a plant depends upon the plant species and the class of livestock using the plant. In addition, digestibility of protein varies appreciably between domestic animal species and somewhat between individuals of a given species.

Minerals are essential for the proper functioning of the bodily processes. Aside from sodium, chlorine, calcium, and phosphorus, most of the essential elements are ample in forages except when grown on mineral-deficient areas, i.e., cobalt in Florida.

The precursors of vitamin A and vitamin D are frequently limiting in range forage. Carotene is the precursor of vitamin A, which is manufactured in the animal body, and ergosterol is the precursor of vitamin D in plants. Cholesterol is the animal form of vitamin D precursor and like ergosterol, it needs sun exposure for transformation into vitamin D (Maynard, 1947). Both of these vitamins play an important role in body processes and growth.

Determination of Nutritive Value

Precise information relating to the feeding value of range forages is notably lacking. This is a reflection of the complexity of plant analysis, as well as the difficulty of interpreting results in terms of actual feeding values.

Early investigators resorted to chemical analyses of various species, and through the years developed a fairly reliable system of chemical analysis procedures. However, it was noted that chemical analysis data had to be interpreted with care. Many plants, found to be highly nutritious by chemical analysis, proved to be worthless as animal forage because they lacked palatability.

Most students have been concerned with only the major forage plants, chemical analyses being made on the parts thought to be consumed or bulk samples of plant material (Clarke and Tisdale, 1945; Hart, *et al.*, 1932; Stoddart and Greaves, 1942). The chemical analysis of consumed plant forage is in itself an incomplete measure of nutritive value, but it can be used as a guide when interpreted with the results of digestibility trials that have been conducted with similar forages (Cook and Harris, 1950).

Later experimenters used digestion trials to test nutritive value. For obvious reasons, the data secured from these trials were not indicative of the actual grazing habits of animals, which show forage preferences. Forages also vary as to palatability and composition when artificially harvested and fed to livestock by man. Consequently, some present-day workers have endeavored to improve field digestion trials by use of specially designed fecal and urinal bags attached to the grazing animal. Even this advanced procedure has its weaknesses, and will require many more years of refinement through trial before the accuracy of results approaches an acceptable level.

Factors Influencing Nutritive Value

The factors influencing the nutritive value of range forage are many and the degree to which they are interrelated may vary considerably from one area to another. The study of these influences is indeed complex, for the experimenter must attempt to study individual factors while keeping the remaining ones as nearly constant as possible. It is essential that due credit be attributed to the correct factor or complex of factors.

The nutritive value of range forage is influenced in a major way by: (1) stage of maturity, (2) edaphic influences, (3) plant species, (4) climate, (5) animal class, and (6) range condition. In this report, an attempt will be made to show how these important factors influence the nutritive value of forage.

Stage of Maturity

The stage of growth seems to be the most important factor affecting the chemical composition and digestibility of range forage. In general all forages are highly succulent in early growth, which markedly enhances their palatability. In addition, their high protein content in relation to a low fiber content at this stage makes them highly nutritious as livestock forage. Thus, grasses and forbs are referred to as "watered concentrates" while in the early stages of growth.

Striking nutritive differences exist between forage classes (browse, grasses and forbs) at maturity. Browse species are less affected by summer drought periods than are forbs and grasses because of their deeper root systems.

Browse:

Protein content of browse tends to decrease as the season advances except in certain species which show an increase in protein during the moist fall period. In snowberry (*Symphoricarpos rotundifolius*), protein decreased from an average of 11.24 percent on July 15 to 9.19 on August 15 to 6.58 percent on September 15 (Stoddart, 1941). However, when various plant parts of *Symphoricarpos vaccinoides* were analyzed separately, it was found in some cases that the protein content increased with advanced maturity (Cook and Harris, 1950a).

Little change occurred in the nutritive value of winter range plants in Utah during the winter grazing season (November 18 to March 14). Normal leaching and translocation of nutrients occurred prior to the winter grazing season, accounting for the constancy in chemical composition of these winter species (Cook and Harris, 1950).

The trend in crude fiber content in regard to stage of maturity is normally the reverse of protein. In California, Gordon and Sampson (1939) found that half-shrubs, *Lotus scoparius* and *Lupinus albifrons,* had an increasing amount of crude fiber until late summer when it decreased due to a larger proportion of leafage on the shoots. In deciduous shrubs such as *Aesculus californica* and *Sambucus glauca,* the crude fiber content stayed rather uniformly low at all stages of growth. As the percentage of crude fiber increases, digestibility usually decreases because crude fiber is resistant to decomposition and it often envelops digestible nutrients rendering them unavailable (Maynard, 1937).

"Nitrogen-free extract" (mainly starches and hemicelluloses) normally decreases with advancing season. Cook and Harris (1950a) found that nitrogen-free-extract content decreased in all plant parts of snowberry.

Phosphorus content normally parallels that of protein in regard to seasonal changes. Phosphorus and magnesium both decreased significantly in *Symphoricarpos rotundifolius* with advancing season (Stoddart, 1941). Deciduous shrubs in California also showed a marked decrease in phosphorus content toward maturity (Gordon and Sampson, 1939).

Calcium, in contrast, generally increases as the season advances (Savage, et al., 1947). The calcium content of several deciduous shrubs was observed to increase uniformly from early leaf stage to maturity (Gordon and Sampson, 1939). The fact that calcium content increased with maturity was explained on the basis of the increased amount of cellular material which is composed principally of this element. McCreary (1927) has suggested that the late-season increases in calcium and ash may be attributed to dust accumulations. Hart, *et al.,* (1932) report no seasonal trend in calcium content. These reported differences in results seem to indicate that there are several interrelated and poorly understood factors which influence the calcium content of shrubs.

Vitamins, essential for animal metabolism, also vary with season. Vitamins are unstable in dry forage and quickly disintegrate as leaves and stems desiccate. Carotene content of shrubs decreases, although slower than in grasses and forbs, as the season progresses.

Forbs:

Generally speaking, the leaves and blades of grasses and forbs mature earlier than shrubs. Seasonal changes alter the nutritive value of forbs (especially spring forbs) much faster than browse or most grass species because the succulent tissues of forbs are subject to desiccation upon exposure to the high temperatures and long photoperiods of the summer months. Therefore, the period of high nutritive value of most forbs is restricted to the early portion of the growing season. The rate of decrease in protein and crude fiber in the broadleaf herbs except legumes is most rapid from early leaf stage to the late blossom period. In California legumes studied by Gordon and Sampson (1939), the protein content declined slowly and uniformly throughout the season, the relatively high content at maturity resulting in part from the high protein level of the seeds of many species. Cook and Harris (1950a) reported an orderly decrease in protein content of yarrow (*Achillea lanulosa*) except for a slight increase at the end of the growing season, attributed to improved moisture conditions during this period.

In general, phosphorus content parallels that of protein in most forbs. Calcium was found to increase with maturity in all plants and plant parts studied by Cook and Harris (1950a). Several species of *Erodium* were found to be remarkably high in silica-free ash and calcium at maturity (Gordon and Sampson, 1939). Silicon, iron and aluminum are "hard" elements (not essential to animals); consequently, plant species having a minimum of these elements are most desirable.

Grasses:

Seasonal changes affect grasses in much the same way as forbs except that certain perennial grasses retain their nutrients after maturity.

Native and tame grasses of western North Dakota lost on an average 71 percent of their protein by September 30 (Whitman, *et al.*, 1951). In an extensive study of forage plants in Utah by Cook and Harris (1950), the grasses had an average protein content of 8.2 percent in early season (July 10 to August 4), 7.2 percent in mid-season (August 15-24) and 4.5 percent in the late season (August 25 to September 13). *Poa scabrella*, a perennial grass, had a protein content of approximately 20 percent at early leaf stage and only 5 percent at maturity; the annuals, *Bromus mollis* and *Avena fatua*, dropped 89 percent from early leaf stage to maturity (Gordon and Sampson, 1939).

Native range grasses of western North Dakota were seen to increase in crude fiber and decrease in phosphorus and carotene with advancing maturity. By the end of September, these native grasses had lost 87 percent of their carotene and 66 percent of their phosphorus (Whitman, *et al.*, 1951). Studies of pasture grasses have shown phosphorus to vary directly with crude protein content. Calcium, on the other hand, generally increases in grass tissue with advancing season. In Montana grasses, lignin increased from 5 percent in May to 18 percent in September (Patton and Gieseker, 1942).

Edaphic Influences

The physical and chemical properties of soils exert almost unlimited influence upon the nutrient content of plants. Orr (1929) concluded that the mineral composition within a species was determined primarily by soil as shown by the response to fertilizers. It has long been known that plants grown on soils rich in certain nutrients usually are also rich in these nutrients.

Physical properties of soil such as texture and porosity affect the nutritive quality of forage more or less indirectly. Poorly aerated soils greatly limit or decrease the absorption of essential elements, especially phosphorus. Soils rich in biotic life show enhanced aeration and fertility.

Chemical properties of the soil may determine the nutrients that plants are able to absorb. For example, phosphorus is most available between pH 6 and pH 7. Phosphorus in soils of low pH reacts chemically with hydrous oxides of iron, aluminum and magnesium to form insoluble compounds which are unavailable to plants. At pH 7 and above, phosphorus again becomes insoluble as calcium phosphate. Holtz (1930) showed that the phosphorus content of oats followed the *total* phosphorus content of the soil, whereas that of red clover followed the *available* phosphorus content of the soil.

Range plants growing on limestone outcroppings in California had relatively high calcium content (Hart, *et al.*, 1932).

Daniel (1934) found that certain species were normally high in calcium and phosphorus even when grown on soils relatively low in these minerals, and plants normally low in calcium and phosphorus had low contents of these minerals when grown on rich soils. This suggests genetic characteristics which are inherent to the specific plants.

Burning of heavy vegetation modifies both the physical and chemical and biological properties of the soil. Mild burning of a range area generally results in the release of minerals, making them available for plant absorption. Wild oats in California (24) had increased percentages of protein, nitrogen-free extracts, crude fat, calcium and phosphorus the first year following a burn (Hart, *et al.*, 1932).

Climatic Influences

Climatic factors such as temperature, humidity, precipitation, light intensity and altitude may be dominant in controlling the nutritive value of plants. Although plants are dependent upon the soil for their mineral nutrients, climatic factors affect respiration, assimilation, photosynthesis and metabolism to the extent that the mineral and organic matter content of plants may be strongly modified by climatic factors even though grown on the same soil.

Plants of *Bromus inermis* grown under full sunlight were found by Watkins (1940) to have higher carbohydrate and lower protein content than plants grown in shade.

Precipitation may have direct and indirect influences upon the quality of forage plants. Rainfall, in general, tends to increase nitrogen, phosphorus and ether extract (the soluble fat constituent). Oklahoma studies by Daniel and Harper (1934) revealed a close relationship between precipitation and the calcium and phosphorous balance in *Andropogon scoparius*. Increased precipitation resulted in an increase in phosphorus and a decrease in calcium and vice versa. Watkins (1940) has shown that droughts may decrease the phosphorus and protein contents and increase the calcium and crude fiber contents. However, Ferguson (1931) found that both calcium and phosphorus decreased in forage during periods of drought. Scott (1929) found no significant relationship between precipitation and the calcium-phosphorus content of native forage species.

Precipitation greatly alters plant nutrients when they are matured. Leaching causes a decrease in all plant nutrients except crude fiber; thus the plant forage becomes less digestible (Guilbert, *et al.*, 1931).

Temperature seems to be the most important factor governing phenology. Low temperatures tend to initiate the transformation of starches into plant sugars which are used in plant metabolism. Benedict (1940) found that low night temperature increased the dry weight of *Agropyron smithii* and *Andropogon furcatus* when subjected to both long and short days.

Altitude affects plant composition through the interrelation of factors such as light intensity, carbon dioxide concentration and precipitation. Western forage plants generally increase in feeding value with increasing altitude (Roberts, 1926). The nitrogen content of high altitude plants seems to be higher than that of plants grown at lower elevations (McCreary, 1927).

Plant Species

A plant may have satisfactory amounts of inorganic and organic nutrients as forage for livestock but is of little value if it lacks palatability. Big sagebrush (*Artemisia tridentata*) is an example. Therefore digestion experiments are mandatory when determining the real forage value of plant species. Furthermore, the palatability and abundance of the various species determine the botanical composition of the grazing animal's diet.

Many workers have concluded that the plant species is more important than the soil or management practices in determining the mineral composition of the forage. However, the soil may govern the type of plants which grow upon an area. Legumes contain more calcium than grasses and their calcium-phosphorus ratio is higher. Leguminous species carry their own nitrogen-factory with them and are able to build up nitrate reserves in the soil which may become available to associated forage species.

Browse species are generally higher in protein content than are grasses and forbs. Browse species retain their protein, carotene and carbohydrates better during periods of drought than either grasses or forbs because of their deep root systems and ability to store food reserves in their stems (Stoddart and Smith, 1955). Forbs other than leguminous species tend to be slightly higher in protein, phosphorus and calcium than grasses during their growth period; however, most of them succumb to the elements soon after maturity.

On winter range areas, browse furnishes the major components of the grazing animal diet because the nutrients in the grasses on these winter ranges are able to supply large quantities of metabolizable energy. Browse species are relatively low in energy values because of their high lignin content in comparison to their cellulose content (Cook and Harris, 1950).

Livestock Class

The various classes of livestock exhibit different behavior patterns when grazing. Sheep and goats tend to be more selective in their grazing, eating plant parts more often than the whole. Minor food preferences also exist among members of the same species.

Non-ruminants such as swine can make only limited use of range forage due to their limited digestive capacity. In certain sections of the United States, hogs are allowed to run at large, their diet consisting largely of mast (acorns and nuts) and limited forage. Hogs utilize such concentrated feeds efficiently, but cannot make good use of sizeable quantities of roughage.

Horses prefer grasses to all other forages. Although they are monogastric animals, the presence of a caecum or "blind gut" in their digestive systems enables them to digest large quantities of roughage.

Ruminants are physiologically adapted for the digestion of complex cellulose and to a limited extent lignin. Micro-organisms within the rumen act to break these complex substances into simpler carbohydrates which the ruminant can digest and metabolize.

Ruminants may eat some plants more readily than others, without relationship to the digestibility or nutritive value of these plants. Many palatable plants are actually very low in nutritive value.

Cattle, like horses, prefer grasses to browse or forbs. Cattle will eat mature, hardened forages more readily than sheep will. Horses and cattle also prefer certain grass species to others.

Sheep prefer forbs and tender grasses, whereas goats prefer browse species. Sheep will graze *Bromus tectorum* when young and succulent but avoid it when it reaches maturity. Grass species such as *Poa secunda* which tend to be rather wiry are avoided by sheep.

Due to these forage preferences, many range areas are well suited for grazing by two classes of livestock or alternate grazing by each class in successive years.

Range Condition

Range condition is influenced essentially by the interplay of grazing intensity, season of use, grazing class, soil and climatic influences.

Grazing intensity influences the ultimate nutrient quality of forage. Livestock normally consume the leaves and more tender stems first and reject the fibrous plant parts. This reduces the photosynthetic area of the plant and the root-shoot balance is disturbed (Cook, *et al.*, 1948). These Utah studies showed that available protein, phosphorus, cellulose and metabolizable energy in the forage decreased with heavier utilization while the lignin content increased. Digestibility of protein and cellulose was found to decrease 10 and 67 percent respectively in some cases as utilization increased.

Native range grasses in Kansas clipped frequently yielded less forage but of a higher protein content than if clipped less often (Aldous, 1926). Sampson and Malmsten (1926) found that the herbage of *Agropyron violaceum* and *Bromus polyanthus* clipped four times a season contained less crude fiber and nitrogen-free extract, more crude protein and approximately the same amount of either extract than forage clipped only once per season. Immature herbage seems to lack "substance." Crude protein in more developed herbage exists in the form of amino acids which are completely assimilated by animals; whereas, the protein of young, succulent forage occurs in the amide form and is not assimilated by the animal to a very high degree.

The stage of succession is also an important part of range condition. In general, climax vegetation of grassland areas produces the greatest quantity of desirable dry matter possible on a given site without irrigation or fertilization. Although the introduced cheatgrass (*Bromus tectorum*) yielded as much forage per acre as crested wheatgrass or native bunch grasses, its period of high nutritive value was limited to a short period during the spring months (Hull and Pechanec, 1947).

Summary

The nutritive value of range forages is affected by stage of maturity, edaphic conditions, climatic influences, plant species, animal class and range condition.

Stage of maturity seems to influence forage quality more than any other factor. Protein, nitrogen-free extract, ether extract, carotene and phosphorus tend to decrease with advancing maturity, whereas crude fiber, lignin and calcium increase. The trend is more abrupt in forbs than in browse species, and intermediate in grasses.

The physical and biological properties of the soil, aeration, texture, and biotic influences are important in regulating physiological processes in plants. Chemical properties of soil, such as pH, available minerals and fertility, control to a certain extent the absorption of minerals by plants. Burning may modify both chemical and physical characteristics of soil. Generally, burning releases many unavailable elements.

Climate affects forage value considerably. Increased precipitation tends to increase the phosphorus content and decrease the calcium content of plants. Light intensity, temperature and carbon dioxide concentration limit forage value if they occur in sub-optimum quantities.

Plant species vary greatly as to palatability, digestibility and nutritive composition.

Animals possess certain forage preferences which increase the problem of proper grazing practices. Range condition is affected mostly by grazing intensity as it operates through other factors. In general browse and perennial grasses withstand grazing better than forbs. The most palatable species are most seriously affected by excessive grazing.

Grazing intensity on a given area should be ample to remove the maximum amount of forage without detriment to the potentialities of the site.

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