The Role of Grazing Sheep in Sustainable Agriculture

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Introduction
The world has challenged agriculture to continue to produce an abundance of food and fiber for an ever-expanding population. The furor, developed over improving the global environment, dictates this production occur in a “clean” environment considered “safe” for all living organisms.

The United States has developed an efficient, highly productive food and fiber system envied by the world because consumers spend a lower percentage (11.8) of their income for food than any other country in the world (Hess, 1991). However, the technology used in this development did not, in many cases, anticipate the potential social, environmental and health costs. An outcome of this magnificent progression is sustainable agricultural systems, which advocate the use of fewer exogenous materials, in smaller amounts, to maintain land productivity. Sustainable systems may require reduced grain feeding to animals, an increased use of crop residues and waste feed materials, reduced use of chemical fertilizers and greater reliance on legumes, reduced use of pesticides and herbicides, more extensive use of soil and water conservation measures and careful attention to water quality. This dichotomy, to produce more with less, points to the birth of significantly altered agricultural production systems in the future. One alteration will be a greater reliance on forages for food and fiber production. One animal which can contribute to feeding and clothing the world population in the future, because of its characteristic efficient use of forages in a sustainable environment, is the sheep.

Sustainable Agriculture
Many descriptions have been promoted for “sustainable agriculture.” In reality, it is simply a collection of agricultural production practices which can be continued over a relatively long period of time (a decade, the career of a farmer or for generations). This system must provide long-range profitability, as well as the most often discussed long-range maintenance and improvement of soil while minimizing the undesirable effects of wind and water erosion on water and air quality. Sustainable agriculture addresses a concern for the environment, yet the increasing world human population must eat. Food is produced within an environment that will always be altered, whether it comes from agricultural lands or the ocean (Debertin, 1992). Profitable production of high quality and quantity of food, with minimum environmental impact, is the goal of sustainable agriculture.

Hauptli et al. (1990) indicated the focal point in sustainable agriculture is the soil. Although others have published how fossil fuel energy use (Stinner and Blair, 1990), the application of conservation tillage (Gebhardt et al., 1985), fertilizer use (Absher et al., 1989), systematic crop diversity (NRC, 1991), pesticide use (Williams et al., 1988), weed control (Parker, 1990), crop residue use (Klopfenstein, 1991), nutrient cycling (Van Soest, 1982), animal integration (Glimp, 1984), waste management (Fontenot et al., 1983) and water quality (Byington and Hart, 1984) are important in sustaining agriculture, all are directly or indirectly related to the soil. In sustainable agriculture, soil is deemed a living system which should be managed for diversity (integration) and the well-being of the organisms living within it. Nutrients are supplied in stable form, but soluble fertilizers are used strategically to limit their mobility through the ecosystem into water bodies. The soil’s physical deterioration is kept to a minimum by using tillage systems which minimize erosion, compaction and oxidation. To maintain its organic state, the soil is kept under continuous cover as much of the year as possible.

Sheep are opportunistic creatures relative to the harvest of solar energy contained in plant biomass produced

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from the soil. Yet, they are synergistic in their abilities to assimilate quality products for human use from forage (Parker, 1990). Enhancing the efficient use of solar energy, recycling nutrients to the soil, use of noncompetitive renewable resources (ligno-cellulosic), contribution to soil and water conservation, low capital investment requirements and adding enterprise flexibility are favorable characteristics of forage farming with sheep. These environmental and economic attributes have been available to humans since sheep were discovered as a food and fiber source some 11,000 years ago. As history has progressed from domestication through the organic chemistry age to sustainable agricultural production, the following myths have evolved regarding sustainable agriculture (Debertin, 1992):

1) “Commercial farmers are interested in maximizing profits only in the short run. They will implement sustainable practices only if forced to do so through legislation or governmental economic incentives.” Although this may be true for a few, agricultural economists agree this is a false philosophy for the majority. Generally, farmers work to increase net worth over a long period of time so maximum farm value can be transferred to the next generation. This philosophy is consistent with that of sustainable agriculture.

2) “Sustainable agricultural production practices always reduce farm profitability in the short run.” This may be true in some cases, but in others a sustainable practice may increase profits in a single production season. For example, chemical fertilizer must be used by the plants to increase crop yields. Fertilizer lost to the farm in runoff represents a non-recoverable cost. Any sustainable practice that increases the efficiency of use of this fertilizer by the plant, through reduced polluted runoff, can thereby increase net profitability.

3) “Sustainable agricultural practices always demand reduced use of chemical fertilizers and pesticides relative to ‘non-sustainable’ production practices.” Sustainable practices may use the same amounts of chemicals, but more strategically so less harm comes to the environment. If a practice increases nutrient uptake by the plant, fertilizer application will not increase pollution from water runoff.

4) “Farming practices that use no purchased inputs are sustainable and will not harm the environment.” In contrast, the inappropriate use of animal waste for fertilization of cropland can, like purchased chemical fertilization, pollute groundwater. The amounts applied and timing of application govern the extent to which either can harm the environment.

5) “Farmers interested in adopting sustainable agricultural practices are the same ones who are interested in organic farming.” Sustainable agriculture and organic farming are two different concepts. While organic farming does not use any chemical fertilizers or pesticides, most sustainable practices reduce, but do not totally eliminate, the use of chemicals.

6) “Most commercial farmers are opposed to sustainable agriculture and are unconcerned about the environment.” Actually, farmers are probably more aware of and have more concern for the environment than non-farmers because their livelihood depends on the benefits of nature. Furthermore, they would not intentionally adopt practices that damage the environment, since such practices would be inconsistent with their long-run strategy of maximizing net worth values for future generations.

7) “Farmers who adopt sustainable practices are different from those who have been early adopters of new conventional technology-based production practices developed through public-supported agricultural research and within the private sector.” Typically, there is an overlap of farmers who are the first to adopt sustainable production practices and those who have been leaders in the early adoption of other technology-based production practices. This will be particularly true if the long-run benefits of specific sustainable agricultural practices can be documented.

Once these myths are addressed an analysis of forage-based sheep production systems reveals sustainable practices have been used for a long period of time, are currently being utilized and most likely will continue in the future.

Sheep

Sheep possess exceptional abilities to transform a wide variety of feedstuffs, produced in many ecosystems, into high-quality products for human use. Vast arid, hilly and mountainous areas of the world preclude cultivation and crop production (Council for Agricultural Science and Technology [CAST], 1982), but allow sheep to convert natural vegetation into products useful to man. Other lands, such as improved grasslands and arable or cropping areas, support large numbers of sheep through integration into cropping systems designed to use crop residues and maintain soil fertility. Sheep offer many production advantages in world-wide ecosystems where improvement of resource utilization and conservation is desired (Parker and Pope, 1983). The natural characteristics of sheep and the diversity of their function, adaptability and performance have helped establish their wide distribution throughout the world. Besides the recognized contribution of over one billion sheep to human needs for meat, milk, fiber, leather and pharmaceuticals, they provide a living and a way of life for millions of people of the world (Coop, 1982).

Sheep are adapted to arid un tillable land and steep slopes. The grazing habits of sheep are often maligned as the primary causes of denudation and erosion of vegetated land, probably because the land has been overstocked and they prefer low-growing, broad-leaf plants (legumes, weeds, browse) which can be grazed close to the ground at repeated intervals. They range over a large area and seek the preferred settings in a repeated
circulating pattern (Grelen and Thomas, 1957). Most improved pastures contain weeds readily consumed by sheep. Sheep increase the uniformity with which rangelands are grazed because they are able to negotiate steeper terrain and make better use of poorly watered areas than cattle. Grazing sheep with other animal populations often reduces losses of other grazers due to poisonous plants because many plants toxic to other grazers can be safely consumed by sheep. Diet selection and nutrient assimilation of sheep are intimately related. Therefore, they do not need to maximize intake of any particular nutrient on a daily basis, considering their ability to tolerate deficiencies of energy, nitrogen and various minerals and vitamins (Booth, 1985).

Sheep serve as scavengers to glean corn fields, clean fence rows and contribute to a reduced need for organic herbicides through their appetite for weeds. Lambs can be “finished” to optimum slaughter weights and body condition from crop residues (corn, milo, soybean), spring growth of cool season grasses and winter small grain pastures with minimum or no energy or protein supplementation. Compared with beef cows, which may produce 60% of their weight in offspring annually, the ewe can produce 150% or more (CAST, 1984). For every 22 pounds of range forage consumed by ewe-lamb combinations, 1.0 pound of lamb is produced for human use (CAST, 1975). It is the unique grazing behavior of sheep that allows millions of acres of otherwise unusable land to become productive in terms of supplying meat for human consumption. In addition, sheep simultaneously produce the “forgotten marketable product” - wool.

Pond et al. (1980) emphasized the finite nature of land, water and fossil fuel energy and the need to use renewable resources more efficiently. If ruminants consume only forage, energy and land resources can be reduced by 60% and 8%, respectively, but the animal protein supply for human consumption will be reduced by 50%. If these projected trends become a reality, the unexcelled abilities of sheep to produce food and fiber from ligno-cellulosic material, while requiring the lowest percentage of fossil fuel energy of all domestic livestock, will be magnified.

Other advantages of sheep, when compared with other ruminant species, include production of more than one offspring and a monetary income at a younger age than beef cattle. Finally, sheep enhance environmental quality by consuming noncompetitive feedstuffs (cellulosic materials) and spread feces uniformly over tillable lands which can become overgrown with weeds if not grazed by these animals.

Worldwide, over 90% of the sheep’s diet is composed of roughage (ligno-cellulosic materials) which cannot be used directly by nonruminants (Hodgson, 1974). Nature has endowed the sheep with a fermentation vat (rumen), containing billions of microorganisms which secrete an enzyme named cellulase (Van Soest, 1977). This is the only enzyme in the gastrointestinal tract of animals capable of degrading cellulose, the most abundant chemical component of plants and the most abundant organic chemical material on earth (CAST, 1975). Since sheep can use cellulose for energy to make food and fiber, they occupy a strategic position relative to mankind and other nonruminants because they do not compete for their food (Van Soest, 1982). The symbiotic relationship between sheep (and other ruminants) and their anaerobic microbes may be the most unique aspect of biochemical evolution. Although the common feedstuffs consumed by nonruminants (concentrates) can be digested to about the same degree by sheep, ligno-cellulosic feedstuffs consumed by sheep are almost totally indigestible by nonruminants (Table 1).

Although sheep are productive, small-sized, highly adaptable and largely noncompetitive with humans, sheep numbers in the United States have declined since 1942. Shortage of skilled labor, predation, low cost of petroleum for expansion of the synthetic industry, increasing cost of land and its development and increasing pressure from recreationists and environmentalists for alternative use of public lands have all contributed to the decline of the sheep industry in this country (CAST, 1982). Beef cattle have replaced sheep even though Stoddart et al. (1975) concluded that this has caused a decrease in the efficiency of rangeland use because many areas are poorly suited to cattle. Furthermore, Cook (1976) reported that range lamb production required the lowest input of cultural energy (machinery, herbicides, pesticides, transportation) of any livestock production system. Gee (1980) estimated the total energy inputs per breeding ewe from 184 Mcal in rangeland operations to 1,112 Mcal in farm flocks. If the breeding ewe weighs 145 pounds, the cultural energy expenditure would equal 1.3 to 7.7 Mcal/lb. These estimates compare favorably with the 1.5 Mcal/pound for range sheep and 8.1 Mcal/pound for feedlot cattle (Cook, 1976).

Table 1. Average digestibility of cellulose in different feedstuffs.

<table>
<thead>
<tr>
<th>Feedstuff</th>
<th>Nonruminant, %</th>
<th>Sheep, %</th>
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</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>20 - 30</td>
<td>40 - 60</td>
</tr>
<tr>
<td>Temperate grass</td>
<td>0 - 20</td>
<td>48 - 90</td>
</tr>
<tr>
<td>Tropical grass</td>
<td>0 - 20</td>
<td>30 - 60</td>
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<tr>
<td>Straw</td>
<td>Negligible</td>
<td>40 - 60</td>
</tr>
<tr>
<td>Soybean hulls</td>
<td>40</td>
<td>90 - 95</td>
</tr>
<tr>
<td>Cottonseed hulls</td>
<td>0 - 10</td>
<td>30 - 50</td>
</tr>
<tr>
<td>Cottonseed hulls</td>
<td>0</td>
<td>23 - 37</td>
</tr>
<tr>
<td>Common newsprint</td>
<td>Low</td>
<td>20 - 99</td>
</tr>
<tr>
<td>All paper</td>
<td></td>
<td>0 - 40</td>
</tr>
</tbody>
</table>

a Van Soest (1982).
Sheep in the U.S. are presently less dependent on harvested grains than are cattle, swine or poultry. For example, Huston (1978) estimated only 1.8 pounds of grain were expended for each pound of lamb marketed in Texas. Comparable values for beef, swine and poultry were 2.5, 3.0 to 4.0, and 2.3 pounds, respectively. Cost savings like these should augment the sustainability of sheep in a competitive livestock industry.

The bottom line in sustainable agriculture is future human food production. With a projected world human population of 6.5 billion by the year 2000 (CAST, 1975), there will be a need for 50% more food when the supply is currently inadequate in some areas of the world. The concern is that present production methods will not be sufficient to maintain our current food supply in the future, much less increase it. While sustainability is critical to future human survival, present-day survivability will take precedence. One way to increase the chances of survival is to increase the role of ruminant animals (sheep) in human nutrition (Figure 1). Sheep can play a central role in human nutrition, now and in the future, because a highly nutritious and palatable food can be produced from a wide variety of feed sources which are not as efficiently utilized by other animals. Over half the daily protein intake by humans is provided by ruminants and this protein has a higher biological value than that derived from plants. Red meat also provides 25% of the energy, 80% of the calcium and 67% of the phosphorus consumed by humans daily. Vitamin B_{12} is present in relatively large amounts in meat, but is absent in higher plant foods. More extensive use of sheep to more efficiently utilize the available forage produced on more than 50% of the un tillable land area of the U.S. could increase the chances of human survival and sustain the productivity of the land for future generations.

As the U.S. population grows and world demand for grain increases, there may be a shift to a greater reliance on forages to produce the food cattle are capable of supplying to humans. Sheep production has already made this transition. The problems are with people; their nutrition, their preferences, their institutions and their economics. Let us solve our own problems and sheep will anthropomorphically sustain our food and fiber needs. Then, perhaps the Spanish proverb, "wherever sheep feet touch the ground, the land turns to gold," will become reality.
Forage
All food is derived from solar energy. Photosynthetic organisms transform this energy into essential organic substances required for life of animal herbivores. In turn, carnivores and omnivores tertiary derive their food from the photosynthetic source.

The net process of photosynthesis is carbon fixation. Without the recycling of fixed carbon back to carbon dioxide through oxidation, from which it can be reduced again by photosynthesis, life on earth would cease (Van Soest, 1982). The oxidation of fixed carbon by non-photosynthetic organisms is necessary to maintain the carbon dioxide supply for continued photosynthesis. Similarly, non-photosynthetic aerobic organisms receive their needed oxygen supply from this photosynthetic process.

Plants have evolved protective systems to ensure their own continued existence and survival. The physical and chemical structures of plants offer resistance to ingestion or attack by heterotrophs (fungi, bacteria, animals). But ruminant animals have evolved with a digestive system capable of degrading these cellulosic plant structures. While the abundance of cellulose in the world is indeed great, its transformation into useful energy is dependent on microbial activity. Cowling (1977) estimated 85 billion metric tons of carbon dioxide were produced annually from this microbial degradation. If such fermentation ceased with photosynthesis unabated, the earth would stagnate in 20 years from a lack of carbon dioxide.

The inefficient use of forage diets has been used as an excuse for feeding more concentrates to ruminants. But, what is often overlooked is that forages produce animal products from lands which cannot be used for grain production. Therefore grazing animal agriculture makes plant agriculture more efficient. If the world's population became entirely vegetarian, a major resource, the animal product from cellulose, would be wasted and more starvation would occur. Byington and Hart (1984) estimated only 8.5 acres of land kept each U.S. citizen from starvation (Figure 2).

Forage resources in the United States have been mismanaged, wasted and ignored (Murphy, 1990) because the nation had too much land available, too few animals to graze it well and no pressing economic need to use the land more efficiently. Today, with a shrinking agricultural land base, farm financial problems and pressure from recreationists and environmentalists, agriculturalists are being forced to take a closer look at all aspects of forage utilization by food-producing animals.

Pasture is a tremendous forage resource, capable of intercepting and storing large amounts of solar energy and consequently supporting high levels of livestock production if managed correctly. Pasture needs to be managed to produce a high-quality, dependable and uniform supply of forage at as low cost as possible (Murphy, 1990) to match the type and production stage of the livestock consuming it. A major factor affecting forage biomass and quality is the seasonal effect as influenced by rainfall and temperature. Van Keuren (1976) estimated 60% of the annual forage yield is produced in the first three months of the growing season in

Figure 2. Distribution of agricultural land in the U.S. (acres of each type per person).
temperate zones. Consequently the seasonal forage supply is believed to be the main cause for the seasonal breeding behavior of sheep. Lambs are generally born during the season of highest forage availability because the nutrient requirements for lactation are greater than any other stage of annual production and the requirements for lamb growth far exceed those for maintenance (NRC, 1989).

Pastures in the U.S. are almost exclusively complex mixed swards with variable plant growth characteristics. Manifestation of these characteristics depends on rainfall, temperature, light and fertility. Two basic methods of grazing management are available: continuous (set) stocking and rotational stocking (Forage and Grazing Terminology Committee, 1991).

When plants are continually exposed to grazing, overgrazing usually occurs in early spring and middle to late summer. The same pastures are likely to be undergrazed in late spring, early summer and fall. When excess forage is available, sheep selectively graze the more palatable plants, leaving the rest to mature, flower, set seed and multiply. Sheep tend to select leaf in preference to stem and young, green material in preference to older, dry material (Kenny and Black, 1984). Consequently, the diet eaten generally contains proportionately more nitrogen and metabolizable energy and less fiber, and has high digestibility (Arnold, 1981). The intake of any component depends on: 1) the potential rate at which it can be eaten (ease of fracture, particle size, water content, the animal’s mouth and degree of satiation; Arnold, 1981); 2) its accessibility (height, density and position of sward in relation to other components; Hodgson, 1982); and 3) its relative acceptability (taste, odor and surface characteristics; Arnold, 1981).

Van Soest (1982) plotted the dry matter yield of temperate forage against its nutritive value (Figure 3) and found they were inversely related. Continuous stocking permits excessive consumption of low-yielding, highly palatable forage in the spring, leaving the higher-yielding, less palatable forage to mature and become low quality during summer. Although the nutritive value rebounds to some degree in the fall, dry matter production declines sharply. Overgrazing the more palatable forages in the spring allows less palatable ones to become lower quality as maturity is reached, encroachment of broadleaf weeds, legumes to be “shaded-out,” decreases in soil nitrogen levels and eventual total production decreases because the more palatable forages completely disappear from the sward. Figure 4 (Bula et al., 1981) shows the inverse relationship between dry matter digestibility and lignin concentration. Even if animals are forced to consume the mature unpalatable forage in summer, utilization of this material for productive purposes is suboptimal (because of low digestibility).

Figure 3. Seasonal production curve and nutritive value of temperate forages.
Rotational stocking uses recurring periods of grazing and rest among two or more paddocks in a grazing management unit throughout the period when grazing is allowed (Forage and Grazing Terminology Committee, 1991). In actuality, pasture forage is rationed to the animal according to its needs while protecting the plants from overgrazing (Voisin, 1959; 1960). Murphy (1990) concluded the optimum rest periods between grazings in the northeast and north central United States to be 18 days in May/June and up to 36 days in August/September (Figure 5). In this example, regrowth accumulates 4,200 pounds of green forage per acre during optimum rest periods. Forage availability decreases to one-third if the rest period is one-half the optimum. If rest periods are shortened even more, available forage drops to 10% of the optimum. This decrease occurs when pastures are grazed off every time they grow tall enough to be consumed (every 6 days in May/June; every 12 days in August/September). If rest periods are longer than optimum, forage accumulates but the fiber content increases, rendering the forage less digestible and lowering its nutritive value (Van Soest, 1982).

Plant growth is the best indicator of conditions for the plant. With adequate rest between grazings, pastures may be grazed for a longer part of the year than would otherwise be possible. The following methods can be used to achieve rest periods that are twice as long in the fall as in the spring:

1) Set aside a portion of the area in the spring and harvest for hay or silage. Rest the harvested area for 25 days, divide into paddocks and include in the rotation.

2) Increase the number of animals in the total area during May, June and early July. This is the only way to graze the area if it is too rough for harvesting machinery. Excess animals are removed by mid-July (sold or transferred to another area).

3) Graze more than one species (sheep and cattle) on the same land area, either simultaneously or one after the other (depending on the production stage of each species). Animals with the highest nutrient requirements are grazed on the best forage. Follow with maintenance animals. The end

Figure 4. Changes in dry matter digestibility and lignin with advancing maturity of cool season grasses (boot) and legume forage (bud).
result is greater animal output per acre (Nolan and Connelly, 1977).

In an intensive rotational stocking system, the sheep industry standard is not to exceed six days on the same paddock. Limiting ewes to two days or less, or 12 to 24 hours for growing lambs, may produce even greater forage utilization. Although specific length of stays in the same paddock have not been established from controlled experiments, generally the longer animals stay in a paddock, the less palatable the forage becomes and the more time and energy they spend searching for palatable forage. Electric fencing technology has made rotational stocking a potentially efficient forage management tool (Parker, 1990) by increasing plant solarization, photosynthesis, dry matter production and biological output.

Forages are used by animals primarily as a source of energy. Of the total energy consumed, only the digestible portion (DE) is usable by the animal. Still, some of the DE is lost from the animal through digestion gas, urine and heat of digestion (heat increment). The energy remaining is net energy (NE) and is used to meet the animal’s maintenance and production needs. The efficiency of NE use depends on whether it is channeled to maintenance, milk production, fiber production or weight gain. From 50 to 100% of the animal’s energy consumption may be needed for maintenance; the amount required for a specific stage of animal production is dependent on forage quality.

Bula et al. (1981) pointed out that ruminants use energy more efficiently for maintenance or milk production than for weight gain. Figure 6 shows the effect of forage DE on efficiency of use for maintenance, milk and gain. At 70% DE, forages are 65 to 70% as efficient as corn grain for meeting maintenance and production needs. Conversely, at 50% DE, forages are less than 20% as efficient as grain for the production of weight gain, but nearly 50% as effective as grain in providing energy for maintenance or milk production.

Daily forage intake (DFI) usually increases as DE increases — up to about 65% DE (Bula et al., 1981). If forages contain less than 50% DE, weight gain is impossible and milk production is possible only at the expense of body weight loss. In this situation, all DE is used for maintenance. Consequently, there are tremendous potential increases in animal production with modest increases in forage DE. Bula et al. (1981) further theorized that an increase of forage DE from 55 to 60% could increase weight gain three-fold. A further increase to 65% DE could potentially double the three-fold increase because of the animal’s innate ability to consume the more highly digestible and palatable forage.

Rotational stocking is recommended when the forage supply is short or when reserves of forage need rebuilding for later use (CAST,

Figure 5. Rest periods and accumulated forage.

![Figure 5](image_url)
Continuous stocking is recommended when the land is grazed at less than its full carrying capacity and intensive management is not required. Production per animal may be greater with continuous stocking than with rotational stocking, but animal production per acre may be less. A significant advantage for rotational stocking that is often overlooked is weed control, especially with sheep.

Improvement of pastures for maximum plant and animal yields requires the addition of mineral elements: nitrogen (N), phosphorous (P) and potassium (K). The level of N required by ruminal bacteria is generally lower than required for plants to produce maximum yield. Neither animal intake nor digestibility is improved when forage crude protein levels (DM basis) are greater than 7%, which Van Soest (1982) considers adequate for many animal functions because of the contribution of salivary recycled N. Forage contains non-protein N and protein N, both of which are rapidly degraded in the rumen. Since sheep are probably dependent on ruminal microbial protein as their main source of N, fertilizer N that maximizes forage yield may be wasted because the resultant level of N in the forage far exceeds the rumen microorganism requirement. Furthermore, N fertilization tends to reduce DM digestibility in some forages (Van Soest, 1982). Figure 7 depicts a dramatic decline of orchardgrass digestibility with increasing N fertilizer rates. Although fescue-dry matter digestibility tended to increase, the magnitude of increase (70 to 72%) was less than the decrease for orchardgrass (72 to 68%). In view of fertilizer costs, incorporation of legumes into pastures for sheep appears to be an economical alternative to maximize utilization of fixed N. Legumes are of greater nutrient value than grasses for high animal performance, even at equal digestibility and intake (Waldo and Jorgenson, 1981). Simultaneously, leguminous forages accumulate soil nutrients to enhance production of crops with high N requirements and serve as cover crops to reduce soil and water losses (Parker, 1990). However, legumes (alfalfa, white clover, red clover) tend to be less competitive than grasses and need to be reseeded periodically with specific strains of nodule-forming bacteria to make N fixation possible. Legumes may also require more P, K and lime; their growth may be sporadic; rainfall is critical in maintaining production; and they require high stocking rates for efficient use (Bryan, 1984). Too often, legumes are recommended and added to a pasture simply because

Figure 6. Relationship of forage digestibility on the efficiency of energy utilization (compared with corn).
“they are good for the soil,” with little or no thought going to their management and ultimate utilization by animals.

Rangelands in the U.S. produce over 200 million animal-unit months (AUM) of grazing for domestic livestock alone. These same lands have a great added value as habitat for wildlife and as recreational areas for humans. Some range-use experts feel these lands could produce over 550 million AUMs, but obtaining this level of production would require substantial investments in improvements. Economic conditions would have to justify these improvements. Two-thirds of the rangelands are in the 17 western states, but the greatest potential increase in grassland productivity is in the humid region of the eastern half of the U.S., if careful selection of plant species, best varieties and best management practices are incorporated (CAST, 1984). The southern portion of this area has no potential for row cropping, rainfall is adequate and the climax vegetation is forest (Van Keuren, 1976). To the north, in the Appalachian area, the principal grass is Kentucky bluegrass accompanied by white clover. Without fertilization and grazing management, production is low. Introduction of orchardgrass, timothy, smooth bromegrass and perennial ryegrass in the North; bermuda, bahia and dallis grass in the South; and the highly adaptable tall fescue anywhere from the lower South to the North Central region results in improved production.

If ruminants are permitted to consume only forages, productivity is likely to be reduced. In contrast, strategic supplementation with concentrates can enhance productivity because use of the forage nutrients by the grazing animal can be maximized. Before maximum forage productivity can be realized, however, legumes will be incorporated into pastures, maximum forage production will be matched to the production phase of the animal, rotationally stocking will become routine and multi-species grazing will be practiced. Development of forage varieties with greater yields, higher ligno-cellulose digestibility and resilience to grazing will aid in reducing feed costs and promote maximum forage use by grazing animals.

Figure 7. The relationship between nitrogen fertilization rate and in vitro digestibility of fescue and orchardgrass dry matter.

![Graph showing the relationship between nitrogen fertilization rate and in vitro digestibility of fescue and orchardgrass dry matter.](image-url)
Integration of Sheep and Forages
Virtually everything is interconnected in today's increasingly integrated economy. The responsibility for sustaining life in a single global ecosystem with the greenhouse effect, the destruction of the ozone layer, the impact of acid rain and the consequences of deforestation is shared by all. However, the greatest world-wide challenge faced by mankind, which we must all share, is learning how to sustain agricultural growth in the future.

One of the most important biological relationships in the world is between herbivores and forages. The solar energy-based ligno-cellulosic material of plants has been an important agricultural product since it was first consumed by animals and assimilated into products for human use. Figure 8 shows the pathways of energy and matter in a livestock grazing system. Mankind is both a harvester and manipulator. He attempts to maximize the flow of nutrients to himself from vegetation and livestock. Only about 1% of the sunlight energy is captured by vegetation (Thomas, 1984). Although this appears inefficient, the ruminant animal does harvest what the plant captures and transforms it into food and fiber for man. Even with this inefficiency, all life is supported, directly or indirectly, by solar energy captured primarily by vegetation through the photosynthetic process. In some cases, insects and rodents capture more of the energy than producing livestock. For example, Haws et al. (1982) estimated 20 grasshoppers per square yard consume as much forage as a 1,000-pound steer (or seven 150-pound ewes). Infestations of 50 to 1,600 grasshoppers per square yard have been reported. The important point is that we need to learn more about energy flow and how to capture more of it for man, insects and animals. Furthermore, man needs to learn how to best tap forage ecosystems, on a sustained basis, for food and/or energy needs (Thomas, 1984).

Previous sections of this paper have described the individual characteristics of sheep and the forage they consume. This portion attempts to show how the capture of solar energy by forages consumed by sheep can sustain human food and fiber consumption in the future.

King (1990) described a non-agricultural system as one in which nutrients move from the soil into plants and are returned to the soil through residue as plants die. Although most of the nutrients are conserved in this cycle, some erosion, leaching, denitrification and ammonia volatilization does occur. Agricultural systems differ because nutrients are removed from the cycle in the harvested product. If agricultural systems are to continue, nutrients must be replaced.

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**Figure 8. Solar energy utilization by forages.**
CAST (1975) recommended that livestock grazing be a component of a crop rotation system because it disperses pasture forage production among intensive plant production operations and contributes to erosion control, soil fertility and the return of nutrients to the soil through manure and plants. The rotation of crops and animals aids in the control of soilborne diseases of both crops and livestock and thereby can markedly increase forage production. If forage is cut for hay, significant amounts of soil nutrients are removed (CAST, 1984). Although the rate of soil depletion is reduced when animal manure is returned, N conservation is most efficient when the forage is grazed. Woodmanese (1978) estimated that 17% of ingested N was retained by grazing animals, whereas Mott (1974) estimated that only 4% of the N, P, Ca, Mg, and S consumed by finishing lambs was retained. The remainder is returned to the soil without intervening losses.

Most forage crops are perennials or self-seeding annuals, so the soil on which they are grown is disturbed only at seeding (CAST, 1984). In the humid regions, the vegetative canopy may completely cover the soil surface during the growing season. This canopy is instrumental in reducing soil erosion by lowering the raindrop impact. In semi-arid to humid regions, forage residue is likely to cover most of the ground surface during a growing season. Concomitantly, roots permeate the surface and aid in binding it together. Many grasses, in contrast to legumes, produce "sod" which effectively reduces soil erosion. Research conducted in seven states with variable soils and slopes ranging from 2 to 16% showed annual soil loss (tons per acre) from row crops and forages was 8 to 112 versus 0 to 0.3, respectively. The percent runoff on the same lands and slopes was 11 to 40 for row crops, but only 1 to 6 for forages (CAST, 1984). This example illustrates the need for maintaining grass cover on sloping land. Because properly grazed forages are as effective as forests in protecting the soil against erosion (CAST, 1984), grass covered slopes can be grazed by sheep.

Furthermore, sheep relish grazing on lower quality land which drains well, prefer higher elevations with lower humidity and tolerate wind.

Animal agriculture, in arid regions, is usually practiced in pastoral systems. In humid regions, crops and animals are commonly integrated to help accomplish economic and environmentally sustainability. Infusion of animals into a cropping system provides economic diversity and alternative pathways for nutrient cycling. It is clear that integration of animals into lower input systems can improve long-term soil fertility (Stinner and Blair, 1990). However, King (1990) concluded the direct return of nutrients through feces of grazing ruminants is an inefficient method of pasture fertilization, especially under continuous stocking. This conclusion was based on the estimate of Petersen et al. (1956) that 10 years would be required before 95% of a continuously stocked pasture would be covered by at least one excretion. However, one can theorize this period would be much shorter under a rotational stocking system where less numbers of animals graze small paddocks for only a few days or hours at a time. Furthermore, these animals may graze the same small paddock five to six times during a growing season. The feces of sheep are more inclined to cover more of the ground surface than cattle because of its higher dry matter content and pelleted form.

In addition to food, fiber, wood, wildlife and recreational opportunities, grazing lands provide another important resource — water. Many of the nation’s watersheds are located on grazing lands (Byington and Hart, 1984). Although plant growth in the western United States may be limited by the water supply, much of the region’s precipitation comes in high-intensity rain or snow storms that produce much runoff. The water supply of most of the cities west of the 100th meridian ultimately traces back to that which fell on rangeland, often far away from its source of consumption. A large proportion of the watersheds in grass or other forage crops produce cleaner water and less silt ing in reservoirs, and aid in the constant supply of water for human use (Byington and Hart, 1984).

Weeds reduce yield and quality of desired forage species, longevity of stand and livestock carrying capacity (CAST, 1984). While some weeds may be poisonous to other animals, in some cases they may be biologically controlled with grazing sheep. Although herbicides make it possible to establish new species in existing stands, to replace existing stands with new species and permit thinning stands to regenerate without plowing and exposing the soil to erosion, many times producers are reluctant to buy herbicides because of their high cost and because they do not consider forage a cash crop. Consequently, straggic herbicide use is usually restricted to intensively managed pastures of high productivity. Herbicide use does not substitute for good management, but contributes to it and, along with an appropriate grazing species, enhances weed control.

Conservation tillage (no-till, strip till, ridge till) can reduce erosion by 75%, but may increase the need for herbicides (Gebhardt et al., 1985). The layer of crop residue remaining on the soil surface may be a habitat for pests, diseases and perennial weeds. Plant growth may be inhibited because of lower topsoil temperature in the spring, plus the topsoil may be more compacted. Correct use of grazing sheep to control weeds, to fertilize the soil and to acerate the soil through hoof action could supplement conservation tillage systems.

Integration of forages and animals leads to diversification and the use of alternative systems within production units (NRC, 1989). Glimp (1984) described an integrated diversified sheep production system in Kentucky that was economically viable and simultaneously protected and improved the resources available to the system. The land was used as pasture for 4 of every 10 years. Rotation with no-till corn, followed by wheat and double-cropped soybeans and back to corn every third year, was practiced during the other 6
years. This approach reduced plant diseases, weed problems and fertilizer needs of a conventional system. The pasture system was built around the use of cool season grass-legume mixtures, rotationally stocked, using periods of stay of six days or less, and a minimum of 21 to 24 days of rest. Rotational stocking depended on the use of electric fence and aided in controlling internal parasites without anthelmintics. Lambs were early-weaned in the spring to the highest quality pasture. They were easier to manage with this system than with a forward grazing technique. Dry ewes followed lambs. Lambs, from 50 to 60 pounds, were supplemented with only whole shelled corn in the spring. The crude protein content (17 to 20%, DM basis) of spring grass eliminated the need for protein supplementation. Initial consumption of 80% forage and 20% corn shifted to 30% forage, 70% corn by the time they reached 100 to 110 pounds (slaughter weight). Ewes utilized alternative crops (catch crops) at different times during the year. No-till turnips seeded into sod, strategically treated with a herbicide and 50 pounds of actual N fertilizer per acre, provided 1150 ewe grazing days per acre (20-pound gain per ewe) from mid-November to January. Costs per ewe per day from turnips was $0.03. Without turnips, the daily ewe cost would have been $0.10. Residues from corn and soybean production provided 200 ewe grazing days per acre in November. Two to four weeks of spring grazing wheat was utilized without affecting ultimate grain yields. Twenty acres of a summer annual (sorghum-sudangrass hybrid) maintained 800 dry ewes from June 15 to September 1 with the following schedule:

- **late June**: 7 days = 5,600 grazing days
- **mid-July**: 5 days = 4,000 grazing days
- **early August**: 5 days = 4,000 grazing days
- **late August**: 3 days = 2,400 grazing days

Estimated cost of grazing this alternative crop (catch crop) was $0.05 per head per day. The use of turnips, crop residue, small grain pastures and summer annuals incorporated into a grass-legume base system provided the opportunity to integrate forages and sheep into an economically viable and environmentally sound production system.

Other catch crops which have been used successfully in sheep production include rape, kale, onions, carrots, sugar beet tops (Newton, 1982) and alfalfa after frost. Chappell et al. (1992) described how integrated sheep production can be a profitable business. Aaron et al. (1992) indicated a key to the success of an integrated sheep production was genetic selection of breeding stock, based on production records, to meet the objectives of the system. Ely et al. (1992) enumerated the nutrition programs for an integrated sheep production system. Basic to the nutrition program was the practice of weaning lambs at 60 days of age, cool season grass-legume mixtures, rotational stocking and the strategic use of herbicides, anthelmintics, commercial fertilizer and alternative forages. Shelled corn was the only concentrate fed to ewes and lambs, and it was only used during periods of the year known to be energy deficient. Rolled bales of hay were fed only during winter. Similar to the program described by Glimp (1984), this system offers economic viability and environmental preservation.

Harwood (1990) described the following as important agricultural development items for the future:

1) To increase the utility of agriculture by maintaining adequate production, providing an adequate livelihood for participants and providing acceptable food with diversity.
2) To increase productivity with more productive biotypes while maintaining soil organic matter, tilth and crop diversity, practicing crop rotation, using integrated animal/fish/crop/tree and practicing nutrient cycling.
3) To maintain a favorable environment for humans by protecting ground water and minimizing pesticide and commercial fertilizer use.
4) To assure the ability to evolve indefinitely through minimizing soil loss and reducing fossil energy use.

The pressure for efficient food production might seem to indicate a need to de-emphasize animal agriculture. However, the technology is available to produce a safe and diverse food supply within a favorable environment for future generations. The use of sheep and forages in integrated production systems is indeed a viable method of sustaining animal agriculture indefinitely.

**Summary**

Much of the U.S. grazing acreage is only suitable for forage production. Many other acres have only limited crop potential, especially if soil and water are to be conserved. The better croplands of this country need to be returned to pasture periodically to reduce soil erosion, control weeds and pests and increase fertility. All of these scenarios require a livestock component to increase diversity for the producer to survive in a changing economic and social environment.

Recognition of the finite nature of land, water and fossil fuel energy and the need to completely utilize renewable resources, especially solar energy, is basic to achieving sustainability in agriculture. As we progress into the future, it is comforting to know that forage production from our finite land base will be available to support the grazing ruminant. It is also comforting to know the grazing sheep will be able to help fulfill our food and clothing needs through its unique ability to utilize the ligno-cellulosic material contained in forages. The analysis drawn by Senator Ingalls of Kansas (Byington and Hart, 1984), "Grass bears no blazonry of blooms; it yields no fruit in earth or air, yet should its harvest fail for a single year, famine would depopulate the world!" is just as true today as it was in 1885.


