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W. F. Wedin (Co-Chairman), H. J. Hodgson (Co-Chairman), J. E. Oldfied (Rapporteur), K. J. Frey (Rapporteur)

C. W. Deyoe, R. S. Emery, L. Hahn, V. W. Hays, C. H. Herbel, J. S. Hillman, T. J. Klopfenstein, W. E. Larson, V. L. Lechtenberg, G. C. Marten, P. W. Moe, D. Polin, J. M. Sweeten, W. C. Templeton, P. J. Van Soest, R. L. Vetter, and W. J. Waldrip

FEED PRODUCTION

SUMMARY

One of the primary constraints to animal production is an adequate supply of feed. As the world human population increases, with consequently increased demand for animal products (especially proteins) in the human diet, there must be increases and improvements in the supply of feed for animal production.

Much of the improvement in animal productivity of meat and milk that has taken place in the U.S. during the past 2 or 3 decades has resulted from extensive use of feed grains. Attention should continue to be given to feed grain production because of its importance, with emphasis on the potential for genetic improvement by plant breeders. There is evidence, however, which suggests that the importance of grain as a feed base may be declining and that its place, especially for ruminant animals, will be taken, to an increasing degree, by forage or alternate feed sources. Other uses of grains, including their export as an international trade item and their domestic use as a fermentation base for liquid fuel production, as well as decreased demand for lean meat, all contribute to this trend.

There is also an increasing emphasis on conservation of resources, which will increase the cost of land and water and the inputs required for feed grain and forage production. Excessive soil loss from mismanaged cropping is coming under increasing criticism and regulation.

Given that animal production systems in the 21st century will be subject to higher energy costs and that instability will result from alternate demands for a limited supply of grain crops, the exact type of enterprise for the future cannot be predicted. Yet the forces impinging on feed production for animals could lead to a new era in which the animal production systems are part of the total resource conservation for nutrients, water, soil and energy, while producing the feed needed.

The need is apparent for establishment of an extended base of animal feedstuffs. Although forage has served as feed for centuries, the technology of its production and processing has not developed to the extent of that applied to the production of grains and other concentrate feeds. Alternate feed sources include both materials already studied and utilized to some degree, as well as materials not currently thought of as animal feed sources.

Given likely constraints of the future, and a history of past research breakthroughs, we can delineate imperative research areas for the future. The imperatives in three major program areas are:

I. Increase utilization efficiency of ligno-cellulosic plant materials.

Ligno-cellulosic (plant fiber) materials comprise one of the most abundant organic compounds on earth. They are renewable but, unfortunately, they are utilized with relatively low efficiency. Through research, their efficiency of utilization can be increased. There are five research areas which require major research attention.

1. Develop basic information on biochemistry of synthesis and degradation of ligno-cellulosic forage materials.
2. Improve procedures for measuring forage quality.
3. Improve harvesting, storing and processing technologies to preserve and enhance feed quality.
4. Enhance forage quality through plant breeding.
5. Optimize feed quality through improved crop management.

II. Increase quantity of animal feed produced.

Increased plant productivity may be accomplished with the inputs presently available, provided a more nutritious plant product can be developed. But because feed for animals, particularly forage, of necessity may be produced on marginal lands that have mineral or water stress, there are both genetic and environmental (and their interactions) factors which must be researched. Four research areas are of urgent importance.

1. Improve forage and grain species by plant breeding.
2. Integrate new crop cultivars into feed production strategies that optimize and preserve natural resources, yet maximize efficiency of energy use.
3. Improve crop management, harvesting and storage methods to minimize losses of plant material.
4. Increase exploitation of legumes that fix their own nitrogen and that have higher feed intake potential and overall forage quality than do grasses.

III. Evaluate alternate feed sources.

Identification of new and different feed materials should be pursued. Particular attention should be given to the recycling of by-products and wastes from agricultural, domestic and industry sources, in the interests of conservation of resources and economy. Favorable yield characteristics of unconventional feed sources, such as certain types of trees (alder, aspen, poplar), may be exploited to further extend the feed base. Feed production areas can be increased through investigation of the nutrient value of aquatic materials, both plants and animals (fish). Three research areas require prompt consideration, such that early progress can be made.

1. Develop efficient methods for delignifying carbohydrate lignin complexes in woody and vegetative tissues of plants.
2. Improve methods used for handling, processing and storing residues to preserve and improve their nutritional quality and safety for use as feed.
3. Identify and evaluate new sources of concentrate feeds.

All of these research imperatives, by increasing the supplies of available nutrients for animal feed, can effectively support a continued productive animal agriculture in this country and the world and, therefore, represent wise investment in the future welfare of mankind.

INTRODUCTION

Feed supply is the basic resource for the animal industry. Adequate feed quantities with appropriate quality for the various classes and ages of livestock are essential for sustained, economic production of human foods from animal origin.

The past several decades have been typified by large increases in the amounts of concentrate feed available, usually at reasonable prices, for livestock. This has brought about efficient production of animal products. Even ruminant livestock have become large consumers of grain and other concentrates.

Feed production, as we presently know it in the U.S., will change in the decades ahead. Factors which are fundamentally agronomic, environmental, social, technical and economic will influence these changes.

Because of anticipated changes in our understanding of what feed shall be in the future, in this chapter we define feed, production and feed production as follows:

<u>Feed</u> - Any material ingested by animals from which they obtain one or more of the major nutrients (carbohydrates, protein, lipids, minerals, vitamins);

<u>Production</u> - Procurement of a product from growing, harvesting or salvaging;

<u>Feed production</u> - The husbanding of inputs (land, nutrients, cardinal growth factors, plants) to procure feed for animals.

Americans consume about 645 kg of food per capita annually, of which some 273 kg are foods of animal origin. If animal production is to sustain this consumption level in the future, especially with anticipated population growth, it is obvious that an expanded feed resource for animals must be provided. Presently, basic components of animal diets in the U.S. are chiefly plant materials, i.e., either concentrates (mostly cereal grains and their by-products) or roughages (vegetative portions of plants in fresh or preserved form) (table 8.1).

Provision of needed animal feeds for the future likely will involve more than simple expansion of the present feed categories. A number of forces are at work which suggest significant departures from the traditional feed supply. In particular, cereal grains for livestock feeding may be limited for several reasons. Grains are a major export commodity. Their export is likely to continue and to grow. Domestically, large quantities of grains may be used to produce liquid fuels. These forces almost certainly will cause substitution of forages for grains in the animal diet, a factor which could change production to patterns using less fossil energy in animal agriculture. Changes in American dietary patterns are demanding less fat in food products of animal origin which argues for less use of grain and greater dependence on forages in livestock finishing diets.

Plans for animal feed production in the future, therefore, must call for a greater variety of feedstuffs. As such, a technology that utilizes agricultural and industrial by-products and wastes as feeds is attractive because of its dual potential to provide nutrients for animal production and to reduce environmental contamination. Also needed are efforts to improve feed materials already used, by increasing their yields of available nutrients, improving their utilization by livestock, preserving their values over prolonged storage periods and removing inhibitory or hazardous factors they may contain. Such efforts, as detailed below, will provide for continued production of foods from animal origin to enhance the health and well-being of the citizens of this country.

BACKGROUND

FEED--RESOURCES, PRODUCTION

Land and Water Resources

Feed production in the U.S. is dependent on soil and water resources. On the other hand, production of animals is a major, or sometimes the only, avenue through which these material resources can be utilized for contributing to our human food supply. That is, much land in this country is marginal and only via animals can products of value be generated from it. In this section, a brief description of land and water use is outlined.

Total land use in the U.S. approximates 918 million hectares (2,264 acres). In 1974 (table 8.2) 17% was in cropland (excluding cropland used only for pasture), 30% in available grassland pasture and range, 32% in forest and woodland, 8% in special uses and 13% in unclassified uses. Urban uses now claim more than twice as much land as in 1950, and highway and airport use is growing. Some land classified as forest and woodland is grazed by livestock. Part of the agricultural land that has been shifted from cropland to other uses since 1950 could be put back into production, even though it has small field size, poor fertility and steep terrain.

Water and related natural resource phenomena also impinge on the animal feed resource base. Water quantity and quality, as well as water utilization, are major factors affecting potential feed and forage production. Other factors in addition to soil and water involve the aggregate productivity: wetlands, riparian vegetation, wildlife habitat, windbreakers, recreation, wilderness areas, landscape resources and others.

Our land and water resource base presently appears sufficient to provide for intermediate-term feed and forage production. Several constraints to be detailed later in this chapter, are mentioned here to further describe the land base. Quality of the land base is dropping because Class, I, II and III lands are diminishing in amount. Wind and water erosion, salt intrusion and other destructive forces are prime obstacles to increasing production. Millions of hectares have been, or are being, converted to urban and other uses. Ground water depletion is serious, and is critical in some areas.

Grain, Hay, Silage and Pasture and Rangeland Production

The plant resources for production of animal feeds consist of forage and silage crops, feed and food grains and crop residues, together with pasture and rangelands and by-products of crops processed for other primary uses.

Areas of land devoted to production of grain, hay and silage crops together with estimated 1979 production, are presented in table 8.3. Nonruminant animals depend heavily on grain and soybean producing lands, while ruminants utilize production from not only cropland shown in table 8.2, but also from pasture, rangeland and other grazing land. Major grain crops occupied 66.8 million hectares and produced some 293 million metric tons of grain in 1979. Corn and wheat production increased from 73% of the total area producing grain crops in 1973 to 81% in 1979.

The last decade represented the culmination of the post World War II period during which grain production increased dramatically as a result of the application of research-based technology. This technology included improved crop cultivars and soil management practices, such as earlier planting, higher plant populations, better pest control and increased use of fertilizer and irrigation. Generally, further increases in yield from these management practices will be difficult, and most additional gains must come from genetic improvement or new, innovative management techniques.

During most of the last decade, the increased grain production, except for wheat, was utilized as livestock feed. Certainly, large quantities of low-priced grain have played a major role in increased animal productivity during this period. Table 8.4 indicates the percentages of the leading grain crops that are used for various purposes. Note that the portion of grain production used as feed declined between 1971 and 1977, while the amount exported rose sharply. Further growth in world population probably will increase the portion of grain production that is exported.

Industrial usage of grain remained relatively constant between 1971 and 1977. Now emerging, however, are new industrial uses such as production of sweeteners and liquid fuels from corn, which may demand substantial portions of our grain production. Some estimates have been as high as 100 to 150 million metric tons of grain annually being converted to liquid fuel production by the year 2000.

Liquid fuel production and export markets will compete with livestock for grain. Unless production is greatly increased, the availability of grain for livestock, particularly ruminants, is likely to be substantially reduced.

Hay and silage production approximates 29 million hectares (table 8.3). Also more than 30 million hectares of cropland are devoted to pasture. Thus, the cropland area devoted to forage production nearly equals the area devoted to grain production. Additionally, permanent pasture and rangeland used some 275 million hectares, most of which is unsuitable for cropland use. Production from these lands, plus crop residues, provides 60% of the feed units for all livestock and 80% for ruminants.

Permanent pasture and rangeland occupy large areas of land unsuitable for the cultivation of crops (too steep, arid, wet, rocky). Alternate uses are restricted, yet major improvement is possible from control of unwanted plants, water-management, revegetation and fertilization, and through management systems with one or more of these improvements.

Breeding herds of sheep and beef cattle receive a substantial portion of their nutrient needs from pasture and range forage. On range, particularly, production per unit area is inherently low, but production per unit of input (capital, labor, energy, etc.) is high.

In contrast to grain production, technology application to forage production is generally low. Thus, the potentials for increasing livestock feed from forage producing lands is large. Application of improved technology to cultivated forages, pastures and rangeland could increase ruminant livestock production several-fold. Increases in yield of dry matter and improvements in dry matter digestibility could occur from fertilizer and lime application, increased use of legumes, more timely harvest and grazing, and improved harvest and storage technologies.

Almost all the forage produced in the U.S. is consumed by ruminant livestock, and there are few competitive uses. Recent interest in the development of technology for the economic conversion of cellulosic materials to liquid fuels, however, have given rise to estimates of several hundred million metric tons of ligno-cellulosic materials being used annually for their new development. Whether such levels are reached by the year 2000 is problematical, but the potentials exist. Should these technologies develop, the impacts on ruminant livestock production would be substantial. Feed production in animal agriculture would remain important, but provisions for research and development to offset this new demand would be necessary. Increased yields resulting from application of presently available technology could make it possible to meet the needs without reducing the amounts of forage currently available to animal agriculture. Additionally, the alternative use would provide an economic market for low quality forage. There would be an incentive for increasing quality of forage fed to animals.

The use of feed grains and concentrates in general is diminishing as more forages are being used for production of ruminant animals (table 8.5). The proportion of the animal diet supplied by forages (corn equivalent basis) increased by 1978 for four animal-type categories. The proportion of the available grains that were actually used for feed in 1971 vs 1977 was given in table 8.4. The alternative uses for grain mentioned earlier may accentuate this trend in the future.

Agricultural Residues

Crop and animal residues provide an animal feed resource that may play a significant role in the future. The crop and animal residues can substitute for grains, or they can increase production through an expanded feed supply. A reasonable level of residue utilization can be compatible with soil conservation practices. Agricultural residues available by regions in the U.S. are summarized in table 8.6. Almost 60% of all residue available is found in the Corn Belt (eight states) and Plains (eight states).

For the U.S. as a whole, stovers of corn and small grain offer the best potential as feed. Furthermore, of the total available crop residue, about 78% occurs in the Corn Belt and Plains regions (table 8.6). Corn, sorghum, barley, oats, wheat and soybeans contribute 95% of these residues, with corn and wheat comprising 54% and 20%, respectively.

Residues of fruit and vegetable crops are local in nature and are not easy to use efficiently. Forestry residues make up a substantial portion of total available agricultural residues (table 8.6), but these residues probably will have the most economical use in the fabrication of new wood products or as fuel. Manure residues comprise about 6% of all agricultural residues (table 8.6). Some of these animal wastes can be fed. It can be concluded that the stovers of corn and small grain, plus cattle and poultry wastes, offers the most promise as feed. In least-cost diets, they often appeared to be potential substitutes for traditional feeds.

Energy Implications

Grain and forage crops have traditionally constituted the major feed source for the U.S. livestock industry. Competitive uses for feed grains, such as exports, food and industrial uses have long existed, but these uses have represented a relatively small proportion of the U.S. feed grain crop. Since 1977 exports of feed grains have increased and now represent approximately one-third of the total U.S. grain production. Exports are expected to represent an even greater proportion of production in the future.

In addition to increased exports, the industrial use of grain crops could increase substantially in the near future. A recent report by the Office of Technology Assessment (OTA) of the U.S. Congress (1980) estimates that the potential exists to produce as much as 11 billion liters of liquid fuel from grain and sugar crops annually by 1985.

Whether this potential is reached depends on economic developments and policy decisions at the national level. Beyond the year 2000, the use of U.S. grain for fuel production appears less certain. The development of other energy alternatives could then reduce the use of grain for liquid fuels. Even if the conversion of grain to liquid fuel does not reach the upper level cited, it is likely that the combination of new industrial uses and exports will result in greater demand for grain in the future.

Shifts in Usage

Expected increase in demand for grain does not imply that feed grains will be unavailable for animal feeding. Likely, they will be expensive and subject to volatile price fluctuations. Animal production systems of the future will need to be flexible enough to effectively use alternative feeds, e.g., high quality forages and by-products from the industrial uses of grain.

If a national policy was adopted to develop renewable energy resources in the U.S., it would not only affect the supply and price of grain for livestock, but would also have a far-reaching impact on the production and use of fibrous crops that have traditionally been used for ruminant livestock feed. If technology currently under development for converting cellulosic crop materials to fuels becomes economically feasible, a competitive nonfeed use will exist for traditional forage crops. The OTA Report (1980) estimates that from 91 to 233 million metric tons of forage and 55 to 78 million tons of crop residues could potentially be used for fuel purposes annually before the year 2000. The diversion of this quantity of cellulosic crop materials to fuel use, without decreasing animal production, could occur only by an increase in annual forage production of 50 to 100% in the Eastern U.S. While this magnitude of increase appears possible technically, challenging problems would arise in integrating such a system with present livestock feed production.

The development of an industrial forage utilization system would create a cash market for forage crops that would greatly stimulate their improved production and management. This could have several important effects on crop and livestock production. Conservation practices which involve forages in rotation could become profitable.

While this development could increase the cost of forage feeds for animals by creating an alternative demand and use, it could also stimulate the production and feeding of high quality forages by providing a stable market for low quality forages, rained-on hay and forages otherwise mismanaged. Higher quality forages could be reserved for animal feeding systems requiring their use.

Protein Sources

It is generally acknowledged that animal protein is a major contributor to the human diet and, because of its amino acid composition in relation to human dietary needs, its continued involvement in human diets is advocated. There is substantial evidence that proteins from meat and

milk played a significant role in the history of human development and that strong and stable cultures and nations have emerged through association with animal agriculture.

The significance of this historical development in relation to feed production is that, in order to produce the protein needed for human use, supplies of protein, or of nitrogen in the case of ruminants, must be found for animal diets. The energetic efficiency of the animal diet depends upon a correct mix of a number of dietary essentials, including protein. It is not enough, therefore, merely to identify sources of energy, but adequate supplies of protein and other nutrients must be available also.

There are two major avenues by which improved supplies of feed proteins can be approached: 1) Existing protein sources can be improved in some way so as to improve their efficiency of utilization by animals; and 2) new and different forms of protein can be identified and tested in animal-feeding experiments.

To assess these approaches, it is necessary to differentiate between the protein requirements of various animal species, particularly between ruminant and nonruminant animals. It has been demonstrated clearly that ruminant animals cannot only exist but also can grow and reproduce on diets containing no preformed protein, if sufficient nitrogen is present. On the other hand, nonruminant species such as the pig require preformed protein of high quality and of high biological availability. The usefulness of dietary protein may be impaired by the presence of indigestible materials.

Plant fiber occurs in close association with protein in many feed sources as, for example, legume and grass forages. Attention has been directed worldwide to the production of "leaf protein concentrates" (LPC) which would effectively free protein from the undesirable association. Several strategies have been proposed. Simple physical separation of leaf from stem in crops such as alfalfa can enhance the protein value of the leaf fraction considerably. Most efforts, however, have been directed toward coagulation of protein from juices expressed from forage plants under pressure. Such processing has reached the point of limited commercial application. The LPC produced has been prosposed for direct consumption by humans; if such a market develops, the residual stemmy materials could find useful outlets in diets for ruminant livestock.

Another example of improving existing protein resources lies in the animal product area. Traditionally, residual materials from slaughterhouses, including blood, hair, viscera and trimmings have been recycled into the animal feed trade as meat and bone meals and tankage. In addition to their recognized nutritional qualities, use of such products is encouraged by their consequent removal as potential pollutants of the environment. The products are frequently less than ideal protein supplements, however, due either to characteristics of their base composition (excess bone gives too high a calcium content, for example) or to problems caused by the processing they have undergone - too high a temperature may damage essential amino acids, such as lysine. Improvement may be obtained by fractionation procedures.

Identification of new sources of protein is one of the most exciting and potentially most valuable research areas in the whole animal feed production picture. It can involve variations on traditional feedstuffs such as high-lysine corn, high-lysine barley and the more recent hybrid cereal, triticale. Other new variants of recognized protein sources have occurred among the residual meals produced in the processing of oil-bearing subcrops. Rapeseed meal, for example, is being produced in great quantity in Canada as a result of encouragement toward crop diversification of wheat lands by the Canadian government. Early experiences with rapeseed meal as a protein source were unsatisfactory due to presence in the meal of glucosinolates with goitrogenic properties. These problems have been overcome through the efforts of Canadian plant breeders who have successfully produced low-glucosinolate cultivars, such as Tower.

An area of great promise in the development of new protein sources is the investigation of microbial cultures (Single-Cell Protein). The ability of microorganisms to synthesize protein and other nutrients, plus their characteristics as "biological filters" in removing or modifying substances that might otherwise result in environmental insult, make their exploitation as protein providers potentially valuable. Single-cell protein production has application in the disposal or recycling of animal manures and of certain industrial wastes that are produced in large quantities in some areas, such as the sulphite liquor effluents from paper manufacturing plants. In some cases, too, microorganisms can be produced from hitherto-unstrapped substrate materials such as hydrocarbons or petrochemical residues. Microbial activity also can be used to enhance the nutrient qualities of feeds, as exemplified by the production of "activated sludges" from domestic and industrial wastes and the generation of needed supplementary nutrient sources, including vitamins and amino acids, through fermentative processes.

FEED--QUALITY, PROCESSING AND STORAGE, UTILIZATION

Forage and Feed Grain Quality

Forage and feed grain quality is crucial to efficient production of food products by animals. High levels of intake of highly digestible and nutritious feeds run hand in hand with efficient production. If intake is high, animals then consume protein, energy, minerals and other nutrients in excess of those needed for body maintenance. These extra nutrients are available for meat, milk and egg production. While nonruminants such as poultry and swine consume most of the protein, energy and other nutrients from feeds that could be used for human food, ruminants such as cattle and sheep consume forage legumes and grasses, as well as other cellulosic feeds, which provide the basic dietary needs. Presently, additional concentrate feeds are fed in substantial quantities to ruminants to insure high levels of meat and milk production in American animal agriculture. The relationship of feed quality to animal needs in different production categories (e.g., brood cows that require lower levels of nutrients than do high-producing milking cows) has often been overlooked.

Management schemes have been devised to increase forage quality. Among these are frequent cutting of immature plants when at high quality, improved fertilization practices, use of legumes with both high intake potential and high protein and use of legume-grass mixtures where they are adapted. Quality of a few selected forage species has been markedly improved by breeding for increased digestibility (e.g., bermudagrass and pearl millet) or for reduced anti-quality constituents (e.g., indole alkaloids in reed canarygrass). Factors that cause bloat in grazing animals on high-quality legumes have been partially identified. Heritability of some of the quality and anti-quality factors and the influence of the environment on their presence have been established. Yet potential for additional quality improvements is great. Through searches for other means of identifying and quantifying quality parameters or anti-quality substances, progress can be made. It is commonly accepted that environmental or genetic control of these quality factors is much greater than that which has already been realized.

In practice, dairy and beef farmers can shift from excessive dependence on feed grains requiring substantial fossil fuel energy input. If high-quality forage is substituted for low-quality forages, high yields of milk and meat can be realized. Top-grade alfalfa hay production is possible on many more farms. The potential for consistent procurement of such high-quality forage can be increased through more research. For grazing, management schemes have included an oversupply of forage early in the pasture season and deficiencies during the "summer slump" and late-autumn periods. More research is needed to determine the potential for integration of alternative high-quality plant species into season-long grazing systems.

In most instances, plant breeders of grain crops have developed cultivars that are high yielding, lodging and disease resistant, but generally they have not bred or monitored for changes in feed quality of grain per se or straw and stover. Some past objectives in breeding grains may have caused indirect reduction in feed quality of cereal residues, e.g., stiff, lodging-resistant corn stalks, which contain a high concentration of indigestible lignin. Certainly, increasing protein and other nutrients in grain crops has not been a primary objective of breeders. In fact, corn in the U.S. today averages about one percentage unit less protein than corn of 40 years ago. Plant breeding research might alleviate this situation.

Processing and Storage

For efficient storage of feed, the harvested nutrients must be conserved. Changes in composition and quality of stored feeds is associated with losses from respiration and fermentation. The alteration in composition results from a replacement of metabolizable components by the products of microorganisms. There is often loss in net mass through respiration. This includes selective loss of the more metabolizable and valuable components, i.e., protein and energy.

Molds and aerobic processes can cause greater loss of organic matter, and can produce more toxins and heat, than is the case with anaerobic fermentation. The heat, in turn, can promote nonbiological degradation of the protein and carbohydrate by means of the nonenzymatic browning reaction.

The losses attendant upon such biological and nonbiological processes are very substantial and unpredictable. The technology controlling and releasing these factors is inadequate, and the mechanisms are incompletely understood.

On most farms, forages are not produced as cash crops. Therefore, forage harvest, storage and processing are not given first priority. Because of inclement weather and other demands for equipment and labor, forages are too often harvested at a stage of maturity beyond maximum quality. Processing and feeding of hay crops is dependent on equipment, fuel and labor. Processing may aid voluntary intake and may be necessary for proper diet mixing in some cases. Self-feeding of livestock from packages may cause feed losses due to trampling and fouling.

Harvesting losses are high in haymaking, especially of alfalfa which comprises over 60% of the hay tonnage. The recent trend has been to reduce labor and further mechanize haymaking by use of large packages (stacks and round bales). Leaf loss in packaging can be appreciable. In humid areas, rain may further decrease yield and quality. Storage losses have also increased with the advent of large package systems because the packages are often not protected from the environment. This reduces storage-building cost, but it increases feed losses.

Alfalfa and grasses stored as silage or haylage are not as subject to harvesting loss problems. However, storage losses of dry matter and quality can be appreciable. Direct cutting of wet forages leads to nutrient seepage in the silo and to fermentation and animal intake problems. Field wilting can overcome these problems, but it increases equipment, fuel and labor costs. There is an inverse relationship between cost and storage efficiency of storage structures for silage.

Other silage crops such as corn, forage sorghum and small grain forages supply large yields. However, storage losses may be large and variable.

Grains are traditionally dried and transported for livestock feeding or for export. Most grains are processed by grinding, rolling or steam flaking before feeding to animals. Energy costs for drying and processing continue to increase and require research on alternatives. Grains scheduled for livestock feeding can be stored and processed as high-moisture feeds to eliminate drying costs and reduce the potential for field harvest losses. Also, chemical processing of grains can enhance storage characteristics.

Feed grains are stored both on the farm and commercially. Farm storage has increased rapidly in many grain producing areas following changes in production, transportation and marketing plans, and as a result of a lack of commercial storage capacity at harvest times. Losses in grains occur as a result of (a) insect infestation, (b) microbiological activity and physical damage and (c) losses during handling. Grain inspections indicate increased occurrence of insect fragments, infestation, damaged kernels and lower grain grades in the trade. These losses are variable and may represent substantial losses of feed grains available for livestock production.

Harvest, storage and feeding of crop residues can be quite expensive relative to their forage quality and economic value. Corn and sorghum residues can be grazed by ruminants with little or no cost, no fuel use and with minimum reduction in soil tilth. The practice is highly weather-dependent and understandably confined to regions where cattle and residues are both produced.

Most crop residue harvesting has been conducted with large hay package equipment. This equipment is expensive unless used for alternative forage harvest on the same farm. Cost of grinding and feeding residues is high and similar to that of hay. The cost of energy for mechanical harvest of forage crops and crop residues may necessitate increased harvest by grazing.

Treatments of residues with sodium hydroxide, calcium hydroxide and ammonia have increased their digestibility by 10 to 20 percentage units. The increased digestibility may be sufficient to cover the cost of harvest and storage.

CONSTRAINTS INFLUENCING FUTURE DEVELOPMENTS IN ANIMAL AGRICULTURE

There are a number of constraints to increased feed production for animals in the next century. These constraints include the limitation of our natural resources (land, water, climate, energy) and the inability of animals to effectively metabolize cellulose.

LIGNO-CELLULOSE METABOLISM

A major factor limiting the supply of feed nutrients for animals is the inefficiency with which food-producing animals utilize ligno-cellulosic feedstuffs.

It is generally agreed that feed grains will be less available for U.S. animal production in the 21st century than at the present time. Alternative feed supplies, therefore, will be needed to sustain high levels of animal production. Cellulosic plant materials are one of the most abundantly produced materials, with production in nearly every climatic region on earth. The energy content of cellulosic plants is equal to that of starchy crops; however, this energy is not efficiently utilized by animals. The major barriers limiting their efficient utilization are the highly ordered structure of cellulose and the association of cellulose with lignin.

A major breakthrough could be achieved if the energy in ligno-cellulose materials could be made readily and efficiently available to animals. This would make possible the use of many alternative feeds in animal production. Crop residues, cellulosic industrial wastes, animal wastes and a wide array of other materials could be utilized.

Low bioavailability of ligno-cellulose is a constraint of such magnitude and far-reaching implication that a major, high priority research effort should be martialed to develop and obtain the information necessary to "unlock" this resource. Success in this area would not only make available an almost inexhaustible supply of animal feed, but also would have profound effects on the ability to produce fuel from cellulosic biomass.

SOILS AND LAND USE

While it might appear that our natural resource base is sufficient for adequate forage and feed production, several current developments impinging upon agricultural land use will greatly tax our soil and water resources. At present we are losing annually from .4-1.2 million hectares (1-3 million acres) to roads, airports, plus industrial and urban development. Some estimates suggest that we may need to convert from 20-28 million hectares (50-70 million acres) to crops being grown for energy purposes only. In addition, many acres are being seriously damaged by wind and water erosion, salt intrusion and other destructive forces. These losses of cultivated land, plus possible major shifts in agricultural land resulting from the high costs of energy, will cause changes in the type and amount of livestock feed produced, as well as where it is grown. For example, USDA estimates that we have about .4 million hectares (100 million acres) of land not now in crops that could be converted to cropland with low to medium risk. Approximately another 12 million hectares (30 million acres) could be converted, but at high risk from erosion and other hazards. While the additional land is scattered and needs development, much of it is located in the Southeast and Lake States. If it becomes necessary to use the additional land, much of it may be best suited for cultivated forage crops to produce feed for ruminants.

The contemporary concern for the soil resource follows a period in which public agencies infused substantial support to reverse trends in soil exploitation. But, because cropping practices have changed markedly in the past 3 decades, today's patterns differ greatly from those of 3 decades ago (table 8.7).

The reliability of the plant resource from which the bulk of the feed in this country is derived is dependent on the continued productivity of the soils themselves, and the environment for plants which grow on those soils. To consider what feed production will entail in the future, it is necessary to assess this land base as a constraint.

Soil erosion resulting from changes in cropping is discussed thoroughly in Special Publication No. 25 of the Soil Conservation Society of America (1979). In general, all of the reports state that the soil loss from cropland in the U.S. is at alarming levels. As a basis for several studies reported therein, crop areas and yields from 1972 to 1977 were compiled for major land resource areas (MLRA) and used in computer models. Soil loss from cropland in all MLRA's is about 2.7 billion metric tons a year (about 40 metric tons per hectare per year), but estimated tolerance level is about 50% of this amount.

It is evident that our present soil degradation should not continue, particularly with the mandated controls related to environmental quality (e.g., Section 208 of Public Law 92-500 concerning nonpoint water pollution). Crop residue management is one of our best means to control soil erosion. The first need for residues is to maintain soil productivity. Amount of crop residue in excess of those needed to maintain adequate soil erosion control were calculated and included in the Soil Conservation Society Special Report (1979). About 49 million metric tons in the Corn Belt or some 36% of the total crop residue produced was

available for removal from the land. The nation's corn crop accounts for 65% of the total residue. Two-thirds of all of the residue which can be removed would come from only four of the 14 MLRA's in the Corn Belt, those soils which are deep and level. In the Great Plains, only 14% could be removed; this is 20% of the residues produced.

Implications to feed production when more restrictive cropping practices are used have been studied in the Center for Agriculture and Rural Development (CARD) at Iowa State University. In one study, four conservation practices (straight row cropping, contouring, strip cropping, terracing) in various crop management systems, and three tillage practices (conventional tillage with the residue removed, conventional tillage with residue left, reduced tillage) as they affect crop production and least-cost diet for livestock were compared. As the level of soil conservation rose, hay acreage showed a steady and substantial increase. Hay acreage expanded because it was economical as a soil conservation measure relative to such alternatives as additional terracing. A further consequence of more hay was a substitution of hay for silage in livestock diets. With increasing soil conservation, a decline in acreage of corn and sorghum silage occurred. Corn production was forced to shift to less productive land, e.g., the Great Plains, and there the amount of fertilizer and pesticide required to raise a bushel of corn increased.

High and low export of feed grains have been examined, also. In a projection to 1985, one study reported that with adequate soil erosion measures, row crops become costly. As a result, the use of corn in livestock feeding declines. The major cost of soil loss to farmers is the loss of future productivity, but future productivity loss is discounted in many cases. In western Iowa, soil loss dropped 30% between 1952 and 1957, but increased 24% between 1957 and 1975, as farmers relaxed use of production practices which control erosion. Shifting to conservation tillage and modifying cropping systems to fully utilize all of the advantages of forages would decrease erosion losses.

CLIMATE

Most of the major feed producing areas of the U.S. are within the temperate zone. Only the deep South and Southwest are outside the temperate region. Within these areas, climate undergoes cyclical changes of a diurnal, seasonal, interannual or periodic nature (e.g., 20-22-year shifts associated with sunspot activity), with considerable variability in each cycle over time at a given location. There is also considerable variability in the weather that makes up climate, whether it is for a small area of a few farms, a few counties or several states. Such climatic diversity has necessitated development of plant cultivars of important forage and grain crop species that can withstand a variety of stresses.

Climatic constraints which influence feed production and availability are temperature, precipitation, thermal radiation, humidity and wind. Lack of historical, current or forecast knowledge of these parameters is also a constraint in decision making (e.g., purchase of an irrigation system, timely use of the irrigation system or scheduling the planting of the crop).

Air temperature is a principal factor which sets the limits where both forage and feed crops can be grown, and in what quantity. It is a dominant factor also in plant composition, which in turn influences feed quality (e.g., lignification). Air temperature also influences the length of the growing season and the time for harvest of forages and grains, which, in turn, constrains the selection of high-producing cultivars.

Precipitation is the primary climatic constraint in feed production. Both the total yearly precipitation and the seasonal distribution markedly affect plant growth. Plant growth in the western range areas in the Plains States is limited by precipitation, unless irrigated. Extended periods of no precipitation during the growing season can drastically reduce yields and interrupt grazing systems.

High intensity precipitation may lead to soil erosion and damage to plants, both resulting in reduced production. Precipitation influences soil salinity, water-containing capacity, or in cases of drought, the threshold value for plant wilting. Precipitation enhancement in dry areas from cloud seeding may impact on areas from which such rain has been shunted to influence crop output. It cannot be assumed that enhanced precipitation will benefit a crop or that a decline in precipitation would be deleterious to feed production (table 8.8). Also, the magnitude of the change is not always predictable (table 8.8). Shifts in the hydrologic cycle and amounts of precipitation may result in large-scale disruptions in current plant productivity and of species distribution.

Precipitation also influences the air moisture content. High air moisture content has a strong adverse impact on natural air drying of harvested forages and grains, and on the long-term storage and quality of those reserves.

Thermal radiation (solar and long-wave) is often a rate-limiting parameter in photosynthesis and plant development. Low intensities of solar radiation, resulting from cloud cover or time of day or season, inhibit photosynthesis. High intensities of solar or long-wave radiation can cause stomatal closure, likewise inhibiting photosynthesis. Excessive outgoing long-wave radiation on clear nights can cause frost damage to plants, even when the air temperature is above freezing.

Wind is usually perceived as a less dramatic constraint in forage and grain crop production. It is an important aspect of evaporation, however, from soil and plant surfaces, and can lead to inhibited plant development. In addition, wind can cause mechanical damage to plants (lodging or blowing soil particles) and can reduce feed production by eroding soil necessary for maximum production.

WATER

Water is essential to plant growth, and maximum growth is favored by an ample water supply. Thus, this resource will be of increasing importance in the future. Although the U.S. is one of the "best-watered countries" in the world, substantial amounts are effectively lost from crop production because of runoff. It is likely that taxpayers increasingly will question the subsidization of high-priced, inefficiently produced feed in irrigated areas. The limited availability of

water for private development will make the high cost of water used in irrigation for agricultural production most economical only on crops such as vegetables, fruit, rice, cotton and corn, all which bring a high return per unit area of land. There are areas where irrigation is economical for alfalfa. Projected ahead, however, there will be shortages of water in many areas.

Each year about 76 cm (30 in) of water falls to the surface of the conterminous United States. The average annual precipitation ranges from less than 10 cm (4 in) in parts of the Great Basin and Lower Colorado Regions to more than 508 cm (200 in) in the coastal area of the Pacific Northwest. In addition to surface water, the nation has large supplies of groundwater. A general overview of those supplies is shown in table 8.9. Regional or local shortages of water occur because of uneven distribution of precipitation. Water shortages are generally associated with the arid West, but many humid eastern areas also have periodic water supply problems.

The dependability of surface water is as important as its location. Both yearly and seasonal variations must be overcome. Reservoirs are used to partly offset the natural variation. Our current capability to offset drought may decline considerably unless groundwater supplies are augmented with surface waters or transfers of interbasic water aquifers is practiced.

Agricultural irrigation, much of which is for feed grain and alfalfa production, has a profound effect on regional water budgets because it diverts and uses large volumes of water. Hence, it is increasingly important that increases in irrigation efficiencies be achieved in a variety of ways, principally through better water management and by delivering water only in those amounts needed by crops.

Summing up, all types of water (i.e., precipitation, surface water, ground water) are absolutely necessary for a productive feed, forage and grazing economy. In fact, water in all its forms and locations may be the resource most limiting to a reasonably priced feed supply in the U.S. Because of the demand for water, the greatest potential for increasing feed production, with existing water resources, is in the eastern half of the U.S. Water is not as serious a constraint to increasing crop production in this part of the country as in the Great Plains and Western States.

PLANT SPECIES

Forage and grain at the time of harvest represent the cumulative results of plant growth over time. Both the genotype of the plant and the environment (i.e., land, climate, water, biotic factors and management practices) in which the plants are grown influence the quantity and quality of forage and grain harvested. The environmental factors can, in some instances, be economically amended so as to modify the quantity and quality of the harvested plant material but, generally, the environment amendment must be repeated with each growth cycle. Genotype modification, on the other hand, once achieved, does not require continued amendment input as long as the genotype is continued in use.

Genotype consideration for contributing to grain and forage productivity and quality begins with a choice of species. Grain productivity has been materially increased via plant breeding, e.g., between 1930 and 1970, yield increases attributable to genetic improvement were 50-60% for corn, 40-50% for wheat, 30-40% for soybeans and 60% for rice. Likewise, yield potential for certain forage species has been phenomenal, e.g., bermudagrass yield potential has been increased at least 100% in the southeastern U.S. For certain forage species, such as alfalfa, however, the increase in genetic potential for yield has not been good, and this lack of a large response in genetic potential for forage yield represents one constraint to alfalfa production in certain midwestern areas.

Future production of forage and grain for animal feed may be more concentrated on lands that are marginal because of severe mineral deficiencies and toxicities. Amending these land areas to be even minimally productive may not be economically feasible, but there is evidence that plant breeding can evolve grain and forage cultivars that could be productive there.

Plant breeding has great potential for improving forage and grain quality also. The primary deficiency of grain crops as a feed for nonruminant animals is their generally low quality protein. Mutant types of endosperm are known in corn, barley and sorghum which will produce grain with protein of quality adequate to sustain good growth in nonruminants. With continued research effort to improve the productivity of these mutants, grains can become more adequate as energy and protein sources in a diet.

Forage quality has several aspects which are subject to substantial genetic manipulation. They are nutrient availability, palatability and antimetabolite concentration. Nutrient availability (digestibility) in feedstuffs has two components, the proportion of the dry matter that is available to the animals, and how rapidly the available nutrients are released. A good, rapid in vitro procedure is widely used in the laboratory to predict forage digestibility. The cellular content is highly digestible, whereas the real problem in nutrient availability is associated with the cell wall constituents including cellulose, hemicellulose, lignin and silica. One successful example of genetic manipulation of nutrient availability is the brown-midrib gene in corn, in which the substitution of this allele reduced lignin percentage by 40%. Feeding of this low lignin stover resulted in a 30% increase in dry matter consumption and .45 kg per day greater gain than when normal corn stover was fed to beef cattle. A second example relates to the d_2 gene, which reduces stem length in pearl millet by 50% and is associated with increased leaf percentage of the forage from 54 to 81%. Resultant average daily gains and live weight gains per unit land area for dairy heifers were 33% greater. Other factors such as the presence of phenolic compounds and alkaloids can affect nutrient availability also. Regarding palatability, plant traits that affect voluntary intake potential of a forage are leafiness, cell wall constituents and factors associated with pest resistance, such as tannins. Generally, factors that affect palatability are not well understood and, therefore, they must be lumped together as "taste related" factors. Good examples of increased potential for intake through breeding are Tiflate-1 pearl millet, Kenhy tall fescue and Morpa weeping lovegrass.

Antimetabolites and their general detrimental role in animal metabolism are not well understood, but prominant groups of such compounds include: a) alkaloids in reed canarygrass; b) saponins in alfalfa, tannins in sorghum and lespedeza; c) cyanogenic glycosides in sorghum, sudangrass and white clover; and d) coumarin in sweetclover. Two examples will suffice to show how breeding can reduce or eliminate antimetabolites in forage. Genes at two loci governed the presence or absence of coumarin in sweetclover, and by substituting the appropriate alleles at these two loci, this compound could be eliminated from sweetclover. Antimetabolites in reed canarygrass are the indole alkaloids, of which there are 10 species. The indole alkaloid series of compounds is controlled by alleles at two loci. A line of reed canarygrass, MN76, with only 1/3 as much indole alkaloid concentration as a commercial check has been developed at the University of Minnesota. Lambs fed these reed canarygrass lines gained weight at twice the daily rate of those fed the commercial check.

Insects and diseases that attack forage plants can and do affect the quantity, and especially the quality of forage produced. Resistance to such pests can be bred into alfalfa varieties.

In addition to breeding programs aimed at improving the quality and yield of individual species, potential exists to improve the soil efficiency of nutrient utilization by plants. This may require that breeding be done simultaneously on various species to ascertain more closely the benefits derived when growing in common and mixed culture. This may increase productivity throughout the growing season and provide better quality of forage.

Thus, we see that plant breeding research can contribute in several ways to the productivity and quality of animal feedstuffs. There are, however, several major constraints to plant breeding making the numerous contributions for which there are potential. These are: 1) all of the factors that contribute to forage quality (from the level of the animal) have not been elucidated; 2) rapid in vitro tests for assaying plant genotypes for many quality factors are generally nonexistent; 3) germ plasm collections of most forage species generally are too small for breeders' needs; 4) available germ plasm collections have not been assayed for forage quality factors; and (5) the inheritance patterns of quality factors have not been elucidated adequately.

ENERGY

The full impacts of energy in the future will likely be immense in relation to feed production. Costs for gasoline and diesel oil have already exceeded those projected and used in studies of the future. It is fast becoming necessary to look closely at the efficiencies of plants, their production and their utilization by animals. Alternative ways in which agriculture can make changes as energy becomes more expensive have been studied recently. Crop rotations can change, forages have a major role and nitrogen fixation by legumes figure prominently in these alternatives. In a 5-year rotation - corn, corn, oats, alfalfa, alfalfa - the use of energy was only 60% as much as with coninuous corn, yet the crop yield in total dry matter produced was only 6% less (Heichel, 1978). Nitrogen is a high energy input into grain crop production systems. The amount of fuel energy used in producing crops undoubtedly can be reduced if some cropping systems which involve legumes were used to provide biologically fixed nitrogen. It is important, however, to recognize that these cropping systems will be voluntarily adopted by farmers on a large scale only if the profitability of the total rotational cropping system is equal to or superior to present continuous grain cropping systems. It cannot be accurately predicted if the relative energy cost of nitrogen will preclude its use in continuous grain cropping systems. Rotations or modifications thereof could become a reality if profitable systems are developed for utilizing greater amounts of the harvested legume herbage.

With respect to the energy in feeds fed to animals, one substitution that has been firmly advocated for more than a decade is the development of the capacity to replace energy from grain with energy from forages, plant materials entirely noncompetitive with food for man. Leading in this advocacy have been Hodgson (1978) and others. Reid et al. (1975) calculated the digestible energy (DE) outputs per unit of fossil energy (FE) inputs in feed production. Cited were DE to FE ratios as follows: pasture herbage, 30-115; grass silage, 8.2; hay, 7.5; corn silage, 4.1; soybean, 2.0; corn grain, 2.5. Energy relationships when ruminant cattle graze have all been studied in situations where considerable energy is expended in the process of obtaining the feed. Tradeoffs occur, obviously, in whether the forage is machine-harvested or grazed. Relative importance of these factors may change in the future.

LOSSES DURING GROWTH, HARVESTING AND STORAGE

Losses during growth, harvesting and storage of feed crops reduce efficiency of animal production, especially from forage-based feeds. Quantity and quality may be lost, lowering feed availability and reducing acceptability, intake and digestibility of the forages by animals. Losses can result from pests, poor management and inclement weather. Some estimated losses from forage pests are shown in table 8.10. Reducing these losses could greatly increase the proportions of available herbage consumed by livestock.

Forage quality decreases markedly with advancing maturity. Weather frequently delays harvesting beyond optimal maturity stages, resulting in losses which may reach 20-25% of the dry matter with even greater decreases in nutritive value. Harvesting during inclement weather increases losses and cost of field operations. Reduction in drying time of hays and wilted silages, which could be accomplished through research on biological, mechanical and chemical procedures, might significantly reduce weather-related losses. Additional research also could reduce mechanical losses.

Losses in dry matter and nutritive value from heat, molds and other causes during storage represent other serious losses in feed value. The extent of these losses in quality are shown in table 8.11. The potential increases in animal production which could be achieved by harvesting earlier, and by reducing postharvest forage losses are presented in table 8.12.

INADEQUATE DATA BASE

Improved methods for acquiring and assembling more accurate statistics should be developed for forages and grains. The need is critical. This is particularly so for forage production where present data are limited and of questionable value. As a result, the importance of and contribution to U.S. agriculture from forages is underestimated. There are limitations also in currently available information on weather forecasting, climatological data and weather modification which, if improved, would facilitate on-farm strategic and tactical decision-making.

Other types of data which are needed relate to land availability and class, crop production estimates, germ plasm information and grading standards for hay.

PUBLIC POLICIES

The feed producer historically has provided an abundant feed supply for animals in American agriculture. The use of a wider variety of inputs (fertilizers and pesticides, etc.) which have increased feed production efficiency has been questioned, in some cases, by the public. In turn, this has led to public policies which in total make feed production more difficult. Consumer advocacy also has influenced the perception of healthful foods. The most evident of policies which constrain feed production in one way or another are briefly described.

The concept of zero tolerance for feed additives that may have carcinogenic effects as exemplified in the Delaney clause of the Food and Drug Act is unworkable in the light of analytical technology presently available. The clause should be superseded by criteria based on dose-response, and the risk-benefit ratios should be established through appropriate controlled research.

Our dwindling land and water resources must be protected from further degradation and loss so that food, fiber and energy production for the future generations is assured. Animal agriculture could be one of the first segments of agriculture to suffer if our soil and water resources become limiting. The need for protection of our natural resources is urgent.

Because export of feed grains and conversion of feed grains and cellulosic crops to fuel are presently on the increase, some policies may be necessary to insure that an adequate feed resource base be available in the future.

A deterrent to efficient range production has been the profusion of some regulatory constaints. These regulations by government agencies, particularly federal, in many instances, have caused significant increases in costs for both producer and consumer. Regulatory decisions should be supported by sound scientific data.

RESEARCH IMPERATIVES

The structure of animal production enterprises in the 21st century is unpredictable Most likely energy will be costly; there will be ultimate demands for a limited supply of grain crops and conservation of natural resources will be a paramount objective. These forces could lead to a new era in which livestock production systems will play a paramount role in a total conservation plan for nutrients, water, soil and energy. For certain, livestock enterprises will continue to play a major role in human nutrition and well-being.

Even though the nature and prominence of livestock production systems and strategies in the 21st century are not predictable now, it has been possible, by studying both research history and the present and predictable future constraints on animal production, to delineate research imperatives.

INCREASE UTILIZATION EFFICIENCY OF LIGNO-CELLULOSIC PLANT MATERIALS

There is growing evidence that cereal grains will be less available as feed in future decades. Ligno-cellulosic (plant fiber) materials are the most likely candidates to replace grain for ruminants and possibly for nonruminant animals. Ligno-cellulosic compounds are the most abundant organic compounds in the world. They are produced in every agricultural system, in every climate and on every soil type. Forages and crop residues comprise a large portion of the herbaceous ligno-cellulosic reservoir. They are utilized by animals, particularly ruminants, but with relatively low efficiency. Great opportunity exists to increase efficiency of their utilization or, in other words, to improve their quality. The most opportunistic means are listed below. (Note that the same research advances which improve utilization of these materials by animals also will render them more useful as biomass resources for liquid-fuel production).

Develop Basic Information on Biochemistry of Synthesis and Degradation of Ligno-cellulosic Forage Materials

This information is fundamental to achieving extensive progress in the subsequent research. Unlocking the ligno-cellulosic bonding by efficient and effective methods is of far-reaching importance.

Improve Procedures for Measuring Forage Quality

Rapid, inexpensive, accurate and precise procedures are needed to identify important attributes of feeds for poultry and livestock.

Procedures to measure specific nutrients and potential digestibility are available. New procedures are needed to identify bioavailability of nutrients and characteristics of feeds which influence the environment within the gut of animals and thereby affect availability of nutrients of other diet components. Techniques are needed to predict rates of fiber, starch and protein degradation. The ability to accurately characterize nutrient content and availability will provide the basis for improvement in feed quality and also allow feedstuff selection and diet balancing for a variety of animals and production levels.

Improve Harvesting, Storing and Processing Technologies to Preserve and Enhance Feed Quality

Losses during and following harvest often are severe and costly. A standing crop of alfalfa at optimum harvest date has 67-70% digestible dry matter. This is often reduced to 55% or less by delayed harvest, and by harvest and storage losses. Dry matter losses commonly reach 25%. Concomitant losses in available protein may also occur. These losses reduce animal production. Research in this area is limited. Payoff potential is very high. Improved methodology here will be beneficial in offsetting reduced availability of grain in ruminant production. Lower quality forage and crop residues can be rendered more valuable by certain postharvest treatments or storage procedures. The potential for increasing nutritive value should be extended and more fully exploited.

Ensiling of forages or high moisture grains reduces harvesting losses but can be associated with considerable storage losses and quality changes. Factors (including additives) which affect nitrogen solubilization, carbohydrate digestion, starch solubilization, feed intake reduction and energy metabolism should be studied further.

Enhance Forage Quality Through Breeding

Genetic improvement of forage quality by breeding and selection includes efforts to develop increased digestion of plant cellulose, increased palatibility to animals, elimination of anti-quality substances in some species and reduction of lignification. This will require understanding of the inheritance of quality factors. Germ plasm resources must be expanded by plant exploration and evaluated for quality factors, and superior cultivars must be developed. Breeding of most forage species is complicated by their polyploid and perennial nature. Furthermore, forage species come from genera in two major plant families, the grasses and legumes.

More plant breeding efforts are needed to improve the content and quality of protein in grains to more nearly fulfill the nutritive requirements of animals, particularly nonruminants. Also, plant breeding may be able to reduce lignification and silicification of cereal crop residues to improve their nutritive value.

Optimize Feed Quality Through Improved Crop Management

Quality varies with crop species, cultivars and maturity. Concurrently, manipulation of management alternatives of forages and livestock offers opportunity to better integrate forage quantity and quality with the needs of animals of differing classes, ages and production levels.

INCREASE QUANTITY OF ANIMAL FEED PRODUCED

Research imperatives for increasing feed supplies for animals are genetic- and management-oriented with respect to plants. They will have the greatest payoff if both research areas are fully integrated.

Improve Forage and Grain Species by Plant Breeding

Genetic improvements of forage species can result in more animal product per unit of land or economic input by increasing plant productivity and nutritive value. Because much animal feed, especially forage, is apt to be produced on marginal land, more emphasis will need to be given to breeding plant varieties that will be productive in stress environments. Furthermore, new varieties will need to be optimally suited to management systems used for animal feed production and have high inherent resistance to diseases and pests.

For range livestock, quantity of forage is often more important than forage quality. Management systems to integrate soil, plant and animal relationships provide opportunity to increase forage production and conserve resources.

Integrate New Crop Cultivars to Feed Production Strategies that Optimize and Preserve Natural Resources, Yet Maximize Efficiency of Energy Use

Maximum production of feed may not be as necessary as optimal production, especially when conservation of natural resources becomes increasingly critical. Production of animal feed is uniquely compatible with conservation practices, but much research is needed to determine the best combinations of plant genotype(s), crop management system(s), and energy and labor inputs to give the optimal results in conservation and animal production in regional and local environments.

Improve Crop Management and Harvesting and Storage Methods to Minimize Losses of Plant Material

The biotic factors (insects, diseases and weeds), management and harvesting methods and storage techniques combine to cause crop and nutrient losses as high as 25% of production. Plant breeding research can provide inherent insect and disease resistances which are nonpolluting, and good field husbandry can reduce weed competition. Research is needed, however, to develop crop management, harvesting and storage strategies that will reduce plant material losses and maintain quality in feed grain and forage.

Increase Exploitation of Legumes in Animal Production

Forage legumes are used alone and in a mixed culture with grass species for pasture, hay and silage. They are unique in their ability to fix atmospheric nitrogen and, when grown with adapted grasses, can

replace up to 300 kg per hectare per year of commercial nitrogen. Moreover, animal production from legumes and legume-grass mixtures is superior to that of pure grasses. Breeding and management research on forage legumes is needed to increase their nitrogen-fixing capacity, to improve their persistence and competitiveness, to alleviate seed production problems and to improve their productivity under grazing and stress environments.

EVALUATE ALTERNATE FEED SOURCES

Identification of new and different feed materials should be pursued. Particular attention should be given to the recycling of by-products and wastes from agricultural, domestic and industry sources, in the interests of conservation of resources and economy. Favorable yield characteristics of unconventional feed sources such as certain types of trees (alder, aspen, poplar) may be exploited to further extend the feed base. Feed production areas can be increased through investigation of the nutrient value of aquatic materials, both plants and animals (fish).

Develop Efficient Methods for Delignifying Carbohydrate-Lignin Complexes in Woody and Vegetative Tissues of Plants

Base and acid treatments are used for this currently, but their use is limited by chemical residue in the delignified product. Biological and new chemical approaches should be investigated to overcome this limitation.

Improve Methods Used for Handling, Processing and Storing Animal Residues to Preserve and Improve Their Nutritional Quality and Safety for Use as Feed

Many animal residues, such as slaughterhouse by-products and manure, have considerable value as animal feeds, but are presently underutilized.

Identify and Evaluate New Sources of Concentrate Feeds

Technology is needed to utilize by-products from new industries that use agricultural products as raw materials. Currently a large industry is developing to use corn as a raw material for liquid fuel production. The distillery residue that remains after the liquid fuel is produced is a protein concentrate that may be useful as a livestock feed. By-products from food production and processing industries, forest and wood processing industries, aquatic plants and other new crops need to be evaluated.

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TABLE 8.1. CONSUMPTION OF FEEDS BY LIVESTOCK IN 1974 (MILLION METRIC TONS OF FEED UNITS[a,b])

Animal type	Concentrates	Forages	Total feed	% Forage
		Metric tons (10^6)		%
Dairy cattle	23.8	41.7	65.5	63
Beef cattle	33.2	171.8	205.0	84
Sheep and goats	.7	6.1	6.8	90
All livestock	157.8	240.3	398.1	60
Hog	43.9	7.0	50.9	16
Poultry[c]	36.6	.7	37.3	3
Other	19.6	13.0	32.6	40
All ruminants	57.7	219.6	277.3	80
% by ruminants	36	91	70	--

[a] A feed unit as used herein is the nutritional equivalent of .45 kg (1 lb) of corn.
[b] Hodgson, 1978.
[c] Hens and pullets, chickens raised, broilers and turkeys.

TABLE 8.2. TRENDS IN MAJOR USES OF LAND IN THE UNITED STATES, SELECTED YEARS FROM 1950 to 1974

Major land use	1940	1950	1959[g]	1969	1974
			ha (10^6)		
Cropland[a]	162	166	159	156	155
Available grassland pasture and range[b]	291	284	283	280	276
Forest and woodland[c]	294	292	295	293	291
Other land[d]	172	179	183	188	196
Special use areas[e]	---	54	59	70	74
Unclassified areas[e]	---	125	124	118	122
Total[f]	919	921	920	917	918

[a] Excludes cropland used only for pasture.
[b] Grassland pasture and other nonforested grazing land plus cropland used for pasture.
[c] Excludes reserved forest land in parks, wildlife refuges and other special land uses.
[d] Includes such special land uses as urban areas, highways, roads, farmsteads, parks and military reservations, and also land having little value for surface use (desert, rock, marshes, tundra, etc.).
[e] Indicates data are not available.
[f] Changes in total land area are attributable to changes in methods and materials used in occasional remeasurements and to increases in the area of artificial reservoirs.
[g] Estimates for 1940-1959 are based primarily on Major Uses of Land and Water in the United States: Summary for 1959 (USDA, Economic Reserach Service) and assume essentially no change in Alaska and Hawaii prior to 1950. The estimates are only approximately comparable.

Source: USDA 1980. SWRCA Program Report and Environmental Impact Statement - Review Draft.

TABLE 8.3 PRODUCTION OF FEED GRAINS, WHEAT, RYE, SOYBEANS, HAY AND SILAGE, 1979[a]

Crop Commodity	ha (10^3)	Metric tons (10^3)
Feed grains	40,967	233,881
Corn	28,726	197,209
Oats	3,979	7,757
Barley	3,022	8,231
Sorghum	5,240	20,684
Wheat	25,334	58,288
Rye	384	624
Soybeans	28,543	61,715
All hay	24,752	132,338
Alfalfa	11,137	79,452
Other	13,615	52,886
Corn for silage	3,238	103,151
Corn for forage	168	---
Sorghum for silage	310	8,175
Sorghum for forage	512	---
All principal crops	136,236	---

[a]USDA, 1980.

Table 8.4. DISAPPEARANCE OF SUPPLIES OF FOOD AND FEED GRAINS, 1971 AND 1977[a]

	Food, seed and industrial %		Feed %		Export %		Tables[b]	
Feed Grains	1971	1977	1971	1977	1971	1977	1973	1979
Corn	9	9	76	58	15	30	45	41
Oats	8	11	90	68	2	1	52	50
Barley	30	38	59	40	11	14	65	58
Sorghum	2	1	83	60	15	27	76	67
Wheat	37	33	20	9	43	55	13	5
Rye	28	59[c]	66	41	6	0	23	19

[a]USDA Agricultural Statistics 1973 and 1979, Washington, DC.
[b]Table number in Agricultural Statistics.
[c]28% used as seed - indicates large usage for grazing.

TABLE 8.5. TOTAL ANIMAL FEED USAGE FROM FORAGES[a] AND CONCENTRATES IN 1972[b] VS 1978[c].

Animal type	Forages (% of Diet)		Concentrates (% of Diet)	
	1972	1978	1972	1978
All livestock and poultry	54	62.5	46	37.5
All dairy cattle	63	61.2	37	38.8
All beef cattle	73	83.0	27	17.0
Beef cattle on feed	--	27.6	--	72.4
Other beef cattle	--	95.8	--	4.2
Sheep and goats	89	91.1	11	8.9
Hogs	14	14.7	86	85.3
Hens, pullets and chickens raised	3	0	97	100.0
Broilers	0	0	100	100.0
Turkeys	5	0	95	100.0
Horses and mules	--	72.2	--	27.8

[a]Referred to as roughage in CAST Rep. No. 82 (1980).
[b]Wedin et al. (1975).
[c]CAST Rep. No. 82 (1980).

Table 8.6. AGRICULTURAL RESIDUES AVAILABLE BY REGIONS[a]

Region	Crop residue	Manure	Forestry	Total	% of interregional total
	Metric tons (10^6)				
New England/ Mid-Atlantic	6.2	2.7	8.8	17.7	4.1
Southeast	28.4	4.3	53.0	85.7	19.9
Corn Belt	108.4	7.2	9.1	124.7	29.1
Plains	103.9	7.0	8.2	119.1	27.8
Intermountain/West	30.8	5.3	45.7	81.8	19.1
Total	277.7	26.5	125.8	429.0	
% of total	64.7	6.2	29.1		

[a]Vetter and Boehlje, 1978.

TABLE 8.7. SOME CHARACTERISTICS OF 1980 AGRICULTURE RESULTING FROM CHANGE IN CROPPING PATTERNS AND LAND USE

Increased mechanization
Increased size of equipment
Narrowed germ plasm base
Expanded use of synthetic nitrogen
Increased pesticide use
Reduced number of farm enterprises
Increased labor costs
Decreased use of legumes in cropping systems
Increased demand for export of corn and soybeans

TABLE 8.8. CROP AND FORAGE YIELDS WHEN EITHER TEMPERATURE OR PRECIPITATION OR BOTH ARE SHIFTED ABOVE AND BELOW NORMAL AVERAGES[a]

	Units of Measure	Change in yields from normal production					
		Change in precipitation		Change in temperature		$+2^{o}C$,	$+2^{o}C$,
		-10%	+10%	$+2^{o}C$	$-2^{o}C$	$-10\% H_2O$	$+10\% H_2O$
Winter wheat (N. Central U.S.)	kg/ha	-13	-13	-188	+54	-269	-202
Soybeans (OH,IN,IA)	%	-5	+4	-6	-8	-9	-1
Winter oats (GA; maximum forage)	t/ha	-.2	+.2	-.6	+.5	-.7	-.4
Grain sorghum (KA)	%	-8	+6	-3	-9	-9	+2

[a]Adapted from CIAP Monogr. 5, Part 2: Climatic Effects, from Imports of Climatic Change of the Biosphere, Final Report of the Climatic Impact Association Program, Dept. of Transportation, Washington, DC. (1975).

TABLE 8.9. THE NATION'S FRESH GROUND WATER SUPPLIES (USDA, 1980)[a]

Water resources regions	Ground water in storage that can feasibly be withdrawn[b]	Portion of total withdrawals from ground water	Ground water withdrawals: Total ground water withdrawals	Withdrawals in excess of recharge: Amount mined	Withdrawals in excess of recharge: Percentage of ground water mined	Water resource subregions: In region	Water resource subregions: With mining
	10^{12} liters	%	liters/day x 10^6	liters/days x 10^6	%	No.	No.
New England	NA[c]	12	2,407	0	0	6	0
Mid-Atlantic	1,326	15	10,085	121	1	6	3
South Atlantic-Gulf	4,245	22	20,652	1,285	6	9	8
Great Lakes	985	3	4,605	102	2	8	1
Ohio	417	5	6,985	0	0	7	0
Tennessee	2,009	4	1,027	0	0	2	0
Upper Mississippi	815	19	8,967	0	0	5	0
Lower Mississippi	4,813	33	18,336	1,561	9	3	3
Souris-Red-Rainy	417	26	326	0	0	1	0
Missouri	1,706	27	39,442	9,691	25	11	10
Arkansas-White-Red	1,895	69	33,526	20,682	62	7	7
Texas-Gulf	2,464	43	27,371	21,141	77	5	5
Rio Grande	4,775	37	8,850	2,490	28	5	4
Upper Colorado	133	2	478	0	0	3	0
Lower Colorado	NA	56	18,980	9,153	48	3	3
Great Basin	379	18	5,397	2,240	42	4	4
Pacific Northwest	682	20	27,849	2,376	9	7	6
California	208	48	72,616	8,327	12	7	5
Conterminous U.S.	NA	24	307,900	79,169	26	99	59
Alaska	4,245	14	167	0	0	1	0
Hawaii	NA	42	2,994	0	0	4	0
Caribbean	61	28	963	49	5	2	1
Total U.S.	NA	24	312,023	79,218	25	106	60

[a]Geological Survey Professional Paper 813 Series (USDI, 1974-1979). Second National Water Assessment (U.S. Water Resources Council, 1978).
[b]Depth, quality and ease of extraction are not nationally consistent.
[c]NA means data not available.

TABLE 8.10. SOME ESTIMATED FORAGE-CROP LOSSES FROM PESTS[a]

Commodities	Kinds of pests: Diseases	Insects	Weeds
Hay			
Alfalfa	24[b]	15	--
Pasture and range	3-9	--	13-20
Seed			
Alfalfa	9	--	--
Other	4-50	15-38	12-18

[a]USDA, 1965.
[b]Values are estimated percentages of the commodities lost by indicated causes.

TABLE 8.11. LOSSES DURING HARVESTING AND STORAGE OF HAY[a]

Causes of loss	Loss in dry matter, %
Respiration	
In good drying conditions	2-8
In poor drying conditions	up to 16
Mowing and conditioning	2-5
Raking	5-25
Baling	
Conventional	3-8
Large-round	1/2-15
Transporting large packages	1-10

[a]N.P. Martin. 1980. Harvesting and storage of quality hay, p. 177. In: Proc. Amer. Forage and Grassland Conf., Louisville, KY.

TABLE 8.12. ESTIMATED EFFECTS ON MILK (DAIRY) AND LIVE WEIGHT GAIN (BEEF) OF VARIOUS LEVELS OF LOSSES IN DRY MATTER AND DIGESTIBILITY OF ALFALFA[a]

Dry matter loss (%)	Digestibility % of dry matter	Milk production, kg[c]		Live weight gain, kg[d]	
		Per day	Per ha	Per day	Per ha
10	60	11.5	6,093	.4	448
15	57	7.8	4,435	.2	268
25	50	1.4	874	0	0

[a]H.J. Hodgson, (Personal communication). 1980.
[b]Assumes an alfalfa crop harvested at first bloom and yielding 8,297 kg/ha of dry matter with 66.6% digestible dry matter.
[c]Based on 650 kg cow weight.
[d]Based on 300 kg growing animal.